UF | IFAS Extension
UNIVERSITY of FLORIDA

Nutrition of Florida Citrus Trees, 3rd Edition

Edited by Kelly T. Morgan and Davie M. Kadyampakeni

UNIVERSITY OF FLORIDA INSTITUTE OF FOOD AND AGRICULTURAL SCIENCES EXTENSION, Dr. Nick Place, Director, in cooperation with the United States Department of Agriculture, publishes this information to further the purpose of the May 8 and June 30, 1914 Acts of Congress; and is authorized to provide research, educational information, and other services only to individuals and institutions that function with non-discrimination with respect to race, creed, color, religion, age, disability, sex, sexual orientation, marital status, national origin, political opinions, or affiliations. This information was published March 2020 as Bulletin no. SL253, UF/IFAS Extension.

Dedication

The first edition of this publication was dedicated to emeritus citrus research scientists Drs. Robert C. J. Koo, Ivan Stewart, and Herman Reitz, UF/IFAS Citrus Research and Education Center, Lake Alfred and Paul Smith, USDA-Agricultural Research Service, Orlando. Their research contributions laid the foundation for citrus nutrition programs in Florida. The editors of the second edition dedicate it to an additional group of emeritus citrus research scientists, extension specialists, and educators: Drs. David P. H. Tucker, Larry K. Jackson, and T. Adair Wheaton, UF/IFAS CREC-Lake Alfred; Dr. David V. Calvert, Indian River Research and Education Center, Ft. Pierce; and Dr. Heinz Wutscher, USDA-ARS, Orlando. The second edition was edited by Drs. Thomas Obreza (professor, Department of Soil and Water Sciences in Gainesville, then and now Senior Associate Dean of Extension) and Kelly Morgan (assistant professor, UF/IFAS Department of Soil and Water Sciences, UF/IFAS Southwest Florida Research and Education Center-Immokalee then, and now center director and professor). Their many years of devoted service furthered our knowledge of nutrient management as the Florida citrus industry entered the era of Best Management Practices and started contending with emerging threats including citrus greening, or huanglongbing.

Contributing Authors

L. Gene Albrigo	UF/IFAS Citrus Research and Education Center
Fernando Alferez	UF/IFAS Southwest Florida Research and Education Center
Brian J. Boman	UF/IFAS Indian River Research and Education Center
Mary E. Collins	UF/IFAS Department of Soil and Water Sciences
James J. Ferguson	UF/IFAS Horticultural Sciences Department
Rhuanito Ferrarezi	UF/IFAS Indian River Research and Education Center
Stephen H. Futch	UF/IFAS Extension Multi-County Citrus
Jim Graham	UF/IFAS Professor Emeritus
Said Hamido	UF/IFAS Southwest Florida Research and Education Center
Edward A. Hanlon	UF/IFAS Southwest Florida Research and Education Center
Evan Johnson	UF/IFAS Citrus Research and Education Center
Davie M. Kadyampakeni	UF/IFAS Citrus Research and Education Center
Kelly T. Morgan	UF/IFAS Southwest Florida Research and Education Center
Thomas A. Obreza	UF/IFAS Department of Soil and Water Sciences

Lawrence R. Parsons	UF/IFAS Citrus Research and Education Center
Arnold W. Schumann	UF/IFAS Citrus Research and Education Center
Tripti Vashisth	UF/IFAS Citrus Research and Education Center
Mongi Zekri	UF/IFAS Extension Multi-County Citrus

With Additional Contributions by

Ashok K. Alva	US Department of Agriculture—Agricultural Research Service
David V. Calvert	UF/IFAS Indian River Research and Education Center (retired)
Frederick S. Davies	UF/IFAS Horticultural Sciences Department (retired)
Larry K. Jackson	UF/IFAS Horticultural Sciences Department (retired)
David P. H. Tucker	UF/IFAS Citrus Research and Education Center (retired)
T. Adair Wheaton	UF/IFAS Citrus Research and Education Center (retired)
Heinz Wutscher	US Department of Agriculture—Agricultural Research Service (retired)

Acknowledgements

The editors gratefully acknowledge the reviewers of the second edition of publication (Mark Colbert, Fred Davies, Hugh English, John Jackson, Chris Oswalt, Mark Ritenour, Steve Smith, Jerry Southwell, Jack Zorn, and all contributing authors) for their time, effort, and suggestions for improvement. The editors are also grateful to the contributions of the reviewers of the third edition, including Dr. Tripti Vashisth, Ms. Laurie Hurner, and Mr. Chris Oswalt.

Funding provided by the Florida Department of Agriculture and Consumer Services to print this document is also gratefully acknowledged.

Table of Contents

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 1. Introduction[1]

Thomas A. Obreza and Kelly T. Morgan[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For references, a glossary, and appendices, please refer to the full document at https://edis.ifas.ufl.edu/ss478.

> The information provided in the 2008 2nd edition is still sound for healthy citrus trees under Florida production conditions. Much of the information provided in this document on nutrients, application methods, leaf and soil sampling, and irrigation scheduling are also effective for huanglongbing (HLB) affected citrus trees. However, research conducted since HLB was detected in Florida in 2005 has established changes in many production practices, including nutrient rates, irrigation scheduling, soil pH management, and use of Citrus Under Protective Screen (CUPS). Changes to the 2nd edition of SL253 will appear in boxes similar to this one at the beginnings of chapters 2, 6, 8, 9, and 11.

Preface

This publication is the second edition of UF/IFAS Bulletin SP169, which has provided guidelines for Florida citrus fertilization since 1995. The objective of the original edition was to provide background information and recommendations to develop a sound citrus nutrition program that will optimize financial returns while sustaining yields and maintaining soil and water quality. The objective of this publication is to incorporate the findings of numerous citrus nutrition research projects conducted during the past decade.

These updated guidelines reflect changes in fertilizer recommendations that have occurred as the Florida citrus industry has entered the era of Best Management Practices (BMPs). In addition to the original chapters, this publication has added chapters on 1) production areas and soil characteristics, 2) using precision agriculture to manage citrus nutrition, 3) irrigation and nutrient management, and 4) environmental issues and BMPs.

Supplemental information on subjects related to citrus nutrition appears in extensive appendices. Color plates depicting nutrient deficiencies and toxicities and a key to mineral deficiency symptoms in citrus are included to aid in visual analysis of tree nutritional status.

Nutrition of Florida Citrus Trees—a Historical Perspective

To maintain a viable citrus industry in Florida, growers must be able to economically produce large, high-quality fruit crops. Prior to the establishment of UF/IFAS and USDA research programs, high production was not possible because citrus nutritional requirements were poorly understood. Early classical studies by Michael Peech and T. W. Young showed that Florida's sandy soils had very low capacity to hold nutrients and water.

1. This document is SL455, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Thomas A. Obreza, professor and senior associate dean for Extension, Department of Soil and Water Sciences; and Kelly Morgan, professor and center director, Department of Soil and Water Sciences, UF/IFAS Southwest Florida Research and Education Center; UF/IFAS Extension, Gainesville, FL, 32611. Includes contributions from David P. H. Tucker, professor emeritus, and Larry K. Jackson, professor emeritus, Horticultural Sciences Department.

The first commercial citrus growers had some understanding of the need for the macronutrients nitrogen (N), phosphorus (P), and potassium (K). Nitrogen was generally applied using natural organic sources like farm animal manure and bird guano. Some mineral N was mined and imported from Chile. Phosphorus was obtained from local mines, and K was imported from Germany.

Meanwhile, worldwide studies demonstrated that plants needed elements in addition to N, P, and K in order to grow properly. In 1939, A. F. Camp and B. R. Fudge showed that secondary and micronutrients were needed to grow citrus on Florida soils. Included were examples of deficiency symptoms of copper (Cu), zinc (Zn), manganese (Mn), magnesium (Mg), boron (B), and iron (Fe). They indicated how each of the above element deficiencies could be corrected with the exception of Fe. At that time, there was no known satisfactory fertilizer source of this element.

Other elements were later found to be necessary for Florida citrus. The problem of yellow spot disease was first reported in 1908. This disease was rather widespread and caused extensive defoliation and tree death. In 1951, Ivan Stewart and C. D. Leonard reported this problem was due to molybdenum (Mo) deficiency that could be corrected by a spray application of as little as 1 oz of sodium molybdate/acre.

Calcium (Ca) is commonly thought of as a soil amendment and is usually applied as lime. However, when W. F. Spencer and R. C. J. Koo planted citrus on new land at the Citrus Experiment Station (now the UF/IFAS Citrus Research and Education Center) in Lake Alfred, they did not add Ca to some of the plots, which resulted in stunted trees that showed leaf symptoms specific to Ca deficiency.

Copper (Cu) deficiency of citrus limited growth and fruit production in many early Florida groves. Following discovery of this problem, high rates of Cu were applied to trees in both foliar sprays and soil applications. Later, I. W. Wander and co-investigators found that Cu was not taken up in abundance by the trees, nor did it leach like many other fertilizer elements, which resulted in its accumulation in the surface soil.

Copper accumulation interfered with Fe uptake by citrus trees, causing leaf chlorosis and defoliation. By 1951, many trees were being removed due to this problem. Stewart and Leonard found that when organically chelated Fe (Fe-EDTA) was applied to the soil, yellow leaves on Fe-deficient trees re-greened.

While S is essential for citrus, its deficiency has not been reported in Florida, because it has been supplied through pesticide sprays and dusts, fertilizer components, irrigation water, and rainfall.

In 1954, the first Florida citrus fertilizer recommendations were made by a joint effort of UF/IFAS Citrus Research and Education Center and USDA Horticultural Laboratory scientists. Based on data accumulated from many years of experiments, Bulletin 536 was published. This bulletin was revised three times and for 41 years was the comprehensive guide for citrus tree nutrition. Rates and sources of eleven essential fertilizer elements were recommended based on results from field experiments.

In the 1960s, UF/IFAS CREC faculty recommended that growers change to high-analysis fertilizers, thus eliminating much of the filler. By so doing, a great deal of the mixing cost was eliminated and transportation and application cost reduced. Further reductions in costs were made when Spencer and Stewart reported that P applied to established groves had not leached but had accumulated in an available form, resulting in reduced P application rates to established groves. Finally, the use of minor elements was recommended only when deficiency symptoms persisted.

Numerous N rate and timing studies were conducted by UF/IFAS and USDA scientists for many years, covering a wide range of soil types, tree ages, varieties, rootstocks, and cultural conditions. The results showed N rates in excess of 200 lb/acre were justified only for very productive groves. In addition, Stewart and Leonard demonstrated that excess N could reduce yield. Maximum production may vary greatly depending on other limiting conditions, but fertilizer N requirements remain similar for a range of production levels and conditions. As a result of these findings, Bulletin SP169 was published in 1995 by D. P. H. Tucker, A. K. Alva, L. K. Jackson, and T. A. Wheaton. This bulletin de-emphasized projected yield or yield goal as the basis to determine mature citrus grove N fertilizer rates in favor of an N rate maximum capped at 200 lb/acre for typical groves and 240 lb/acre for "exceptional" groves (defined as groves producing 700 or more boxes/acre annually).

Florida Enters the BMP Era

In the late 1980s, the Florida Department of Environmental Protection (FDEP) surveyed drinking water quality across the state and detected nitrate-N in 63% of the wells tested. The nitrate-N concentration in 15% of the wells was greater than the EPA drinking water standard of 10 ppm. A large majority of the high-nitrate wells were located in Lake, Polk, and Highlands counties, the heart of Florida's central Ridge citrus production area.

Although the influence of citrus N fertilization on groundwater nitrate concentration was unknown, the combined circumstances of large citrus acreage, relatively high annual N fertilization rates, high annual rainfall, and extremely inert, porous soils led the Florida Department of Agriculture and Consumer Services (FDACS) to implement a set of voluntary BMPs for N fertilization of Ridge citrus trees designed to protect water quality. These were the first official nutrient BMPs for Florida citrus production. A grower implementing the program receives a presumption of compliance with water quality standards from FDACS.

Subsequently, citrus production BMP manuals were written for the Indian River, Peace River, and Gulf production areas, and grower implementation is now taking place. These BMPs go beyond nutrient management to include irrigation and drainage management, erosion prevention, pesticide use, and aquatic weed control. Essentially the entire commercial citrus industry in Florida now has access to a voluntary BMP umbrella. Producing citrus under BMP implementation allows a grower to farm profitably without the threat of administrative penalties if groundwater standards are violated.

This publication provides an understanding of concepts and issues of nutrition that can address environmental issues and concerns about profitability of Florida citrus in a highly competitive global market.

UF | IFAS Extension UNIVERSITY of FLORIDA

SL456

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 2. Production Areas, Soils, and Land Preparation[1]

Thomas A. Obreza, Mary E. Collins, Kelly Morgan, Jim Graham, and Fernando Alferez[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For references, a glossary, and appendices, please refer to the full document at *https://edis.ifas.ufl.edu/ss478*.

Information in the box below applies to citrus trees affected by HLB. Other information in this chapter is valid for healthy citrus trees and trees with HLB.

Recommendations for HLB-affected trees:

Soil pH Management—Kelly Morgan, Jim Graham, and Fernando Alferez.

Because HLB symptoms worsen in groves irrigated with wells and surface water containing dissolved bicarbonates, pH management should be adopted to maintain pH in the same 6.0–6.5 range. This is because high pH reduces availability of Ca, Mg, Fe, Zn, and Mn. In groves with high bicarbonate levels, feeder root density and root lifespan decrease and function in nutrient uptake is reduced. However, not all rootstocks are equally sensitive; Swingle is the most sensitive. Soil and water quality should be managed by a frequent application of water and nutrients to the reduced root system by the effect of HLB. This can be achieved by water conditioning with N-phuric acid or sulfuric acid, or by soil conditioning with sulfur in the wetted zone, where microjet irrigation concentrates bicarbonates. More detailed information is given in chapters 8 and 9.

With HLB incidence close to 100% in Florida, efforts should be made to make nutrients more available to the weakened root system, and for this, pH should be maintained between 6.0 and 6.5. This ultimately would result in reduction of stress on feeder roots and would increase nutrient uptake and root longevity with improved color and vigor in foliage.

Soil Organic Matter Management—Fernando Alferez

Because of its benefits to soil fertility and its increased availability since the mid-1990s, organic matter addition has become more practical. This is especially true in the case of HLB-affected trees. In poor and depleted soils that are low in organic matter, addition of compost has clear benefits: soil structure improvement, higher water- and nutrient-holding capacity, an additional nutrient source, decreased soil erosion, insulating properties against heat and cold, buffer soil pH, good aeration (which results in better root growth), and an increase in populations of beneficial microorganisms and earthworms.

1. This document is SL456, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Thomas A. Obreza, professor and senior associate dean for Extension, Department of Soil and Water Sciences; Mary E. Collins, professor emeritus, Department of Soil and Water Sciences; Kelly Morgan, professor and center director, Department of Soil and Water Sciences, UF/IFAS Southwest Florida Research and Education Center; Jim Graham, professor emeritus, Department of Soil and Water Sciences, UF/IFAS Citrus REC; and Fernando Alferez, assistant professor, Horticultural Sciences Department, UF/IFAS SWFREC; UF/IFAS Extension, Gainesville, FL 32611. Includes contributions from Larry K. Jackson, professor emeritus; Ashok K. Alva, US Department of Agriculture–Agricultural Research Service; David P. H. Tucker, professor emeritus; and David V. Calvert, professor emeritus.

Composting can be an important part of a Best Management Practices program to minimize N and P losses because it has the potential to enhance root health by providing a complex, slow release carbon source to feed beneficial soil microorganisms. Compost can be applied any time after the trees are established. However, the best benefits will be achieved when composting is done as a part of the land preparation. If trees are already planted, composting should be done at shallow depth to avoid root damage.

General Information

Florida soils are not particularly favorable for management of water and agrichemicals. Most Florida citrus is grown on naturally infertile soils that are unable to retain more than a minimal amount of soluble plant nutrients against leaching by rainfall or excessive irrigation. Florida citrus soils range from well-drained Entisols on relatively high, rolling landscapes to poorly drained Alfisols and Spodosols on low-lying Flatwoods (Figure 1). The root zones of these soils are dominated by sand and contain only minor quantities of silt, clay, and organic matter, which make the management of water and nutrients a challenging task for grove managers.

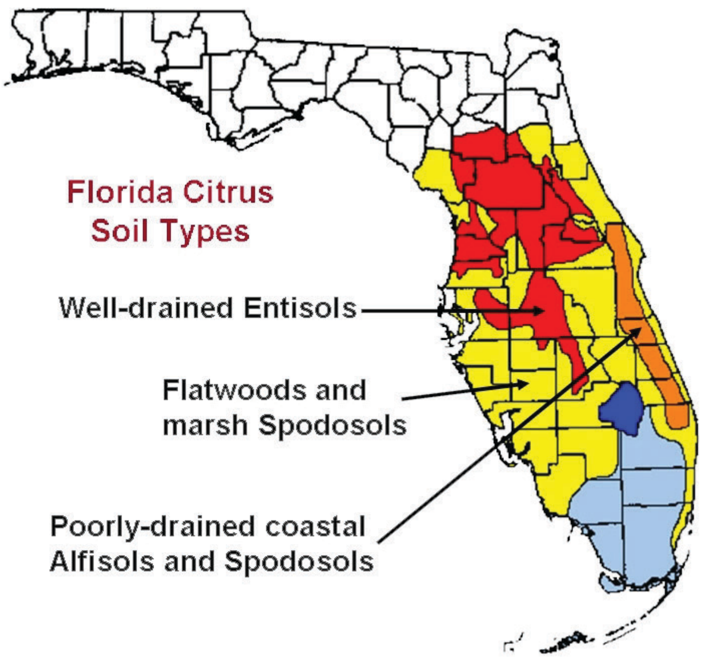

Figure 1. Distribution of soil types planted to citrus in Florida.

Well-drained soils are found through the central part of the Florida peninsula as far south as Highlands County on the central Florida Ridge. Their main advantages are good drainage, good aeration, and a deep root zone. The main disadvantage is the need for frequent irrigation during dry periods. Soil uniformity, lack of hardpan, and a low water table allow for deep, extensive root systems. Such an extensive rooting zone enables the tree to overcome the low water- and nutrient-holding capacity of these soils to some extent.

Poorly drained soils are found in coastal areas and on the Flatwoods of central and south Florida. The soils on the east coast usually are naturally acidic with a subsurface hardpan, but some may have marl or shell in the profile that makes them alkaline. The water table is close to the surface and the soil may pond during the wet season. These soils must be drained and bedded before planting citrus. Their principal advantages are higher natural fertility and water-holding capacity. Disadvantages include poor drainage and increased alkalinity or clay content of the surface layer due to deposition of subsurface materials over the natural surface during the bedding process.

Characteristics of Soil Orders Important to Florida Citrus Production

A soil order is the most basic category of soil classification and gives a general idea about some of the physical and chemical characteristics of a soil. For Florida citrus soil orders, characteristics important to production are described below.

- Entisols are sandy mineral soils low in organic matter, natural fertility, and water-holding capacity (Figure 2). They have weak or no diagnostic subsurface layers and are well to excessively well drained.

Figure 2. Candler sand, an Entisol, with surface (A) and subsurface (E) horizons.
Credits: Mary Collins, UF/IFAS

- Spodosols are sandy mineral soils low in organic matter and natural fertility in the surface layer (Figure 3). They contain an acidic subsurface restrictive layer composed of aluminum and iron "cemented" together with organic matter.

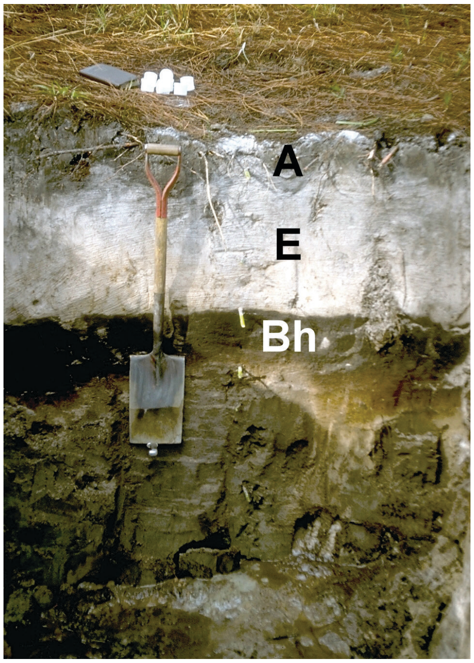

Figure 3. Myakka sand, a Spodosol, with surface (A), leached (E), and restrictive (Bh) horizons.
Credits: Mary Collins, UF/IFAS

- Alfisols are sandy mineral soils low in organic matter in the surface layer but higher in relative natural fertility compared with Spodosols (Figure 4). They contain a subsurface layer of loamy material (a mixture of mostly clay and sand with little silt) that has a relatively high water-holding capacity.

Soil Series Typically Found in Citrus Groves

A soil series is the most specific category of soil classification. There are 15 soil series that represent most of the soils on which Florida citrus groves have been planted (Table 1). Entisols (other than Basinger) occur on high Ridges and upland plains at an elevation greater than 100 ft above mean sea level in the central Ridge production area. Alfisols, Spodosols, and the Basinger series occur on broad, low flat areas or in sloughs at elevations from 10 to 40 ft in the Gulf and Indian River production areas, and 35 to 100 ft in the Peace River production area. Some Alfisols and Spodosols can also occur in depressional areas, even though they are normally located higher on the landscape.

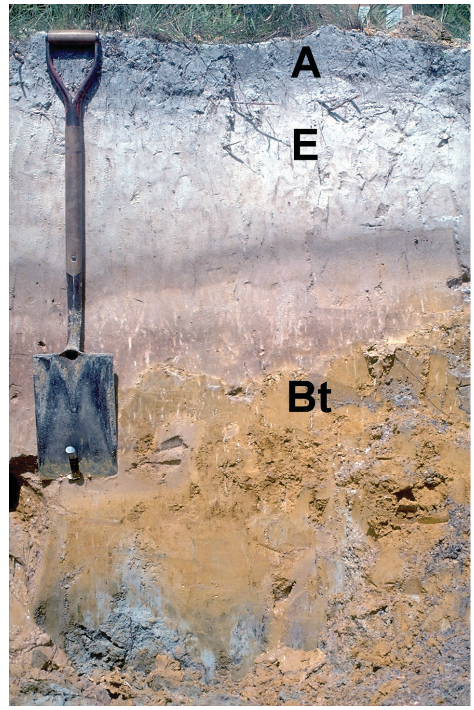

Figure 4. Riviera sand, an Alfisol, with surface (A), leached (E), and restrictive (Bt) horizons.
Credits: Mary Collins, UF/IFAS

Table 1. Common soils used for citrus production in Florida.

Series	Drainage	Typical Location (Counties)
----------------------------- Entisols -----------------------------		
Astatula	Excessive	Polk, Highlands
Basinger	Poor	Highlands
Candler	Excessive	Polk
Tavares	Moderate	Polk
------------------------------ Alfisols ------------------------------		
Boca	Poor	Hendry, Collier
Holopaw	Poor	Hendry
Pineda	Poor	St. Lucie, Indian River, Martin, Collier
Riviera	Poor	St. Lucie, Indian River, Martin
Winder	Poor	St. Lucie, Indian River
---------------------------- Spodosols ----------------------------		
Immokalee	Poor	Hendry, Collier, DeSoto
Myakka	Poor	DeSoto, Hardee, Highlands
Oldsmar	Poor	Hendry, Collier
Pomona	Poor	Hardee
Smyrna	Poor	DeSoto, Hardee
Wabasso	Poor	St. Lucie, Indian River, Martin

Soil Physical and Chemical Properties Important to Citrus Nutrient Management

The soil on which citrus is grown greatly influences how irrigation water and nutrients should be managed to maximize production, minimize resource use, and protect water quality. Soil properties important to nutrient management include texture, water-holding capacity, organic matter content, soil pH, cation exchange capacity, and coatings on sand grains (see Appendix A).

- Soil texture is the relative proportion of sand, silt, and clay in a mineral soil. Texture influences how much water a soil can hold against drainage by gravity and how quickly water will drain away. Most citrus soils contain 94% to 98% sand in the root zone, which makes irrigation water management extremely difficult because sand has little capacity to hold water. If too much irrigation water is applied at one time, the excess will be lost below the root zone, which can induce nutrient leaching.
- Soil organic matter includes any organic carbon-based material, from freshly deposited plant residues to highly decomposed humus or compost. In their native state, typical citrus soils may contain as much as 5% organic matter, but after a grove is planted organic matter decreases, eventually stabilizing around 1% or 2% by the time the grove matures. In general, the more chronically wet a citrus soil is, the higher its organic matter content tends to be. Soil organic matter is rapidly lost by oxidation to carbon dioxide in Florida's warm and humid climate, and it is not replaced in large quantities by citrus trees. Use of herbicides beneath tree canopies also decreases organic matter accumulation. In a sandy soil, organic matter is an extremely valuable component because it provides both water- and nutrient-holding capacity, and its decomposition provides recycled nutrients to plants.
- Soil water-holding capacity is directly related to the amount of silt, clay, and organic matter present. Because most Florida citrus soils contain only small amounts of these components, water-holding capacity is rarely greater than 1 inch per foot of soil depth, and is often less than 0.75 inches per foot. Low water-holding capacity soils require light and frequent irrigation to minimize nutrient leaching.
- Soil pH affects the availability of plant nutrients, including P, Ca, Mg, and the micronutrients. Most Florida soils are acidic in their native state, so they require lime applications before planting and every few years thereafter, depending on fertilizer and irrigation water sources. The optimum soil pH range for citrus is 6.0 to 6.5. The pH of Florida citrus soils can change rapidly as a result of chemical reactions caused by lime or fertilizer applications. An exception to this tenet is a calcareous soil. Some of the Alfisols in Table 1 can be calcareous due to a substratum of natural calcium carbonate rock or shell that dominates their chemistry. The pH of a calcareous soil remains relatively constant around 8.2.
- Cation exchange capacity (CEC) is a measure of the ability of the soil to hold positively charged nutrients like Ca, Mg, K, and ammonium-N (NH_4^+) against leaching (Figure 5). Generally speaking, as CEC increases, soil fertility increases. Soil CEC is supplied by clay and organic matter. Florida citrus soils are low in CEC, so nutrient management is difficult. The best fertilizer use efficiency can be obtained by applying mobile nutrients like N and K frequently in small doses, similar to irrigation water. Entisols are the least fertile citrus soils, followed by Spodosols and Alfisols. The increased fertility of Spodosols reflects their slightly higher organic matter content, while the fertility of Alfisols is greatest because they contain some clay as well as organic matter.

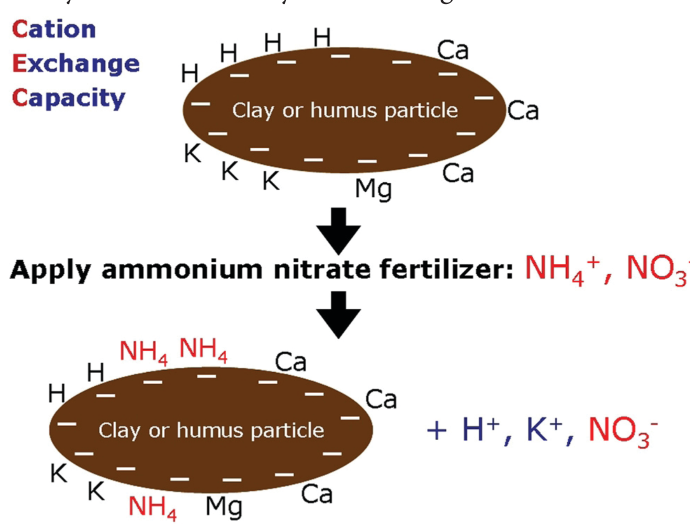

Figure 5. Example of the cation exchange reaction that occurs when a soil is fertilized with ammonium nitrate.

- Coated and noncoated sands relate to the P fixation capacity of Florida soils, which is important because the movement of P from agricultural fields to surface water bodies has become an environmental concern. Most soils nationwide have a moderate to high capacity to adsorb or hold soil P against leaching because they contain considerable quantities of silt and clay that provide a chemical mechanism to bind P. Florida soils dominated by quartz sand lack appreciable amounts of these silts and clays. However, in many cases the sand particles are coated with iron and/or aluminum compounds that also have some capacity to adsorb P.

One way to judge if coated sand grains are present is to observe the soil color (Figure 6). Yellow, orange, or brown sand is more likely to be coated, while bright white sand is not. Therefore, citrus groves on soils containing coated sands have the ability to build up a soil P reserve following P fertilizer applications. The presence of this P reserve can be determined with soil testing, and P fertilization should be curtailed if high soil test P is found. Conversely, citrus groves on noncoated sandy soils lack the ability to hold P. In this case excessive P fertilization may induce P leaching, so P fertilizer should not be used indiscriminately because it may be lost to the environment.

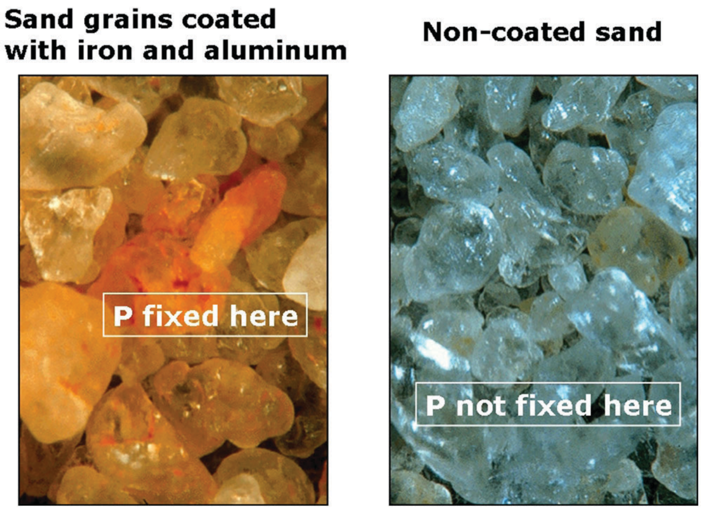

Figure 6. Coated and noncoated sand grains.

Vulnerable Soils

The presence of fertilizer and agricultural chemicals in groundwater has become an issue in a number of agricultural production areas around the world. More than half of the total fresh water used in Florida comes from groundwater, and more than 90% of the public relies on groundwater supplies for drinking.

Of all fresh water withdrawn in Florida, one-third is consumed and two-thirds is returned to the groundwater. The quality of this water is important because it may come in contact with soluble nutrients, pesticides, or heavy metals prior to returning to the surficial aquifer or flowing off site. Florida's unique hydrogeologic features, including a thin surface soil layer, high water table, and porous limestone in many areas, make the soil susceptible to downward movement of nutrients. Soils used for citrus production on the central Ridge are particularly subject to leaching and are referred to as *vulnerable* soils (Figure 7). These soils are well drained with low organic matter and provide ideal conditions for leaching of plant nutrients, including soil-applied N fertilizer. Removal of N by denitrification is minimal in these soils.

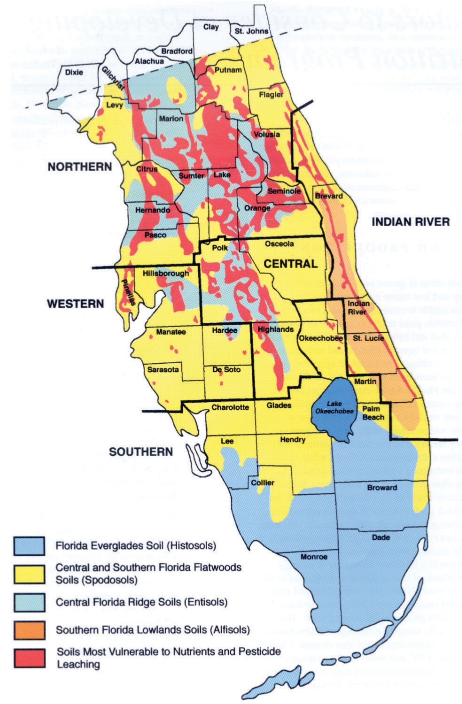

Figure 7. Approximate location of vulnerable soils in citrus production regions. See Table 2 for a list of vulnerable soil series.
Credits: James Turk and Juan Vega, USDA-NRCS, Gainesville

The soils in Table 2 have been categorized by the Florida Department of Agriculture and Consumer Services (based on USDA-Natural Resource Conservation Service information) as highly permeable and well drained and, therefore, at risk in terms of groundwater contamination through agrichemical leaching. Although such soils dominate throughout the Ridge citrus production area, many are scattered throughout other Florida citrus producing areas. Consult your local NRCS office or county soil survey to determine if a grove contains one or more vulnerable soils. County soil surveys can be viewed on the NRCS website at http://websoilsurvey.nrcs.usda.gov/app/.

Table 2. Soil series classified as vulnerable to nutrient leaching.

Adamsville	Dade	Palm Beach
Archbold	Florahome	Paola
Astatula	Fort Meade	Satellite
Bahiahonda	Gainesville	St. Augustine
Broward	Lake	St. Lucie
Canaveral	Lakewood	Tavares
Candler	Neilhurst	Orsino
Cocoa	Orlando	

Grove Site Selection and Land Preparation

When developing a grove site, it is important to determine general soil fertility by testing the soil for pH, organic matter, and Mehlich 1 (double-acid) extractable P, Ca, and Mg. If the site has been previously used to grow citrus or vegetables, extractable Cu concentration should also be checked.

If the soil is found to be acidic (pH 5.3 or less), the pH should be raised to the 5.5 to 6.5 range by adding lime. The higher target pH should be used for soils with Mehlich 1–extractable Cu greater than 25 mg/kg (ppm).

Renovating old Flatwoods groves by rebedding and ditching can have profound effects on fertility, water relations, and tree rooting volume. Often the renovation is beneficial, but problems may occur in some cases if high pH materials or clay are brought up into the rooting zone. An increasingly important factor to consider, especially in the HLB era, is drainage. Although this is not an issue in central Florida sandy soils, in the eastern and southwestern production areas of the state, drainage systems are required. Examples of these drainage systems are water furrows, ditches, and tile drains, combined with raised beds. Because most Flatwood soils have a restrictive layer that may affect tree water relations by perching the water table, this should be monitored frequently for adopting adequate irrigation and drainage decisions.

Effects of Leveling and Bedding on Soil Fertility in Flatwoods Citrus Groves

In contrast to central Ridge citrus groves that are planted along the natural contour of the land, Flatwoods grove sites must be leveled, slightly sloped, and bedded before planting to provide artificial drainage. The topsoil of native Alfisols and Spodosols is no more than 6 to 8 inches thick. Below this layer is the first subsoil layer, which is usually white or light gray sand that is extremely low in fertility and water-holding capacity. Occasionally, land leveling removes all of the topsoil from a higher part of the field and transports it to a lower part, leaving the light-colored sandy subsoil as the new surface (Figure 8). Citrus tree growth and production in these areas (commonly referred to by Flatwoods citrus growers as scraped areas or sand ponds) is usually poor.

Figure 8. Effect of leveling a Flatwoods citrus site on topsoil (A horizon) thickness. Note the thick, dark topsoil on the left and lack of same on the right.
Credits: Mace Bauer, UF/IFAS

After leveling, soil beds are constructed by cutting parallel wide and shallow V-shaped furrows about 50 ft apart. The soil removed from these furrows is shaped into a convex bed between them on which the citrus trees are planted. The vertical distance from the bottom of the furrow to the top of the bed is usually about 2 to 3 feet. When constructing beds, the original soil surface is covered by subsoil that may have significantly different physical or chemical characteristics than the surface soil. The overburden soil can be either coarser or finer-textured than the surface soil, but it is almost always lower in organic matter. If the soil series has limestone in the profile, the overburden may be calcareous. Therefore, the root zone soils in bedded groves are often less fertile and lower in water-holding capacity compared with the buried original surface layer.

The restrictive subsurface layer in Flatwoods soils can affect citrus production in two ways. If it is relatively deep, it remains intact after bedding and will impede downward water percolation. Citrus rooting can be affected by this layer due to its influence on shallow water table depth and duration. Typically, almost all Flatwoods citrus roots reside in the top 18 inches of soil due to the effect of the restrictive layer.

Some Flatwoods soils have relatively shallow restrictive layers that can be excavated during the bedding process, so these subsurface materials are sometimes mixed into the root zone. The chemical and physical properties of a restrictive layer differ substantially from the sandy surface layer (Appendix A). Material from a loamy (Bt) layer is higher in clay, while a sandy dark red, brown, or black (Bh) layer is higher in organic matter. Loamy layers can be either acidic or alkaline in pH, while organic-stained layers are always highly acidic. In addition, water-holding and cation exchange capacities are higher in restrictive layers. The magnitude of influence that soil from these layers might have on root zone soil properties is directly related to the amount of material that was excavated and mixed in during bedding.

Soil pH and Liming

Soil pH measures soil acidity or alkalinity and is used to make liming decisions. Soil pH measurement is quick, easy, and inexpensive. Soil pH control is important because the availability of most plant nutrients, as well as of those nutrients that are toxic to plants, is affected by it. If soil pH is too low, the Adams-Evans Buffer pH test determines the rate of lime needed to raise it to 6.5.

Irrigation water from Florida's deep aquifers frequently contains dissolved limestone that can slowly raise soil pH. Higher soil pH is particularly evident in the areas wetted by microirrigation emitters. Florida soils vary considerably in Ca content. The majority of soil Ca exists as sparingly soluble minerals, including Ca-phosphates and Ca-carbonate. Calcium must dissolve from these compounds to become plant-available. Florida's coarse-textured soils are low in Ca because they are mostly quartz sand. On the other hand, calcareous soils are extremely high in Ca. Calcium in soils may be classified as non-exchangeable (mineral forms), exchangeable (adsorbed to clay or organic matter colloids), or soil solution Ca. Exchangeable Ca is the major Ca reserve in soils that is available to plant roots. Calcium availability is largely a factor of the supply in the soil.

The target pH of 6.0 for Florida citrus production is based on a study of pH and Ca interactions conducted on a Ridge soil (Candler fine sand). A clear advantage of pH 6.0 over pH 5.0 was evident, and pH 7.0 was no better than pH 6.0 at all Ca concentrations. Therefore, if a soil test does not show excessive Cu accumulation, a soil pH of 6.0 is sufficient for citrus production. Soil pH should be raised to 6.5 when soil tests show a buildup of Cu.

Soil pH can be increased by applying either calcitic or dolomitic lime. In addition to affecting soil pH, calcite is an effective source of Ca, whereas dolomite supplies both Ca and Mg. Therefore, although either calcite or dolomite could be effectively used for citrus production, the choice of dolomite would be more appropriate for soils that also require Mg.

In groves with favorable soil pH but low soil Ca, gypsum can be used as a source of available Ca. In most bearing groves, soil pH is generally above 6.0, so liming would not be required. Gypsum is an alternate source of Ca with no effect on soil pH. Although the application of dolomite can alleviate Mg deficiency, tree response is usually slow. Application of dolomite as a source of Mg is not recommended if the soil pH is in the desired range. Under this condition, applying $MgSO_4$ or MgO to the soil or $Mg(NO_3)_2$ as a foliar spray can correct Mg deficiency.

The current soil pH recommendations for nonbearing and bearing citrus take into account: 1) higher pH soils now in production, 2) the high pH of groundwater used for irrigation, 3) greater use of rootstocks like Swingle citrumelo that grow poorly in high pH soils, and 4) widespread field observations relating to increased blight incidence under higher pH and/or Ca soil conditions.

Organic Matter

As discussed earlier, organic matter is an extremely valuable component of sandy soils because it provides both water- and nutrient-holding capacity, and its decomposition provides recycled nutrients to plants. The opportunity to add imported organic matter to a citrus grove is greatest prior to planting because it can be more readily applied and incorporated into the soil where the tree rows will be located.

Florida citrus has been successfully grown for decades without external organic matter addition, so it historically has not been a necessary practice. However, because of its benefits to soil fertility and its increased availability since the mid-1990s, organic matter addition has become more practical. Florida landfills no longer accept horticultural waste, so some county waste disposal operations have turned to mulching or composting for disposal. These materials are usually provided to consumers at no cost other than transportation. Materials intended as mulches are not recommended for application to citrus groves as soil amendments because they may rob N from trees as they decompose. Finished compost is appropriate for immediate soil application, but mulch would need to be composted on site before it would be safe to incorporate it.

There is no particular target rate for composted organic matter application. A general rule is, some is better than none, and more is better than less. A grower's decision to apply organic matter should be based on the proximity of a suitable supply and the cost to transport, spread, and incorporate it. Because of the large volumes required for meaningful application rates (e.g., 10 to 50 tons/treated acre), uniform application of a lower rate across an entire grove is not recommended. Rather, the grower should identify the weaker soils in the grove and concentrate higher rates of organic matter application in those areas.

Ozores-Hampton et al. (1998) suggested optimum physical and chemical properties for compost applied to agricultural land:

- 35% to 55% moisture by weight.
- 50% or more organic carbon.
- pH between 5.0 and 8.0.
- 20% to 60% water-holding capacity by weight.
- Less than 6.0 dS/m soluble salts.
- 500 to 1000 lb/yd^3 fresh bulk density.
- Particle size passes 1-inch screen.
- 15:1 to 25:1 C-to-N ratio.
- No viable weed seeds.

Of these characteristics, the two most important are C-to-N ratio and soluble salts. Lower values of each indicate compost more favorable for application to a Florida citrus grove.

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 3. General Soil Fertility and Citrus Tree Nutrition[1]

Thomas A. Obreza, Mongi Zekri, and Stephen H. Futch[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For references, a glossary, and appendices, please refer to the full document at https://edis.ifas.ufl.edu/ss478.

Essential Nutrients

Seventeen elements are essential for the growth and functioning of green plants. Carbon (C), hydrogen (H), and oxygen (O), which make up about 95% of tree biomass, are provided by nature. C and O are taken up by leaves as carbon dioxide (CO_2) from the air, and they combine with H, taken up as water by the roots, to produce carbohydrates. Photosynthesis takes place in chlorophyll-bearing cells, using light as an energy source. Carbohydrates, together with proteins, fats, and other organic compounds derived from them, are the true plant foods. They are used to make new plant tissues and provide energy for growth and fruiting.

The other 14 mineral elements are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), zinc (Zn), manganese (Mn), boron (B), copper (Cu), molybdenum (Mo), chlorine (Cl), and nickel (Ni). Florida's sandy soils often do not contain a sufficient supply of these nutrients, so growers may need to provide them through fertilizer application.

When any essential element is in short supply, tree function is restricted. A severe shortage of an element typically produces a characteristic deficiency symptom exhibited by the leaves, which usually persists until the deficiency is corrected. Sometimes twigs and fruits may also exhibit characteristic symptoms. Sometimes two or three elements are deficient in varying degrees, resulting in confusing visual symptoms. Conversely, excessive amounts of some elements may be present in the soil and may prevent the tree from functioning properly. Visual symptoms and leaf and soil analysis are all useful to evaluate nutritional status.

Mineral nutrients are divided into macronutrients, which are elements that plants require in large amounts (N, P, K, Ca, Mg, S), and micronutrients, which are needed only in small amounts (Fe, Zn, Mn, B, Cu, Mo, Ni, Cl) (Table 1). The macronutrients are divided into two groups, primary elements (N, P, and K) and secondary elements (Ca, Mg, and S). Micronutrients are sometimes referred to as "minor" or "trace" elements, but these terms are misleading. For example, the role of Fe in plant metabolism should not be considered less important than the role of K. Iron deficiency can result in total crop loss, so its role is not a "minor" one, and it is not of minor importance. The difference between Fe and K is in the amount required by plants, so the use of the terms micro- and macronutrients is more appropriate.

1. This document is SL457, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Thomas A. Obreza, professor and senior associate dean for Extension, Department of Soil and Water Sciences; Mongi Zekri, Extension agent IV, UF/IFAS Extension Hendry County; and Stephen H. Futch, Extension agent IV (retired), UF/IFAS Citrus Research and Education Center; UF/IFAS Extension, Gainesville, FL 32611. Includes contributions from Larry K. Jackson, professor emeritus; Ashok K. Alva, US Department of Agriculture–Agricultural Research Service; David P. H. Tucker, professor emeritus; and David V. Calvert, professor emeritus.

Table 1. Relative essential mineral element composition of a 6-year-old 'Hamlin' orange tree (excluding Cl and Ni). (Derived from Mattos et al. 2003).

Element	No. of atoms relative to Mo
Mo	1
Cu	100
Mn	200
Zn	300
Fe	600
B	800
S	11,000
P	13,000
Mg	18,000
K	66,000
Ca	98,000
N	237,000

Macronutrients and Citrus Production

Nitrogen (N) is of primary importance in citrus production. It has more influence on tree growth, appearance, fruit production, and fruit quality than any other element. When N is in short supply, growth is limited and the foliage becomes pale green or yellowish in color. When N is supplied to bearing trees at sub-optimal rates for a long period of time, the trees adjust by recycling N from the oldest leaves into the new ones, and the old leaves are shed prematurely, leading to a thin canopy. Inside leaves that should function for up to 2 years or more are reduced to a life of 1 year or less. The green color of the remaining leaves may be nearly normal, but the canopy is hollow inside. Yield can be reduced somewhat, but the typical yield response curve (Figure 2) shows that a rather large decrease in N supply is required before yield is greatly decreased.

In cases of persistent N shortage, defoliation, fruit drop, and shoot death can occur. When N is present above visible deficiency, shoot growth and yield increase with increasing N supply up to an optimum N rate. A sufficient N concentration in the tree is required for maximum vegetative growth, flowering, and fruit yield. A high N concentration increases tree growth and may require increased applications of other elements, particularly K. Luxury consumption of N can lead to excessive vegetative growth at the expense of yield.

Phosphorus (P) is listed on a fertilizer label as P_2O_5, referred to as available phosphoric acid. Most sandy soils used to produce citrus contain sufficient residual P that accumulated from previous fertilizer applications. Phosphorus does not readily leach if the soil pH is 6.0 or higher, and the fruit crop removes very little (Table 3). Therefore, regular P fertilizer application is usually not necessary. Some previously noncultivated soils used for new citrus plantings are naturally low in P, so fertilizer P may be needed for several years.

Potassium (K) (also called potash) is listed on a fertilizer label as K_2O, and is important to yield, fruit size, and juice quality. Potassium does not accumulate to a great extent in sandy soils used to produce citrus, even with repeated fertilizer applications. Potassium deficiency is not common but may develop with high N rates and high fruit production. Too little K can slow vegetative growth and result in thinning of the topmost foliage. A deficiency reduces fruit number and size, increases fruit creasing, plugging, and drop, and decreases juice soluble solids, acid, and vitamin C content. A high K fertilizer rate does not increase cold hardiness of citrus trees.

Calcium (Ca) is the most abundant element by weight in citrus trees, residing mainly in the leaves. Ca is rarely deficient in a tree because occasional applications of $CaCO_3$ (lime) are used to control soil acidity and because Ca is present in irrigation water. Florida's alkaline soils have an abundance of Ca because they contain free limestone.

Magnesium (Mg) is needed to produce chlorophyll. A deficiency produces a characteristic chlorotic pattern and may cause premature defoliation. Seedy varieties may need more Mg than seedless ones because seeds store a large amount of Mg. Dolomitic limestone is often used to correct acidity and supplies slowly available Mg. Calcium is abundant in alkaline soils, which can be antagonistic to Mg uptake.

Sulfur (S) is utilized by citrus trees in an amount similar to P uptake. It is supplied with fertilizers including ammonium sulfate and sulfates of micronutrient metals. Sulfur is a major component of the soil organic fraction and becomes available to plants as organic matter decomposes. Sulfur is also present in some irrigation water sources. When S is deficient in a citrus tree, the symptom looks like N deficiency.

Micronutrients and Citrus Production

Iron (Fe) deficiency causes a chlorotic pattern that first appears on young shoots. It occurs in trees growing in alkaline soil, waterlogged soil, or very low organic matter soil (sand ponds). Other Fe deficiency problems have occurred where Cu is high in the soil.

Copper (Cu) deficiency causes conditions known as fruit corking, ammoniation, and dieback, which can be corrected by applying Cu fertilizer to the soil. Copper should not be included in fertilizer if foliar Cu sprays are used, or if a grove soil test shows sufficient Cu (see Chapter 4). For new plantings on previously noncultivated Flatwoods soils, Cu should be included in the fertilizer.

Zinc (Zn) deficiency symptoms are expressed in citrus trees as severe chlorosis where leaf tissue becomes nearly white, except for green veins. New leaves grow progressively smaller as the deficiency becomes more severe, and shoot internodes become shorter, causing a rosette effect. Severe Zn deficiency restricts growth and reduces fruit yield.

Manganese (Mn) deficiency produces a mild form of chlorosis on acidic, sandy soils. The "marl chlorosis" found on calcareous soils is the result of combined deficiencies of Mn and Zn, and sometimes Fe. A temporary mild deficiency pattern on new shoots is not detrimental to growth or fruiting of citrus trees. Corrective measures should only be taken in the case of persistent deficiency symptoms.

Boron (B) deficiency causes excessive fruit drop, gum formation on the outside of the fruit, and brown areas in the albedo and central axis. It sometimes occurs when growers use only high-analysis fertilizers (without micronutrients), or following a prolonged drought. Boron should be applied every year either as a soil or foliar application but not both.

Molybdenum (Mo) deficiency produces a symptom described as "yellow spot." Unlike other nutrients, Mo is less available in acidic soils than in slightly alkaline soils. Mo deficiency is rare in Florida. If it occurs, the soil usually has become undesirably acidic with time. Liming the soil is effective in relieving the deficiency.

Supplying Nutrients to Citrus Trees

A sufficient supply of essential nutrients is critical to nutrient management and sustainability. If a single element is below the critical availability level, crop growth and yield will fall even if the other elements are in sufficient supply. A balance of available nutrients is a key component to profitability because it allows for positive nutrient interaction. For example, in the case of N fertilization, a shortage of another nutrient could decrease N uptake, reduce N use efficiency, and increase the potential for N loss.

Soil application of macronutrients is favored over foliar application due to the high uptake demand by citrus trees. However, fertilizer applied to the soil is subject to various fates including leaching, runoff, and fixation to forms not available to plants. Solution fertilizers applied to the tree foliage are less prone to these losses, but only small quantities of nutrients can enter leaves. Foliar fertilizer application may be considered for nutrients including N, P, K, Mg, Zn, Mn, and B. It is especially useful when soil properties like high pH inhibit nutrient availability.

Foliar fertilizer application can reduce or eliminate soil applications of micronutrients since they are required in low amounts (Table 1). Foliar application is the fastest method of getting nutrients into plants over the short term when a nutritional deficiency is diagnosed, but it should not be relied upon for long-term tree nutrition unless the soil is calcareous (see Chapter 11).

Fertilization represents a relatively small percentage of the total cost of citrus production, but it has a large effect on potential profitability. Visual evaluation of nutritional status, soil and plant analysis, field history, production experience, and economics are all important guidelines to use when making fertilizer rate and source decisions.

Nutrient Behavior in Florida Soils

Plant nutrients exist in both organic and inorganic forms in soil. Organic forms are found in fresh plant residue, soil organic matter (humus), living soil organisms (e.g., bacteria and fungi), soil amendments (e.g., biosolids or compost), and synthetic organic materials (e.g., some N fertilizers). Organic materials are the key component of nutrient recycling. They are a stable storehouse of plant nutrients because they are not readily lost from the soil.

Nutrients associated with organic matter are not immediately plant-available, but are slowly released as the material is decomposed by soil microbes. The decomposition rate depends on the material's physical and chemical characteristics and the climate. Florida's warm and humid conditions are ideal for decomposition of almost any organic material, so organic matter does not typically accumulate in citrus grove soils. Nutrients are continuously released in inorganic form as decomposition proceeds. The recycling process is complete once these nutrients are taken up by growing plants. Many of the nutrients in citrus tree residues (dropped leaves, twigs, and fruit; dead roots) are returned to the tree in this manner.

Inorganic plant nutrients exist in solid form (minerals or precipitates), in adsorbed form (bonded to a solid phase material), on the cation exchange complex (Chapter 2, Figure 5), or in the soil solution. The ionic nutrient forms that plants use (Table 2) must dissolve, desorb, or exchange into the soil solution before they can be taken up. If the soil solution is not replenished with nutrients rapidly enough to satisfy plant demand, plant nutrition will be less than optimum.

In an intensive crop production system, fertilizers added to the soil supplement the natural nutrient supply and prevent nutrient deficiencies. Most fertilizers applied to citrus trees are inorganic minerals or soluble salts that quickly dissolve into plant-available (ionic) form. The soil can react with some of these ionic forms, rendering them unavailable to plants. In the absence of these reactions, nutrients may leach with water that percolates through the root zone. The general characteristics and behavior of nutrients in sandy Florida soils planted to citrus are outlined below.

Nitrogen

- 95% of the natural N that resides in the soil is associated with organic matter. Soil humus contains about 5% N. The N release from organic matter depends on how much is there and how fast the material decomposes. This release rate is fast enough to support plant growth in a natural landscape, but it is too slow for intensive agricultural production on sandy soils.
- Biological ammonification converts organic N to mineral N (NH_4^+). Ammonium is also a component of some mineral N fertilizers. Nitrification, which also depends on microbial activity, converts NH_4^+ to NO_3^- in days to weeks. Thus, soil solution N is dominated by nitrate, which is negatively charged. There is no mechanism to hold nitrate in the soil, so it leaches easily.
- Most of the N lost from soils is a result of N <u>loading</u> of the soil from fertilizer or animal waste application, followed by N <u>leaching</u> from the soil with excessive rainfall or irrigation.

Phosphorus

- P occurs naturally in some Florida soils as calcium phosphate minerals. These minerals can also slowly form following P fertilizer application. Soil phosphates are relatively insoluble, which can affect plant availability.
- If a soil has the capacity to adsorb, or “fix” P, then added P will accumulate in the root zone. Phosphorus fixation occurs when soluble P forms nearly insoluble compounds with Fe or aluminum (Al) at low pH, or Ca at high pH. The best P availability in these soils occurs around a pH of 6.5.
- Florida’s sandy soils may or may not have the capacity to hold applied P fertilizer, depending on the type of sand present. Sand coated with Fe or Al compounds can fix P in the root zone, while noncoated sand cannot (Chapter 2, Figure 6). If a soil is dominated by noncoated sand, P may leach.
- Adsorbed P can be transported via surface runoff (erosion), while soluble P can be transported via leaching. Phosphorus loss from the soil results from long-term **loading** of the soil with P from animal wastes or fertilizers, followed by **erosion** of soil and organic matter particles or **leaching**, depending on the soil.

Potassium

- Florida soils are naturally low in K, so intensive agricultural production requires the use of K fertilizer.
- The ionic form of K can be held by the soil cation exchange complex (Chapter 2, Figure 5), which delays leaching. However, Florida soils planted to citrus have naturally low cation exchange capacity in the root zone (Appendix A, Table 26), so K^+ leaches almost as readily as NO_3^-.
- K is not fixed in sandy soils and does not form insoluble compounds, so it is easily lost from the root zone. Thus, K fertilizer application is required every year in Florida citrus groves.

Calcium and Magnesium

- Ca and Mg exist as solid compounds in the soil (mostly in combination with carbonate or phosphate) and in ionic forms held by the cation exchange complex.
- Solid forms of Ca and Mg are sparingly soluble and can reside in the soil for many years if the pH is not too acidic. Dissolution is more rapid at low pH, which is the basis of the liming reaction.
- Because they are divalent cations, Ca and Mg dominate on the cation exchange complex, which limits their mobility in soil.

Sulfur

- 90% of the S that occurs naturally in soils is associated with organic matter. Soil humus contains about 0.5% S. Like N release, S release from organic matter depends on quantity and decomposition rate. Organic S release combined with S from other sources like rain or irrigation water usually provides this nutrient to plants fast enough even in intensive agricultural production.
- The plant-available form of sulfur (sulfate) is a negative ion, which makes it prone to leaching. Sulfate can be adsorbed by soils, but this reaction is stronger deeper in the soil profile than the main root zone.

- Calcium sulfate (gypsum) is a sparingly soluble compound that is applied as a long-term source of available Ca, but it also supplies S to plants.

Copper, Iron, Manganese, and Zinc

- These micronutrients form compounds that are only slightly soluble in sandy soils; thus, they are not mobile nutrients. Solubility increases somewhat as pH decreases (Figure 1), so it is important to not overlime a soil. At alkaline pH, some plants suffer micronutrient deficiencies due to almost total insolubility.

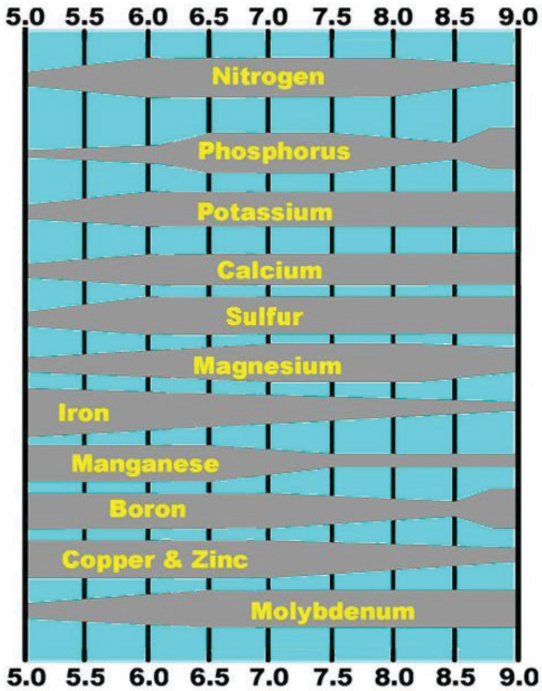

Figure 1. Effect of soil pH on nutrient availability. Nutrient movement in sandy soil is summarized in Table 2.

- If applied to the soil as soluble fertilizer, these micronutrients will precipitate near the soil surface.

Boron

- The plant-available form of B is negatively charged (borate), so it can easily leach from sandy soil.
- B needs to be applied regularly in Florida citrus groves, but there is a narrow range between deficiency and toxicity.

Molybdenum

- Mo is the only micronutrient that increases solubility as soil pH increases. Thus, it is an immobile nutrient within the soil pH range that is favored for citrus tree growth.

Citrus Nutrient Requirements

This section describes the typical citrus yield response curve and discusses nutrient requirements in relation to anticipated yield. Fertilizer rate guidelines for nonbearing and bearing trees are provided in Chapter 8.

The relationship between nutrient supply and yield of a wide variety of annual and perennial crops has been studied for decades. The relationship between plant response (yield) and fertilizer rate is called the yield response curve. The shape of this curve is similar for a range of crops and conditions.

The curves in Figure 2 illustrate how citrus yield increases with increasing N rate for two conditions. Fertilizer N is used in this example, but the nature of the response curve is similar for other limiting nutrients. At very low N rates there is a large yield response to each added unit of N. As yield increases, each additional unit of N results in a smaller increment in yield. This smaller response to increasing input is also referred to as the law of diminishing returns. The two response curves in Figure 2 compare the effect of N rate when other factors are not limiting and the response when yield is limited to one-half by a second factor. The shapes of the curves are similar, and the rate of N where the slope levels off is only slightly higher for the more productive grove.

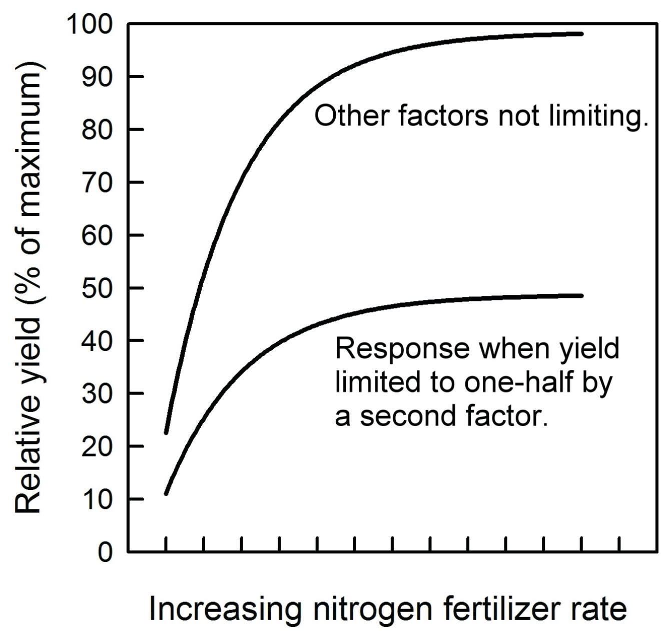

Figure 2. Generic response of citrus yield to N fertilizer rate.

The yield response curves shown never completely flatten out, indicating that ever higher N rates theoretically will produce small additional yield increases. Because fertilizer cost has traditionally been a small portion of total production cost, high N rates were commonly applied to produce the highest possible yield. However, experiments with citrus have rarely demonstrated a benefit of N fertilizer rates higher than about 200 lb/acre, regardless of the production potential. Instead, yield declined in several experiments when N rate was increased beyond the optimum range.

Nutrients removed with the harvested crop must be replaced. The amount the crop removes varies from a fraction of a lb/acre for some of the micronutrients to as much as 100 lb/acre of N or K from a high-producing grove (Table 3). For oranges, approximately 0.12 lb N/box is removed with the harvest. Therefore, crop removal ranges from 12 lb N/acre for a 100 box/acre yield to around 100 lb N/acre for a grove producing 800 boxes/acre.

Nutrient uptake from applied fertilizers is not 100% efficient, so more nutrients must be applied than the minimum required by the tree. N use efficiency, expressed as lb N removed by the crop divided by lb N applied, ranges from 0.2 to 0.4 in groves with low to moderate yield. However, N efficiencies around 0.5 have been observed in groves with a good production record. Application of 200 lb N/acre supplies sufficient N for an 800 box/acre orange yield when N use efficiency is 0.5. A grower using the latest fertilization technology (e.g., fertigation, controlled-release fertilizers) with good irrigation management may be able to exceed an N use efficiency of 0.5.

Nutrition and Fruit Quality

Florida has the highest citrus fruit quality standards in the world. The most important quality factors for Florida citrus growers, production managers, processors, and packers include fruit juice content, soluble solids and acid concentrations, soluble solids/acid ratio, fruit size, and color. Florida citrus growers discern between quality factors for the fresh and processing markets. For example, fruit size, shape, color, and maturity date are most important for fresh fruit, but high juice content and soluble solids are desired for processed fruit. Fruit quality is affected by factors including cultivar, rootstock, climate, soil, pests, irrigation, and nutrition.

The effects of nutrition and irrigation on fruit quality should be understood and taken into consideration by citrus growers to increase profitability, enhance sustainability, and improve worldwide competitiveness. Excessive irrigation and fertilization reduce fruit quality, so supplying sufficient nutrition and using sound irrigation scheduling techniques should be high priorities of every grower. Citrus trees require a properly designed, operated, and maintained water management system and a balanced nutrition program formulated to provide specific needs for tree maintenance and expected yield and fruit quality.

Irrigation is a major component of fertilizer program efficiency. Citrus trees with sufficient water and nutrients grow stronger, tolerate pests and stresses better, yield more consistently, and produce good-quality fruit. On the other hand, excessive or deficient irrigation or fertilization may result in poor fruit quality.

The most important management practices influencing fruit quality are irrigation and N, P, K, and Mg nutrition. Some micronutrients like B and Cu can also affect fruit quality, but only if they are deficient. In general, when any nutrient element is severely deficient, fruit yield and fruit quality will be negatively affected.

Trends in fruit quality response to increasing nutrient and water availability are described and summarized below:

Nitrogen

- Increases juice volume and color, total soluble solids (TSS), and acid concentration.
- Increases TSS per box and per acre. However, excessive N, particularly with inadequate irrigation, can result in lower yields with lower TSS per acre.
- Decreases fruit size, weight, and peel thickness.
- Increases green fruit at harvest. High N may delay color break and increase re-greening of Valencia oranges
- Increases creasing and scab, but decreases peel blemishes like wind scar, mite russeting, and rind plugging.
- Reduces stem-end rot and green mold of fruit in storage.

Phosphorus

- Reduces acid concentration, which increases TSS/acid ratio.
- Increases number of green fruit.
- Reduces peel thickness.
- Increases expression of wind scar but reduces that of russeted fruit.

Potassium

- Decreases juice content, TSS, TSS/acid ratio, and juice color.
- Increases acid content.
- Increases fruit size, weight, green fruit, and peel thickness.
- Reduces splitting, creasing, and fruit plugging.

- Reduces stem-end rot of fruit in storage.

Magnesium

- Slightly increases TSS/box and TSS/acid ratio.
- Slightly increases fruit size and weight.
- Decreases rind thickness.

Irrigation

- Increases juice content and TSS/acid ratio.
- Reduces TSS and acid concentration.
- Increases fruit size and weight and green fruit at harvest
- Decreases rind thickness.
- Increases blemish from wind scar, scab, and *Alternaria* brown spot, but reduces rind plugging.
- Reduces stem-end rot, but increases green mold of fruit in storage.

Specific effects on juice and external fruit qualities summarized in Table 4 are based on numerous field experiments conducted over many years that evaluated the response of oranges to irrigation and fertilization practices. Most of these effects were consistently observed, but some of them appeared to depend on local conditions and growing regions. These observations are useful to help develop a strategy aimed at improving fruit quality for a particular variety or location.

Grove Management Practices

Management practices that improve fertilizer nutrient-use efficiency include:

- Using a leaf and soil testing program (Chapter 4).
- Selecting fertilizer materials, ratios, and blends that match nutrient requirements (Chapters 6 and 8).
- Carefully placing fertilizer over the root zone (Chapter 7).
- Timing to avoid the rainy season (Chapters 8 and 10).
- Split applications (Chapter 8).
- Irrigation management to maximize production and minimize leaching (Chapter 9).
- Applying N fertilizer at a rate consistent with historical or expected production (Chapter 8).

Groves with non-nutritional limiting factors do not produce more fruit if the grower exceeds basic fertilizer requirements in an attempt to boost yield. Instead, excess fertilizer is not used by the tree, efficiency declines, and potential for leaching loss increases.

Interactions of Nutrition with Other Grove Practices

Nutrition management interacts with irrigation, pest control, weed management, and vegetative growth control (hedging and topping). Nutrition and irrigation are linked through fertigation and the need to provide maximum nutrient uptake while minimizing nutrient leaching. Water and nutrient uptake efficiency increases as trees mature due to greater interception by closely interwoven root systems. Fertilization and irrigation outside the root zone is economically and environmentally unsound and promotes weed growth.

Nutrient Considerations for Disease and Insect Control

Luxuriant growth caused by excessive fertilization or irrigation may increase incidence of foliar and blossom fungal diseases like scab, *Alternaria* brown spot, and postbloom fruit drop (PFD). Excessive vegetative growth may also increase insect pest problems including the citrus leafminer and the Asian citrus psyllid, which vectors huanglongbing (citrus greening) disease. Controlling tree growth at containment size through pruning is more difficult when vegetative growth is promoted by excessive inputs. Such excess vegetative growth competes with fruit production and may suppress it.

Until specific fertilization recommendations for groves infected with citrus greening disease are developed, groves should be provided with sufficient nutrition to maintain current fruit production (see Chapter 8). However, if a grove is being visually monitored for greening symptoms, it is important to minimize signs of Zn deficiency so the disease can be more easily detected. Likewise, tree growth (particularly of young trees) during the fall and winter makes it difficult to control psyllids, so fertilizer application during this period is discouraged.

Table 2. Nutrient movement summary.

Nutrient	Ionic form taken up by plants	Nutrient subject to precipitation or sorption?	Nutrient mobile in sandy soil?
N	NH_4^+, NO_3^-	No	Yes
P	PO_4^{3-}	Yes	Yes/No*
K	K^+	No	Yes
Ca, Mg	Ca^{2+}, Mg^{2+}	Yes	No
S	SO_4^{2-}	Yes	Yes/No*
Cu, Mn, Fe, Zn	Cu^{2+}, Mn^{2+}, Fe^{3+}, Zn^{2+}	Yes	No
B	H_3BO_3	No	Yes
Mo	MoO_4^{2-}	Yes	No

*Depends on soil properties (see discussion above).

Table 3. Total amounts of various nutrients in 100 boxes[1] of orange fruits.

Nutrient	Hamlin[2]	Hamlin[3]	Hamlin[4]	Parson Brown[3]	Valencia[3]	Sunburst[3]	Average
	lb nutrient/100 boxes of fruit						
N	12.5	10.6	10.8	11.3	13.5	13.6	12.1
P	1.4	1.5	1.7	1.5	2.0	1.8	1.7
K	17.6	13.6	13.9	13.3	14.4	14.0	14.5
Ca	4.5	4.0	5.2	4.9	4.3	3.4	4.4
Mg	1.9	1.1	1.0	1.2	1.2	1.0	1.2
S	1.1	---	0.8	---	---	---	1.0
Fe	0.024	0.020	0.036	0.030	0.072	0.036	0.036
B	0.020	---	0.025	---	---	---	0.023
Zn	0.020	0.032	0.008	0.032	0.029	0.041	0.027
Mn	0.011	0.020	0.004	0.023	0.023	0.023	0.017
Cu	0.006	0.005	0.006	0.006	0.007	0.007	0.006

[1] 1 box of fruit = 90 lb.
[2] A. K. Alva, unpublished data.
[3] Paramasivam et al. (2000).
[4] Mattos et al. (2003).

Table 4. Specific internal and external fruit quality effects resulting from macronutrient, micronutrient, and irrigation applications to Florida citrus groves (Koo 1988).

Measurement	Macronutrient element					Micronutrient element					Irrigation
	N	P	K	Ca	Mg	Mn	Zn	Cu	Fe	B	
Juice quality											
Juice content	+	o	–	o	o	o	o	o	o	o	+
Soluble solids (SS)	+	o	–	o	+	o	o	o	+	o	–
Acid (A)	+	–	+	o	o	o	o	o	o	o	–
SS/A ratio	–	+	–	o	+	o	o	o	o	o	+
Juice color (red)	+	o	–	?	?	?	?	?	?	?	o
Juice color (yellow)	+	o	–	?	?	?	?	?	?	?	+
Solids/box	+	o	–	o	+	o	o	o	+	o	–
Solids/acre	+	+	+	o	+	o	o	o	o	o	+
External fruit quality											
Size	–	o	+	o	+	o	o	o	o	o	+
Weight	–	o	+	o	+	o	o	o	o	o	+
Green fruit	+	+	+	o	o	o	o	o	?	o	+
Peel thickness	–[1]	–	+	o	–	o	o	o	o	o	–
Peel blemishes											
Wind scar	–	+	o	?	?	?	?	?	?	?	+
Russet	–	–	o	?	o	o	o	o	o	o	o
Creasing	+	o	–	?	?	?	?	?	?	?	o
Plugging	–	o	–	?	?	?	?	?	?	?	–
Scab	+	o	o	?	?	?	?	?	?	?	+
Storage decay											
Stem-end rot	–	o	–	?	?	?	?	?	?	?	–
Green mold	–	o	o	?	?	?	?	?	?	?	+
Sour rot	o	o	o	?	?	?	?	?	?	?	o

Increase (+), Decrease (–), No change (o), No information (?).
[1] Except in young trees where peel may be thicker.

UF | IFAS Extension
UNIVERSITY of FLORIDA

SL458

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 4. Soil and Leaf Tissue Testing[1]

Thomas A. Obreza, Mongi Zekri, and Edward A. Hanlon[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For references, a glossary, and appendices, please refer to the full document at https://edis.ifas.ufl.edu/ss478.

Introduction

Nutrient deficiency or excess will cause citrus trees to grow poorly and produce suboptimal yield and/or fruit quality. Diagnosis of potential nutritional problems should be a routine citrus-growing practice. Quantifying nutrients in soils and trees eliminates guesswork in adjusting a fertilizer program (Figure 1).

Figure 1. Proper soil and leaf tissue sampling and analysis can accurately gauge citrus grove nutrition and help improve fertilizer programs.
Credits: Mongi Zekri, UF/IFAS

This chapter explains the value of leaf and soil analysis in determining fertilizer programs that increase fertilizer efficiency while maintaining maximum yield and desirable fruit quality. Soil testing and leaf tissue testing have different uses or purposes depending on the property or nutrient, so care must be taken to use the correct test when diagnosing citrus nutrition (Table 1).

Table 1. Summary of the usefulness of soil testing and leaf tissue testing as citrus nutrient management tools.

Property or nutrient	Soil testing	Leaf testing
pH	✓	
Organic matter	✓	
N		✓
P	✓	✓
K		✓
Ca	✓	✓
Mg	✓	✓
Cu	✓	✓
Zn, Mn, Fe, B		✓

Benefits of Leaf Analysis

Leaf tissue analysis is the quantitative determination of the total mineral nutrient concentrations in the leaf. Tissue testing includes analysis for N, P, K, Ca, Mg, S, Mn, Zn, Cu, Fe, and B. Chlorine concentration is usually sufficient given most field conditions, but Cl may become excessive where

1. This document is SL458, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Thomas A. Obreza, professor and senior associate dean for Extension, Department of Soil and Water Sciences; Mongi Zekri, Extension agent IV, UF/IFAS Extension Hendry County; and Edward A. Hanlon, professor emeritus, Department of Soil and Water Sciences, UF/IFAS Southwest Florida Research and Education Center; UF/IFAS Extension, Gainesville, FL 32611.

soil or irrigation water is saline. Similarly, Mo deficiency or toxicity is rare. The goal in tissue analysis is to adjust fertilization programs such that nutritional problems and their costly consequences are prevented.

Leaf analysis is a useful tool to detect problems and adjust fertilizer programs for citrus trees because leaf nutrient concentrations are the most accurate indicator of fruit crop nutritional status. Because citrus is a perennial plant, it is its own best indicator of appropriate fertilization. Leaves reflect nutrient accumulation and redistribution throughout the plant, so the deficiency or excess of an element in the soil is often reflected in the leaf. Considerable research involving citrus leaf testing has established its reliability as a management tool, but sampling guidelines should be followed precisely to ensure that analytical results are meaningful.

Tissue analysis:

- Determines if the tree has had a sufficient supply of essential nutrients.
- Confirms nutritional deficiencies, toxicities, or imbalances.
- Identifies hidden toxicities and deficiencies when visible symptoms do not appear.
- Evaluates the effectiveness of fertilizer programs.
- Provides a way to compare several fertilizer treatments.
- Determines the availability of elements not tested for by other methods.

Leaf analysis integrates all the factors that might influence nutrient availability and uptake. Tissue analysis shows the relationship of nutrients to each other. For example, K deficiency may result from a lack of K in the soil or from excessive Ca, Mg, and/or Na. Similarly, adding N when K is low may result in K deficiency because the increased growth requires more K.

Steps in Leaf Sampling

Procedures for proper sampling, preparation, and analysis of leaves have been standardized to achieve meaningful comparisons and interpretations. If done correctly, the reliability of the chemical analysis, data interpretation, fertilization recommendations, and adjustment of fertilizer programs will be sound. Therefore, considerable care should be taken from the time leaves are selected for sampling to the time they are received at the laboratory for analysis.

Leaf Sample Timing

- Leaf samples must be taken at the correct time of year because nutrient concentrations within leaves continuously change. As leaves age from spring through fall, N, P, and K concentrations decrease, Ca increases, and Mg first increases and then decreases (Figure 2). However, leaf mineral concentrations are relatively stable from 4 to 6 months after emergence in the spring.
- The best time to collect 4-to-6-month-old spring flush leaves is July and August (Figure 3). If leaves are sampled later in the season, summer leaf growth can easily be confused with spring growth.

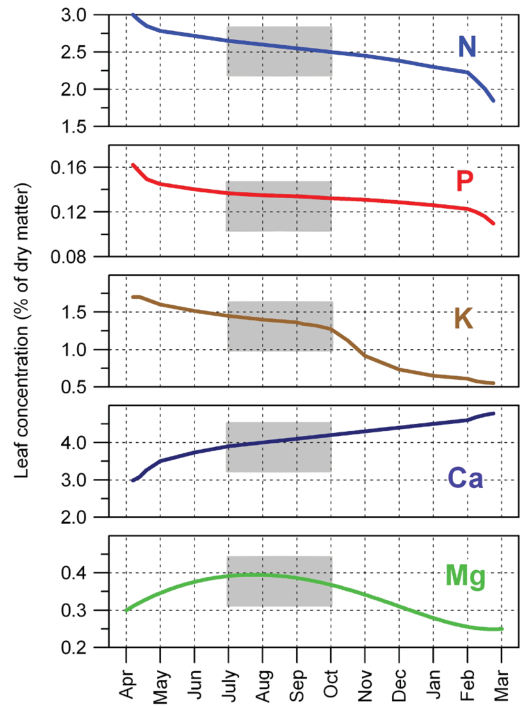

Figure 2. Changes in concentration of N, P, K, Ca, and Mg in citrus leaves with age. The shaded areas denote the recommended sampling period and the optimum concentration range for each element.

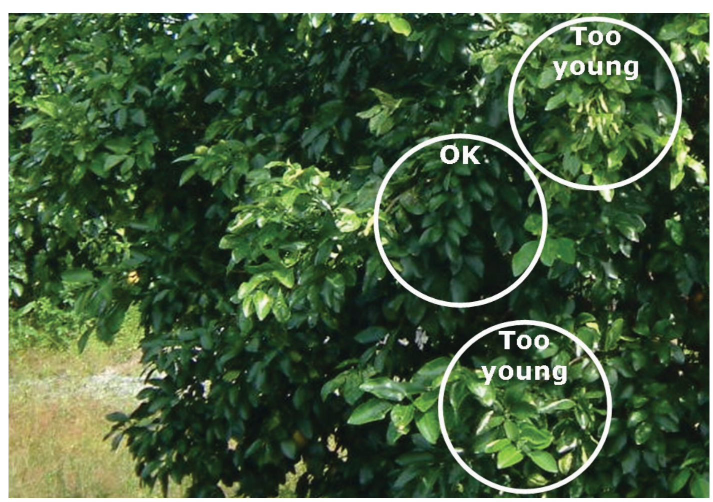

Figure 3. Sample 4-to-6-month-old spring flush leaves from nonfruiting twigs.
Credits: Thomas Obreza, UF/IFAS

Leaf Sampling Technique

- A sampled citrus grove block or management unit should be no larger than 20 acres. The sampler should make sure that the selected leaves represent the block being sampled.
- Each leaf sample should consist of about 100 leaves taken from nonfruiting twigs of 15 to 20 uniform trees of the same variety and rootstock that have received the same fertilizer program.
- Use clean paper bags to store the sample. Label the bags with an identification number that can be referenced when the analytical results are received.
- Avoid immature leaves due to their rapidly changing composition.
- Do not sample abnormal-appearing trees, trees at the edge of the block, or trees at the end of rows because they may be coated with soil particles and dust.
- Do not include diseased, insect-damaged, or dead leaves in a sample.
- Select only one leaf from a shoot and remove it with its petiole (leaf stem).

Special Case: Diagnosing Growth Disorders

- Collect samples from both affected trees as well as normal trees.
- Trees selected for comparison sampling should be of the same age, scion type, and rootstock.
- If possible, confine the sampling area to trees that are close to each other.

Handling of Leaf Samples

- Protect leaves from heat and keep them dry. Place them in a refrigerator for overnight storage if they cannot be washed and oven-dried the day of collection.
- For macronutrient analysis, leaves do not need to be washed.
- If accurate micronutrient analysis is desired, the leaves will need to be washed (see below).
- Dry the leaves in a ventilated oven at about 140°F.

Preparation for Analysis

- Leaves that have been sprayed with micronutrients for fungicidal (Cu) or nutritional (Mn, Zn) purposes should not be analyzed for those elements because it is almost impossible to remove all surface contamination from sprayed leaves.
- For accurate Fe and B or other micronutrient determinations, leaf samples require hand washing, which is best done shortly after collection before they dehydrate.
- For micronutrient determinations, rub the leaves between the thumb and forefinger while soaking them in a mild detergent solution, then thoroughly rinse with pure water. It is difficult to remove all surface residues, but this procedure removes most of them.

Analysis and Interpretation

- The laboratory determines the total concentration of each nutrient in the leaf sample. Because **total** concentration is determined, there should be no difference in leaf analysis results between different laboratories.
- To interpret laboratory results, compare the values with the leaf analysis standards in Table 2. These standards are based on long-term field observations and experiments conducted in different countries with different citrus varieties, rootstocks, and management practices, and they are used to gauge citrus tree nutrition throughout the world.
- The goal in nutrition management is to maintain leaf nutrient concentrations within the optimum range (Table 2) every year. If the interpretation for a particular nutrient is not optimum, various strategies can be used to address the situation (Table 3).

Benefits of Soil Analysis

Soil analysis measures organic matter content, pH, and extractable nutrients, which are useful in formulating and improving a fertilization program. Soil analysis is particularly useful when conducted for several consecutive years so that trends can be observed. However, a citrus grower cannot rely on soil analysis alone to formulate a fertilizer program or diagnose a nutritional problem in a grove.

Similar to leaf analysis, methods to determine organic matter and soil pH are universal, so results should not differ between laboratories. However, soil nutrient extraction procedures vary from lab to lab. Several accepted chemical procedures exist that remove different amounts of nutrients from the soil because the extractants vary in strength. To draw useful information from soil tests, consistency in use of a single extraction procedure from year to year is important to avoid confusion when interpreting the amount of nutrients extracted.

A soil extraction procedure does not measure the total amount of nutrients present, nor does it measure the quantity actually available to citrus trees. A perfect extractant would remove nutrients from the soil in amounts that are exactly correlated with the amount available to the plant. Therefore, the utility of a soil testing procedure is how well the extractable values correlate with the amount of nutrient a plant can take up. The process of relating these two quantities is called calibration.

A soil test is only useful if it is calibrated with plant response. Calibration means that as a soil test value increases, nutrient availability to plants increases in a predictable way (Figure 4). Low soil test values imply that a crop will respond to fertilization with the particular nutrient in question. High soil test values indicate the soil can supply all the plant needs, so no fertilization is required. The soil test value that separates predicted fertilizer response from nonresponse is called the **critical** or **sufficiency** soil test value (Figure 5).

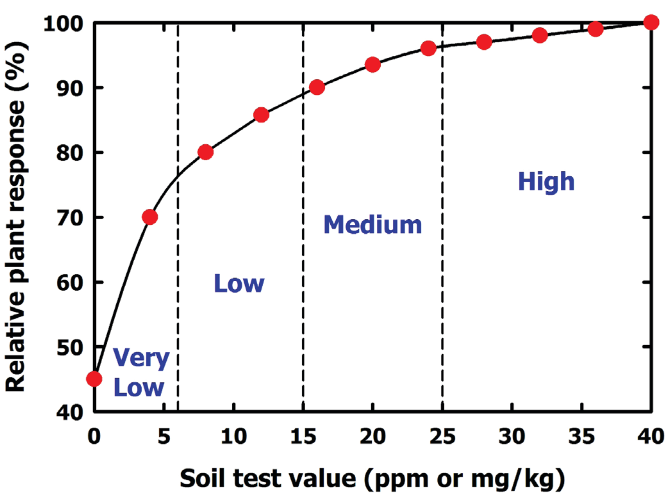

Figure 4. Ideal soil test calibration curve.

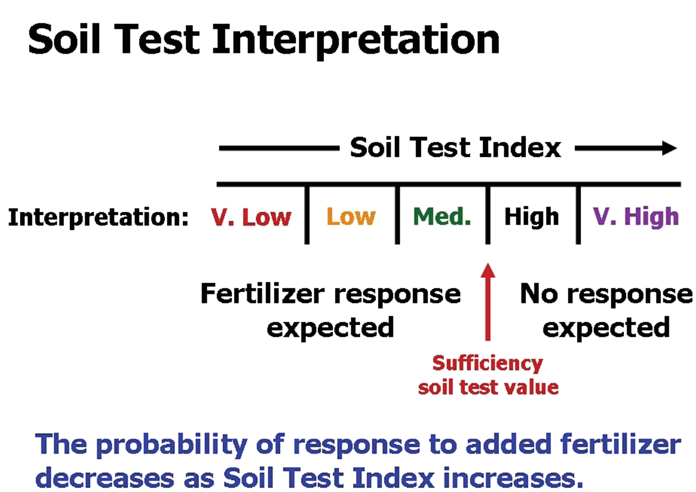

Figure 5. Soil test interpretation categories and their relationship to expected fertilizer response.

In Florida, soil testing for mobile, readily leached elements like N and K has no practical value. In addition to organic matter and pH, soil testing is important for P, Mg, Ca, and Cu. The UF/IFAS Extension Soil Testing Laboratory (ESTL) has used the Mehlich 1 (double acid) extraction procedure since 1977. The Mehlich 1 test was developed for sandy soils with pH < 6.5, CEC < 10 meq/100 g, and organic matter < 5%. Most of the soils used to produce citrus in Florida meet these criteria. The exceptions are the calcareous soils of the Indian River production area that do not meet the pH requirement.

UF/IFAS soil test interpretations for P, K, and Mg (Table 4) were established from experiments with annual field and vegetable crops conducted for many years. Limited soil test calibration work with Florida citrus trees suggests that the interpretations in Table 4 are suitable for citrus.

Some commercial agricultural laboratories use the Mehlich 1 extraction procedure, but others use procedures different from Mehlich 1 as their preferred soil test method. Additional extractants used to determine P include Mehlich 3, ammonium acetate buffered at pH 4.8, and Bray P1. Other extractants for Ca and Mg include Mehlich 3 and ammonium acetate buffered at either pH 4.8 or pH 7.0. Some interpretations for these extractants were developed by Koo et al. (1984) through experimentation, field observation, and best professional judgment (Table 5). Others were derived from correlations with the Mehlich 1 extractant (Alva 1993; Sartain 1978).

The single most useful soil test in a citrus grove is for pH. Soil pH greatly influences nutrient availability (Chapter 3, Figure 2). Some nutrient deficiencies can be avoided by maintaining soil pH between 6.0 and 6.5. Deficiencies or toxicities are more likely when the pH is outside this range. If soil pH is too low, the soil test laboratory runs a buffer test to determine the rate of lime needed to raise the top 6 inches of soil to pH 6.5.

In some cases, soil tests can determine the best way to correct a deficiency identified by leaf analysis. For example, Mg deficiency may result from low soil pH or excessively high soil Ca. Dolomitic lime applications are advised if the pH is too low, but magnesium sulfate is preferred if soil Ca is very high and the soil pH is in the desirable range. If soil Ca is excessive and soil pH is relatively high, then foliar application of magnesium nitrate is recommended.

A poor relationship may exist between soil test values and leaf nutrient concentrations in perennial crops like citrus. Often fruit trees contain sufficient levels of a nutrient even though the soil test is low. On the other hand, a high soil test does not assure a sufficient supply to the trees. Tree nutrient uptake can be hindered by problems like drought or flooding stress, root damage, and cool weather. Tissue analysis combined with soil tests can help identify the problem.

Steps in Soil Sampling

Standard procedures for sampling, preparing, and analyzing soil should be followed for meaningful interpretations of the test results and accurate recommendations.

Soil Sample Timing

- In Florida, soil samples should be collected once per year at the end of the summer rainy season and before fall fertilization (August to October).
- It is convenient to take annual soil samples when collecting leaf samples to save time and reduce cost.
- The accuracy of soil test interpretations depends on how well the soil sample represents the grove block or management unit in question.

Soil Sampling Technique

- Each soil sample should consist of one soil core taken about 8 inches deep at the dripline of 15 to 20 trees within the area wetted by the irrigation system in the zone of maximum root activity (Figure 6).

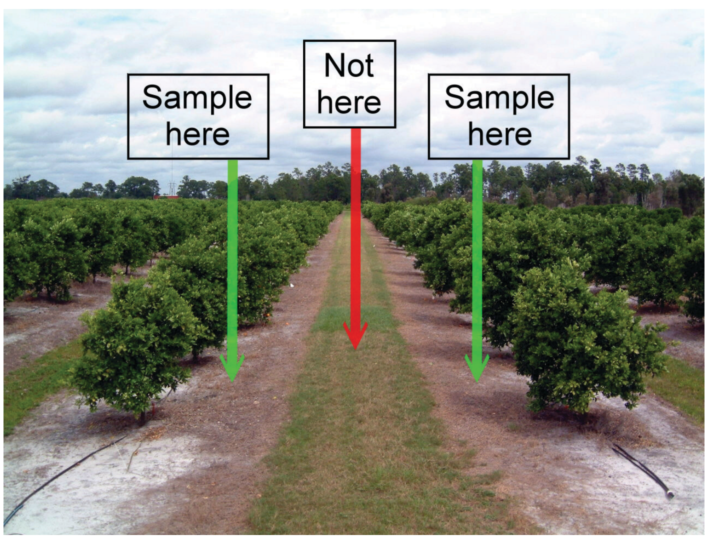

Figure 6. Sample soil near the dripline of the trees, not in the row middle.
Credits: Thomas Obreza, UF/IFAS

- Sampled areas should correspond with grove blocks where leaf samples were collected. The area should contain similar soil types with trees of roughly uniform size and vigor.
- Thoroughly mix the cores in a nonmetal bucket to form a composite sample. Take a subsample from this mixture and place it into a labeled paper bag.

Special Case: Diagnosing Growth Disorders

- Collect soil samples from beneath affected trees as well as normal trees and analyze them separately.
- If possible, confine the sampling area to trees that are close to each other.

Preparation for Analysis

- Soil samples should be air-dried before shipping to the laboratory for analysis.

Analysis and Interpretation

- The basic soil analysis package run by most agricultural laboratories includes soil pH and extractable P, K, Ca, and Mg. Organic matter is sometimes part of the basic package or it may be a separate analysis. Extractable Cu is normally determined upon request.
- Because **extractable** nutrients are measured, the magnitude of soil test values may differ between different laboratories, but this difference is not a concern as long as the extraction method is calibrated for citrus.
- The laboratory interprets each soil test result as very low, low, medium, high, or very high, and it may also provide fertilizer recommendations accordingly. Citrus growers can independently interpret the numerical results according to UF/IFAS guidelines based on the extractant used (Tables 4 and 5).
- The interpretations should be used to make management decisions regarding soil pH adjustment or fertilizer application (Table 6).

Traditional vs. Alternative Sampling Strategies

A practical nutrient management strategy uses tissue and soil analysis results as tools to help determine nutrient requirements for large grove blocks, followed by uniform fertilizer application across the entire area. An inherent problem with this approach is that some trees may be overfertilized and others may be underfertilized. Citrus grove variability is common, especially on Flatwoods soils. It is important to take this variability into consideration so the grove can be managed more efficiently.

A basic principle of traditional sampling is to return to roughly the same sampling locations from year to year. This technique assumes that the selected area is less variable but also representative of the entire grove or major portion of the block. Representative sites are selected based on tree observation, past experience, crop yield, soil type, and/or remotely sensed images. Traditional sampling minimizes sampling errors, the number of samples taken, cost, and time required, but it does not fully indicate field variability.

With technological advances, the popularity of grid sampling for precision agriculture has increased in Florida's citrus industry. The first step in this strategy is to place a 1- to 5-acre grid over a grove map. The second step is to take soil and/or leaf samples either at the center of each grid section or at the point where the grid lines intersect (Figure 7). The individual taking the samples records the geographic location of each point with a Global Positioning System (GPS) instrument. The third step is to match the analysis results with the geographic data and construct variability maps using Geographic Information System (GIS) software. If appropriate, fertilizer or lime may be custom-applied using an applicator equipped with variable rate technology (VRT).

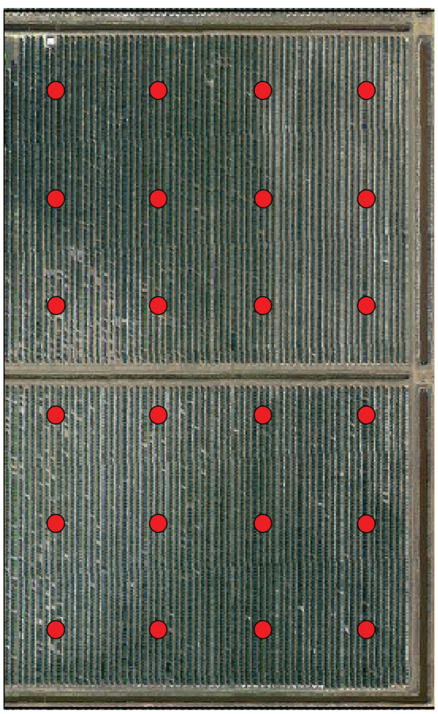

Figure 7. Example of the grid sampling strategy for selecting soil and leaf sampling locations. The red dots show predetermined sampling locations that will be recorded with GPS equipment and used to construct variability maps.

Nutrient management using grid sampling information is still in development, and more research is needed before VRT becomes widely used to manage Florida citrus tree nutrition. Dense grid sampling can be quite expensive and has limited practicality. Growers should carefully compare the potential for a positive return with the cost of the program before employing this method.

Between traditional and grid sampling strategies lies the "management zone" method (Figure 8). Knowledge of grove characteristics such as soil types, high- and low-yielding areas, soil water- and nutrient-holding capacities, and depth to the water table allows a grower to delineate management zones. The zone concept requires less sampling than the grid method, but it is more targeted than the traditional strategy. With this technique, different fertilizer rates can be applied to a smaller number of zones without VRT equipment.

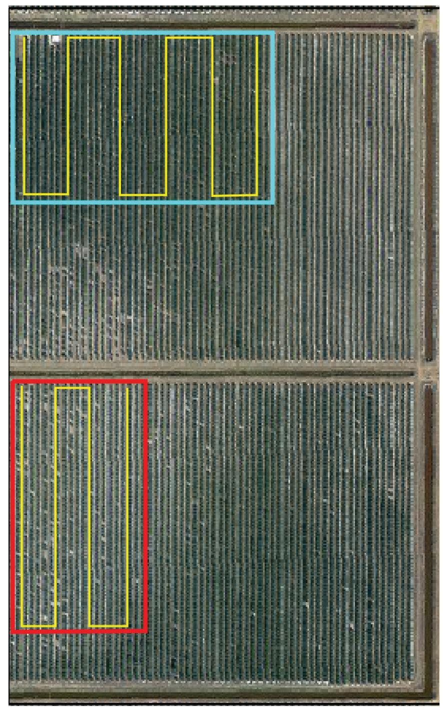

Figure 8. Example of soil and leaf tissue sampling locations using the management zone method. The grove zone area delineated by the blue rectangle is a productive area, while that delineated by the red rectangle is a weak area. The yellow zigzag line denotes the sampling pattern within each management zone.

Growers should remain flexible and prepared to adjust sampling and management strategies. Emerging technology will continue to refine sampling systems and integrate information such as yield, tree age, tree size, and soil maps, aerial photographs, and satellite images into nutrient management decision-making.

Summary

Tissue and soil analysis are powerful tools to confirm nutrient deficiencies and toxicities, identify "hidden hunger," evaluate fertilizer programs, study nutrient interactions, and determine fertilizer rates. However, if any steps in site selection, sampling, or analysis are faulty, the results may be misleading.

Experience interpreting sample results is essential due to the many interacting factors that influence the concentrations of elements in soil and leaf tissue. Tree age, cropping history, sampling techniques, soil test interpretations, and leaf analysis standards all must be considered before making a final diagnosis. If done properly, tissue and soil analysis will lead to more economical and efficient use of fertilizers because excessive or insufficient application rates will be avoided.

Soil and Leaf Tissue Analysis Checklist

Use this checklist as a guide for starting a soil and leaf tissue testing program:

- A sampling program is most effective if it is done annually.
- Leaf tissue testing is valuable for all elements.
- Soil testing is most useful for pH, P, Ca, Mg, and Cu.
- Use the standard sampling procedures for soil and leaves described in this chapter.
- Be aware that spray residues or dust on leaf surfaces affect sample results; wash leaves for accurate micronutrient analysis. Avoid sampling recently sprayed trees.
- Be aware that a number of different soil extracting solutions exist, and they can differ in their ability to extract plant nutrients, especially P.
- Interpretation of leaf and soil tests should be used to make fertilizer or liming decisions. Wise use of the results allows optimal citrus production and minimizes fertilizer loss.

Table 2. Guidelines for interpretation of orange tree leaf analysis based on 4-to-6-month-old spring flush leaves from nonfruiting twigs (Koo et al. 1984).

Element	Unit of measure	Deficient	Low	Optimum	High	Excess
N	%	< 2.2	2.2–2.4	2.5–2.7	2.8–3.0	> 3.0
P	%	< 0.09	0.09–0.11	0.12–0.16	0.17–0.30	> 0.30
K	%	< 0.7	0.7–1.1	1.2–1.7	1.8–2.4	> 2.4
Ca	%	< 1.5	1.5–2.9	3.0–4.9	5.0–7.0	> 7.0
Mg	%	< 0.20	0.20 – 0.29	0.30–0.49	0.50–0.70	> 0.70
Cl	%	---	---	< 0.2	0.20–0.70	> 0.70[1]
Na	%	---	---	---	0.15–0.25	> 0.25
Mn	mg/kg or ppm[2]	< 18	18–24	25–100	101–300	> 300
Zn	mg/kg or ppm	< 18	18–24	25–100	101–300	> 300
Cu	mg/kg or ppm	< 3	3–4	5–16	17–20	> 20
Fe	mg/kg or ppm	< 35	35–59	60–120	121–200	> 200
B	mg/kg or ppm	< 20	20–35	36–100	101–200	> 200
Mo	mg/kg or ppm	< 0.05	0.06–0.09	0.10–2.0	2.0–5.0	> 5.0

[1] Leaf burn and defoliation can occur at Cl concentration >1.0%.
[2] ppm = parts per million.

Table 3. Adjusting a citrus fertilization program based on leaf tissue analysis.

Nutrient	What if it is less than optimum in the leaf? Options:	What if it is greater than optimum in the leaf? Options:
N	Check yield. Check tree health. Review water management. Review N fertilizer rate.	Check soil organic matter. Review N fertilizer rate.
P	Apply P fertilizer (see Chapter 8).	Do nothing.
K	Increase K fertilizer rate (see Chapter 8). Apply foliar K fertilizer.	Decrease K fertilizer rate.
Ca	Check soil pH. Check soil test Ca status. Consider applying lime or soluble Ca fertilizer depending on soil pH.	Do nothing.
Mg	Check soil test Mg status. Check soil pH. Consider applying dolomitic lime or soluble Mg fertilizer depending on pH.	Do nothing.
Micronutrients	Check soil pH and adjust if needed. Apply foliar micronutrients. Include micronutrients in soil-applied fertilizer.	Check for spray residue on tested leaves. Do nothing.

Table 4. Interpretation of soil analysis data for citrus using the Mehlich 1 (double-acid) extractant.

	Soil test interpretation				
Element	**Very Low**	**Low**	**Medium**	**High**	**Very High**
	mg/kg (ppm)[1]				
P	< 10	10–15	16–30	31–60	> 60
Mg[2]		< 15	15–30	> 30	
Ca[2]			250[3]	> 250	
Cu			< 25[4]	25–50[5]	> 50[6]

[1] parts per million (ppm) x 2 = lb/acre.
[2] A Ca-to-Mg ratio greater than 10 may induce Mg deficiency.
[3] The UF/IFAS Extension Soil Testing Laboratory does not interpret extractable Ca. Work with Florida citrus trees suggests that a Mehlich 1 soil test Ca of 250 mg/kg or greater is sufficient.
[4] Cu toxicity is unlikely even if soil pH is less than 5.5.
[5] Cu toxicity is possible if soil pH is less than 5.5.
[6] Cu toxicity is likely unless soil pH is raised to 6.5.

Table 5. Soil test interpretations for other extraction methods compared with Mehlich 1.

Extractant	**Nutrient**	**Soil test interpretation**				
		Very Low	**Low**	**Medium**	**High**	**Very High**
		(Less than sufficient)			**(Sufficient)**	
Mehlich 1	P mg/kg (ppm)[1]	< 10	10–15	16–30	31–60	> 60
Mehlich 3[2]		< 11	11–16	17–29	30–56	> 56
Ammonium acetate pH 4.8[3]		≤ 11			> 11	
Bray P1[3]		≤ 40			> 40	
Bray P2[3]		≤ 65			> 65	
			Low	**Medium**	**High**	
Mehlich 1	Mg mg/kg (ppm)		< 15	15–30	> 30	
Mehlich 3[4]			< 25	25–33	> 33	
Ammonium acetate pH 4.8[5]			< 14	14–26	> 26	
		Less than sufficient			**Sufficient**	
Ammonium acetate pH 7.0[3]		≤ 50			> 50	
		Less than sufficient			**Sufficient**	
Mehlich 1	Ca mg/kg (ppm)	≤ 250			> 250	
Mehlich 3[4]		≤ 200			> 200	
Ammonium acetate pH 4.8[5]		≤ 270			> 270	
Ammonium acetate pH 7.0[3]		≤ 250			> 250	

[1] parts per million (ppm) x 2 = lb/acre.
[2] Estimated from unpublished correlation data (T. A. Obreza 2006).
[3] From Koo et al. (1984).
[4] Estimated from correlation data (Alva 1993).
[5] Estimated from correlation data (Sartain 1978).

Table 6. Adjusting a citrus fertilization program based on soil analysis.

Property or nutrient	What if it is below the sufficiency value in the soil? Options:	What if it is above the sufficiency value in the soil? Options:
Soil pH[1]	Lime to pH 6.0.	Do nothing. Use acid-forming N fertilizer. Apply elemental sulfur. Change rootstocks.
Organic matter[2]	Do nothing (live with it). Apply organic material.	Do nothing.
P	Check leaf P status. Apply P fertilizer if leaf P is below optimum (see Chapter 8).	Do nothing.
K	Apply K fertilizer (see Chapter 8).	Lower K fertilizer rate.
Ca	Check soil pH and adjust if needed. Check leaf Ca status.	Do nothing. Check leaf K and Mg status.
Mg	Check soil pH and adjust with dolomitic lime if needed. Check leaf Mg status.	Do nothing.
Cu	Do nothing.	Lime to pH 6.5.

[1] The sufficiency value for soil pH is 6.0.
[2] There is no established sufficiency value for soil organic matter.

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 5. Precision Agriculture for Citrus Nutrient Management[1]

Arnold W. Schumann and Edward A. Hanlon[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For references, a glossary, and appendices, please refer to the full document at https://edis.ifas.ufl.edu/ss478.

Common Elements of Precision Agriculture

The term precision agriculture includes equipment that improves citrus management for high-quality fruit production. Proper water management is a key component for efficient nutrient management, and precision agricultural tools may improve nutrient- and water-use efficiencies. In turn, producers can anticipate lower production costs through effective nutrient and water resource management with the expectation of sustained high yields and improved chance for profit.

- **Remote sensing** applies to nondestructive measurements. Remote sensing typically involves acquiring and processing satellite or aerial images photographed in the visible or near-infrared portions of the spectrum. Useful information derived from remote sensing includes grove variability, tree canopy size and health, soil type, and water stress in trees. Today, many more tools are available including ultrasonic and laser scanners for canopy volume or electromagnetic soil sensors for detecting profile properties below ground.
- A **geographic information system (GIS)** is a computerized "graphic database" allowing storage, retrieval, display, and processing of digital images or drawings with known positions on the earth's surface. Several technologies are involved with GIS. Maps of an area can be digitized and used to plot positional information captured from global positioning system receivers. Differences in spectral reflectance of groves from aerial or satellite images can be used by grove managers to locate high-yielding or low-yielding areas within a grove.
- By obtaining signals from several satellites, a **global positioning system (GPS)** can be used to precisely locate a position on the earth's surface, a position within a grove, or specific trees within a grove. This system works equally well to locate the path of a vehicle through the grove. Position location (georeferencing of data, observations, objects, maps, and images with GPS) is essential for meaningful processing and display on a GIS.
- **Mobile computing and data storage**: Portable computers collect and analyze sensor data, GIS information, and GPS data streams. The integration of these technologies allows for decision management on the fly as a vehicle moves through the grove. Handheld computers are valuable for making and recording field observations during scouting, leaf sampling, or soil surveying. When used in conjunction with a GPS and GIS software, a handheld computer can be used to navigate through the field, which allows location and marking of trees, plots,

1. This document is SL459, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Arnold W. Schumann, professor, Department of Soil and Water Sciences, UF/IFAS Citrus Research and Education Center; and Edward A. Hanlon, professor emeritus, Department of Soil and Water Sciences, UF/IFAS Southwest Florida REC; UF/IFAS Extension, Gainesville, FL 32611.

soil types, or other information already contained in the GIS.

- **Soil mapping**: Once the purview of the USDA-Natural Resource Conservation Service (NRCS), most county soil surveys and related maps have been digitized. These maps can be used as one of the layers in a GIS decision management system. Soil mapping with geophysical survey or electromagnetic induction instruments such as the EM38 (Geonics, LTD) or the Veris 3000 (Veris Technologies) allows rapid collection of digital geo-referenced map data correlated with chemical and physical properties of soil profiles.
- **Variable-rate inputs**: Using the technologies described above, grove managers can use additional controllers on traditional agricultural equipment to precisely apply fertilizers and other chemicals at spatially varying rates as needed.

Objectives of Precision Agriculture for Nutrient Management

Many possible objectives exist for different precision agriculture programs. Four important objectives related to citrus nutrient and irrigation management are:

- Reduce fertilizer amounts per unit land area to lower citrus production costs.
- Increase fertilizer nutrient-use efficiency to lower environmental impacts.
- Increase fruit yield and quality through optimal nutrient and water management.
- Automate and digitally record grove operations to speed data analysis and increase efficiency and convenience.

Remote Sensing

Field Measurements of Soil Electrical Conductivity

Soil profile properties can be measured remotely using geophysical survey or electrical conductivity (EC) sensors. The use of EC sensors for nutrient management is an indirect measurement, reflecting the dissolved salt and hence also the ion concentrations in the soil. Because fertilizers are salts, changes in dissolved and adsorbed fertilizer can be sensed as changes in electrical conductivity. Because the measurement involves all salts in the soil, the portion attributed to fertilizer can only be estimated, but this estimation has been attempted for some crops in uniform soils with relatively small changes in salinity. Both nutrients and salts from other sources (e.g., saline well water) are measured by this remote sensing equipment. Distinguishing salty water from fertilizer salts can be difficult, especially if the soil varies naturally throughout the grove.

Another use of this type of sensor is to detect limiting layers in soil profiles. A soil must provide sufficient soil volume for proper tree root growth and nutrient uptake. Improper soil volume for tree root growth may lead to tree stunting, with resulting loss of yield and quality, or to tree mortality. Common soil profile limitations in citrus production are described below.

- Along the central Florida Ridge production area, soils are deep and well-drained but infertile and droughty.
- In citrus Flatwoods production areas, root damage may result due to shallow (perched) water tables and associated capillary rise.
- Flatwoods production areas also exhibit shallow clay layers and/or cemented spodic horizons that restrict or prevent root growth.
- In most citrus production areas, soils are sandy with low organic matter content and fertility, especially in the E-horizon of the subsoil.
- Sandy soils are often prone to soil compaction due to vehicular traffic.

Because field EC can be measured with mobile sensors, these data can be linked with GPS information to create relevant maps of each grove.

Ultrasonic Canopy Measurements

Citrus tree canopy height and volume can be measured remotely from airborne platforms or with ground equipment using laser scanners or ultrasonic ranging sensors—for example, a vertical sensor array that sends out ultrasonic pulses and detects the distance to the tree canopy (Figure 1). The sensor array has a differential global positioning satellite system (DGPS) instrument that records its position within the grove. Both the DGPS and ultrasound readings are recorded and processed by a computer program to create a map of the canopy volumes within the grove (Figure 2).

Calculated canopy volumes (light green) are superimposed on an aerial photograph of the grove (Figure 2), which has a considerable number of resets. From this map, tree canopy sizes can be displayed on a frequency diagram (Figure 3). When shown in this manner, new resets, resets planted in 1989 after a freeze, and original grove trees can be identified.

Because citrus yield is directly related to canopy volume, this type of diagram can help growers make decisions concerning long-term operations within their groves. For example, this grove has a wide range of canopy volumes and can be expected to have a considerable range in yield as well. Managing for somewhat less canopy volume variability in this grove could improve yields and reduce environmental impacts of agrichemicals.

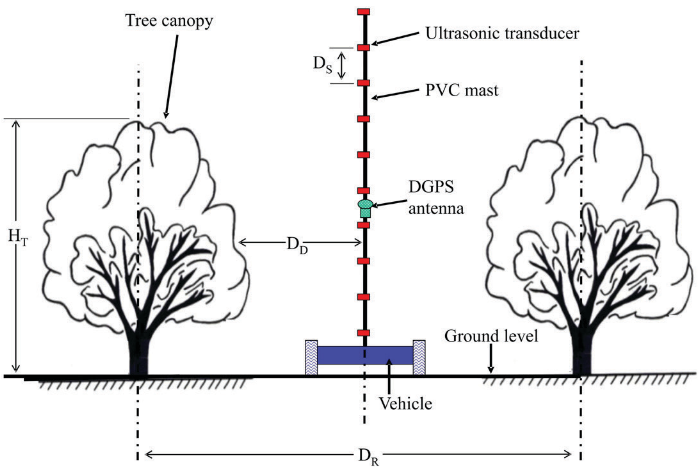

Figure 1. Sensing the height and volume of the tree canopy.

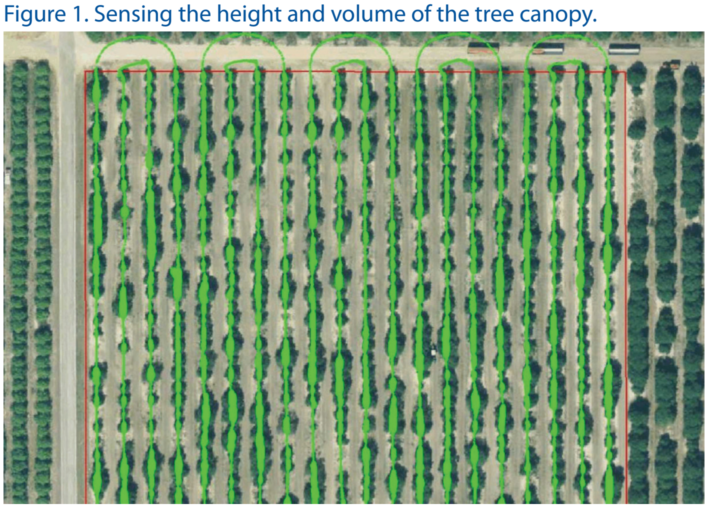

Figure 2. Map of citrus tree canopy volume.

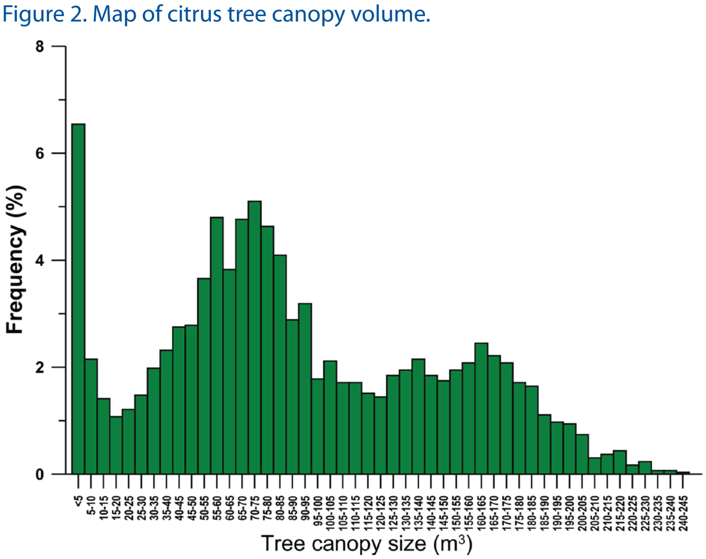

Figure 3. Frequency histogram of tree size within a citrus grove.

Canopy volume measurements can also be used to aid other management strategies, such as changes in irrigation for drought or delineation of wet zones within the grove, soil textural changes that influence tree growth in production, or the impacts of debilitating diseases like citrus HLB.

Citrus Yield Mapping

An automatic tub position logger can record the grove position where fruit was harvested using GPS technology (Figure 4). One tub (red dot) is equivalent to 10 boxes of fruit. Yield maps produced from the positioning data and the number of tubs per unit grove area can be used to identify both high and low production sites within the grove. In the example shown in Figure 5, the high-yield locations are dark green (maximum yield of 543 boxes/acre). Low-yielding locations (light yellow) produced only 181 boxes per acre. The average for the entire grove was 336 boxes per acre.

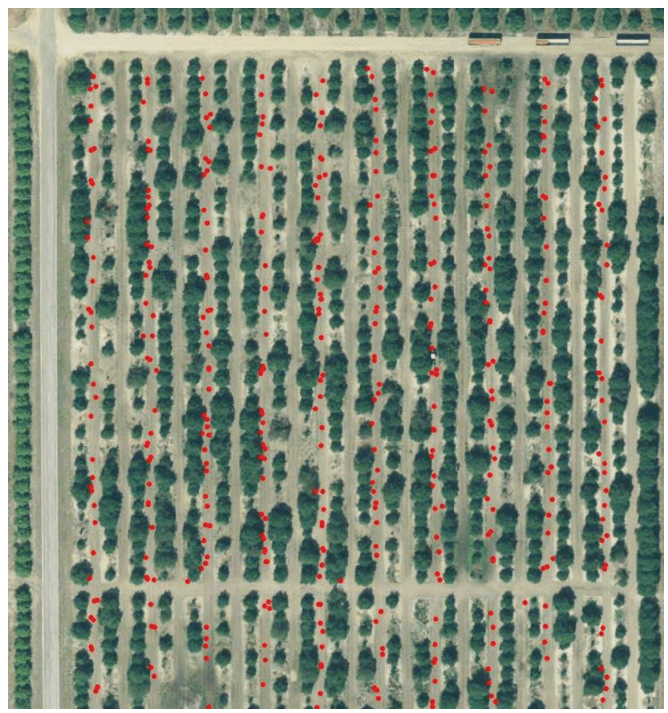

Figure 4. Locations of harvested tubs of fruit are marked by the red dots.

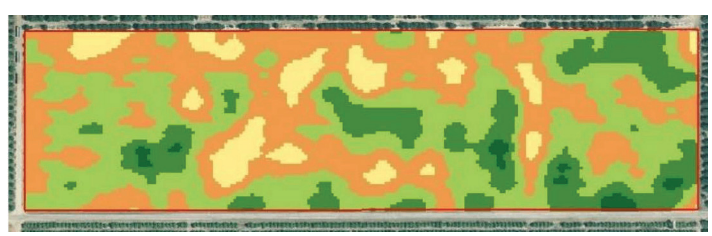

Figure 5. Citrus yield map identifying areas of high (dark green) and low (yellow) production.

Precision Nutrient Application—Variable-Rate Fertilization

After determining canopy volume and yield throughout the grove, the next step is to apply fertilizers only where supplemental nutrients are needed. Variable-rate fertilizer spreaders can reduce fertilizer use in citrus groves by as much as 40%. In addition to reducing production costs, risk of nutrient movement from the grove is minimized. In variable-rate fertilization of citrus groves, granular fertilizer is accurately placed in independent left and right "bands" under the trees. The amount of fertilizer is regulated according to either a GPS-guided prescription map, or by the number of sensors that detect a tree canopy in left- or right-hand rows.

Roots are the primary target for fertilizer applications, and their growth pattern in the soil follows tree canopy volume growth above the surface. Fertilizer should not be placed where roots are not present. Tree spacing and bedding also affect root growth patterns. Immature trees or resets should not receive the same fertilization as mature trees (see Chapter 8). If dry fertilizer is uniformly band-applied to a grove with varying tree sizes, fertilizer will be wasted (Figure 6). This problem can be solved with variable-rate application equipment that uses canopy sensors in a look-ahead mode, rapidly positioning fertilizer dispenser valves on each side of the spreader to:

- Avoid dispensing fertilizer where there are no trees.
- Adjust the applied fertilizer rate based on tree size (canopy volume).
- Make these measurements and valve adjustments in a synchronized fashion as the spreader is moving through the grove.

Sensing and valve adjustment must be automatically synchronized with the speed of the application equipment to apply fertilizer properly to the correct trees. Variable-rate fertilization is most effective in groves with high spatial variability, because the technology is designed to exploit variability. Perfectly uniform groves with no gaps between canopies would not benefit from variable-rate technology. A grove containing a mixture of mature trees, young trees, and/or resets (such as that in Figure 3) will benefit the most from using this technology to apply fertilizers.

Not all variable-rate applicator controllers perform well on the fly. Some commercial controllers do not support the look-ahead feature to allow accurate fertilizer placement under trees while avoiding other locations where fertilizer is not needed. Other controllers and their valves have response times that are too slow to cope with the rapidly changing fertilizer requirements of a variable grove.

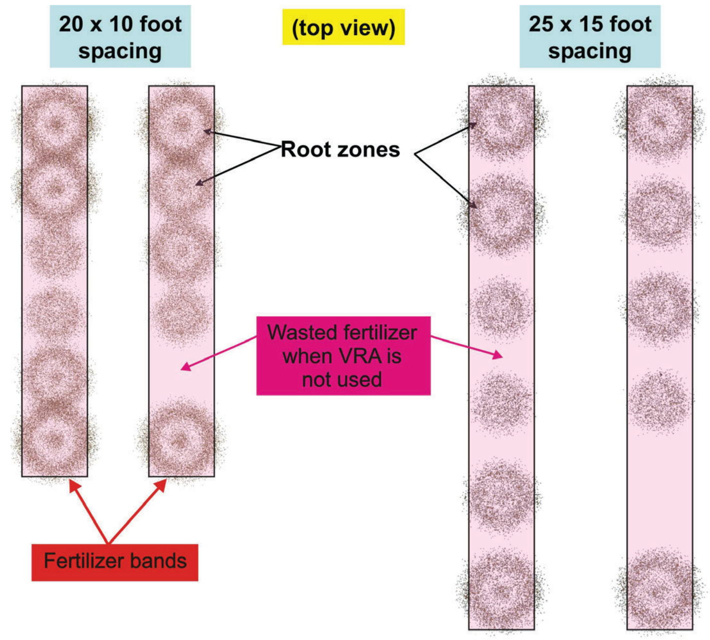

Figure 6. Areas in the tree row where fertilizer can be wasted when using simple band placement. The fertilizer bands cover considerably more area than the area in which citrus roots are located. Fertilizer applied in areas without roots is wasted.

Figure 7 shows the use of photoelectric diffuse reflectance sensors with look-ahead and tree-height sensing capabilities. Sensor angle increases with vertical height, allowing sensors to be placed lower than the height of the tallest trees. For smaller trees, the angle of the sensors is decreased. Trigonometry calculations allow the estimate of sensor height to be calculated accurately as a function of the sensor angle. Compare the benefits of this sensor arrangement with that in Figure 1, and note the reduced height of the sensor array in Figure 7.

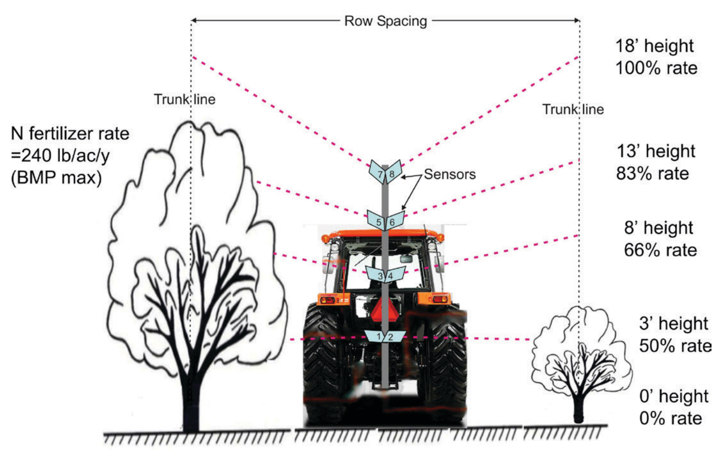

Figure 7. Variable-rate fertilization is linked to measurements of tree height.

Because canopy volume is related to yield and tree height, fertilizer rates can be adjusted based on tree height. The proportion of fertilizer to be applied is shown as a function of tree height in Figure 7. The look-ahead sensing capability must be coupled with the mechanical parts of the fertilizer application equipment. Calculations must be based on the ground speed of the vehicle, the height of the tree, and the time delay for the equipment to respond to the demand for changing fertilizer rates. Slow reaction time for a variable-rate application system means that fertilizer will be applied at the wrong rates (Figure 8). To avoid this bias in fertilizer application, the variable-rate application system must be responsive and properly tuned. When purchasing a variable-rate spreader, insist on rapid response times and look-ahead sensing using well-matched components. The target rate is the UF/IFAS-recommended fertilizer rate proportioned using the percentages shown in Figure 7 for applicable tree heights in this particular example.

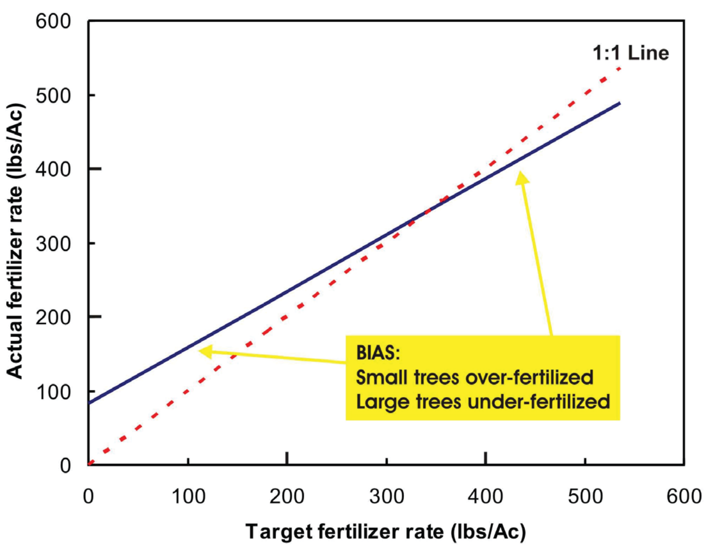

Figure 8. Bias in actual applied fertilizer rate compared with the required rate when using a variable-rate spreader with slow response times.

Summary

- Precision agriculture tools can add considerable strength to grove management decisions.
- Sensing devices can be used to determine water table depth and other soil properties that aid in irrigation, drainage, and fertilizer management decisions.
- Tree-sensing equipment can be used to estimate canopy volume and canopy height.
- Canopy volume and tree height can be used when planning tree replacement strategies, fertilizer management, and zone irrigation decisions.
- In combination with variable-rate applicators and appropriate look-ahead technology, fertilizers can be applied accurately based on tree need and production. Accurate application of dry fertilizers to root zones is particularly important for HLB-impacted trees because the root system is compromised. The costs of citrus production are also inflated by HLB disease, which makes the agrochemical savings achieved by variable-rate applicators especially important.
- Grove managers should consider use of precision agriculture tools to keep production costs low and improve citrus yields while avoiding potential environmental concerns.

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 6. Fertilizer Sources and Formulations[1]

Thomas A. Obreza, Brian J. Boman, Davie Kadyampakeni, Mongi Zekri, Kelly Morgan, and Tripti Vashisth[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For references, a glossary, and appendices, please refer to the full document at https://edis.ifas.ufl.edu/ss478.

Information in the box below applies to citrus trees affected by HLB. Other information in this chapter is valid for healthy citrus trees and trees with HLB.

Recommendations for HLB-affected trees:

Controlled-Release and Liquid Fertilizers—Davie Kadyampakeni, Mongi Zekri, Kelly Morgan, and Tripti Vashisth

Citrus tree growth, fruit quality, yield, and tree health are closely affected by plant nutrition. There are many fertilizer sources and formulations available for commercial citrus production. There are also different methods of applying fertilizers. Applying the right fertilizer type at the right rate at the right time and at the right location within the root zone is very important to improve nutrient use efficiency, especially for HLB-affected trees. For managing HLB-affected trees, constant supply of nutrients throughout the growing season is critical.

Controlled-release fertilizers (CRFs) contain one or more plant nutrients in a form that either delays their availability for plant uptake after application or extends their availability significantly longer than rapidly available fertilizers like ammonium nitrate, urea, or potassium chloride. CRFs were initially developed for their horticultural benefits, but they have also attracted attention in the best management practice (BMP) and HLB eras. CRFs have the advantages of inducing more growth and yield due to a continuous rather than a fluctuating supply of nutrients, reducing rates and frequency of fertilizer application, minimizing potential negative environmental effects, and bringing about substantial labor, time, and energy savings.

Liquid fertilizers applied weekly, biweekly, or monthly appear to improve the performance of HLB-affected trees. Repeated application of small amounts of nutrients improves canopy size, trunk growth, root development, and fruit yield by synchronizing nutrient applications with tree seasonal nutrient demand.

1. This document is SL460, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Thomas A. Obreza, professor and senior associate dean for Extension, Department of Soil and Water Sciences; Brian J. Boman, professor emeritus, Department of Agricultural and Biological Engineering, UF/IFAS Indian River Research and Education Center; Davie Kadyampakeni, assistant professor, Department of Soil and Water Sciences, UF/IFAS Citrus REC; Mongi Zekri, Extension agent IV, UF/IFAS Extension Hendry County; Kelly Morgan, professor and center director, UF/IFAS Citrus REC; and Tripti Vashisth, assistant professor, Horticultural Sciences Department, UF/IFAS Citrus REC; UF/IFAS Extension, Gainesville, FL 32611.

References:

Kadyampakeni, D. M., K. T. Morgan, and A. W. Schumann. 2016. "Biomass, Nutrient Accumulation and Tree Size Relationships for Drip- and Microsprinkler-Irrigated Orange Trees." *Journal of Plant Nutrition* 39: 589–599.

Kadyampakeni, D. M., K. T. Morgan, A. W. Schumann, P. Nkedi-Kizza, and K. Mahmoud. 2014. "Phosphorus and Potassium Distribution and Adsorption on Two Florida Sandy Soils." *Soil Science Society of America Journal* 78: 325–334.

Kadyampakeni, D. M., K. T. Morgan, A. W. Schumann, P. Nkedi-Kizza, and K. Mahmoud. 2014. "Ammonium and Nitrate Distribution in the Soil Using Drip and Micro-sprinkler Irrigation for Citrus Production." *Soil Science Society of America Journal* 78: 645–654.

Introduction

Nitrogen fertilizers are classified as inorganic (e.g., ammonium nitrate), synthetic organic (e.g., urea), or natural organic (e.g., animal manure). Inorganic and synthetic organic N fertilizers are high-analysis materials that are most economical to use in citrus groves. They are rapidly available to plants unless coated as a component of controlled-release fertilizer. Natural organic materials are more slowly available and lower in analysis, so higher application rates are needed to supply equal amounts of available N compared with high-analysis fertilizer. For this reason, they are usually more expensive per unit of N.

Nutrients other than N are usually applied as inorganic fertilizers. An exception is when a grower applies a natural organic material like animal manure that contains a wide range of nutrients. Major P and K fertilizers are manufactured from mined products. Calcium, Mg, and S fertilizers are derived from mined sources like limestone and gypsum.

Micronutrients are usually applied as inorganic or synthetic organic fertilizers. Common micronutrient fertilizers and their analyses are listed in Appendix B. Salt index values for typical fertilizer sources and examples of how to calculate the salt index of a fertilizer blend are shown in Appendix C.

Solid Sources for Soil Application

Solid sources are typically bulk-blended into N-K_2O or complete N-P_2O_5-K_2O fertilizers, often including micronutrients, for spreading in citrus groves. Uniform particle size is required to prevent bulk blends from separating during transport to the grove or transfer from delivery trailer to spreader (Figure 1).

Figure 1. Unloading dry solid fertilizer from a delivery trailer to a grove spreader.
Credits: Stephen Futch, UF/IFAS

Most solid nutrient sources are readily water-soluble and rapidly available for tree uptake (Appendix D, Table 33). Solid fertilizers are applied with conventional spreading equipment but are sometimes applied by hand to young trees. Common solid sources applied to citrus grove soils include:

Nitrogen
- Ammonium nitrate
- Ammonium sulfate
- Urea
- Calcium nitrate
- Potassium nitrate
- Diammonium phosphate

Phosphorus
- Ordinary superphosphate
- Concentrated superphosphate
- Diammonium phosphate

Potassium
- Potassium chloride
- Potassium sulfate
- Potassium-magnesium sulfate
- Potassium nitrate

Calcium
- Calcium carbonate (calcitic lime)
- Calcium sulfate (gypsum)
- Calcium nitrate

Magnesium

- Magnesium carbonate (dolomitic lime)
- Potassium-magnesium sulfate
- Magnesium sulfate
- Magnesium oxide

Sulfur

- Ammonium sulfate
- Potassium sulfate
- Potassium-magnesium sulfate
- Ordinary superphosphate
- Calcium sulfate (gypsum)
- Elemental sulfur

Iron

- Iron oxy-sulfate
- Iron EDTA and HEDTA
- Iron DTPA
- Iron EDDHA
- Iron sucrate
- Iron humate

Manganese

- Manganese sulfate
- Manganese oxy-sulfate
- Manganese oxide
- Manganese nitrate

Zinc

- Zinc sulfate
- Zinc oxide
- Zinc nitrate
- Zinc EDTA and HEDTA

Copper

- Copper sulfate

Boron

- Borax (Sodium tetraborate)

Molybdenum

- Ammonium molybdate
- Sodium molybdate

Solid N Fertilizer Sources and Ammonia Volatilization

Loss of N fertilizer through ammonia volatilization is a concern in citrus groves because solid N sources applied to the soil surface are rarely incorporated. Up to 50% of the N in solid **urea** or **ammonium-containing fertilizer** sources can volatilize to the atmosphere when applied to citrus under two circumstances: 1) surface-applied ammonium fertilizer sources on calcareous or freshly limed soils; and 2) surface-applied urea on acid or alkaline soils.

Ammonia is easily lost from urea because it rapidly converts to ammonium carbonate following surface application. If not incorporated or watered in, ammonium carbonate readily decomposes to produce ammonia and carbon dioxide gases. An ammonium carbonate solution has a pH of about 8.6, which causes large ammonia losses whenever the gas is free to escape to the atmosphere as with surface application. Thus, urea volatilizes readily because it creates its own alkaline environment around each granule. If solid urea is dissolved and moved into the soil by irrigation or rainfall immediately after application, volatilization becomes insignificant.

When ammonium-containing fertilizers are surface-applied to soils containing free calcium carbonate (e.g., calcareous or freshly limed soils), an alkaline environment is maintained that allows conversion of ammonium ions to ammonia gas. The degree to which this reaction proceeds depends on the anion associated with the ammonium fertilizer. Those N fertilizers that react to form Ca-reaction products of low solubility will lose considerably more ammonia than fertilizers producing reaction products of relatively higher solubility. For example, ammonium sulfate will produce low-solubility gypsum ($CaSO_4$) in combination with soil calcium, while ammonium nitrate will produce highly soluble calcium nitrate. Thus, if ammonium sulfate and ammonium nitrate are surface-applied to calcareous soil and are not immediately irrigated into the soil, more ammonium will volatilize from ammonium sulfate. It should be noted that N fertilizer in the nitrate form is not subject to volatilization.

Solution Sources—Fertigation

Fertigation is the application of solution fertilizer with irrigation water, typically through a microsprinkler or drip system (Figure 2; see chapter 7). The two most common nutrients applied to citrus through fertigation are N and K. Fertilizer injected into a microirrigation system should be a true solution with no solid contaminants. Solutions are made by dissolving readily soluble sources of plant nutrients in water.

Figure 2. Nutrient solution sources for fertigation are stored in large plastic tanks at the irrigation pump station.

Nutrient sources used to manufacture true solutions include:

Nitrogen
- Ammonium nitrate
- Urea
- Urea-sulfuric acid
- Ammonium sulfate
- Ammonium thiosulfate
- Calcium nitrate
- Potassium nitrate

Phosphorus
- Ammonium polyphosphate
- Phosphoric acid

Potassium
- Potassium chloride
- Potassium nitrate
- Potassium sulfate
- Potassium thiosulfate

Calcium
- Calcium nitrate

Magnesium
- Magnesium nitrate
- Magnesium sulfate

Micronutrients
- Borax
- Copper sulfate (acidified)
- Manganese sulfate (acidified)
- Manganese nitrate
- Zinc sulfate
- Zinc nitrate
- Zn, Mn, Cu, and Fe chelates (EDTA, DTPA, and/or EDDHA)

Growers should be cautious when applying solutions containing P through a microirrigation system. If the pH of the fertilizer-water mixture is not kept acidic, solution P can combine with dissolved Ca in the irrigation water to form an insoluble precipitate that will clog irrigation emitters. Some commonly used liquid formulations, their analyses, and weights per gallon are shown in Appendix D.

Solution Fertilizer Salt-Out

Solution fertilizer salt-out (crystallization) in storage tanks can be a problem during the winter. The most important factor affecting salt-out temperature of a fertilizer solution is the amount of N and K in it. The higher the analysis of a solution, the higher the crystallization temperature. For example, a 10-0-10 solution fertilizer made from ammonium nitrate and potassium chloride will salt-out at about 60°F, while 8-0-8 and 6-0-6 solutions made from the same sources will salt out at about 41°F and 27°F, respectively. Solutions made with potassium nitrate will salt-out a few degrees lower than solutions made with potassium chloride. The addition of micronutrients to the solution will result in a minimal change in salt-out temperature.

Solution fertilizer suppliers can provide salt-out temperatures for specific mixtures. If prolonged temperatures below the salt-out temperature are expected, crystallization should be prevented by diluting the solution with water. Adding enough water to lower the N and K grades to less than 5% will prevent salt-out most of the time. If there is no room in the storage tank for dilution, adding polyphosphate can lower the salt-out temperature several degrees. However, polyphosphates are most effective when used with lower analysis solutions.

Solution Sources—Foliar Sprays

Both foliar-applied urea and potassium phosphite have been shown to increase flowering, fruit yield, and total soluble solids yield of Valencia orange trees in Florida. Foliar N has also been used as a substitute for part of a soil-applied N fertilization program in an effort to decrease N leaching potential.

If urea is to be foliar-applied, only spray-grade, low-biuret (less than 0.25%) material should be used to avoid biuret toxicity. Tank-mixing with pesticides, crop oil, and other products should be approached with caution, because urea can be phytotoxic when applied at higher rates, particularly in combination with oil.

Nutrient sources applied in foliar sprays include:

Nitrogen
- Low-biuret urea

Phosphorus
- Potassium phosphite
- Ammonium phosphite
- Phosphorous acid

Potassium
- Potassium nitrate
- Monopotassium phosphate

Micronutrients
- Manganese/zinc nitrates
- Manganese/zinc sulfates
- Copper sulfate
- Synthetic and natural organic chelates (many forms)
- Borax

Suspension Sources

Suspensions are fluid fertilizers in which solids are prevented from settling by a suspension agent, usually a swelling-type clay like attapulgite or bentonite. Suspensions are higher in concentration than true solution fertilizers because they contain both dissolved and nondissolved fertilizer. They can be uniformly applied to the soil surface as part of fertilizer-herbicide mixtures that sometimes include micronutrients. Mechanical agitation may be necessary to maintain fertilizer concentration uniformity in the tank. Suspensions are made from the same fertilizers sources used to make true solutions (see previous section on fertigation).

Slow-Release Sources

Slow-release sources are materials of limited water solubility that release plant-available nutrients as they decompose or degrade in the soil following application. Except for a few slow-release K sources, almost all slow-release fertilizers are N sources. The release process is either biological or chemical, and slow-release fertilizers are grouped accordingly. For example, release of N from urea formaldehyde requires both dissolution of the fertilizer and microbial decomposition, while release of N from isobutylidene diurea (IBDU) involves slow dissolution only. Processed waste products release N through microbial degradation. Examples include biosolids, composts, and tankages.

Slow-release nutrient sources applied to Florida citrus include:

- Sulfur-coated urea
- Urea formaldehyde
  - Ureaform
  - Methylene urea
- IBDU
- Organiform (tankage)
- Animal manures
- Municipal biosolids
- Municipal composts

Controlled-Release Sources

Controlled-release fertilizers (CRFs) contain one or more plant nutrients in a form that either delays their availability for plant uptake after application or extends their availability significantly longer than rapidly available fertilizers like ammonium nitrate, urea, or potassium chloride. CRFs were initially developed for their horticultural benefits, but they have also attracted attention in the BMP and citrus greening era. CRFs have the advantages in inducing more growth and yield due to a continuous rather than a fluctuating supply of nutrients, reducing rates and frequency of fertilizer application, minimizing potential negative environmental effects, and bringing about substantial labor, time, and energy savings.

Controlling the release of nutrients is accomplished by surrounding conventional water-soluble fertilizer sources with a coating (Figure 3). Substances successfully used as coatings either alone or in combination include polymers, plastics, waxes, and sulfur. The standard (reference) release rate of a particular material is controlled by varying the coating thickness or physical characteristics during manufacture, but nutrient release is also typically influenced by soil temperature, water content, and microbes.

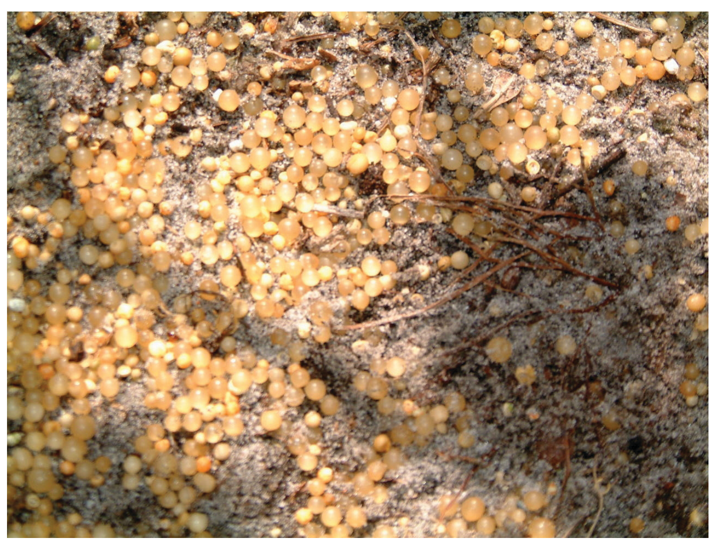

Figure 3. Coated fertilizer sources control the release of water-soluble nutrients to citrus trees and can last up to 12 months.

Controlled-release fertilizers are substantially more expensive than conventional sources, so their use may be limited to special situations such as young tree fertilization or nutrient management in environmentally sensitive areas. Many diverse CRF products have been developed, and the technology continues to advance. Most CRFs contain a complete N-P-K fertilizer combination with small amounts of micronutrients. Growers are advised to consult the label of such products to determine release characteristics and recommended application rate.

Citrus fertilization research conducted in Florida within the past 30 years showed that tree growth and fruit yield where part or all of the fertilization program included CRFs were similar or greater than growth and yield resulting from an all-conventional water-soluble N fertilization program. CRFs are more efficient, have low plant injury hazard, and have less leaching and volatilization potential than conventional soluble fertilizers.

Formulating Fertilizer Products

More than 80% of the fertilizer sold in Florida is bulk-blended at the request of the customer. It is possible to obtain almost any requested combination of nutrients through blending of the various base sources shown in Appendix B. In most fertilizer plants, blends are prepared by mixing the base sources and conveying the mixture to a bulk trailer or into bags. An example of the procedure used to formulate a fertilizer mixture is shown in Appendix E.

Nutrient Sources for Organic Citrus Production

Organic citrus production relies on plant and animal materials as nutrient sources and some mined raw minerals as opposed to inorganic chemical-based sources, so essentially all manufactured or synthetic fertilizers are prohibited. In particular, materials containing chloride, nitrate, and highly soluble phosphate cannot be used. Although biosolids (processed wastewater residuals) are organic materials, they are prohibited from organic farming due to concerns about metals content.

An example list of nutrient sources that can potentially be used for organic citrus production is given below. Some are allowed with no restrictions, while others are restricted to special cases. Organic growers should consult their certifying organization for specific rules and guidelines.

- Legumes
- Composted food and forestry by-products
- Wood ash
- Crop residues
  - Green manures
  - Peat moss
  - Straw
  - Seaweed
- Animal manures
  - Beef
  - Bird or bat guano
  - Dairy
  - Poultry
  - Swine
- Meals
  - Alfalfa
  - Bone
  - Blood
  - Cottonseed
  - Fish
  - Feather
  - Hoof and horn
  - Leather
  - Soybean
- Minerals and salts
  - Agricultural limestone
  - Basalt
  - Borax
  - Bordeaux mixtures
  - Chilean sodium nitrate
  - Colloidal phosphate
  - Greensand (glauconite)
  - Granite (ground)
  - Gypsum (mined raw material only)
  - Kiln dust
  - Langbeinite (K-Mg sulfate—mined raw material only)
  - Micronutrient-sulfate salts
  - Natural rock phosphate
  - Potassium sulfate (mined only)
  - Sodium nitrate (mined only)—limited use
  - Sodium molybdate
  - Sulfur (mined only)
  - Zinc sulfate

Chapter 11 (section on Organic Citrus Production) presents additional information about soil fertility and nutrient management guidelines for organic citrus production.

SL461

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 7. Methods of Fertilizer Application[1]

Thomas A. Obreza, Brian J. Boman, Mongi Zekri, and Stephen H. Futch[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For references, a glossary, and appendices, please refer to the full document at https://edis.ifas.ufl.edu/ss478.

Applying Dry Fertilizers

The choice of fertilizer application method becomes important as growers seek to improve nutrient-use efficiency and reduce losses to leaching and runoff. Dry-solid fertilizer spreaders should apply materials directly over the root zone, avoiding the row middle. It may be necessary to prune tree skirts to improve the spreading pattern and uniformity. When applying fertilizers to young trees, managers should take advantage of manual or electronic spreader adaptations that deliver fertilizer rates accurately to small tree root zones while leaving out the area between trees where roots are not present. Effort should be made to reduce surface movement of applied fertilizers by rainfall or wind.

Aerial application of micronutrients and other sprays is an accepted practice in Florida's citrus industry, but this application method is not recommended for dry fertilizers.

For economical and efficient fruit production, it is essential that spreaders be calibrated to apply exact amounts of fertilizers per acre. Plant nutrients should be applied according to individual crop requirements. Reduced yield may result from insufficient nutrient application, while excess nutrient application can lead to accumulation in soils and adjacent surface or groundwater.

Equipment needed to calibrate a typical grove spreader such as that shown in Figure 1:

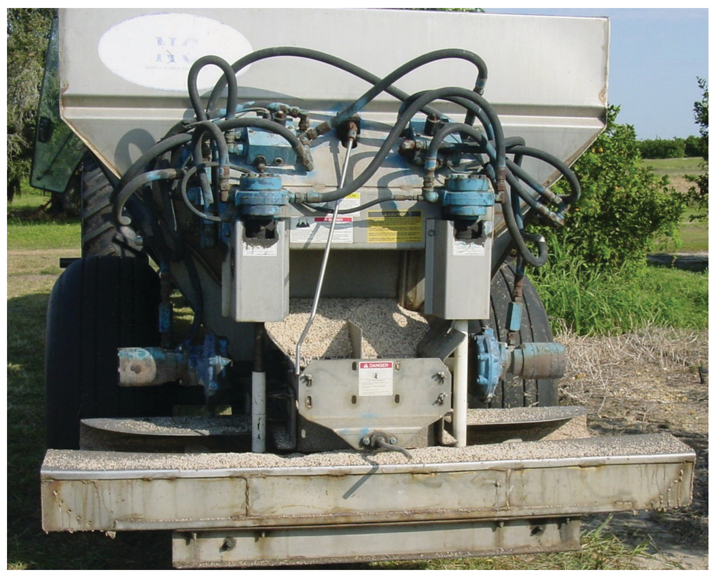

Figure 1. Conventional fertilizer spreader equipped with a split chain and rear deflector plates to apply dry, solid fertilizer beneath the citrus tree canopy.
Credits: Mongi Zekri, UF/IFAS

1. This document is SL461, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Thomas A. Obreza, professor and associate dean for Extension, Department of Soil and Water Sciences; Brian J. Boman, professor emeritus, Department of Agricultural and Biological Engineering, UF/IFAS Indian River Research and Education Center; Mongi Zekri, Extension agent IV, UF/IFAS Extension Hendry County; and Stephen H. Futch, Extension agent IV (retired), UF/IFAS Citrus REC; UF/IFAS Extension, Gainesville, FL 32611. Includes contributions from David P. H. Tucker, professor emeritus, Horticultural Sciences Department, UF/IFAS Citrus REC.

- A tray (catch pan) that slides under the opening where the chain pulls fertilizer from the hopper. This tray fits just above the fans.
- A spring scale or balance to weigh the fertilizer.

Calibration steps:

1. Position the empty tray so it will catch the fertilizer that comes out of the hopper during calibration.
2. Drive the tractor and spreader along a row middle or edge of a block as if fertilizing normally for a distance of exactly five trees. Record the speed, RPM, and gear of the tractor.
3. Collect the fertilizer discharged into the tray and weigh it.
4. Repeat the above procedure several times until a reliable average weight is obtained.
5. Use this equation to convert the weight of material to application rate in lb/acre, **assuming the spreader is fertilizing two rows at a time**:

Fertilizer material application rate (lb/acre) =

$$\frac{\text{Weight collected (lb)}}{[10 \text{ trees} \div \text{tree density (trees/acre)}]}$$

For example, if an average of 27 lb of fertilizer were collected and the grove density was 145 trees/acre, the application rate would be: 28 lb ÷ (10 ÷ 145) = **406 lb/acre**

Fertigation

Fertigation is the application of soluble fertilizers with irrigation water. Advantages of fertigation:

- Fertilizer is placed in the wetted area where the most active roots are located.
- Fertilizer may be applied more frequently in small amounts so that it is available when the tree needs it.
- Increased fertilizer application frequency can increase fertilizer efficiency and reduce leaching.
- Compared with conventional ground application, fertigation can produce similar or better tree growth, yield, and fruit quality with less fertilizer.
- Application cost is lower than that of dry or foliar fertilizer application because fertilization is incorporated into the normal irrigation schedule.

Disadvantages of fertigation:

- Fertilizer application uniformity and coverage depend on proper design, installation, and maintenance of the irrigation system.
- Extra equipment (injection device, tank, backflow prevention system) must be added to the irrigation system (Figure 2).

Figure 2. Fertigation equipment, including fertilizer tank (left), filters (center), and injector (right).
Credits: Mongi Zekri, UF/IFAS

- Soluble fertilizers are more expensive than granular fertilizers.
- Fertilizers injected into an irrigation system may contribute to emitter plugging.

To effectively fertigate citrus trees, growers must properly maintain their microirrigation systems to apply water and fertilizer uniformly (see Obreza 2004). In addition, growers must determine:

- the most suitable fertilizer formulations for injection;
- the most appropriate fertilizer analysis for different age trees and specific stages of growth;
- the fertilizer amount to apply during a given fertigation cycle or event; and
- the timing and frequency of applications per season.

Properly managed applications of plant nutrients through irrigation systems significantly enhance fertilizer efficiency while maintaining or improving yield and fruit quality. On the other hand, poorly managed fertigation may result in substantial yield loss. Keep in mind that if a very wet soil is fertigated when following a predetermined fertigation schedule, fertilizer and water will be wasted because water and nutrient uptake are drastically reduced if the soil is saturated.

Nutrient solutions for fertigation are available in different forms and concentrations. Formulations usually contain two or more nutrients, and the solubility of various formulations vary significantly. Fertilizer solubility is critical when preparing stock solutions for fertigation, especially when dissolving dry materials in water. Preparing "homemade" nutrient stock solutions from dry fertilizers may require considerable time and effort and can generate sediments. Therefore, commercially prepared true-liquid fertilizer solutions are preferred.

Solutions are convenient because they can be directly injected into the irrigation water stream with a variable-rate injection pump. Although transportation cost makes liquids more expensive, they save time and labor and prevent problems associated with handmade mixes. They also eliminate problems caused by insoluble materials found in some dry fertilizers.

Be careful when injecting fertilizers containing P or S into microirrigation systems. These elements may react with dissolved calcium and magnesium in the irrigation water to form insoluble precipitates that can clog irrigation lines and emitters. However, phosphoric acid can be safely injected into most water sources because it acidifies the solution, preventing precipitation. Most N sources have low clogging potential except for ammonium phosphate. This material increases water pH, which may cause Ca and Mg to precipitate.

Injected fertilizers must remain in solution throughout the entire time that the irrigation system is running. To help avoid plugging, a properly designed microirrigation system should include:

- a method of filtering irrigation water;
- a means of injecting chemicals into the water;
- equipment for flushing the system; and
- in some cases, a settling basin to allow aeration and the removal of solids.

Most fertilizers are highly corrosive and are a potential health threat where in contact with human skin. When fertigating, take these safety precautions:

- Wear appropriate protective clothing and eyewear when handling liquid fertilizers.
- Inspect all system components including pumps, injection devices, lines, filters, and tanks prior to use.
- Establish a routine fertigation monitoring program that emphasizes the start-up and shutdown periods in particular.
- Calibrate and frequently recheck injection rates and times to ensure proper system operation.
- Prevent leaks, runoff, excess applications, and application to areas near surface water.
- Flush all system components with clean water following each fertigation.

Fertilizer salts in irrigation water can burn leaves even if relatively low-salinity water is used. When injecting fertilizers, check the electrical conductivity (EC) of the irrigation water-fertilizer mixture and try to maintain it below 1.5 dS/m (mmhos/cm), which is equivalent to about 1000 ppm total dissolved solids. It is preferable to inject small doses of fertilizer more frequently rather than less frequent injections of larger doses.

It is essential to have legal backflow prevention devices installed in the irrigation system to keep fertilizer from siphoning back into the water supply (Figure 3). Managers should consult state and local regulations that address their equipment needs based on the type of water supply and selected injection device.

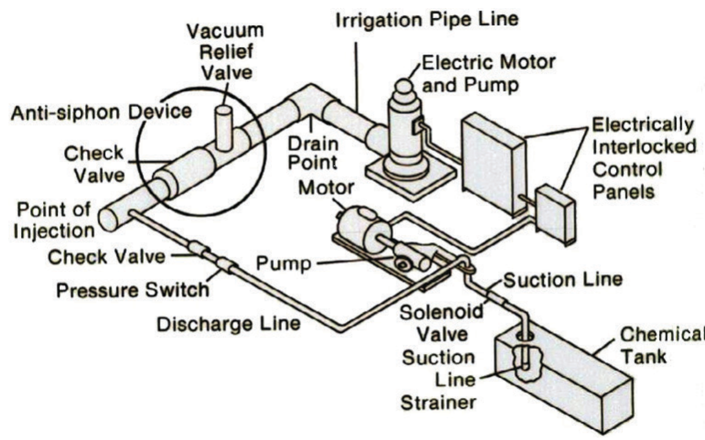

Figure 3. Schematic diagram of fertigation equipment with backflow prevention devices circled.

The injection system should be made of corrosion-resistant materials like reinforced ethyl vinyl acetate (EVA) hoses, nylon or polypropylene fittings, and polypropylene or fiberglass tanks. The injection device should have its own check valve plus a screen to prevent nondissolved particles from entering the system. Fertilizer injection should take place upstream of filters so that any contaminants or precipitates can be filtered out. Injection should stop during filter backwashing. If the system has a filter that uses part of the supply water to continuously backwash, fertilizer must be injected downstream of it. Injection of highly acidic or corrosive materials should take place downstream of filters that may be subject to corrosion.

Fertigation rates and timing should be calibrated for each irrigation zone. A single injection should last at least as long as the time it takes for water to travel from the injection point to the farthest emitter when the system is operating at normal pressure and flow rate. There is a large increase in EC when fertilizer is present in irrigation water, so fertilizer movement through an irrigation system can be traced by following changes in EC with a portable EC meter. The time from the beginning of an injection to a sudden increase in EC at the farthest emitter from the injection point indicates the travel time of the fertilizer. For many systems, this time is 20 to 30 minutes. Flush time should be longer than travel time so that nutrients do not remain in the tubing; otherwise microbial growth will be enhanced. An alternate method to determine travel time is to inject liquid soap and observe the time it takes for bubbles to appear at the farthest emitters.

The maximum injection time depends on soil type, nutrients, and water requirement of the trees. Flush time should not be too long, so as to avoid the application of too much water, because excessive water leaches plant nutrients below the root zone. Furthermore, too much water saturates the soil, causing damage to roots.

Fertilizer injection rates can be measured with a chemical flow meter or volumetrically. If a chemical flow meter is used on the high-pressure side of an injector, the flow meter should be rated for the pressure used. Volumetric measurements can be made by determining the time needed to inject a known volume of fertilizer under normal operating conditions.

For all fertigation methods, the required fertilizer injection volume can be calculated with the equation:

Volume = (Acres × N) ÷ (F × Density)

where

Volume = volume of fertilizer to be injected (gal)

Acres = grove area to be fertigated (acres)

N = amount of N to be applied per acre (lb N/acre)

F = percentage of N in the fertilizer expressed as a decimal (e.g., F = 0.08 for an 8-0-8 analysis)

Density = fertilizer solution density (lb/gal)

The weight per gallon of the liquid fertilizer solution can be obtained from the supplier. Alternately, a known volume of solution can be weighed and converted to a weight per gallon. Appendix D lists the density of many common fertilizer solutions.

Example

- The desired N rate is 150 lb/acre/year.
- Fertilizer is to be applied in 20 equal doses.
- The fertilizer solution is an 8-0-8 analysis made from ammonium nitrate and muriate of potash.
- The fertilizer solution density is 9.7 lb/gal.
- The grove to be fertilized is 80 acres with a 12.5 ft × 24 ft tree spacing (145 trees per acre).
- Each tree is irrigated with microsprinklers discharging 10.5 gal/hr at operating pressure.

Calculations

Dividing the annual rate of 150 lb N/acre into 20 fertigations results in a single-dose application rate of 7.5 lb N/acre. The volume of fertilizer to be injected is then calculated from the equation:

Volume = (80 acres × 7.5 lb N/ac) ÷ (0.08 N × 9.7 lb/gal) = 773 gal

Injecting the fertilizer during a 60-minute period would require 773 gal/60 min = 12.9 gal/min. Alternately, 10 gal/min of fertilizer could be injected for 77 minutes, resulting in 770 gallons injected. Injection rates may have to be adjusted to compensate for equipment capacities. If 10 gal/min is above the range of the injection system, increase the injection time and/or fertigate more frequently.

In mature groves irrigated with typical microsprinklers that apply water between 0.10 and 0.15 inches/hr within the irrigation pattern, fertigation and flush cycles should be completed in 2 to 3 hours. Injection intervals that are too short result in tree exposure to high rates of salinity, and salt burn may result if the irrigation pattern contacts lower leaves and fruit. Injection times that are too long may result in leaching if the water-holding capacity of the root zone soil is exceeded before irrigation is completed.

Special attention is needed when fertigating young trees equipped with downspray microsprinklers that confine the irrigation pattern to a 3-to-4-foot diameter circle. The water application rate of these emitters can result in excessive irrigation and nutrient leaching. For example, a 15 gal/hr emitter with a 4-foot diameter wetted area has an effective application rate of 1.9 inches/hr. This rate may result in leaching even if a fertigation-flush cycle requires only 1 hour to complete. To minimize leaching while downsprays are attached to emitters, post-injection irrigation must be the minimum required to flush the lines.

As trees mature and the root system expands to a much larger soil volume, the wetted area must be increased for fertigation to succeed. The wetted area for a mature tree should cover most of the area under the canopy, or at least 50% of the total land area. Patterns that irrigate less than 30% of the total land area may be unable to supply nutrients to enough of the root zone and may cause leaching. Knowledge of the application rate of the irrigation system and the soil water content prior to irrigating is critical to fertigation management. The use of soil moisture sensors may be beneficial, particularly those that measure water content at multiple depths.

Applying Suspension Fertilizers

Suspension fertilizers are applied with a standard herbicide boom that places the fertilizer directly over the root zone (Figure 4). Nozzles used to apply suspension fertilizers are larger than those typically used to apply herbicides (e.g., flooding or flood-jet nozzles). It is important to continuously agitate fertilizer in the tank to ensure application uniformity. Air sparging or mechanical recirculation can be used for agitation.

Figure 4. Boom applicator used to apply suspension fertilizers.
Credits: Stephen Futch, UF/IFAS

Boom application equipment should be modified with manifolds and nozzles made of a salt-resistant material like stainless steel. Applying fertilizer with a boom provides the opportunity to apply other agrichemicals like herbicides, insecticides, and fungicides at the same time. The salt effect of the liquid fertilizer can complement residual herbicides by burning existing weeds. However, care should be taken to avoid incompatibility when mixing materials.

Applying Foliar Fertilizers

Foliar nutrient application to citrus trees is common for economic and environmental reasons. Under specific conditions, it can improve nutrient uptake efficiency because nutrients are directly absorbed by the leaves. Foliar spraying can provide specific nutrients on a timely basis during critical stages of tree growth, flowering, and fruit development.

A well-planned foliar nutrition program can supplement soil fertilizer applications, especially when the citrus root system is unable to keep up with crop demand or when soil nutrients are unavailable. In some cases, a significant portion of nutritional needs can be met with a foliar program. Foliar application is not intended to replace a soil-applied N-P-K fertilization program. However, some macronutrients can be foliarly applied at rates sufficient to influence young tree growth, yield, and fruit quality.

Foliar application is an excellent means to supply plant requirements of secondary and micronutrients like Mg, Zn, Mn, Cu, B, and Mo. Foliar application of micronutrients is more effective than soil applications with the exception of Fe. Foliar sprays are taken up more rapidly by the tree, but their effects typically last only as long as it takes for the targeted growth flush to mature.

Foliar application can be integrated into an annual citrus nutrition program. It can be used to help trees through short but critical periods of nutrient demand, such as bud differentiation, flowering, fruit set, and fruit development. It is also useful when soil or environmental conditions are unfavorable for nutrient uptake by roots, such as cold weather, prolonged wet or dry soils, calcareous soil, or any other condition that decreases the tree's ability to take up nutrients when there is a demand. Foliar spraying is particularly useful when a nutritional deficiency is diagnosed, because it is the most rapid way to effect nutrient uptake by citrus trees.

Foliar fertilizers are usually applied to citrus trees with a conventional grove airblast sprayer (Figure 5), typically in 100 to 500 gal of water per acre. The goal of airblast spraying is to replace the air contained within in the tree canopy with spray-laden air. Sprayer travel speed must be slow enough to create air momentum to penetrate the canopy. However, unlike fungicide or miticide applications, it is not necessary to achieve highly uniform spray coverage of leaves or fruit. In many cases, nutrient sprays can be applied exclusively from the bed tops in 2-row bedded Flatwoods groves and from alternate row middles in Ridge groves.

Figure 5. Airblast sprayer used to apply soluble nutrients to citrus tree foliage.
Credits: P. Chris Wilson, UF/IFAS

Nutrient absorption is most rapid during the first several hours after application. Environmental conditions that cause stomata (leaf openings) to close reduce nutrient uptake efficiency. It is best to apply foliar sprays when air temperature is cool and humidity is high, such as early morning or late evening. Applying fertilizer during these times also decreases the chance of leaf burn. Maximum benefit of Zn, Mn, and Cu is obtained when spraying young leaves that are two-thirds to nearly fully expanded, but before hardening off. Treating the spring flush is preferable to later growth flushes.

Micronutrient and other nutrient sources including chelates and nitrate-based materials are often applied together with pesticides, spray oils, surfactants, and other products. Sometimes the chemistry of these mixes combined with the environmental and tree conditions at the time of application causes phytotoxicity and sometimes abscission of foliage and fruit. Reduced product efficacy may also occur. Information on compatibility of various product mixtures in the spray tank and the interaction of the components following deposition on the foliage and fruit surface is scarce. Poor-quality water, particularly due to salinity and/or high pH, can also contribute to the problem. Additives with strong penetrant activity should not be included in foliar-spray tank mixes. Reducing the number of components in tank mixes and spraying when trees are under minimal stress should reduce the potential for damage.

When applying foliar nutrients, it is important to ensure that the pH of the spray solution is between 6 and 7. Solution pH control is particularly important when applying urea. If the pH of a urea spray solution exceeds 7, free ammonia may be generated that dramatically increases the potential for leaf burn. Take this precaution especially when growing fruit for the fresh market, where fruit blemishes (burn) can substantially reduce marketable yield.

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 8. Recommended Fertilizer Rates and Timing[1]

Thomas A. Obreza, Kelly T. Morgan, L. Gene Albrigo, Brian J. Boman, Davie Kadyampakeni, Tripti Vashisth, Mongi Zekri, Jim Graham, and Evan Johnson[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For References, a glossary, and appendices, please refer to the full document at https://edis.ifas.ufl.edu/ss478.

Information in the box below applies to citrus trees affected by HLB. Other information in this chapter is valid for healthy citrus trees and trees with HLB.

Recommendations for HLB-affected trees:

Nutrient Management—Kelly Morgan, Davie Kadyampakeni, Tripti Vashisth, and Mongi Zekri

Leaf chlorosis develops as a result of infection with *C*Las, including interveinal chlorosis of young leaves. Symptoms are similar to Mn and Zn deficiencies that develop early in the growing season, followed by blotchy mottling of older leaves that develops later in the growing season. Leaf analysis of HLB-affected trees indicate deficiency of K, P, Mg, Ca, Mn, Zn, and Fe. HLB causes fibrous roots to decline within a few months after infection and before foliar symptoms develop. Fibrous roots are responsible for the bulk of nutrient uptake, and their decline likely explains the deficiency symptoms that develop in the canopy.

Traditionally, citrus growers try to achieve optimum nutrition through fertilizer management. A five-year study of foliar applications of Mn, Zn, and B on 5-to-7-year-old Valencia trees on Swingle rootstock was recently concluded in a commercial grove with the goal of determining the effect of improved leaf nutrient status on canopy density and yield (Morgan et al. 2016)*. The first analysis conducted was to determine whether foliar application of potassium nitrate (KNO_3) affected foliar concentrations of N and K and growth and productivity of the trees. The lack of an increase in foliar N after application suggests that N moves from the mature leaves to the new growth. Unlike leaf N, foliar K concentration of K-deficient trees increased to the optimum range after KNO_3 application. The application of KNO_3 increased canopy volume compared to the controls. However, yields for KNO_3-treated trees were not significantly greater than yields for the controls. One interesting result of this study was that the amount of Mn and Zn taken up into the leaf was not affected by KNO_3, as some have speculated.

1. This document is SL462, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Thomas A. Obreza, professor and senior associate dean for Extension, Department of Soil and Water Sciences; Kelly T. Morgan, professor and center director, Department of Soil and Water Sciences, UF/IFAS Citrus Research and Education Center; L. Gene Albrigo, professor emeritus, Horticultural Sciences Department, UF/IFAS Citrus REC; Brian J. Boman, professor emeritus, Department of Agricultural and Biological Engineering, UF/IFAS Indian River REC; Davie Kadyampakeni, assistant professor, Department of Soil and Water Sciences, UF/IFAS Citrus REC; Tripti Vashisth, assistant professor, Horticultural Sciences Department, UF/IFAS Citrus REC; Mongi Zekri, Extension agent IV, UF/IFAS Extension Hendry County; Jim Graham, professor, Department of Soil and Water Sciences, UF/IFAS Citrus REC; and Evan Johnson, research assistant scientist, Plant Pathology Department, UF/IFAS Citrus REC; UF/IFAS Extension, Gainesville, FL 32611. Includes contributions from James J. Ferguson, professor emeritus, Horticultural Sciences Department; Frederick S. Davies, professor emeritus, Horticultural Sciences Department; David P. H. Tucker, professor emeritus, Horticultural Sciences Department; Ashok K. Alva, US Department of Agriculture–Agricultural Research Service; and T. Adair Wheaton, professor emeritus, UF/IFAS Citrus REC.

Mn, Zn, and B were applied to trees separately at three rates, plus nonsprayed controls. The three rates were 0.5, 1.0, and 2.0 times the current UF/IFAS foliar recommendations (Table 7). The nutrient sprays were applied three times per year following flushes in March, May, and September. Thus, the three rates (0.5, 1.0, and 2.0 times UF/IFAS) resulted in a total of 1.5, 3.0, and 6.0 times UF/IFAS recommendations on an annual basis. For example, the UF/IFAS recommendation for Mn and Zn is five pounds per acre per year, so trees receiving 3 times UF/IFAS recommendation would receive 15 pounds per acre per year. The highest rates of Mn and Zn application had the greatest increase in those foliar nutrients. Although increases in leaf Mn and Zn concentration were observed immediately after application, no differences were found compared with controls prior to the next foliar application. Because Mn and Zn are mobile in plants, it is suggested these nutrients move out of the leaves to growing points. Canopy volume increased with increased application of Mn and Zn, but not B. Yield increased with the 1.5 and 3.0 annual rates of Mn and Zn but was lower for the 6.0 rate compared with the 3.0 rate. These results indicate increased growth of trees proportional to Mn and Zn within the range tested but reduced yield at the highest rate. Reduced yield at high rates of nutrients is common, because excess nutrient results in increased growth at the expense of yield and could partially explain variability in tree response to nutrient applications by citrus growers.

Conclusions from the five-year study indicate that the optimum range of leaf Mn and Zn concentrations should be in the upper half of the current recommended range (Table 7). However, the current maximum optimum range should not be exceeded unless larger and/or denser tree canopies are desired at the risk of lower yields. The new suggested leaf concentration ranges can be found in the table below.

Table 1. Suggested optimum leaf manganese and zinc concentrations for HLB-affected citrus trees.

Nutrient	Current optimum range (ppm)	Suggested optimum range (ppm)
Manganese	25–100	75–100
Zinc	25–100	75–100

Research has demonstrated that HLB symptoms can be reduced by foliar applications of micronutrients, especially Mg, Mn, and Zn. However, foliar nutrient applications are not likely to lead to pre-HLB production levels in the short term. Despite some essential nutrients being low in the leaves, the nontreated control trees continued to increase in canopy volume and yield during the course of the study. These responses have promoted development and use of enhanced foliar nutritional programs in Florida. Efficacy of these programs has been a topic of considerable discussion and debate. Fertilization programs vary considerably among growers and consist of various rates and application schedules of essential macro- and micronutrients.

Production managers should consider foliar fertilization to complement soil-applied fertilization to ensure nutrient availability. Field research has shown that supplemental foliar feeding can increase yield by 10%–25% compared with conventional soil fertilization.

Reference:

*Morgan, K. T., R. E. Rouse, and R. C. Ebel. 2016. “Foliar Applications of Essential Nutrients on Growth and Yield of ‘Valencia’ Sweet Orange Infected with Huanglongbing.” *HortScience* 51(12): 1482–1493.

pH Moderation and Root Management—Kelly Morgan, Jim Graham, and Evan Johnson

Typically, citrus trees in Florida groves irrigated with low-volume microsprinklers concentrate fibrous roots in the wetted zone. In recent decades, soils in the irrigated zone under citrus tree canopies have increased in pH and bicarbonate concentrations because of irrigation with alkaline water from deep wells extending into Florida’s limestone aquifers. As soils become more alkaline, some nutrients become more available (e.g., N and Mg) for uptake by plants, while others (e.g., Fe, Mn, Zn, and B) become less available. However, declines in tree vigor and productivity caused by HLB alone have been documented in trees growing in soils impacted by alkaline irrigation water.

In a recent greenhouse study, water uptake by trees receiving water supplemented with calcium bicarbonate was significantly reduced (10%–15%) compared with healthy trees and was further reduced by HLB (>20%). Tree heights were similar for HLB-affected and healthy trees irrigated with calcium carbonate but significantly smaller than healthy trees not receiving modified irrigation water. The cause of reduced water and nutrient uptake was found to be reduced root density (examples shown in tables below).

Two field studies determined that Ca, Mg, Mn, Zn, and B concentrations in leaves were greater with irrigation acidification and reduced soil pH than in nontreated controls. Leaf Ca, Mg, Mn, and Zn concentrations were significantly different among treatments in the mature tree grove, but only significantly different for Ca, Mn, and Zn at the young tree grove when averaged over the entire 3-year study period. Root density samples indicated a significantly greater root length density with soil pH below 6.5. These results verify previous finding that leaf nutrient concentrations increase with soil pH below 6.5.

Table 2. Effect of reduced soil pH on root density in 3-year field study.

Sulfur	pH	Root Density (mg/cm^3)
No	6.4	1.1
Yes	5.9	1.4*
*Significant difference P<0.05		

Table 3. Changes in yield as a result of low or high pH.

Grove status	No. of blocks surveyed	Root mass density (mg/cm^3)	Change in block yield from 2009–12
Low pH stress Ridge	14	0.6	Increased 6%
High pH stress Ridge	10	0.4	Decreased 3%
High pH stress Flatwoods	13	0.2	Decreased 20%

Fertilizer Rates, Application Frequency, and Timing for Nonbearing Trees (First 3 Years in Grove)

Solid Plantings

Nitrogen

Management of young trees requires managing irrigation, nutrition, weeds, diseases, pests, and cold protection at intensities that stimulate rapid canopy growth. Irrigation and N availability are the most important factors affecting growth of young trees. Obtaining optimum growth requires substantial irrigation and N inputs, but excesses of either are nonproductive and costly, and may result in loss of N by leaching or runoff.

Numerous young-tree fertilization studies across Florida led to N recommendations for nonbearing trees (Table 4 and Figure 1). These guidelines include a range of rates by tree age because a number of factors influence the N fertilizer requirement. Criteria for selecting a rate within the recommended range include:

- Soil type—Trees planted in soils high in organic matter (i.e., 2% or greater) or with a loamy texture require less fertilizer than trees on low-organic-matter sandy soils.
- Land history—New plantings on land previously used for pasture or vegetable production require less fertilizer during the first 1 to 2 years compared with trees replanted in established groves due to mineralization of accumulated organic matter.
- Fertilizer source—Use of controlled-release formulations may allow a reduction in fertilizer rate.

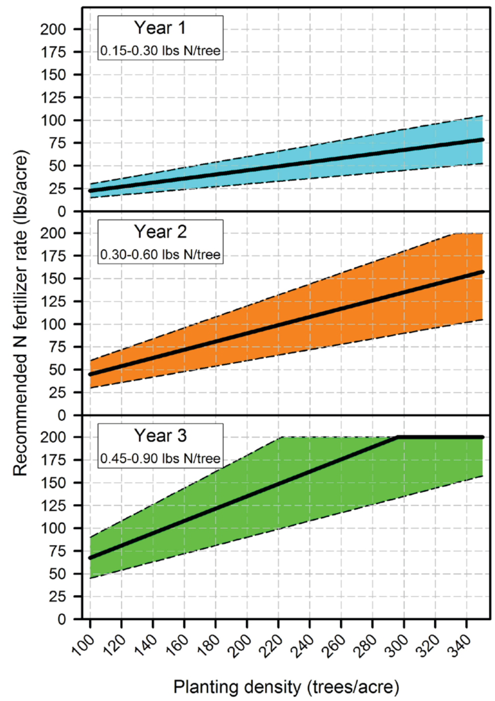

Figure 1. Recommended N rates for nonbearing citrus trees on a **per-acre** basis as a function of planting density. To determine the per-acre rate, find the planting density on the x-axis, move up into the colored band, and find the recommended N rate range on the y-axis.

Phosphorus

Before deciding to apply P fertilizer to young trees, test the soil for P and compare the results with the ranges in Chapter 4, Tables 4 or 5.

- If soil test P is in the high or very high range, do not apply P fertilizer.
- If soil test P is in the medium range, apply P fertilizer at a P_2O_5 rate equal to 50% of the N rate.
- If soil test P is in the low range, apply P fertilizer at a P_2O_5 rate equal to 75% of the N rate.
- If soil test P is in the very low range, apply P fertilizer at a P_2O_5 rate equal to the N rate.

If soil testing justifies P fertilizer application, test the soil again the following year and compare with Chapter 4, Tables 4 or 5 to determine if P fertilization can be decreased or omitted. Initiate a leaf tissue testing program for P in year 3, and compare the results with the standards in Chapter 4, Table 2.

Potassium

Apply K fertilizer at a K_2O rate equal to the N rate.

Calcium

If the soil pH is in the optimum range of 5.5 to 6.5, there is no need to apply Ca. If soil pH is below 5.5, the soil should be limed to pH 6.5, which will supply needed Ca. If soil pH is above 6.5, the soil will contain abundant Ca.

Magnesium

If soil test Mg is medium or lower (Chapter 4, Tables 4 and 5), apply Mg fertilizer at a rate equal to 20% of the N rate. Curtail Mg fertilizer application if a subsequent soil test shows Mg in the high range.

Micronutrients

If trees are planted on previously cultivated land (e.g., complete grove renovation or land converted from other agricultural uses where fertilizer was applied), do not apply micronutrients unless leaf analysis indicates they are below optimum or leaf/twig/fruit deficiency symptoms appear.

If trees are planted on previously noncultivated land, apply Mn, Cu, and B at 5%, 2.5%, and 0.33% of the N rate, respectively, until soil and leaf analysis and/or tree appearance indicate that one or more may be omitted. Boron may need to be applied every year because it leaches readily. Do not routinely apply Zn, Fe, or Mo unless prompted by visual symptoms.

Nutrient Management

Applying fertilizer in several small doses increases fertilizer efficiency by maintaining more constant N availability and by reducing leaching if unexpected rain occurs. A minimum of 4 to 6 applications of dry fertilizer is recommended. Splitting fertigation into 10 or more applications per year is common. The cost of liquid injection during irrigation is relatively small, particularly if the injection can be automated. One or two applications of controlled-release fertilizer are satisfactory because nutrients are protected from leaching rains. Controlled-release formulations may be applied preplant, incorporated after planting, or broadcast to ensure uniform distribution of nutrients throughout the enlarging root zone of young trees.

Nonbearing trees fertilized after October 1 may be slightly less cold-hardy. However, citrus tree growth is triggered by favorable temperatures and soil moisture, not by fertilization. Omitting fertilizer in the fall will not prevent growth. Fertilizer uptake is reduced at lower soil temperatures. This condition is particularly true for trees on Swingle citrumelo rootstock, which can become quite chlorotic in appearance during the winter months, even with fall fertilization.

Irrigation management of young trees is critical because water stress can occur rapidly as the soil surrounding the limited root system dries, and because young tree growth is particularly sensitive to water stress. Some instances where young tree growth improved after a grove was converted to fertigation may have been due more to improved soil water regime than nutrient delivery method.

Excessive irrigation is often a problem when managing young trees. Small microsprinkler wetted patterns used to irrigate small trees apply water at high rates. Short irrigation durations of 30 minutes or less may be required to avoid nutrient loss below the root zone. Irrigation line flushing times after fertigation must also be minimized to avoid nutrient leaching.

Resets in Established Groves

Resets in established groves should be fertilized similarly to solid-set nonbearing trees. Resets may not grow well if they only receive fertilizer during mature tree application because only a small amount of material may be deposited in the young tree root zone. Resets will most likely not require P fertilizer, but this can be checked with a soil test. Controlled-release materials can be applied 1 to 2 times per year without compromising tree growth in reset situations. In closely spaced groves, reset growth may be restricted due to competition from the adjacent older trees.

Example Fertilizer Program for Nonbearing Trees

Fertilizer rates for trees during the first 3 years in the grove are calculated on a per tree basis. For example, if a 2-year-old tree is scheduled to receive 0.4 lb N per tree per year in four equal applications, then 0.1 lb N will be applied each time. Using a fertilizer containing 10% N, the tree will receive 1.0 lb of fertilizer per application.

Fertilizer Rates for Bearing Trees (4+ Years in Grove)

Nutrient management for bearing trees requires many of the same considerations important for nonbearing trees. Nitrogen continues to be the most important element for tree growth, fruit yield, and fruit quality, but others also have substantial effects on production and fruit quality. Harvesting the crop removes a significant amount of nutrients from the grove, but fruit production accounts for only part of the fertilizer requirement.

Nitrogen

Continued strong vegetative growth is an objective for several years after fruit production begins, so N fertilizer application supports both canopy expansion and fruit production. In addition, fruit quality becomes important for both processed and fresh fruit. Orange and grapefruit groves tend to receive higher N fertilizer rates if the fruit is grown for processing, because returns are based on lb solids/acre (total sugar) production. If the fruit is grown for the fresh market, where fruit size, shape, peel thickness, texture, and color are important, the N fertilizer rate is usually lower, perhaps two-thirds or three-quarters of the processed fruit rate.

Young bearing trees (years 4 through 7 in the grove). Recommended N fertilizer rates (Table 5) provide enough N for canopy expansion toward containment size while producing maximum economic yields of high-quality fruit. The N rate selected should be based on soil characteristics, yield potential, and tree needs as indicated by leaf analysis interpretation (Chapter 4, Table 2).

- For grapefruit, the recommended annual N rate is **120 to 160 lb/acre**.
- For oranges and other varieties, the recommended annual N rate is **120 to 200 lb/acre**.

Mature bearing trees (years 8+ in the grove). Once trees reach containment size, further canopy growth is not desired, so nutrition inputs can be stabilized and possibly reduced. Nitrogen fertilizer management should focus on 1) maintaining tree biomass, 2) generating sufficient vegetative growth to replenish fruiting wood, and 3) replacing N exported with the harvested crop. The guidelines for annual N fertilizer rates accounts for the needs of both vegetative growth and crop removal (Table 8.2).

Grapefruit

- The recommended annual N rate is **120 to 160 lb/acre**. For groves producing more than 800 boxes/acre, 180 lb/acre may be considered. The N rate selected should be based on tree needs as indicated by leaf analysis interpretation, soil characteristics, desired fresh-fruit quality characteristics, and yield potential.
- **The optimum leaf N concentration associated with best grapefruit quality is around 2.2% (Figure 2), which is lower than the optimum leaf N range for orange production (2.5% to 2.7%).** To achieve high yields of large fruit, growers should adjust N fertilizer rates to maintain grapefruit leaf N around 2.2%.

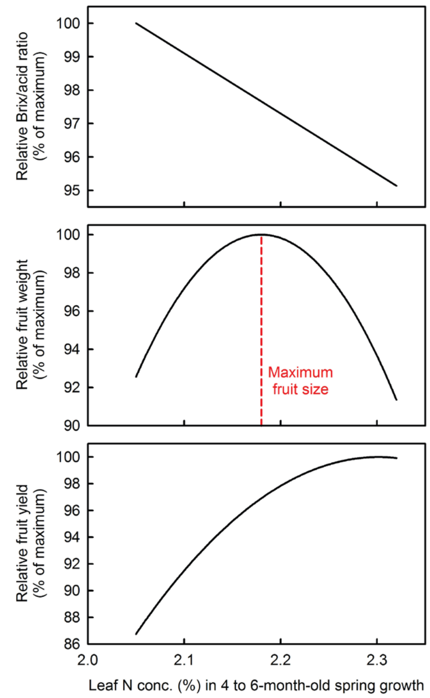

Figure 2. As grapefruit leaf N increases from 2.0% to 2.3%, yield increases and Brix/acid ratio decreases slightly. Fruit size increases as leaf N approaches 2.2%, then decreases substantially (He et al. 2003).

Oranges

- The annual N rate should fall within the range of **125 to 245 lb/acre**. The recommended rate for a specific grove depends on either **expected yield potential** (for 8-to-11-year-old trees) or **4-year running average production history** (for trees 12 years or older) expressed as either fruit yield or soluble solids production (Figure 3).
- When basing N fertilization on expected yield potential, the rate should be selected considering 1) how well the young bearing trees have produced and 2) leaf tissue analysis.
- **If leaf N is consistently maintained in the optimum range, additional fertilizer will not increase yield (Figure 3) and may reduce some aspects of fruit quality.**
- The base N rate recommendation (125 lb/acre) is for groves producing 200 boxes/acre or 1300 lb solids/acre.
- The high end of the N rate range (245 lb/acre) is for groves producing 1000 boxes/acre or 5800 lb solids/acre.
- Beginning at the base N rate, the recommended N rate increases:
  - lb N/acre for every 100 box/acre increase in expected yield potential or 4-year running average yield; **or**

- 7 lb N/acre for every 100 lb solids/acre increase in expected yield potential or 4-year running average yield.

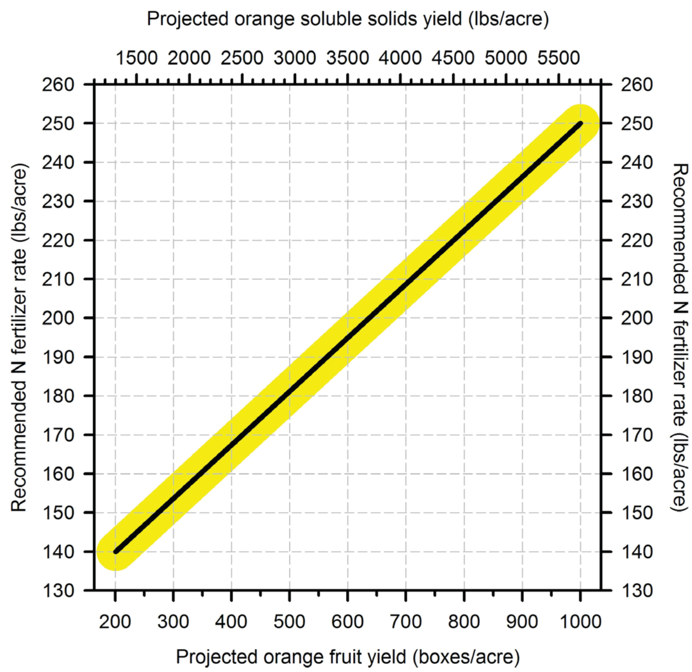

Figure 3. Production-based N fertilizer rate recommendations for Florida oranges. Find the expected yield potential (8-to-11-year-old trees) or 4-year running average production (trees 12 years or older) on the x-axis, move up or down to the straight line, and find the recommended N rate range on the y-axis.

Other Varieties

- For other varieties, the recommended annual N rate is **125 to 245 lb/acre** using the method above to calculate a production-based rate for specific groves.
- For the special case of Orlando tangelos, the high end of the annual recommended N rate range is 250 lb N/acre.
- For the special case of Honey tangerines (Murcotts), the high end of the annual recommended N rate range is 300 lb N/acre.

Example N fertilizer rate calculation for mature, bearing orange trees using box/acre yield:

Recommended N rate = Base N rate +

{[(Avg. yield – 200 boxes/acre)/100] × 15 lb/acre}

If a grove has produced an average of 500 boxes/acre during the past 4 years, then

Recommended N rate = 125 lb N/acre +

{[(500 – 200)/100] × 15 lb N/acre}

= 125 + 45 = 170 lb N/acre

Example N fertilizer rate calculation for mature, bearing orange trees using lb solids/acre yield:

Recommended N rate = Base N rate +

{[(Avg. yield – 1300 lb sol./acre)/100] × 2.7 lb/acre}

If a grove has produced an average of 3500 lb solids/acre during the past 4 years, then

Recommended N rate = 125 lb N/acre +

{[(3500 – 1300)/100] × 2.7 lb N/acre}

= 125 + 59 = 184 lb N/acre

Leaching rain rule. If more than 3 inches of rain falls within 72 hours after an N fertilization, “replacement” fertilizer may be applied up to one-half of the N rate affected by the rain (not to exceed 30 lb/acre). If the affected N fertilizer source was 100% slow-release or controlled-release, this rule does not apply. If the source was a mixture of water-soluble and slow- or controlled-release N, this rule applies only to the soluble N fraction.

Phosphorus

Determine the need for P fertilization using leaf tissue and soil test results.

- Sample leaves and soil using the procedures described in Chapter 4.
- Compare the analytical results with the interpretations provided in Chapter 4, Tables 2, 4, and 5.
- Follow the P fertilization guidelines in Table 6.

Potassium

Apply K fertilizer at a K_2O rate equal to the N rate. If leaf K is consistently below optimum from year to year, increase the K_2O rate by 25%, especially if the grove soil is calcareous.

Calcium

If the soil pH is in the optimum range of 5.5 to 6.5, there is no need to apply Ca. If soil pH is below 5.5, the soil should be limed to pH 6.5, which will supply needed Ca. If soil pH is above 6.5, the soil will likely contain abundant Ca.

Magnesium

If soil test Mg is medium or lower (Chapter 4, Tables 4 and 5) or if leaf Mg is below optimum (Chapter 4, Table 2), apply Mg fertilizer at a rate equal to 20% of the N rate. Alternatively, Mg may be applied in a foliar spray. Curtail

Mg fertilizer application if a subsequent soil test shows Mg in the high range, or if leaf Mg improves to optimum or greater.

Micronutrients

The quantities of micronutrients in 100 boxes of fruit are extremely small (Chapter 3, Table 3). Removal of micronutrients by the harvested fruit, even from a high-producing grove, is negligible compared with the amount present in the soil. In high pH (>7) soils, micronutrient availability (except Mo) decreases considerably. Micronutrients (with the exception of B and Cu) should be applied as needed based on visual, **persistent** foliar deficiency symptoms or low leaf-analysis values. Recommended methods, timing, and rates for micronutrient application to citrus groves are shown in Table 7.

Factors influencing the effectiveness of foliar sprays include the formulation used, metallic rate per acre, and timing of the spray with respect to leaf age. Many commercially available micronutrient formulations, when applied at their recommended label rates, will maintain sufficient leaf concentrations but usually will not correct moderate to severe deficiencies. Water-soluble micronutrient fertilizers may be included with postbloom or summer sprays after full expansion of leaves.

Copper. Some central Ridge and Atlantic Coast grove soils contain 300 to 400 lb Cu/acre in the top 6 inches of soil. A moderate routine disease-control spray program contributes an additional 3 to 4 lb Cu/acre/year, so no soil application of Cu fertilizer is needed in this situation. A soil pH below 5.5 can solubilize soil Cu, which is toxic to plants. As little as 1 ppm Cu in the soil solution can kill roots. Maintaining soil pH close to neutral is recommended to reduce the potential for Cu toxicity. Some rootstocks (e.g., Swingle citrumelo) that perform poorly in high-pH soils are also sensitive to high soil Cu. When replanting on old grove sites with low soil pH, the potential for toxicity is high.

While the emphasis with old grove soils is on managing high soil Cu, most previously noncultivated Florida sandy soils are deficient in Cu. If a grove is developed on a virgin sandy soil, Cu fertilizer should be included in the fertilizer blend (see section “Solid Plantings”).

Iron. Soil applications of non-chelated, inorganic Fe fertilizers usually cannot correct visible Fe deficiency symptoms. Because these Fe fertilizers readily precipitate, they are unavailable to the tree. In neutral to slightly acidic soils, Fe deficiency can also be a problem if Cu is present at high concentration.

Calcareous soils may contain high total Fe, but it is extremely insoluble. Visible Fe deficiency is common on these soils. The primary factor causing Fe chlorosis in an alkaline soil is the effect of the bicarbonate ion (HCO_3^-) on Fe uptake and/or translocation in the plant. The result is an inactivation or immobilization of Fe in plant tissue. Citrus rootstocks vary widely in their ability to overcome low Fe stress (Table 8). The easiest way to avoid alkaline-induced Fe chlorosis in citrus trees to be planted on calcareous soils is to use tolerant rootstocks.

Iron chlorosis should be corrected by soil application of chelated Fe fertilizer. Chelates are superior sources of Fe for plants because sufficient Fe can be supplied at lower rates compared with inorganic Fe sources. The effectiveness of an Fe chelate depends greatly on soil pH (Table 9). Fe-EDTA and Fe-HEDTA, which are relatively inexpensive, will correct Fe deficiency if soil pH is less than 6.5. Do not apply these chelates to alkaline soil, because they will readily break down, resulting in loss of available Fe by precipitation.

Iron chlorosis of citrus trees on susceptible rootstocks growing on calcareous soil is not easily remedied. Effective Fe chelates for these soils are available, but the treatments can be expensive and leaf greening is usually transient. Fe-DTPA should be chosen for mildly alkaline soils (pH 7.5 or less), whereas Fe-EDDHA is the chelate of choice for highly calcareous soils (pH greater than 7.5).

Organically complexed Fe exists in by-products like wastewater residuals (biosolids) or certain drinking-water treatment residuals (Fe-humates). Biosolids are potentially useful because they contain a high concentration of Fe that exists in a complexed form that does not readily precipitate. Research with Fe-humate applied to citrus trees showed that moderate to severe Fe deficiency could be corrected at relatively low cost.

Zinc. Soil pH is the most important factor regulating plant-available Zn. At alkaline pH, Zn precipitates and availability markedly decreases, so soil pH less than 7 is the preferred situation. Although there are natural mechanisms in the soil-plant system that increase the availability of Zn in alkaline soils, Zn deficiencies are common.

Special consideration should be given to groves being visually monitored for HLB symptoms (see section 3.9). Trees on Carrizo citrange rootstock tend to show Zn deficiency symptoms more readily, even though the tree is not likely Zn deficient.

Application of foliar Zn fertilizer is usually combined with pesticide sprays scheduled in April or May at 3 to 5 lb of metallic Zn/acre using either ZnO or $ZnSO_4$. A number of other formulations are available for foliar application, including nitrates and organically chelated forms using lignin sulfonate, glucoheptonate, or alpha-keto acids. Practically speaking, inorganic and organic Zn fertilizer sources are about equally effective with respect to foliar absorption.

Application of Zn directly to acidic soils is not economically practical due to the massive rates required to correct a deficiency. Zinc should not be ground-applied to groves on calcareous soils because the alkaline pH renders the Zn unavailable almost immediately.

Manganese. The behavior of Mn in the soil is similar to that of Zn, especially with respect to relative availability in acidic and alkaline soils. Either sulfate, oxysulfate, or some oxide forms of Mn can be used to correct Mn deficiency, with the degree of effectiveness decreasing in that order. Soil application of Mn is not recommended on calcareous soils where Mn deficiency is commonly encountered.

For groves on acidic soils that show **persistent** Mn deficiency symptoms on young foliage, soil application of 7 to 10 lb of Mn as $MnSO_4$ per acre is recommended. On calcareous or heavily limed acid soils, foliar application of 3 to 5 lb of Mn per acre is recommended. A special effort to prevent Mn deficiency symptoms should be made in groves being visually monitored for citrus greening disease symptoms (see section 3.9).

Boron. Boron is required in very small amounts, and there is only a small range between deficient and toxic amounts. It should be applied annually as a foliar spray or in a dry fertilizer mixture at approximately 1/200 of the N fertilizer rate. Irrigating citrus with reclaimed water may provide sufficient B such that supplemental fertilization is not required.

Molybdenum. Molybdenum is also required in very small amounts. If Mo deficiency occurs, it usually means that the soil is very acidic. The deficiency is corrected by a foliar spray, which may last for several years. Soil applications are not satisfactory.

Timing and Frequency of Fertilizer Application for Bearing Trees

Bearing-tree nutrition management must support both vegetative growth and the current fruit crop. Spring vegetative growth is particularly important because it forms the fruiting wood for the following year's crop. The period of highest nutrient requirement begins in late winter and extends through early summer. During this time, flowering and fruit development competes with spring vegetative growth flushes. Flowers and fruitlets take up accumulated nutrients, but some of these are temporarily lost during the flower-fruitlet shedding process. The tree is then left with the fruit it can sufficiently support to maturity. This process continues until the May–June drop of fruitlets is completed. Nutritional requirements for fruit development decrease after this period. Best fruit quality is obtained when fall and early winter nutritional status, particularly N, is moderately low.

Based on the nutritional demands during a typical year, a basic fertilizer application schedule divides the total annual requirement into three equal increments:

- The first increment should be made available between early February and the time flowering occurs.
- The second increment should be made available between flowering and mid-June.
- The third increment should be made available between mid-June and mid-October, **avoiding the summer rainy season as much as possible**. Thus, this increment should be applied during late summer or early fall.

Fertilizer may be applied during the fall and winter, particularly in the southern portion of the citrus-growing region, where trees often grow throughout the year. Any time growth is induced by warm weather, sufficient nutrients should be available. However, be aware that fall or winter fertilizer applications can make psyllid control more difficult (see section 3.9), delay fruit color development, and increase the susceptibility of trees to freeze injury.

Much of Florida's citrus industry exists on shallow Flatwoods soils with intensive irrigation, so the danger of root damage from high salinity is greater than it is on deep sandy soils. Split fertilizer applications minimize salt damage potential, decrease leaching during the summer rainy season, and help maintain a continuous nutrient supply during south Florida's long growing season.

Slow-Release and Controlled-Release Fertilizers

Slow-Release N Sources

Citrus growers can reduce the number of fertilizer applications per year when slow-release N sources like sulfur-coated urea, urea formaldehyde, methylene urea, or IBDU make up 40% to 60% of the total N in the fertilizer. For example, a grower applying 100% water-soluble N fertilizer (e.g., ammonium nitrate) four times per year could cut the application frequency to twice per year if the N source was changed to a 50-50 blend of ammonium nitrate and IBDU. However, the total N rate applied per year should be the same in both cases.

If a natural organic material like manure or biosolids is included as part of the N applied to citrus, the mineralization rate must be considered when determining the rate to apply. Organic matter decomposes relatively quickly in Florida's warm and humid environment, so N mineralizes much faster than it would in a cooler northern climate. Roughly half of the N in biosolids and two-thirds of the N in poultry (layer) manure becomes plant-available during the first year after application. For example, if a poultry manure application supplied 100 lb/acre of total N to a grove, about 66 lb N/acre would become available to the trees during the next 12 months.

Research conducted in several Florida locations showed that N mineralization is front-loaded in the case of both poultry manure and biosolids (Table 10). Most of the N becomes plant-available in the first month after application, followed by a gradual release of the remainder during the subsequent 11 months. Research has shown that the amount of plant-available N released from either material after 12 months is negligible. The N not accounted for by the plant-available fraction most likely volatilizes, denitrifies, is used by soil microbes, or remains in the soil as recalcitrant organic matter.

Controlled-Release Fertilizers

Commercial fertilizer companies have blended together individual coated fertilizer materials, each with a different release rate, to create controlled-release mixtures suitable for single annual applications to citrus. For example, a fertilizer made to match the nutrient requirements of citrus trees might be composed of a suite of water-soluble 3-month, 6-month, and 9-month materials. A blend like this would be applied once, in February. Ideally, it would release two-thirds of its nutrients from February to June, and the remaining one-third would gradually release between June and October.

Coated fertilizers provide the highest nutrient uptake-efficiency potential of any fertilizer class. Recent research suggests they can sustain equal or increased fruit production when applied at lower N rates compared with a standard water-soluble N fertilization program. Because they are considerably more expensive than water-soluble materials, applying coated fertilizers at lower rates may be necessary to keep a fertilizer program economically competitive. Because the marketing of coated fertilizers for mature citrus groves is relatively new, growers are encouraged to consult the fertilizer manufacturer or blender for the latest rate recommendations.

Foliar Application of N, P, and K

The amount of plant nutrients that can be taken up through the leaves of a citrus tree is miniscule compared with the amount that can enter through the roots. Micronutrients can be successfully applied with foliar sprays because the tree does not require them in large amounts (Chapter 3, Table 1), but leaves are not usually thought of as a major uptake site for macronutrients. However, there are special instances where foliar application of N, P, and/or K is justified. Citrus growers should realize that in the cases of N and P, a positive response to foliar sprays may be due to additional effects of the materials on tree physiology beyond simple enhancement of tree nutrition.

Nitrogen

Commercial forms of urea are available that can be readily absorbed by citrus leaves, particularly if applied with a non-ionic surfactant. Foliar urea sprays applied during the winter have enhanced the number of flowers and yield of Valencia oranges in both research plots and commercial trials. These sprays presumably work only if some induction has taken place from natural cold or drought stress. Therefore, for effective use in the winter, urea sprays should be applied after some natural flower induction has occurred but before most bud differentiation starts. In Florida, significant induction may not start until late December some years, while in other years some buds may be differentiating by early January. After some cool temperature induction or 30 days of drought stress, foliar sprays of 50–60 lb of spray-grade urea per acre can enhance flower bud induction and may increase fruit yield. **Care must be taken to apply the correct rate, because leaf damage can occur if urea application is excessive**.

Maximum penetration of urea into citrus leaves occurs within 12 to 24 hours after spray application. Optimum conditions for foliar uptake include:

- Air temperature between 77°F and 88°F
- High relative humidity
- Spray solution with a pH between 7 and 8 to prevent urea breakdown

Under favorable environmental conditions, roughly half of foliar-applied urea penetrates the leaves, while most of the other half is lost through volatilization. **The rate of foliar-applied N should be considered as part of the total annual N rate applied to the grove**. For example, a foliar spray of 50 lb urea/acre applies 23 lb N/acre. If the fertilization plan calls for a total of 180 lb N/acre/year, only 157 lb N/acre should be included in the soil-applied fertilizer program.

In Florida citrus production areas where groundwater nitrate contamination exists or is seen as a potential problem, urea sprays should be evaluated to provide a portion of the tree N requirements, especially during the summer months when the leaching potential is greatest.

Phosphorus

Citrus leaves are extremely impervious to the phosphate (PO_4^{3-}) form of P, so foliar application of a liquid P material like ammonium polyphosphate is not recommended. Conversely, the phosphite (PO_3^{3-}) form of P is more readily absorbed into plant tissue, and once inside the plant it remains stable. Phosphite does not readily convert to phosphate in the plant, so the nutritional value of absorbed PO_3^{3-} is uncertain. However, phosphite is officially recognized by FDACS as a source of P for crops.

In California, research showed that foliar applications of phosphite were able to replace standard P fertilization in citrus crops suffering from P deficiency. The conversion of phosphite to phosphate likely occurred prior to plant absorption, resulting from slow chemical oxidation or by oxidizing bacteria and fungi found living on citrus leaves. Phosphite also showed fungicidal activity and increased citrus floral intensity, yield, fruit size, total soluble solids, and anthocyanin concentration, usually in response to a single foliar application.

In Florida, a prebloom foliar application of 2.6 quarts of 28% P_2O_5 as potassium phosphite per acre to Valencia oranges significantly increased flower number, fruit yield, and total soluble solids yield compared with an untreated control. These results suggest that the effect of phosphite was not due to the molecule's fungicidal attributes, but due to other growth-stimulating properties.

Citrus growers should identify their production goal for the year (e.g., increased yield, increased fruit size, or improved fruit quality) to determine if a phosphite application is justified. Be aware that phosphite materials, if not formulated correctly, have significant phytotoxicity potential and may induce adverse reactions with other materials in the spray tank, like micronutrients or pesticides.

Potassium

Many factors contribute to the size of fruit in a particular year, such as fruit load, rainfall pattern, fertilization program, hedging and topping, and rootstock/scion combination. However, it is difficult to predict how these factors combine to affect final fruit size at harvest. The easiest factor to manipulate is nutrient management. Among other fruit qualities, increased K fertilization is associated with larger size (Chapter 3, Table 4).

Effects of low K on fruit yield and quality generally precede appearance of leaf deficiency symptoms. Decreased yield and small fruit have been observed on trees with leaf K in the range of 0.5% to 0.8%, while K concentrations of 1.2% or more have been associated with maximum yield of high-quality fruit.

Applying foliar sprays of K cannot entirely substitute for soil-applied fertilizer, but they can serve as a supplement, and their ability to increase fruit size has been demonstrated. Foliar-applied K has also corrected K deficiency of citrus on calcareous soil. Applying potassium nitrate (KNO_3) in this manner increases leaf K more rapidly compared with soil-applied fertilizers because plant uptake is much faster, but the positive effect is shorter-lasting.

Salt index. The salt index of a fertilizer (discussed in Chapter 11, section "Saline Soils and Water") measures its tendency to increase the osmotic pressure of the soil solution compared with an equal amount of sodium nitrate. High soluble salt concentrations in the soil may develop an osmotic pressure exceeding that of the plant sap, possibly resulting in dehydration and permanent injury. When salt solutions are sprayed on leaf surfaces, similar results may occur. Typically, the higher the salt index, the greater the potential to burn leaves or fruit.

Materials. Potassium sources used for foliar K application include KNO_3 (13-0-44), monopotassium phosphate (MKP, 0-52-34), and dipotassium phosphate (DKP, 0-18-20). DKP is made by combining MKP and potassium hydroxide. When applying MKP or DKP, a small amount (3% to 5%) of low-biuret urea should be included to enhance uptake. KNO_3 is usually applied without surfactants or urea.

Application rates and timing. Research in the Indian River production area showed that about 8 lb of K_2O per acre were needed per foliar application to achieve satisfactory results. Higher rates did not show additional benefit, and lower rates resulted in less fruit enlargement. Beyond spring applications, successive sprays through the summer did not improve performance.

If foliar spraying with 100 or more gal of water/acre, any K source is acceptable, so the least expensive should be chosen. When applying foliar K with low-volume equipment, MKP or DKP should be used to minimize the burn potential. MKP has been applied to grapefruit at rates as high as 106 lb MKP in 125 gal water per acre under hot, dry conditions with no adverse effects. The low salt index of MKP (only 1/6 that of KNO_3 per unit of K_2O; see Appendix C, Table 1) makes it very "safe" to use.

Caution: Be careful if tank-mixing MKP with other materials. The MKP-water solution has a pH of about 4.5, which may not be suitable for some tank-mix combinations. DKP makes a pH-neutral solution that would be a better choice if tank-mixing with other materials.

Timing is important for K applications to enhance fruit size. Potassium is a primary component of cell walls, accounting for more than 40% of fruit mineral content. About 70% of final fruit size is related to the number of cells in the fruit, so more cells usually means larger fruit. Cell division typically stops by late April, and size change throughout the rest of the year comes from cell enlargement. Therefore, the maximum effect of foliar K is achieved from applications that make it available during bloom and postbloom when it can be used during both cell division and rapid cell enlargement phases. An additional application with the summer spray (normally in July) is also recommended to ensure sufficient K through the summer growing season.

Grapefruit size enhancement occurred in about half the fall field trials in the Indian River area, suggesting that late summer or fall K applications may be effective some years. Fall applications were most effective in years with wet summers and falls. Shorter day lengths and cooler weather results in a dramatically decreased fruit expansion rate after mid-October in most years. Thus, if foliar K applications for fruit enlargement are considered during late summer or fall, they should be made in August or September to be most effective.

Expected results. Studies on Sunburst and Valencia showed that foliar-applied K produced 25% to 33% more larger-sized fruit compared with nontreated plots. In addition, there was a corresponding increase in soluble solids yield in the Valencia experiments. Combining prebloom, postbloom, and summer K sprays can increase average fruit diameter 0.16 to 0.24 inches, which can equal 1 or more pack sizes. When fall application was successful, grapefruit diameter increased 0.08 to 0.16 inches, or about ½ to 1 size category. Foliar K will not produce large fruit from small fruit, but it can move a significant portion of the fruit into a larger size class. The following observations and recommendations are based on the Indian River–area experiments:

- The recommended program for most citrus varieties is 8 lb K_2O/acre per application, applied prebloom (typically February), postbloom (typically April), and summer (July).
- If the summer and fall are wetter than usual, later K applications may be considered. When exercising this option, schedule the applications for August and September.
- Foliar K application has had little or no effect on juice volume, acid, Brix, or Brix:acid ratio.
- Diameters of smaller fruit tended to increase more than larger fruit when foliar K applications were made.
- Fruit burn was not observed at the following spray concentrations:
  - lb KNO_3/acre applied in 125 gal of water/acre.
  - lb MKP/acre applied in 32.5 gal of water/acre.
  - lb MKP/acre applied in 10 gal of water/acre by airplane.

Calcium, Magnesium, and Micronutrients

Foliar applications of Ca, Mg, and micronutrients (Zn, Mn, Cu, B, and Mo) have proven to be an excellent means of satisfying citrus tree requirements. However, there can be difficulties associated with leaf tissue absorption and translocation of Ca, Mg, B, and Mo. Choosing the correct fertilizer sources for these nutrients can be critical. Foliar application of nutrients is of great importance when the root system is unable to keep up with crop demand or when the soil has a history of problems that inhibit normal nutrient uptake. Foliar nutrition is proven to be useful under prolonged periods of wet conditions, droughty conditions, calcareous soil, cold weather or any other condition that decreases the tree's ability to take up nutrients when there is a demand. Foliar feeding may be effectively utilized when a nutritional deficiency is diagnosed. Foliar application is absolutely the quickest method of getting nutrients into plants. However, if the deficiency can be observed on the tree, the crop has already lost some potential yield.

Application of Zn sprays on the spring flush is recommended, but it may be necessary on each major flush of growth to keep the trees free of deficiency symptoms, because Zn does not translocate readily to successive growth flushes. Maximum benefit is obtained if spray is applied to the young growth when it is two-thirds to nearly fully expanded and before it hardens off. Soil application of Zn in the fertilizer is neither an economical nor an effective way to correct Zn deficiency.

Foliar spray application of Mn quickly clears up deficiency symptoms on young leaves, but older leaves respond less rapidly and less completely. When Mn sprays are given to Mn-deficient orange trees, fruit yield, total soluble solids in the juice, and pounds solids per box of fruit increase. Foliar spray of a solution containing Mn on two-thirds to fully expanded spring or summer flush leaves is recommended. Adding 7 to 10 lb of low-biuret urea will increase Mn uptake.

In Florida, foliar spray applications of B have been found much safer and more efficient than soil application. Soil applications frequently fail to give satisfactory results during dry falls and springs and may result in toxicity problems if made during the summer rainy season. Foliar spray may be applied during the dormant period through postbloom, but preferably during early flower development. Treating at this growth stage is important because boron does not move very readily from other parts of the tree to the buds. Applying B at this time will assist in flower initiation and pollen production, satisfy the needs for pollen tube growth, and enhance fruit set. Use care not to apply more than the recommended amount, because it is easy to go from deficiency to toxicity.

Table 4. Recommended N rates and minimum number of applications for nonbearing citrus trees.

Year in grove	lb N/tree/year (range)	Lower limit of annual application frequency		
		Controlled-release fertilizer	Dry soluble fertilizer	Fertigation
1	0.15–0.30	1	6	10
2	0.30–0.60	1	5	10
3	0.45–0.90	1	4	10

Table 5. Recommended N rates and minimum number of applications for bearing citrus trees.

Year in grove	Oranges	Grapefruit	Other varieties	Lower limit of annual application frequency		
	------------ lb N/acre/year (range) ------------			Controlled-release fertilizer	Dry soluble fertilizer	Fertigation
4 through 7	125–200	120–160	120–200	1	3	10
8 and up	125–245 Yield-based[1]	120–160	120–300[2]	1	3	10

[1] See Figure 1 for specific production-based N fertilizer rate recommendations.
[2] For Orlando tangelos, the maximum recommended N rate is 250 lb/acre. For Honey tangerines (Murcotts), the maximum recommended N rate is 300 lb/acre.

Table 6. Recommendations for P fertilization of bearing citrus trees based on leaf tissue and soil tests taken according to the guidelines described in Chapter 4 (leaf and soil samples taken in July or August of each year).[1]

If leaf tissue P is…	…and soil test P is…	…the recommendation for P fertilization is:
Excessive High	Soil test P value is not applicable.	Do not apply P fertilizer to the soil for 12 months following leaf and soil sampling, then sample again and reevaluate.
Optimum	Sufficient	
Optimum	Less than sufficient	Apply 8 lb P_2O_5/acre to the soil for every 100 boxes/acre of fruit produced during the current year. Sample leaves and soil again in 12 months and reevaluate.
Low	Less than sufficient	Apply 12 lb P_2O_5/acre to the soil for every 100 boxes/acre of fruit produced during the current year. Sample leaves and soil again in 12 months and reevaluate.
Deficient	Less than sufficient	Apply 16 lb P_2O_5/acre to the soil for every 100 boxes/acre of fruit produced during the current year. Sample leaves and soil again in 12 months and reevaluate.

[1] These recommendations do not pertain to foliar-applied P.

Table 7. Recommended methods, timing, and rates for micronutrient application to citrus groves.

		Mn	Zn	Cu	B	Fe
Method	Foliar	Yes	Yes	Yes	Yes	No
	Soil	Yes[1]	No	Yes	Yes	Yes
Timing	Foliar	When spring flush leaves reach full expansion				
	Soil	Anytime as needed				
		lb metallic equivalent/acre				
Rates	Foliar	3 to 5	3 to 5	3 to 5	¼	---
	Soil	7 to 10	---	5	1	See below[2]

[1] Soil applications of Mn are not recommended on calcareous soils.
[2] Acid soil: Fe-EDTA, ⅔ oz elemental Fe/tree; calcareous soil: Fe-EDDHA, 1¾ oz elemental Fe/tree.

Table 8. Citrus rootstocks ranked according to Fe-chlorosis susceptibility.

Sour orange (*C. aurantium*)	Lowest susceptibility
Rough lemon (*C. jambhiri*)	
Cleopatra mandarin (*C. reticulata*)	
C. macrophylla	
C. volkameriana	
Sweet orange (*C. sinensis*)	Moderate susceptibility
Carrizo citrange (*C. sinensis* × *P. trifoliata*)	
Trifoliate orange (*P. trifoliata*)	Highest susceptibility
Swingle citrumelo (*C. paradise* × *P. trifoliata*)	

Table 9. Effective pH range of various Fe chelates.

Iron chelate	Effective soil pH range
Fe-EDTA	4.0 to 6.5
Fe-HEDTA	5.0 to 6.5
Fe-DTPA	4.0 to 7.5
Fe-EDDHA	4.0 to 9.0
Fe-citric acid	Not suitable for soil application

Table 10. Approximate rate of N availability from poultry (layer) manure and biosolids following application to the soil (Hanselman et al. 2004).

Time after application (months)	Poultry manure	Biosolids
	Available N as a percentage of total N applied	
0–1	50	35
1–3	6	8
3–6	4	6
6–12	4	7
Total	64	56

UF | IFAS Extension UNIVERSITY of FLORIDA

UF/IFAS PEER REVIEWED SL463

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 9. Irrigation Management to Improve Nutrient Uptake[1]

Kelly T. Morgan, Thomas A. Obreza, Davie Kadyampakeni, Said Hamido, Rhuanito Soranz Ferrarezi, and Mongi Zekri[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For references, a glossary, and appendices, please refer to the full document at https://edis.ifas.ufl.edu/ss478.

Information in the box below applies to citrus trees affected by HLB. Other information in this chapter is valid for healthy citrus trees and trees with HLB.

Recommendations for HLB-affected trees:

Citrus Water Requirements—Kelly Morgan, Davie Kadyampakeni, Said Hamido, and Mongi Zekri

With HLB, irrigation scheduling is critical. HLB-affected trees cannot afford water stress or water excess. Current UF/IFAS citrus irrigation recommendations estimate citrus tree water requirements for mature trees based on data collected prior to introduction of HLB into Florida. Citrus trees affected by HLB are known to lose substantial foliage and up to 80% of the root mass depending on disease severity, thus negatively influencing water and nutrient uptake.

Premature fruit drop is increased if water stress is experienced by citrus trees and canopy size is reduced as is the number of fruit and fruit size. Benefits of proper irrigation scheduling include reduced loss of nutrients through leaching due to excess water applications and reduced pollution of groundwater or surface waters.

A study was conducted in a Florida commercial citrus grove from 2011 to 2015 with the objective of determining irrigation requirements of HLB-affected citrus trees compared with healthy trees. Results from the field study indicated that healthy trees consumed approximately 25% more water than HLB-affected trees. Reduced water uptake by HLB-affected trees resulted in significantly greater soil water content. The relationship between leaf area and water uptake indicated that diseased trees with lower canopy density and corresponding lower leaf area index take up less water and consequently less nutrients from the soil. The elevated soil water content may partially explain higher rates of root infection with *Phytophthora* spp. observed in some HLB-affected trees.

Improvements in Scheduling and Soil Moisture Measurement—Kelly Morgan, Davie Kadyampakeni, Rhuanito Soranz Ferrarezi, and Mongi Zekri

Irrigation must be managed to allow growers to maintain or increase crop production without depletion of water

1. This document is SL463, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Kelly T. Morgan, professor and center director, Department of Soil and Water Sciences, UF/IFAS Citrus Research and Education Center; Thomas A. Obreza, professor and senior associate dean for Extension, Department of Soil and Water Sciences; Davie Kadyampakeni, assistant professor, Department of Soil and Water Sciences, UF/IFAS Citrus REC; Said Hamido, postdoctoral associate, UF/IFAS Southwest Florida REC; Rhuanito Soranz Ferrarezi, assistant professor, citrus horticulture, UF/IFAS Indian River REC; and Mongi Zekri, Extension agent IV, UF/IFAS Extension Hendry County; UF/IFAS Extension, Gainesville, FL 32611.

resources. Increase in water-use efficiency is achieved by selecting a proper irrigation scheduling method and application timing. Proper irrigation scheduling applies an appropriate volume of water to a citrus grove at the appropriate time based on tree need, soil properties, and weather conditions.

Two three-year studies were conducted in three commercial citrus groves to compare soil moisture sensor and ET-based irrigation schedules on tree growth, yield, and water use. Results from the first study indicated water use managed with soil moisture sensors and ET-based models were similar and reduced average monthly water use by approximately 14% of the conventional irrigation practice without reducing yields. The second study aimed to determine proper irrigation scheduling for HLB-affected trees. The second experiment was conducted in three commercial groves on Ridge and Flatwoods soils. Irrigation schedules consisted of current UF/IFAS ET-based recommendations, daily irrigation, and an intermediate schedule, all using the same amount of water on a monthly and annual basis. The UF/IFAS schedule was determined weekly using the Citrus Irrigation Scheduler found at the Florida Automated Weather Network (FAWN) website (http://fawn.ifas.ufl.edu/tools/irrigation/citrus /scheduler/), and resulted in irrigation schedules ranging from daily in May to every 10–14 days in the winter months from November to February. Daily irrigation schedules were determined by dividing the UF/IFAS irrigation duration by the number of days between irrigations. "Intermediate" irrigation was half the UF/IFAS interval for half the time.

Daily irrigation increased tree water uptake and soil water content compared with intermediate and UF/IFAS schedules. Daily and intermediate irrigation increased canopy density (as measured by leaf area index) compared with the UF/IFAS schedule. Fruit drop per square foot of the under-canopy area was lower for daily irrigation schedules in the second year of the study, but yields were similar among all irrigation schedules.

These studies show that for HLB-affected trees, **irrigation frequency needs to be increased and amounts of irrigation water per application decreased to minimize water stress from drought or excess water**, while ensuring optimal water availability in the root zone at all times. It is recommended that growers maintain soil moisture in the root zone (top 3 feet for Ridge and 18 inches for Flatwoods soils) using soil moisture sensors or irrigation apps. The FAWN and SmartIrrigation apps provide the option of daily irrigation schedules. As noted above, HLB-affected trees with lower canopies use less water than do healthy trees. Therefore, if the irrigation scheduling app is used, the irrigation time should be reduced by 10% to 20%. For example, if the app suggests an irrigation time of 1 hour, this time could be reduced by 6 to 12 minutes for HLB-affected trees.

References:

Hamido, S. A., K. T. Morgan, and R. C. Ebel. 2017. "Improved Irrigation Management of Sweet Orange with Huanglongbing." *HortScience* 52: 916–921.

Hamido, S. A., K. T. Morgan, and D. M Kadyampakeni. 2017. "The Effect of Huanglongbing on Young Citrus Tree Water Use." *HortTechnology* 27: 659–665.

Kadyampakeni, D. M., and K. T. Morgan. 2017. "Irrigation Scheduling and Soil Moisture Dynamics Influence Water Uptake by Huanglongbing Affected Trees." *Scientia Horticulturae* 224: 272–279.

Water Supply

Competition for water is increasing in all citrus production areas. Florida's expanding population increases water demand in the urban sector, which reduces water availability for agriculture. Growing a high-quality citrus crop is water-intensive; however, growers do have options to remain competitive. By increasing water uptake efficiency (the amount of water taken up by the trees compared with the amount of water applied to the grove), growers can continue to achieve normal production while reducing water withdrawals.

If more water is applied than the soil can hold, it drains below the root zone and is wasted. Nutrients, especially N, move with water as it passes through the soil (leaching), either downward to groundwater or laterally toward ditches and canals. When nutrients are leached, they are no longer available to the trees and may become an environmental concern. Understanding how water and nutrients move through the soil is important in improving their use.

Production Region Characteristics Important to Irrigation Management

The central Florida Ridge (Chapter 2, Figure 7) features well-drained, sandy Entisols (Appendix A). These soils permit rapid infiltration of rain and irrigation water, making them vulnerable to nutrient leaching. Nitrate leaching is a major concern to citrus producers on the Ridge. The maximum irrigation depth to wet the majority of the root zone in these soils is 3 to 4 ft.

The Gulf, Peace River, and Indian River citrus production areas are dominated by poorly drained Flatwoods soils (Chapter 2, Figure 7) that require artificial drainage to produce high-quality citrus. Nitrate leaching is greatly reduced in Flatwoods soils compared with the Ridge. The citrus root zone in these soils is typically 18 inches or less.

Nutrient Uptake Efficiency

Improving water uptake efficiency will also improve nutrient uptake efficiency (the amount of nutrients taken up by the plant compared with the amount of nutrients applied as fertilizer). In Florida's sandy soils, nutrient and water uptake efficiencies are linked. Management methods that improve irrigation water uptake efficiency will increase the proportion of applied nutrients that are taken up by the tree, potentially leading to increased growth and yield.

Allowable Soil Water Depletion

The following terms are important for developing a workable and efficient irrigation schedule:

1. Field Capacity

This is the amount of water remaining in saturated soils 2–3 days after free drainage water has been removed by the downward forces of gravity. This value of field capacity assumes that the water removed from the soil profile is only removed by gravity, not through plant transpiration or soil evaporation. The matric potential at this soil water content is around -$\frac{1}{10}$ bar.

2. Permanent Wilting Point

This is the water content of a soil when plants growing in that soil wilt and fail to recover upon watering. It is when the volumetric water content is too low for the plant to remove water from the soil. The matric potential at this soil water content is commonly estimated at -15 bars.

3. Plant-Available Water

This is the portion of water that can be absorbed by plant roots. It is the amount of water available between field capacity and the permanent wilting point.

As soil dries out, water becomes increasingly more difficult for trees to remove, which can eventually cause water stress. Tree health and yield will suffer if the soil is allowed to get too dry. To provide adequate water for flowering, fruit set, and vegetative growth, maximum soil water depletion should be no more than 25% to 33% of available water from February to June. Once the rainy season starts, the maximum depletion level can be increased to 50% of available water. This additional allowable depletion increases the capacity of the soil to hold rainfall without leaching nutrients. The same depletion levels in the fall and winter months will save water without reducing yield.

Irrigation Scheduling

Despite our large yearly rainfall of 50–60 inches, which exceeds the citrus water requirement or evapotranspiration (ET), Florida citrus growers and production managers should keep in mind that they cannot grow citrus successfully and competitively without supplemental irrigation. Through research and field experience, we know that irrigation is necessary because of the non-uniform distribution of the rainfall and the very limited water-holding capacity of Florida sandy soils. Irrigation is of particular importance during the dry period (February–May), which coincides with the critical stages of leaf expansion, bloom, fruit set, and fruit enlargement. Citrus production managers should accurately determine when and for how long to irrigate. With proper irrigation scheduling, yield will not be limited by water stress. Any degree of water stress or imbalance can produce a deleterious change in physiological activity of growth and production of citrus trees. The number of fruit, fruit size, and tree canopy are reduced, and premature fruit drop is increased with water stress. Extension growth in shoots and roots and leaf expansion are all negatively impacted by water stress. Other benefits of proper irrigation scheduling include reduced loss of nutrients from leaching as a result of excess water applications and reduced pollution of groundwater or surface waters from the leaching of nutrients and other chemicals.

Successful irrigation management maintains sufficient water and nutrients in the root zone to maximize plant growth and health. Growers who focus on improving water and nutrient uptake efficiency will reduce N and P losses and decrease environmental impacts at the same time. While some nutrient loss is unavoidable due to excess rainfall, loss due to management decisions can be minimized.

Proper irrigation scheduling applies an appropriate volume of water to a citrus grove at the appropriate time based on tree need, soil properties, and weather conditions. Scheduling methods include:

- Experience
- Calendar method (e.g., 0.8 inches every 4^{th} day)
- Monitoring soil water status
- Calculating a water budget

Soil Water Measurement

Experience or the calendar method can provide a reasonably good irrigation schedule, but they are not accurate enough to maximize water uptake efficiency and prevent nutrient leaching. Using soil moisture sensors improves accuracy because they quantify changes in soil water status. These devices may be fixed in one location, portable, or handheld. They may measure soil moisture at one depth or at multiple depths. General categories include:

- Tensiometers
- Electrical resistance blocks
- Time domain reflectometry (TDR) probes
- Capacitance probes

Tensiometers are simple, easy to manage, and inexpensive devices that determine water status in terms of the soil-water tension the plants are experiencing. They are used successfully in determining the need for irrigation when the soil water content is being kept near field capacity. It has been shown that their use could result in avoiding tree stress and excessive water applications. A tensiometer consists of a porous cup, generally of ceramic material, connected through a water-filled tube to a vacuum gauge. When the cup is placed in the soil where the suction measurement is to be made, the bulk water inside the cup comes into hydraulic contact and tends to equilibrate with the soil water through the pores of the ceramic walls. The suction is indicated by the vacuum gauge. As soil water is depleted by drainage or plant uptake, or as it is replenished by rainfall or irrigation, corresponding changes on the tensiometer's gauge occur. Tensiometers cease to function at soil suctions above 0.85 bar due to air entering the system. Tensiometers are easy to use but may give faulty readings if they are not installed properly and maintained regularly.

Electrical resistance blocks. The most common indirect field device for metric potential or metric pressure measurement is the porous conductivity block. This method is based on the fact that the electrical resistance of certain porous materials, such as gypsum, nylon, and fiberglass, is related to their water content. It involves burying a small block containing a pair of electrodes surrounded by a porous matrix and running the lead wires to a resistance bridge. The water in the block reaches matric potential equilibrium with that in the soil, and the resistance measured at the bridge gives the electrical conductivity of the solution between the electrodes. Because of the pore size of the material used in most electrical resistance blocks, particularly those made of gypsum, the water content and thus the electrical resistance of the block does not change dramatically at suctions less than 0.5 bar. Therefore, resistance blocks are best suited for use in fine-textured soils, such as silts and clays. Electrical resistance blocks are not reliable for scheduling irrigation in sandy soils. These devices also need to be recalibrated more frequently because they are sensitive to temperature and can deteriorate in the soil.

Time-Domain Reflectometry (TDR) is widely used to measure soil water content and bulk electrical conductivity. A TDR instrument has a device capable of producing a series of precisely timed electrical pulses with a wide range of high frequencies used by different devices, which travel along a transmission line (TL) that is built with a coaxial cable and a probe. The TDR probe usually consists of 2 parallel metal rods that are inserted into the soil acting as waveguides. At the same time, the TDR instrument uses a device for measuring and digitizing the energy (voltage) level of the TL. When the electromagnetic pulse traveling along the TL finds a discontinuity (i.e., probe-waveguides surrounded by soil), part of the pulse is reflected. This produces a change in the energy level of the TL. The advantages of TDR over other soil water content measurement methods are high accuracy, minimal soil disturbances, no need for soil-specific calibration, a lack of radiation hazard associated with neutron probe or gamma-attenuation techniques, and automation and multiplexing, which allow it to provide continuous measurement. TDR systems are relatively expensive.

Capacitance probe systems consist of a solar-powered, central logging facility connected by cable to probes fitted with capacitance sensors. The sensors utilize electrical capacitance to measure the complex dielectric constant of the soil and water medium. The changing ratio of air to water at each soil depth can be measured very quickly and accurately. The sensor readings are converted to volumetric soil water depth content using calibration equations. Soil water content data are downloaded to a computer and displayed in easy-to-read graphs that directly reflect crop water use and irrigation needs. Volumetric soil water content at each sensor is expressed as either a percentage or a depth of water in mm water per 10 cm of soil. Multisensor capacitance probes were demonstrated to be a highly successful and accurate technique in measuring real-time soil water dynamics for irrigation scheduling. Capacitance probe systems are relatively expensive.

Considerations when using soil moisture sensors to schedule irrigation include:

- Knowing the soil water-holding capacity and tree root zone depth (Appendix A).
- Placing sensors where the majority of roots are located, such as at the dripline of the tree.
- Using multiple sensors, both across the grove and with depth, to fully characterize the tree root zone.
- Moving sensors to follow root growth as the tree canopy expands in developing groves.
- Basing irrigation on the soil depth containing the greatest root density.
- Managing root zone soil moisture between field capacity and the maximum allowable available water depletion (one-fourth to two-thirds depletion, depending on time of year).

Figure 1 shows an example of how a multilevel capacitance probe could be used to adjust an irrigation schedule to maximize water uptake efficiency and minimize nutrient leaching. The four graphed lines represent soil moisture content at 4-inch (red), 8-inch (blue), 12-inch (purple), and 20-inch (green) depths in the soil and the x-axis shows a 16-day time period separated into 2-day increments.

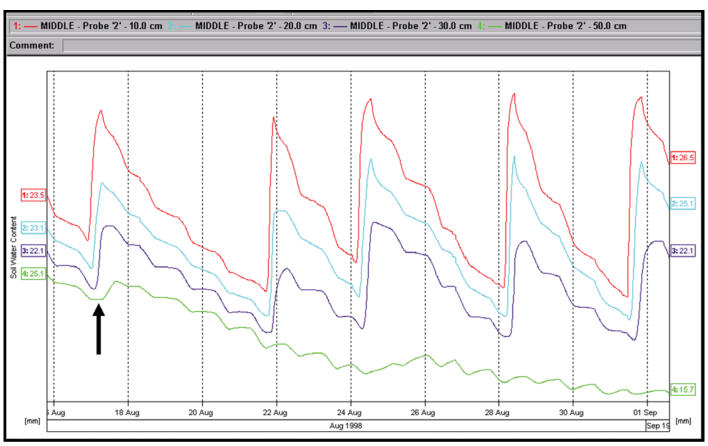

Figure 1. Continuous monitoring of soil moisture at 4-, 8-, 12-, and 20-inch depths in the soil by a multilevel capacitance probe installed in the root zone of a mature citrus tree.

The effect of irrigation is easily observed as sharp increases in soil moisture at the 4-, 8-, and 12-inch depths. However, note that the first irrigation increased soil moisture at the 20-inch depth as well (black arrow), which is below the zone of highest root density. Because the goal was to keep the irrigation water in the top 18 inches of soil, the grower reduced the duration of subsequent irrigations. The steadily decreasing water content at 20 inches during the following 2-week period shows that the grower had attained optimum irrigation water management.

Water Budgeting

An alternative method to schedule irrigation uses a computer program that estimates tree water consumption (evapotranspiration, or ET) from weather data. Reference ET and convenient irrigation scheduling management tools for all Florida citrus production regions can be found on the Florida Automated Weather Network website at http://fawn.ifas.ufl.edu. The computer program uses the soil water-holding capacity of specific soil series to determine field capacity. Irrigation schedules are determined using the strategies and equations described below.

SMARTPHONE APPS

Mobile smart devices (e.g., smartphones, tablets) have become popular because of convenience and ease of use, making them ideal for disseminating information on a regular basis with real-time data. Tools developed for use on mobile smart devices are typically called "apps" and are available for a variety of functions.

Due to the increasing popularity of smartphones and apps, FAWN developed an app for the iPhone and Android platforms that allows users to view data from grower-owned weather stations, provided as a cost share from the Florida Department of Agriculture and Consumer Services, on their smartphones, in much the same way that the data can be viewed on the FAWN webpage.

UF/IFAS has also developed smartphone apps for crop irrigation scheduling using FAWN weather data. The FAWN and irrigation scheduling apps are available to download in the App Store and Play Store at no cost. The goal is to provide users with an easy-to-use mobile app to access information to improve irrigation scheduling for a wide range of crops, including citrus. By using the app instead of a set time-based schedule for irrigation, users achieve accurate irrigation. The irrigation scheduling app has the potential of reducing water and fertilizer use, resulting in reduced irrigation and fertilizer costs and possibly reduced nutrient leaching.

Irrigation Strategies to Improve Nutrient Uptake and Reduce Leaching

Developing an irrigation strategy to reduce nutrient leaching has the objective of not applying more irrigation water than the root zone can hold. Considering the low water-holding capacity of citrus grove soils, this objective is very difficult to accomplish, even for the most experienced and diligent irrigation managers. The major questions to be answered in this procedure are:

- How much water can the root zone hold?
- What is the maximum irrigation system run time before leaching occurs?

Example

A central Ridge citrus grove has the following characteristics:

- Tree spacing: 12½ ft within the row and 25 ft between rows.
- Tree canopy diameter: 17½ ft
- Root zone depth: 3 ft.
- One 16 gal/hr microsprinkler per tree with a 16-foot diameter wetted pattern.
- The citrus root zone is continuous from tree to tree, existing both inside and outside of the wetted pattern.
- The irrigated system wets approximately 60% of the total root zone (Figure 2).

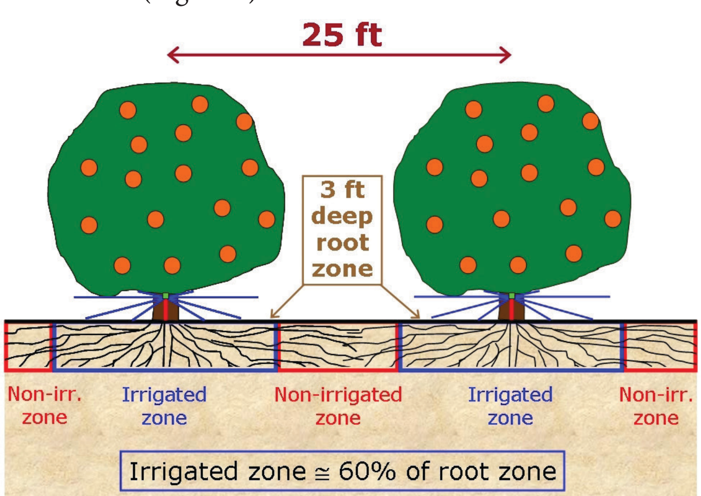

Figure 2. Scaled diagram of example citrus grove described above.

Nutrient leaching risk in this grove is higher within the wetted pattern due to potential overirrigation plus the fact that most fertilizers are applied to that zone (Figure 3). A good irrigation manager will control this risk with careful water management.

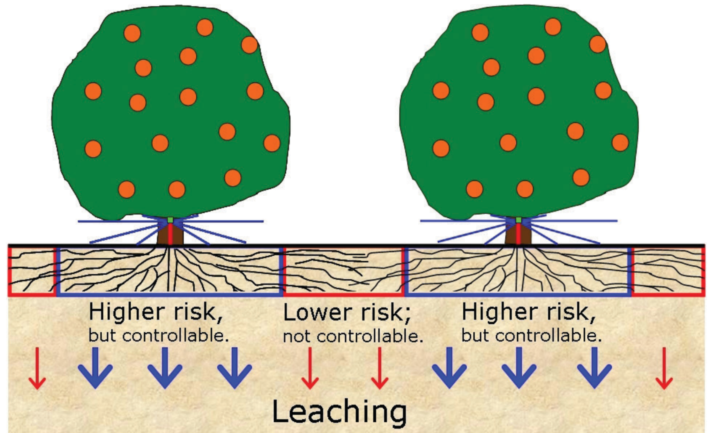

Figure 3. Irrigated and non-irrigated zones in a citrus grove have different leaching potentials that depend on irrigation scheduling and fertilizer placement.

Note: The following depictions of water content changes in the citrus tree root zone (Figures 4 to 7) do not represent the actual water extraction pattern. The blue shading shows 1) approximately where water extraction occurs beneath the canopy, and 2) the relative soil water content with respect to available soil water-holding capacity.

This example starts with the entire grove at field capacity moisture content following a heavy rain (Figure 4). The citrus trees begin to remove water from the soil in response to the atmospheric ET demand. After several days have passed (depending on time of year), the water content in the root zone decreases to 50% of available water capacity (Figure 5).

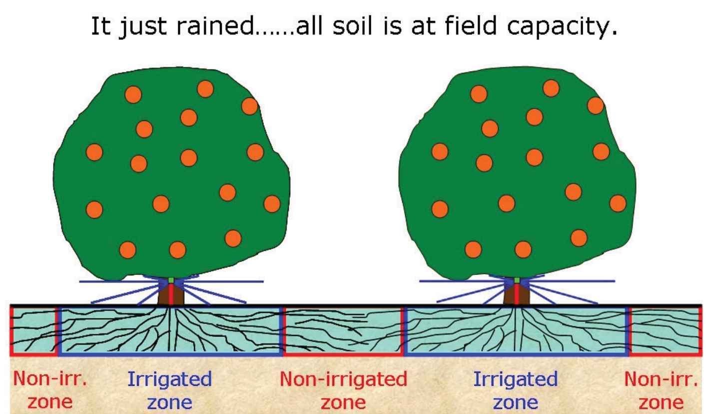

Figure 4. The citrus grove at field capacity soil water content (time = 0).

At this point, the grove manager turns on the irrigation system and operates it long enough to return the soil in the wetted pattern back to field capacity (Figure 6). From this point until the next significant rainfall, only the soil water content in the irrigated zone can be influenced by the irrigation manager. The water content in the non-irrigated zone rapidly decreases to the point where little to no soil water can be extracted by the tree.

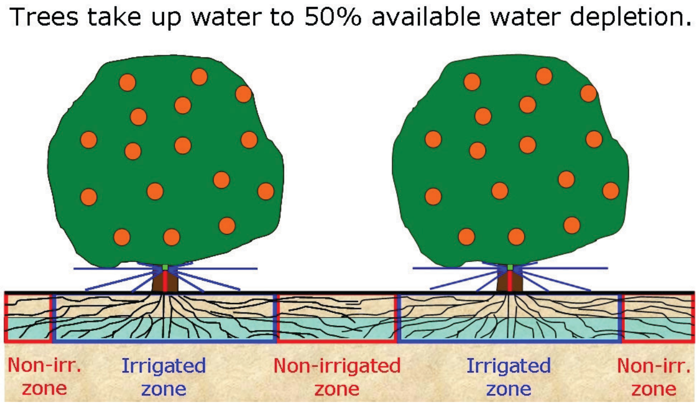

Figure 5. The citrus grove several days later, after half of the available water has been removed from the root zone. Note that water extraction has occurred from both the irrigated and non-irrigated zones.

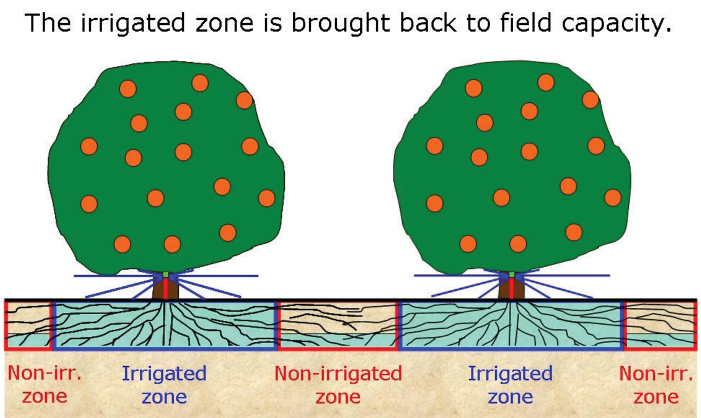

Figure 6. The citrus grove after irrigation returns the wetted zone to field capacity. Note that the non-irrigated zone contains very little available water.

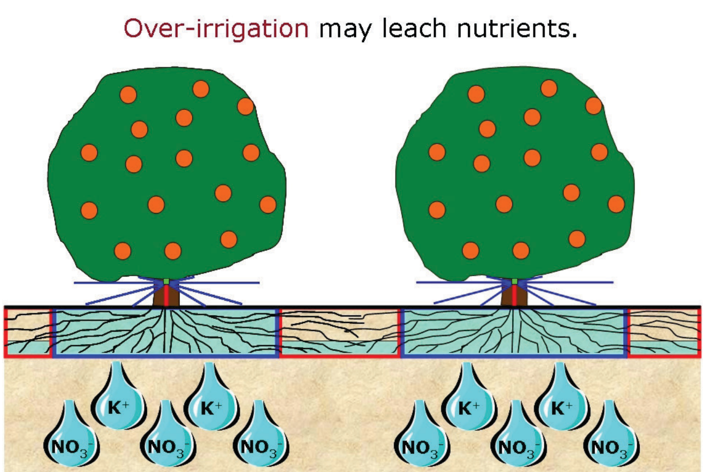

Figure 7. Excessive irrigation leaches mobile nutrients like nitrate and potassium.

If the grove manager operates the irrigation system too long and applies more water than the soil can hold, water will move beneath citrus tree roots. If water-soluble nutrients like nitrate or potassium are present in the irrigated zone during the irrigation period, a portion will leach (Figure 7).

How much water can the root zone hold?

From Appendix A, Table 26:

- Central Ridge soils: 0.3 to 0.7 inches/ft
- Flatwoods soils: 0.3 to 1.2 inches/ft

What is the maximum system run time before leaching occurs?

Information needed:	In this example:
Soil water-holding capacity	0.6 inches/ft
Maximum allowable depletion	50%
Root zone depth	3 ft
Surface area wetted by microsprinklers	60%
Microsprinkler flow rate	16 gal/hr
Tree spacing	12½ ft × 25 ft

Calculations

1. Volume of water the root zone can hold: **0.6 inches/ft × 3 ft deep root zone = 1.8 inches**

2. Volume of water to refill at maximum depletion: **1.8 inches × 50% = 0.9 inches**

3. Volume of water this represents per tree space: **0.9 inches/tree × 1 ft/12 in × (25 ft × 12½ ft) × 7.5 gal/cu ft × 60% coverage = 105 gal/tree**

4. Maximum system run time: **105 gal ÷ 16 gal/hr emitter flow rate = 6.6 hr**

5. Adjust for system delivery efficiency of 90%: **6.6 hr ÷ 0.9 = 7.3 hr**

Therefore, the irrigation system should never be run longer than about **7 hours** for any single cycle, provided that the available soil water is at least 50% depleted when the irrigation begins. If the soil is less than 50% depleted of available water, then the maximum run time decreases accordingly.

Considerations

Ideal maximum system run time vs. practical field management. There may be management limitations that prevent stopping irrigation at or before the ideal maximum run time, such as limitations of the irrigation system design or lack of sufficient personnel. Growers should evaluate their overall irrigation management and take corrective action if possible.

Theory vs. reality. Calculating maximum run time from grove and irrigation system characteristics provides a starting point, but the irrigation system or soil may behave differently than the model situation. Thus, growers should fine-tune the maximum run time in the field.

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 10. Environmental Issues and Best Management Practices[1]

Brian J. Boman, Thomas A. Obreza, and Kelly T. Morgan[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For references, a glossary, and appendices, please refer to the full document at https://edis.ifas.ufl.edu/ss478.

Environmental Nutrient Issues Related to Florida Citrus Production

Nitrogen is required for tree growth and fruit production. In a mature grove, however, there is little net increase in tree size. Nitrogen used for leaf growth or taken up by a cover crop is largely recycled as leaves drop or the cover crop dies, the vegetative material decomposes, and mineralization releases the N for reuse by the tree. This recycled N supplies most of the continuing need for new leaves, and relatively little fertilizer N is needed for growth. Replacement of the N removed by fruit harvest becomes the main N requirement in a mature grove. Figure 1 illustrates the citrus tree as a component in the environmental N cycle.

A 600 box/acre crop of oranges removes about 72 lb of N/acre from the grove. If this mature grove receives 200 lb N/acre annually, approximately 128 lb of N/acre remains to be accounted for after crop removal. The fate of this N is not completely understood. Some goes into new roots and shoots, and some is taken up by weeds. A portion of the rest may be lost by volatilization or denitrification, although denitrification in vulnerable soils is minimal. In controlled leaching studies, about 40% of the N applied to the soil is not recovered even when water is supplied soon after fertilizer application. Although unknown mechanisms may partially reduce the soil N concentration, a substantial portion of the N applied in fertilizer is subject to leaching as indicated by elevated N in groundwater beneath some groves. Clearly, excess N application should be avoided on vulnerable soils where the potential for leaching exists.

In the Flatwoods, most soils are slowly permeable due to the presence of spodic and/or argillic horizons (Chapter 2), so nitrate leaching to groundwater is less important than on the Ridge. In addition, nitrate that passes through the root zone to the shallow water table can be reduced to gaseous N through denitrification, which then disperses in the atmosphere.

1. This document is SL464, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Brian J. Boman, professor emeritus, Department of Agricultural and Biological Engineering, UF/IFAS Indian River Research and Education Center; Thomas A. Obreza, professor and senior associate dean for Extension, Department of Soil and Water Sciences; and Kelly T. Morgan, professor and center director, Department of Soil and Water Sciences, UF/IFAS Citrus REC; UF/IFAS Extension, Gainesville, FL 32611. Includes contributions from Larry K. Jackson, professor emeritus, Horticultural Sciences Department; Ashok K. Alva, US Department of Agriculture–Agricultural Research Service; David P. H. Tucker, professor emeritus, Horticultural Sciences Department, UF/IFAS Citrus REC; and D. V. Calvert, professor emeritus (deceased), UF/IFAS Indian River REC.

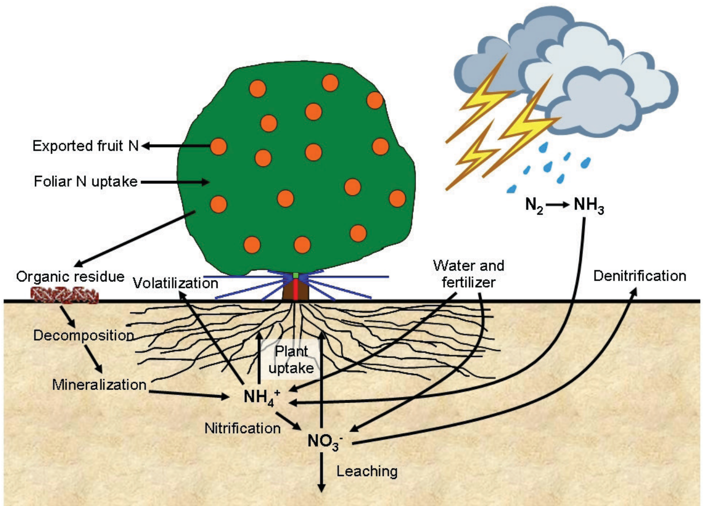

Figure 1. The citrus tree as a component of the environmental N cycle.

Surface water contamination by nitrate is more likely to be a factor in the Flatwoods. Soluble nutrients that move more than about 30 inches below ground level become unavailable to Flatwoods citrus trees because of their shallow rooting depth. Dissolved nutrients, including P, may move laterally above the hardpan rather than vertically through the restrictive layers. As a result, leached nutrients can move into water furrows if rainfall or irrigation is excessive. Nutrients removed as a grove drains are readily used by algae, bacteria, and aquatic plants that often clog irrigation/drainage canals and ditches. Excessive vegetative growth in water furrows may be an indication of lateral nitrate movement.

The Best Management Practices (BMP) Era

In the late 1980s, FDEP surveyed the water quality from 3949 shallow (<100 ft) drinking-water wells across the state. Nitrate-N was detected in 2483 (63%) of these wells, and 584 contained a nitrate-N concentration greater than the national maximum contamination limit (MCL) of 10 ppm. Nearly 90% of the high-nitrate wells were located in Lake, Polk, and Highlands counties, the heart of Florida's central Ridge citrus production area (Chapter 2, Figure 7).

In response to water quality concerns, a Nitrogen BMP bill was passed by the Florida Legislature in 1994 that authorized FDACS "to develop fertilizer BMPs designed to meet ground water standards…. These BMPs are not mandatory, but if the grower implements the BMPs…., the landowner or lessee will not be subject to administrative penalties if nitrate ground water standards are violated. The Department of Environmental Protection is authorized to conduct field monitoring…."

The definition of a BMP is a *practice or combination of practices determined by the coordinating agencies, based on research, field-testing, and expert review, to be the most effective and practicable on-location means, including economic and technological considerations, for improving water quality in agricultural and urban discharges*.

The first BMP that FDACS adopted by rule in response to the 1994 law was called "Nitrogen Best Management Practices for Florida Ridge Citrus." It specified N fertilizer sources, annual N rates, maximum N rate per application, fertilizer application timing, irrigation management, and record-keeping for citrus grown on permeable better-drained sandy soils typical of Florida's central Ridge. The purpose was to minimize the risk of leaching nitrates from fertilizers to groundwater.

Citrus production BMP development then followed in the Indian River growing region in response to surface-water quality concerns in the Indian River Lagoon and St. Lucie Estuary. These BMPs were developed for citrus on poorly drained Flatwoods soils. They expanded beyond nutrient management to include water volume, sediment transport, pesticides, and aquatic plants. Since then, similar BMP manuals have been developed for the Peace River and Gulf citrus-growing areas, so essentially all commercial Florida citrus groves can potentially come under the auspices of a BMP program if the grower so desires. Citrus growers are referred to the FDACS Office of Water Policy for more detailed information (http://www.floridaagwaterpolicy.com/).

The following are the steps that growers need to take to get involved in their regional BMP program:

- Assess the grove operation and list BMPs that are already present or will be enacted.
- Submit the summary of practices to FDACS in a "Notice of Intent to Implement" BMPs.
- Once enrolled, maintain records and provide documentation regarding BMP implementation.
- Receive a "presumption of compliance" with water quality standards from FDACS.

After enrollment, growers become eligible for cost-share funding or drainage permit exemptions, depending on grove location.

Characteristics of a successful BMP program:

- A "cradle-to-grave" approach.

- A stakeholder-driven process from manual development through BMP implementation.
- Distribution of printed manuals to growers.
- Adoption of BMP manual by rule, followed by availability of cost-share for implementation.
- Growers keep good production records and use self-assessment tools.
- Third-party implementation teams help growers enroll and take part in BMPs.
- Field studies determine the effectiveness of BMPs.
- BMP education is a continuous process.

General Nutrient BMPs for Citrus Production

Nutrient BMPs do not represent exotic or unfamiliar fertilizer management practices to modern Florida citrus producers. In fact, most BMPs are simple, common-sense, "good housekeeping" practices that many grove managers already use in their normal caretaking. The following list summarizes typical nutrient BMPs found in Florida's various citrus BMP manuals:

- Educate and train field operators who handle, load, or apply fertilizers about fertilizer placement, avoiding waste, and preventing contamination of open water.
- Develop a nutrient management plan based on crop nutrient requirements.
- Use tissue and soil analysis to make fertilization decisions.
- Use appropriate application equipment.
- Properly calibrate and maintain application equipment.
- Apply fertilizers to target sites.
- Avoid high-risk applications such as before forecasted rainfall, on bare soils with extreme erosion potential, or when the water table is near the surface.
- Store fertilizer to prevent contamination of nearby ground and surface water. Always store fertilizer in areas protected from rainfall.
- If fertilizer is spilled on the ground, collect it and apply as normal. Use a tarp on ground surfaces where fertilizer is transferred.
- Use caution when loading near ditches, canals, and wells. Locate loading activities away from these sites if possible.
- Use multiple fertilizer loading and transfer sites to prevent concentration of nutrients in a single area.
- Use backflow prevention devices on irrigation and spray-tank filling systems to prevent entry of nutrients into surface or groundwater.
- Split fertilizer applications throughout the growing season.
- Use erosion-control practices to minimize soil loss and runoff.
- When irrigating, try to wet only the root zone. Do not overirrigate.
- Add organic matter to the soil whenever possible.
- Prevent groundwater contamination by plugging wells that are not in use.
- Use appropriate fertilizer sources and formulations based on nutritional needs, season of year, and anticipated weather conditions to achieve greatest efficiency and reduce potential for off-site transport.

UF | IFAS Extension UNIVERSITY of FLORIDA

SL465

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 11. Special Situations[1]

Thomas A. Obreza, Brian J. Boman, Mongi Zekri, Stephen H. Futch, Lawrence R. Parsons, James J. Ferguson, Rhuanito Ferrarezi, and Arnold Schumann[2]

This publication is part of SL253, *Nutrition of Florida Citrus Trees*, 3rd Edition. For references, a glossary, and appendices, please refer to the full document at https://edis.ifas.ufl.edu/ss478.

Information in the box below applies to citrus trees affected by HLB. Other information in this chapter is valid for healthy citrus trees and trees with HLB.

Recommendations for HLB-affected trees:

Citrus under Protective Screen (CUPS) Production System for HLB-free Trees—Rhuanito Ferrarezi and Arnold Schumann

Completely enclosed screen houses can physically exclude contact between the Asian citrus psyllid (ACP, *Diaphorina citri*) and young citrus trees, preventing huanglongbing (HLB) disease development. The benefits of eliminating HLB include rapid tree growth, little fruit drop, and higher yields with premium-quality fruit. One of CUPS' main advantages is the reduced frequency of insecticide sprays to control psyllids.

This new production system is designed for the fresh-fruit market due to its high installation and maintenance cost. It relies on precision irrigation, hydroponic systems, electronic soil water sensing, fertigation, and canopy management to maximize plant growth and yield. Structural engineering is also important for screen houses to cope with Florida's weather conditions. Several CUPS practices, such as pest and disease robotic scouting, automated pesticide spraying, fertilizer application through the irrigation system, canopy hedging, and topping, require different techniques, tools, and approaches because CUPS operations are more intensive or different from open-air citrus operations. For example, the fertigation system can be automated using computer controllers, soil moisture sensors, and electrical conductivity sensors to provide the trees with water and fertilizers on demand. Nutrients can be delivered in real time to match crop requirements and maximize high-value fruit production. Most other technologies that could impact citrus production are no different in CUPS than in open-air groves, including soil and leaf sampling, liquid fertilizers for fertigation, controlled-release fertilizer (CRF) or soluble

1. This document is SL465, one of a series of the Department of Soil and Water Sciences, UF/IFAS Extension. Original publication date February 2020. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Thomas A. Obreza, professor and senior associate dean for Extension, Department of Soil and Water Sciences; Brian J. Boman, professor emeritus, Department of Agricultural and Biological Engineering, UF/IFAS Indian River Research and Education Center; Mongi Zekri, Extension agent IV, UF/IFAS Extension Hendry County; Stephen H. Futch, Extension agent IV (retired), UF/IFAS Citrus REC; Lawrence R. Parsons, professor emeritus, Horticultural Sciences Department, UF/IFAS Citrus REC; James J. Ferguson, professor emeritus, Horticultural Sciences Department; Rhuanito Ferrarezi, assistant professor, citrus horticulture, UF/IFAS Indian River REC; and Arnold Schumann, professor, Department of Soil and Water Sciences, UF/IFAS Citrus REC; UF/IFAS Extension, Gainesville, FL 32611. Includes contributions from David P. H. Tucker, professor emeritus, Horticultural Sciences Department; Heinz Wutscher, US Department of Agriculture–Agricultural Research Service (retired); Ashok K. Alva, US Department of Agriculture–Agricultural Research Service; and David V. Calvert, professor emeritus (deceased), UF/IFAS Indian River REC.

dry fertilizers, irrigation emitters, freeze protection requirements, etc.

There are several important differences between CUPS and conventional open-air groves (see below). Such differences may affect the interpretation of information presented in this edition of *Nutrition of Florida Citrus Trees* or require modification of the recommendations.

CUPS compared to conventional open-air groves:

1. Potential evapotranspiration, ET_o, is 23% lower in CUPS compared to open-air groves (Ferrarezi et al. 2017a), and therefore using the FAWN irrigation scheduling is not advised; automated digital soil moisture sensors are the best choice.

2. Growth rates are nearly twice as high in CUPS than outside (Ferrarezi et al. 2017b), so young tree fertilizer rates and timings recommendations should be modified for CUPS.

3. Increased plant growth rates induce vigorous flushing, and canopy needs to be frequently managed by mechanical or hand pruning to control plant growth and increase fruit yield.

4. Liquid fertilizers applied daily or weekly or CRF dry fertilizer blends are recommended to maximize growth and production.

5. Vegetative growth of trees in CUPS is promoted by the unique light (23% lower shortwave radiation), wind gusts (4× lower), and temperature (11% higher) environment, which also affect tree photosynthetic rates. Fertilizer N-P-K nutrient ratios may need adjustment in a CUPS environment.

6. Leaf and soil nutrient sampling and thresholds are the same for CUPS as for open-air groves but should emphasize nutrition of healthy trees grown for fresh-fruit production.

7. Due to the high temperature and humidity induced by the screen-house covering, higher populations of thrips, rust and spider mites, and other secondary pests such as snow scales must be managed to avoid fruit damage and quality reduction. Greasy spot disease becomes a major issue due to high humidity and temperature in CUPS and has to be controlled, especially by fungicide sprays and by removing debris and fallen leaves to reduce the inoculum pressure.

8. Due to the presence of poles and trellises, special machinery for spraying, hedging, topping, loading fertilizer, hauling fruit, and repairing the screen and poles are necessary in CUPS, particularly in higher-density plantings. Attention to machinery movement between adjacent screen houses is required to avoid disease spreading.

Details about how to implement those exceptions can be obtained from Schumann et al. 2019 (EDIS article CMG19, available at https://edis.ifas.ufl.edu/hs1304). A comprehensive Quick Start Guide will soon be released on the UF/IFAS EDIS website.

References

Ferrarezi, R. S., B. R. Wright, B. J. Boman, A. W. Schumann, F. G. Gmitter, and J. W. Grosser. 2017a. “Protected Fresh Grapefruit Cultivation Systems: Anti-psyllid Screen Effects on Environmental Variables inside Enclosures.” *HortTechnology* 27(5): 675–681.

Ferrarezi, R. S., A. L. Wright, B. J. Boman, A. W. Schumann, F. G. Gmitter, and J. W. Grosser. 2017b. “Protected Fresh Grapefruit Cultivation Systems: Antipsyllid Screen Effects on Plant Growth and Leaf Transpiration, Vapor Pressure Deficit, and Nutrition.” *HortTechnology* 27(5): 666–674.

Schumann, A. W., A. Singerman, A. L. Wright, and R. S. Ferrarezi. 2019. *Citrus under Protective Screen (CUPS) Production Systems*. CMG19. Gainesville: University of Florida Institute of Food and Agricultural Sciences. https://edis.ifas.ufl.edu/hs1304.

Scions

Orlando Tangelo

While the nutritional requirements of oranges and grapefruit are well known, the requirements of many commercially grown hybrids are obscure. Orlando tangelos may require the highest N and K rates recommended in Chapter 8, with emphasis on fall application to prevent yellowing and defoliation. Transient yellowing of foliage in the winter should not be the sole reason for increasing the fertilizer rate.

Honey Tangerine

Mature honey tangerines (Murcotts) may require up to 300 lb/acre of N and K_2O each year to reduce the incidence of tree collapse during heavy crop years. At least one-third of the annual fertilizer rate should be applied in the fall to coincide with greater tree stress from crop load. Some studies have indicated that heavy fruit set leads to root starvation and death, resulting in reduced mineral uptake. Therefore, the fruit crop should be mechanically or chemically thinned in heavy crop years, with reduced rates of fertilization in light crop years.

Navel orange

There is no evidence that Florida navel oranges require different fertilizer formulations or additional nutritional or foliar N applications compared with other sweet orange cultivars. It is prudent to maintain leaf nutrient concentrations within guidelines established for sweet oranges without excessive fertilization. Optimum but not excessive nutrition will ensure sufficient tree vigor without compromising fruit yield and quality.

Rootstock/Nutrition Interaction

Citrus rootstocks influence nutrient uptake and can make the difference between a productive and nonproductive grove. Best known is the poor performance that can occur when trees budded on trifoliate and trifoliate-hybrid rootstocks, like Carrizo citrange and Swingle citrumelo, are planted on soils with pH above 7. These trees typically exhibit Zn, Mn, Fe, and Mg deficiency symptoms. Soils with high concentrations of shell, limestone rock, and/or subsoil clay are particularly unsuitable for Swingle and Carrizo rootstocks.

The widespread planting of trees on Swingle citrumelo rootstock has brought the important influence of rootstock on citrus tree nutrition to the forefront. Trees on Swingle rootstock often grow relatively poorly with chlorotic foliage when planted on alkaline soils. Iron deficiency has become more prominent with the increased use of Swingle rootstock. Trees on Swingle also sometimes show general starvation symptoms (of N and other elements) during the winter, even though soil temperatures may not attain the critical 55°F threshold associated with reduced root function. This "winter chlorosis" occurs in spite of sufficient soil nutrient supply and supplemental winter fertilizer applications.

While rootstock-related nutrient deficiencies can be overcome by appropriate fertilizer applications (although at high cost), the only way to alleviate toxicities is through reduced input of phytotoxic elements or the use of less-sensitive rootstocks. For example, *C. macrophylla* is highly B tolerant, and trees on Rangpur lime are Cl tolerant.

Cleopatra mandarin is the most Cl-tolerant rootstock. Sun Chu Sha is efficient in taking up Mg when soil Mg availability is low. Trifoliate orange, and to a lesser extent citranges and citrumelos, are susceptible to Fe chlorosis on high pH (>7) soils. The above rootstocks also accumulate B and Cl and as a result are not tolerant to saline soils.

Soils High in Copper

Repeated use of Cu both as a soil application and as foliar fungicide sprays has caused Cu to accumulate to toxic concentrations in some older citrus-grove soils with acidic soil pH. Trees experiencing Cu toxicity may exhibit Fe chlorosis on the foliage. For most Florida soils under citrus production, the Mehlich 1 soil test Cu interpretations in Chapter 4, Table 4 can be used as a rough estimate of potential Cu toxicity.

Although useful as a guide, soil test Cu may not predict Cu toxicity well in many cases. Cu is more toxic when soil pH is less than 6.0. However, if soil pH is maintained above 6.0 by liming, Cu bioavailability is negligible. When the soil is found to contain high Cu, the following steps should be taken:

- Discontinue using Cu except where it is required to control fruit and foliage fungal diseases where no alternative control exists.
- Lime the soil to pH 6.5 and maintain it there.
- Avoid using Swingle citrumelo rootstock, which is Cu-sensitive.

As Cu is present in the soil solution at low concentration and accumulates in feeder roots with time, its extraction from roots may be used to diagnose Cu toxicity. Field and greenhouse studies have indicated that both total feeder root Cu and Cu extracted with 1*M* hydrochloric acid are correlated with extractable Cu in sandy soils. In high Cu soils, root Cu concentration is a better indicator of Cu toxicity than leaf Cu. While a critical root Cu concentration is not well defined, toxicity in mature groves has been associated with feeder root Cu in the 350 to 800 mg/kg range.

Calcareous Soils

Calcareous soils are alkaline (pH > 7) due to the presence of excess calcium carbonate ($CaCO_3$). These soils can contain from 1% to more than 25% $CaCO_3$ by weight, with pH in the range of 7.6 to 8.4. In a Florida calcareous soil, the pH is not usually higher than 8.4 regardless of $CaCO_3$ concentration.

Many Florida Flatwoods soils contain one or more horizons (layers) that are calcareous. A typical characteristic is an alkaline, loamy horizon less than 40 inches deep that can be brought to the surface during land preparation for citrus planting. Increased nutritional management intensity is often required to successfully grow citrus on calcareous soils. Some sites (e.g., ditch banks) are comprised of soils containing considerable amounts of lime rock or shell. It may not be economically justifiable to plant these sites with certain rootstocks considering the management problems and costs involved.

Citrus fertilizer management on calcareous soils differs from that on noncalcareous soils because of the effect of soil pH on soil nutrient availability and chemical reactions that affect the loss or fixation of some nutrients. The presence of $CaCO_3$ directly or indirectly affects plant availability of N, Mg, K, Mn, Zn, Fe, and Cu. The behaviors of Fe, Zn, and Mn in high-pH soil and recommendations for alleviating their deficiency have already been discussed in chapter 8. The remaining discussion deals with N, Mg, and K. The availability of soil Cu is also affected but is not discussed here because the citrus Cu requirement is normally satisfied through Cu fungicide foliar sprays.

Management of Fertilizer Nutrients

Soil pH affects biological and chemical reactions involving **nitrogen** and can influence plant N use efficiency. Nitrification (the conversion of NH_4^+ to NO_3^- by soil bacteria) is more rapid in soils with pH between 7 and 8. Volatilization of ammoniacal-N fertilizer can be significant if the pH of the soil surface is greater than 7 where the fertilizer is applied. This condition occurs in calcareous soils or where the breakdown of the N fertilizer material produces alkaline conditions (e.g., urea decomposition).

Nitrogen fertilizer should be managed to minimize ammonia volatilization. If rainfall is not imminent following application of ammoniacal-N to the surface of a calcareous soil, the fertilizer should be immediately moved into the soil with irrigation water. Urea applied to the surface of any soil should also be irrigated in. Fertigation using either of these sources is a suitable application method because the N immediately enters the soil.

Low leaf-**potassium** concentrations are common in groves planted on calcareous soils. If low yield, small fruit, fruit splitting, or creasing is observed, application of additional K fertilizer is justified. One approach is to increase the $N:K_2O$ fertilizer rate ratio to 1:1¼, that is, to apply 25% more K_2O than normal.

If the trees do not respond to soil application, an alternative approach to increasing leaf K is foliar sprays of KNO_3 or KH_2PO_4 (Chapter 8). Applications of 20 lb KNO_3 per 100 gal of water sprayed to foliar runoff (roughly 20 to 30 lb KNO_3 per acre) have effectively increased leaf K, especially if applied more than once during the year. Precautions should be taken to avoid foliar burns from high spray concentrations. The N applied in the spray is as equally available as soil-applied N, so the rate of N applied as KNO_3 should be taken into account when determining the annual N fertilizer rate for the citrus grove.

Low leaf-**magnesium** concentration in groves on calcareous soils can be addressed by applying foliar Mg sprays using $Mg(NO_3)_2$.

Acidification to Reduce Soil pH

Soil acidification can improve nutrient availability in calcareous soils by decreasing soil pH. The rate of a soil acidifier required to cause a plant response depends on the amount of $CaCO_3$ in the soil. The chance of a positive plant response to broadcast applications of an acidifier is near zero if lime rock or shell is visible in the root zone. In contrast, it is feasible to acidify soils with lower $CaCO_3$ content (e.g., from overliming) or those that have become alkaline from repeated application of high-bicarbonate irrigation water.

Soil acidifiers include elemental S and ammonium or potassium thiosulfate [$(NH_4)_2S_2O_3$, $K_2S_2O_3$]. The sulfur in these compounds converts to sulfuric acid in the soil, which neutralizes $CaCO_3$ (Table 1) and decreases soil pH. Ammonium sulfate [$(NH_4)_2SO_4$] acidifies the soil through nitrification, which releases H^+ as NH_4^+ converts to NO_3^-.

Table 1. Materials that can be used to lower soil pH, and their acidifying power relative to $CaCO_3$.

Acidifier	Amount needed to neutralize 1000 lb of pure $CaCO_3$
Elemental sulfur	320 lb
Concentrated (98%) sulfuric acid	68 gal
Ammonium thiosulfate 12-0-0-26S	1600 lb
Potassium thiosulfate 0-0-25-17S	3800 lb
Ammonium sulfate 21-0-0	900 lb

Elemental S is the most effective soil acidifier. The powder form can be difficult to handle due to dustiness and fire hazard, and it can cause severe root burn if not applied properly. To overcome these problems, some S products have been formulated into porous pellet-like particles that are much easier to handle and apply.

Ammonium thiosulfate and potassium thiosulfate are clear liquid fertilizers containing $S_2O_3^{2-}$. They can be blended with N, P, and K solutions to form a wide variety of N-P-K-S formulations. Thiosulfates are noncorrosive and not hazardous to handle, and they are well adapted to the methods used to apply fertilizer solutions. Application of ammonium thiosulfate to calcareous soils has been shown to increase the amount of extractable Fe in the soil.

The soil within the wetted pattern of a microirrigation emitter often becomes alkaline when the water source contains bicarbonate, while the surrounding soil may be neutral or acidic. Lowering the soil pH in this situation requires an application of acid or acidifying fertilizer to the wetted pattern only. Application of acid or thiosulfate fertilizer through the irrigation system can be effective in treating this problem.

Saline Soils and Water

All natural waters and soil solutions contain soluble salts. Salt concentration is reported several ways:

- Milligrams per liter (mg/L), or parts per million (ppm) of total dissolved solids (TDS). The units mg/L and ppm are interchangeable.
- Electrical conductivity (EC), expressed as deci-Siemens per meter (dS/m), millimhos per centimeter (mmhos/cm), or micromhos per centimeter (μmhos/cm). The units dS/m and mmhos/cm are interchangeable, and μmhos/cm = mmhos/cm × 1000.

Salts in solution exist as ions that can conduct an electric current, so EC increases as dissolved salt concentration increases. The EC of Florida waters usually ranges between 0 and 5 dS/m.

The conversion from EC to TDS depends on the kind of salts present in the solution. TDS (in ppm) can be estimated by multiplying EC (in dS/m or mmhos/cm) by 700. This conversion factor is an average value appropriate for converting the EC of Florida soil extracts and irrigation waters to TDS. Many conductivity meters that provide a direct salinity reading in ppm have a built-in conversion factor in the range of 630 to 640. Care must be taken to ensure that measurements made by different conductivity meters are comparable.

Vast amounts of salts can be deposited on the soil by long-term irrigation with high-salinity water. For example, 100 gallons of water at 3000 ppm TDS contains about 2.5 lb of salt. Because the weekly irrigation requirement of a bearing citrus tree can exceed three times this amount, soil salts can quickly accumulate. Even 1000 ppm TDS water (containing 0.8 lb salt in 100 gallons) can create salt stress.

Because soil salt concentration depends on soil water content, soil salinity is often related to a standard saturation extract (ECe). The ECe standardizes soil salt concentration to the saturation soil water content. Thus, salinity around tree roots may be several times greater than ECe when soil moisture is at field capacity or less. In sandy soils, where salts are easily leached, management decisions based solely on ECe measurement are not advised. ECe of these soils only indicates soil salinity at the time of measurement and can change rapidly following irrigation or rainfall.

The main citrus tree response to excess salts in soil and irrigation water is growth reduction. Injury symptoms caused by saline irrigation water are not usually permanent, but affected trees may remain stunted compared with trees not receiving salty water, especially if they are young.

Salts in solution exert an osmotic effect that reduces water availability through both chemical and physical processes. Roots are not able to extract as much water from a solution high in salts compared with one low in salts. In effect, the trees must expend more energy to move water through them, which reduces root growth followed by reductions in shoot growth and yield.

The critical salinity concentration will vary with the buffering capacity of the soil (that increases with clay and organic matter content), the climate, the rootstock used, and the soil moisture status. Salinity-induced symptoms like 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 the leaves. Chloride toxicity, which appears as burned necrotic or dry-appearing edges on leaves, is one of the most common visible salt injury symptoms. Sodium toxicity symptoms are seldom seen in Florida, but sometimes high Na may cause an overall leaf "bronzing" accompanied by reductions in growth. As with Cl, high leaf Na can cause nutrient imbalances at much lower concentrations than those required to produce visible symptoms. Because Na and Cl are highly soluble in soil water, evaluating salinity stress by measuring their concentration in the soil has little diagnostic value.

Common citrus rootstocks tolerate soil salinity differently. In general, the ranking of rootstocks from most tolerant to least tolerant of salinity is: 1. Cleopatra mandarin; 2. sour orange; 3. sweet orange; 4. Swingle citrumelo; 5. Carrizo citrange; 6. rough lemon. Grapefruit trees tend to be less salt tolerant than orange trees.

Fertilizer application frequency directly affects soil solution TDS concentration. A fertilization program that frequently applies low rates of soluble salts will normally result in less salinity stress than programs applying only two or three high-rate doses per year. Use of controlled-release fertilizers or fertigation can minimize salt stress if high-salinity irrigation water must be used. Growers using salty irrigation water usually observe a marked improvement in water quality when summer rains begin.

Selecting nutrient sources that have a relatively small osmotic effect on the soil solution can help reduce salt stress. The osmotic effect of a fertilizer is defined as its salt index relative to sodium nitrate, which arbitrarily has a salt index of 100. Phosphorus sources have a low salt index and present little problem. Conversely, N and K sources can have a high salt effect (Appendix C). The salt indexes of inorganic and natural organic fertilizers are low compared with commonly used soluble fertilizers. High-analysis fertilizers may have a lower salt index per unit of plant nutrient than lower-analysis fertilizers because they may be made with lower salt-index materials. Thus, at a given fertilization rate, a high-analysis formulation will likely produce less salt injury.

Selecting nutrient sources that do not add a potentially harmful ion to already high concentrations in irrigation water can reduce the likelihood of a salinity problem. The Cl^- in KCl or Na^+ in $NaNO_3$ add potentially harmful salts to the soil solution. High application rates of fertilizer salts can raise soil pH and decrease soil nutrient availability. Specific ions can also aggravate nutrient imbalances in soil and trees. For example, Na^+ displaces K^+, and to a lesser extent Ca^{2+}, in soil solutions. Displacement of K^+ by Na^+ can lead to K deficiency and in some cases even Ca^{2+} deficiency in leaves when repeatedly irrigating with water high in Na^+. Nutrient deficiencies compound the effects of salinity stress. Problems can be minimized if sufficient nutrition is maintained through either soil or foliar fertilizer application.

Nutrient Management with Saline Irrigation Water

- Routinely evaluate irrigation water salinity with an EC meter. TDS below 1000 ppm is excellent. A salt problem may become evident as TDS increases from 1000 to 2000 ppm and is highly likely if TDS exceeds 2000 ppm.
- If excess salts accumulate in the soil, keep the soil moist so they are less concentrated.
- Fine-textured soils and areas of compacted soils or poor drainage may need special management to flush excess salts from the root zone.
- Do not allow salty water to contact leaves, especially when evaporation demand is high.
- Use nighttime irrigation whenever possible to minimize evaporation and salt deposition.
- Choose fertilizer formulations with the lowest salt index per unit of plant nutrients.
- Increase fertilization frequency, which will help reduce the salt content of each application, and will aid in preventing excess salt accumulation in the root zone.
- Maintain optimum but not excessive nutrient concentrations in the leaves.
- Base fertilization rates on the long-term production of the grove. Decrease fertilizer rates applied to trees irrigated with salty water compared with trees irrigated with good-quality water, because production is probably lower.
- Use leaf tissue analysis to detect excessive leaf Na or Cl or deficiencies of other elements caused by salt-induced nutrient imbalance.

Using Reclaimed Water for Irrigation

Reclaimed municipal effluent is an excellent citrus irrigation water source as long as it is produced under strict quality control. As Florida's population continues to grow, treated wastewater will become increasingly important for irrigation.

Long-term use of large quantities of reclaimed water can increase soil pH and soil test P and Ca. Leaf analysis may sometimes show increased Na, Cl, and B concentrations with no observed tree injury. Differences in uptake of various elements in the water (Table 2) can be expected to occur among varieties and rootstocks.

Essential elements in reclaimed water contribute to citrus tree nutrition, so it may be possible to reduce fertilizer rates if reclaimed water is the sole source of irrigation. For example, applying 50 acre-inches/year of reclaimed water containing 10 ppm N would supply 113 lb N/acre. It has been determined that P and B inputs could be reduced or eliminated when using large quantities of reclaimed water. Leaf Na, Cl, and B should be routinely monitored to avoid their reaching toxic levels under reclaimed water irrigation.

Limited studies have shown that it is feasible to grow citrus using citrus processing effluent as an irrigation source. However, certain variables must be considered in the design and management of irrigation systems for use of this water. Daily flow from the processing plant, weekly loading depth to the land, and the storage capacity of the soil should all be considered when determining the needed land area. As with other reclaimed water sources, effluent monitoring procedures at the processing facility are needed to ensure that acceptable quality is maintained.

Nutrient concentrations in citrus processing wastewater are too low to sustain tree growth (Table 11.3), so supplemental fertilization is necessary. Rootstocks and scion varieties should be selected for their tolerance to excess Na contained in processing effluent.

Fertilization Strategies for Damaged Trees

Wind Damage

Strong sustained winds from tropical storms or hurricanes can damage citrus trees by removing canopy and fruit. Root damage may also occur if a storm produces flooding rains. The main nutritional factors related to severe canopy thinning are loss of leaf N and K reserves and interruption of the natural nutrient recycling that occurs as tree residues decompose and mineralize in root zone soil. As a result, subsequent vegetative growth may deplete remaining tree and soil reserves of N and K. Additional fertilization beyond the normal program is justified to aid grove recovery in this situation as long as the root system is not significantly damaged.

To determine how much additional N and K_2O to apply, start with the assumption that every 10% loss of leaf canopy from an average grove represents a loss of about 10 lb N/acre, then estimate a target fertilizer rate based on the relative amount of leaf canopy that the grove has lost and the efficiency of the fertilizer application method to be used. Keep the following considerations in mind when attempting to replace lost canopy N and K with additional fertilizer as the grove recovers:

- Reduce the fertilizer rate for smaller trees.
- It will take time to rebuild a full, healthy canopy.
- Distribute additional N and K fertilizer throughout the following growing season as normal. Do not front-load all of it in the spring.
- Consider foliar application in place of soil application.
- Remember that bloom and fruit set in the following year will depend more on environmental conditions and less on fertilizer rates.

When root systems are extensively damaged from prolonged flooding, the tree canopy will recover more slowly. In this case, fertilization should be reduced until the root system can rejuvenate. Surviving roots are more likely to be close to the soil surface, with the lower ones damaged or killed. Addition of fertilizer at rates normally applied to vigorous trees may further damage roots.

Freeze Damage

Trees should not be fertilized or irrigated following a severe freeze until the extent of damage is determined and regrowth is evident. Stored nutrients in bearing trees on a regular fertilizer program can mobilize to new shoots and leaves, especially after severe wood damage. No more than 50% of the recommended N rate should be applied to severely damaged citrus trees that will not produce a crop the following year, provided that optimum tree water status is maintained. It may be necessary to apply only N and foliar micronutrients. There is strong evidence that soil-applied fertilizer may not even be necessary for bearing trees in the first postfreeze season if they have received sufficient fertilization in the years prior to the freeze. Reduced fertilizer rates may be applied to 2-to-4-year-old trees with moderate freeze damage provided no crop is set following the freeze.

Nutritional Deficiencies Enhanced by Environmental or Pathological Factors

Zinc deficiency patterns can be enhanced by citrus blight disease. When trees have blight, leaf symptoms will look the same as Zn deficiency. Leaves are reduced in size and off-color, and small blotches of yellow between green-colored veins in the leaf will appear. In many cases, the leaf Zn deficiency pattern may not be evenly distributed within the tree canopy.

Iron deficiency can result from flooding injury to the citrus root system. Root damage can occur if the root zone soil is flooded for several days in the summer but may take weeks to occur in the cooler winter months. The pattern will first appear on young, expanding leaves. The leaf turns light green, while the veins and midrib remain darker green.

Nitrogen deficiency, or "winter chlorosis," can occur in late winter or early spring when rapid tree growth begins and the soil temperature is too cool for normal root function and nutrient uptake. When this occurs, the midrib will begin to yellow while the remaining portion of the leaf remains darker green.

Phytophthora-induced N deficiency occurs when the roots or tree trunk become infected, resulting in partial or complete girdling that causes the tree to decline. Leaves express visual symptoms of yellowing of the veins, typical of N deficiency. The deficiency pattern may be associated with individual limbs in the case of foot rot or could involve the entire tree in the case of root damage. The deficiency appears as the ability of the roots or trunk to transport N upward into the tree canopy is reduced.

Organic Citrus Production

General Information

The exclusive use of certified organic nutrient sources in an organic production program may not be a viable alternative for large-scale Florida commercial citrus production mostly because of insufficient supply of nonsynthetic fertilizers (manures, composts, etc.), sometimes slow availability of nutrients with time from these materials, and the logistics of their transport, storage, and application. For the small producer, organic citrus production may be feasible depending on the availability and quality of acceptable sources, customer acceptance of the product, and expected returns on investment. Yields, production costs, and market returns for organic citrus production have not been clearly defined in Florida.

Certified organic groves must have distinct, defined boundaries between fields managed organically and those managed conventionally. Storage facilities and records for certified organic fields must be maintained separately from noncertified fields. A production unit may be certified as organic only if harvest occurs at least 36 months after the most recent use of prohibited pesticides or fertilizers. Records of all fertilizer and soil amendment use must be kept for at least 3 years prior to certification.

Organic fertilization programs for citrus emphasize methods to improve soil fertility and health through the use of organic fertilizers and soil amendments. Soil management includes increasing soil organic matter (humus) content by mowing, grazing, growing green manure and N-fixing cover crops in row middles, and applying manures, composts, and natural fertilizers. Annual nutrient application rates for organically grown young trees and bearing trees should be similar to those recommended for conventionally grown trees.

Citrus production operations applying for initial or ongoing organic certification must comply with regulations established under the National Organic Program (NOP) and applicable organic production regulations. Information about various aspects of the NOP is available on the internet at http://www.ams.usda.gov/NOP/NOPhome.html. This web page provides links to several other web pages where additional information can be found.

The USDA does not provide organic certification but instead accredits state, private, and foreign organizations, groups, or persons to become "certifying agents." FDACS has not assumed this role, so growers must choose a private USDA-accredited organic certification agency.

Soil Fertility and Crop Nutrient Management Guidelines

(These guidelines are summarized from Section 205.203 of the NOP final rule.)

- Producers should implement tillage and cultivation practices to maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion.
- Producers should manage crop nutrients and soil fertility through rotations, cover crops, and application of plant and animal materials.
- Producers should manage plants and animal materials to maintain or improve soil organic matter in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances. Animal and plant materials include:
  - Raw animal manure (feces, urine, other excrement, and bedding produced by livestock that has not been composted):
    - can be applied to land used for a crop not intended for human consumption;
    - must be incorporated into the soil not less than 120 days before harvesting a product that comes into contact with the soil surface or soil particles; and
    - must be incorporated into the soil not less than 90 days before harvesting a product that does not come into contact with the soil surface or soil particles.
  - Composted plant and animal materials produced through a process that:
    - established an initial carbon-to-nitrogen ratio between 25:1 and 40:1; and
    - maintained temperature between 131°F and 170°F for 3 days using an in-vessel or static aerated pile system, or

    - maintained temperature between 131°F and 170°F for 15 days using a windrow composting system, turning the materials at least five times.

- noncomposted plant materials.

A producer may apply:

- crop nutrients or soil amendments allowed for use in organic production;
- mined substances of low solubility;
- mined substances of high solubility, provided that it is used in compliance with the conditions established on the national list of nonsynthetic materials prohibited for crop production;
- ash obtained from the burning of a plant or animal material, provided it has not been treated or combined with a prohibited substance or the ash is not included on the National List of nonsynthetic substances prohibited for use in organic crop production; and
- plant or animal material that has been chemically altered by a manufacturing process, as long as it is included on the national list of synthetic substances allowed for use in organic crop production.

A producer may not use:

- any fertilizer or composted plant and animal material that contains a synthetic substance not included on the national list of synthetic substances allowed for use in organic crop production;
- biosolids; or
- burning as a means of disposal for crop residues produced on the operation. (Exception: burning may be used to suppress the spread of disease.)

Table 2. Chemical composition of reclaimed municipal effluent from Orange County's Water Conserv II project compared with typical well water and drinking water standards (Parsons et al. 2001).

Element or parameter	Drinking water MCL[1] (ppm)	Typical well water (ppm)	Typical Conserv II water (ppm)
EC (µmhos)	781	360	720
Arsenic	0.05	---	<0.005
Boron	---	0.02	<0.25
Cadmium	0.005	---	<0.002
Calcium	---	39	42
Chloride	250	15	75–81
Chromium	0.1	---	<0.005
Copper	1.0	0.03	0.002–0.05
Lead	0.015	---	<0.003
Magnesium	---	16	9
Manganese	0.05	0.01	0.006–0.042
Nickel	0.1	---	0.01
Nitrate-N	10	3	6–7
Phosphorus	---	0.01	1.1
Potassium	---	6	12
Sodium	160	18	50–70
Sulfate	250	23	29–55

[1] Maximum contamination limit.

Table 3. Average chemical composition of citrus processing wastewater (Koo 1973).

	Source A		Source B	Source C
	Not treated	Treated	Treated	Treated
pH	**7.2**	**7.7**	**7.8**	**5.7**
	-------------------- ppm --------------------			
TDS	639	612	412	225
Total N	119	7	8	10
Nitrate-N	2	2	4	3
P	1	2	1	1
K	35	33	22	12
Ca	44	47	32	37
Mg	10	10	7	3
Na	169	137	81	24
Cl	81	48	48	14
Fe	2	1	0.4	16
Mn	0	0	0	0.2
Zn	0.01	0.05	0.03	0.1
B	0	0	0	0.2

UF | IFAS Extension
UNIVERSITY of FLORIDA

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 12. References and Further Reading

Refereed Journal Articles

Albrigo, L. G. 1999. "Effects of Foliar Applications of Urea or Nutriphite on Flowering and Yields of Valencia Orange Trees." *Proc. Fla. State Hort. Soc.* 112: 1–4.

Alva, A. K. 1993. "Comparison of Mehlich 3, Mehlich 1, Ammonium Bicarbonate-DTPA, 1.0M Ammonium Acetate, and 0.2M Ammonium Chloride for Extraction of Calcium, Magnesium, Phosphorus, and Potassium for a Wide Range of Soils." *Commun. Soil Sci. Plant Anal.* 24(7&8): 603–612.

Alva, A. K., S. Paramasivam, T. A. Obreza, and A. W. Schumann. 2006. "Nitrogen Best Management Practice for Citrus Trees: I. Fruit Yield, Quality, and Leaf Nutritional Status." *Scientia Horticulturae* 107: 233–244.

Hanselman, T. A., D. A. Graetz, and T. A. Obreza. 2004. "A Comparison of In Situ Methods for Measuring Net Nitrogen Mineralization Rates of Organic Soil Amendments." *J. Env. Qual.* 33: 1098–1105.

He, Z. L., D. V. Calvert, A. K. Alva, D. J. Banks, and Y. C. Li. 2003. "Thresholds of Leaf Nitrogen for Optimum Fruit Production and Quality in Grapefruit." *Soil Sci. Soc. Am. J.* 67: 583–588.

Lea-Cox, J. D., and J. P. Syvertsen. 1995. "Nitrogen Uptake by Citrus Leaves." *J. Amer. Soc. Hort. Sci.* 120: 505–509.

Mattos, D., Jr., J. A. Quaggio, H. Cantarella, and A. K. Alva. 2003. "Nutrient Content of Biomass Components of Hamlin Sweet Orange Trees." *Scientia Agricola* 60(1): 155–160.

Orbovic, V., D. Achor, P. Petracek, and J. P. Syvertsen. 2001. "Air Temperature, Humidity, and Leaf Age Affect Penetration of Urea through Grapefruit Leaf Cuticles." *J. Amer. Soc. Hort. Sci.* 126: 44–50.

Ozores-Hampton, M., T. A. Obreza, and G. Hochmuth. 1998. "Using Composted Wastes on Florida Vegetable Crops." *HortTechnology* 8: 130–137.

Paramasivam, S., A. K. Alva, K. H. Hostler, G. W. Easterwood, and J. S. Southwell. 2000. "Fruit Nutrient Accumulation of Four Orange Varieties during Fruit Development." *J. Plant Nutrition* 23(3): 313–327.

Parsons, L. R., T. A. Wheaton, and W. S. Castle. 2001. "High Application Rates of Reclaimed Water Benefit Citrus Tree Growth and Fruit Production." *HortScience* 36(7): 1273–1277.

Nonrefereed Journal Articles

Boman, B. J. 1997. "Effectiveness of Fall Potassium Sprays on Enhancing Grapefruit Size." *Proc. Fla. State Hort. Soc.* 110: 1–7.

Boman, B. J., and J. W. Hebb. 1998. "Post Bloom and Summer Foliar K Effects on Grapefruit Size." *Proc. Fla. State Hort. Soc.* 111: 128–135.

Boman, B. J. 2001. "Foliar Nutrient Sprays Influence Yield and Size of 'Valencia' Orange." *Proc. Fla. State Hort. Soc.* 114: 83–88.

Koo, R. C. 1973. "Irrigation of Citrus with Citrus Processing Wastewater." *Proc. Fla. State Hort. Soc.* 86: 233–237.

Koo, R. C. J. 1988. "Fertilization and Irrigation Effects on Fruit Quality." In *Factors Affecting Fruit Quality—Citrus Short Course Proceedings*, edited by J. J. Ferguson and W. F. Wardowski. 35–42. Gainesville: University of Florida Institute of Food and Agricultural Sciences.

Morgan, K. T., T. A. Obreza, and T. A. Wheaton. 2006. "The Basis for Mature Citrus Nitrogen Fertilizer Recommendations." *Proc. Fla. State Hort. Soc.* 119: 168–171.

Sartain, J. B. 1978. "Adaptability of the Double-Acid Extractant to Florida Soils." *Soil Crop Sci. Soc. Proc.* 37: 204–208.

Extension and Related Articles and Books

Boman, B. J. 2002. *Water and Florida Citrus: Use, Regulation, Irrigation, Systems, and Management*. SP281. Gainesville: University of Florida Institute of Food and Agricultural Sciences.

Lovatt, C. J., and R. L. Mikkelsen. 2006. "Phosphite Fertilizers: What Are They? Can You Use Them? What Can They Do?" *Better Crops Plant Food* 90(4): 11–13.

Obreza, T. A. 2004. Maintenance Guide for Florida Microirrigation Systems. CIR1449. Gainesville: University of Florida Institute of Food and Agricultural Sciences. https://ufdc.ufl.edu/IR00004237/00001.

Historical Documents

Koo, R. C. J., C. A. Anderson, I. Stewart, D. P. H. Tucker, D. V. Calvert, and H. K. Wutscher. 1984. *Recommended Fertilizers and Nutritional Sprays for Citrus*. Bulletin 536D. Gainesville: University of Florida Agricultural Experiment Stations.

Tucker, D. P. H., A. K. Alva, L. K. Jackson, and T. A. Wheaton. 1995. *Nutrition of Florida Citrus Trees*. SP169. Gainesville: University of Florida Institute of Food and Agricultural Sciences.

UF | IFAS Extension
UNIVERSITY of FLORIDA

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 13. Glossary

Acid-forming fertilizer—A fertilizer capable of increasing soil acidity, derived principally from the nitrification of ammonium salts by soil bacteria.

Association of American Plant Food Control Officials—An organization of officers and their deputies charged by law with regulating the sale of fertilizers, and of research workers employed by state or federal agencies engaged in the investigation of fertilizers. Its object is to promote uniform and effective legislation, definitions, and rulings, and to enforce the laws relating to the control of sale and distribution of fertilizers and fertilizer materials.

Basic fertilizer—A fertilizer capable of decreasing soil acidity.

Biuret—A phytotoxic impurity formed when urea molecules condense (combine) during fertilizer manufacture.

Brand—Term, design, or trademark used in connection with one or several grades of commercial fertilizer.

Bulk fertilizer—A fertilizer distributed in a nonpackaged form, usually in semitrailers.

Clear liquid fertilizer—A fertilizer in which the N-P-K and other materials are completely dissolved.

Commercial fertilizer—Any substance containing one or more recognized plant nutrients that is designed for use or claimed to have value in promoting plant growth or that is designed for use or claimed to have value in controlling soil acidity or alkalinity (except nonmanipulated animal and vegetable manures).

Complete fertilizer—A mixed fertilizer that contains the three major plant nutrient elements: nitrogen, phosphorus, and potassium.

Coning—The formation of a pyramidal pile or cone of dry bulk-mixed fertilizer such as may occur while being loaded into a holding hopper or transport vehicle and cause separation and segregation of the fertilizer components.

Dealer—Any person, other than the manufacturer, who offers for sale, sells, barters, or otherwise supplies commercial fertilizer.

Deconing—Any accepted process employed by a manufacturer that will prevent or minimize coning.

Deficiency—The amount of nutrient found by analysis less than that guaranteed, which may result from lack of nutrient ingredients or from lack of uniformity.

Dry bulk blending—The process of mechanically mixing solid fertilizer materials.

Excess—The amount found by analysis over and above that guaranteed on the label.

Fertilizer—Any substance containing one or more recognized plant nutrients that is used for its plant nutrient content. Unprocessed animal and vegetable manures, marl, lime, limestone, wood ashes, and other products are exempt from this definition.

Fertilizer formula—An expression of the quantity and analysis of the materials in a mixed fertilizer.

Fertilizer grade—The percentages in mixed fertilizer of total nitrogen (N), available phosphoric acid (P_2O_5), and the soluble potash (K_2O), stated in whole numbers in the same terms, order, and percentages as in the "guaranteed analysis" form (15-5-15, for example). Mixed fertilizer containing a total of 5% or less of total N, P_2O_5, and K_2O may be guaranteed in other than whole percentages; however, a minimum guarantee shall be established by rule.

Fertilizer material—A fertilizer that either:

- contains important quantities of no more than one of the primary plant nutrients nitrogen (N), phosphoric acid (P_2O_5), and potash (K_2O); or
- has 85% or more of its plant nutrient content present in the form of a single chemical compound; or
- is derived from a plant or animal residue or by-product or natural material deposit that has been

processed in such a way that its content of plant nutrients has not been materially changed except by purification and concentration.

Fertilizer ratio—Refers to the relative percentages of N, P_2O_5, and K_2O (a 15-5-15 has a 3-1-3 ratio).

Filler—A "make-weight" material added to a mixed fertilizer or fertilizer material to make up the difference between the weight of the added ingredients required to supply the plant nutrients in a ton of a given analysis and 2000 lb.

Fluid fertilizer—Clear or suspension liquid fertilizers.

Granulation—The process of manufacturing fertilizer particles of reasonably uniform size and stability.

Label—A display of written, printed, or graphic matter upon the immediate container of any commercial fertilizer or accompanying same when moved in bulk.

Manufacturer—A person engaged in the business of importing, preparing, mixing, blending, or manufacturing commercial fertilizer for sale, either to direct consumers or through other media of distribution.

Mixed fertilizer—A fertilizer containing any combination or mixtures of commercial fertilizers designed for use or claimed to have value in promoting plant growth.

Non-acid-forming, or "neutral," fertilizer—A fertilizer that is guaranteed to leave neither an acidic nor a basic residue in the soil.

Official sample—Any sample of commercial fertilizer taken by FDACS or its representative, in accordance with the provisions of the fertilizer law.

Organic—A material containing carbon and one or more elements, other than hydrogen and oxygen, essential for plant growth. When the term "organic" is used on the label, it shall be qualified as either "synthetic organic" or "natural organic," with the percentage of each specified. When the term "organic" is used, it must be clearly indicated that it refers only to the nitrogen or other applicable portion of the fertilizer.

- "Natural organic" is a by-product from processing of animal or vegetable substances that contain sufficient plant nutrients to be of value as fertilizers.
- "Synthetic organic" is a material that is manufactured chemically (by synthesis) from its elements or other chemicals, as contrasted to those found ready-made in nature.

Percent—Indicates percentage by weight.

Primary plant nutrient—Any form of nitrogen, phosphoric acid, or potash, or any combination of these substances.

Registrant—The person who registers commercial fertilizer under the provisions of the fertilizer law.

Secondary plant nutrient—Any element or substance useful as plant nutrient other than the primary plant nutrients.

Slow- or controlled-release fertilizer—A fertilizer containing a plant nutrient in a form that delays its availability for plant uptake and use after application, or which extends its availability to the plant significantly longer than a reference "rapidly available nutrient fertilizer," like ammonium nitrate or urea, ammonium phosphate, or potassium chloride. When slow- or controlled-release nutrient is claimed or advertised, the guarantee for such a nutrient shall be shown as a footnote and shall be expressed as percent of actual nutrient. When a slowly released nutrient is less than 15% of the guarantee for either total nitrogen, available phosphoric acid, or soluble potash, as appropriate, the label shall bear no reference to such designations.

Soil amendment—A material applied to improve or enhance soil characteristics for plant growth.

Specialty fertilizer—Commercial fertilizer in packages sold or offered for sale for home use.

Suspension fertilizer—A fertilizer in which some of the fertilizer materials are suspended as fine particles.

Tolerance—The variation authorized by law or regulation from the guaranteed analysis.

Unit of plant nutrient—1% of a ton, or 20 lb.

Water insoluble nitrogen—Nitrogen not soluble in water. All organic nitrogen soluble in water shall be classified as "water-soluble organic nitrogen." However, soluble organic nitrogen derived from urea may be classified either as "urea nitrogen" or "water-soluble organic nitrogen," at the option of the registrant. Nitrogen in the nitrate or ammoniacal forms shall be so classified.

UF | IFAS Extension
UNIVERSITY of FLORIDA

Nutrition of Florida Citrus Trees, 3rd Edition: Chapter 14. Appendices

Appendix A. Physical and Chemical Properties of Typical Florida Citrus Soils

Table 26. Typical root zone[1] soil physical and chemical properties for common soil series found in Florida citrus groves.

Soil series	Physical properties						Chemical properties	
	Soil texture			Organic matter	Water-holding capacity		pH	Cation-exchange capacity
	Sand	Silt	Clay					
	%				inches per ft	inches in the root zone		meq/100 g
ENTISOLS								
Astatula	98.5	0.75	0.75	0.5–1.0	0.3–0.6	0.9–1.8	4.5–6.5	2–4
Basinger	98.5	0.5	1.0	0.5–1.0	0.4–0.8	0.6–1.2	3.6–7.3	2–4
Candler	97.5	1.25	1.25	0.5–1.0	0.3–0.7	0.9–2.1	4.5–6.0	2–4
Tavares	97.0	1.5	1.5	0.5–1.0	0.3–0.6	0.9–1.8	3.6–6.0	2–4
ALFISOLS								
Boca	94.0	3.0	3.0	1.0–2.5	0.4–0.9	0.6–1.4	5.1–8.4	6–10
Holopaw	94.0	3.5	2.5	1.0–2.5	0.7–1.2	1.1–1.8	5.1–7.3	3–7
Pineda	96.0	2.5	1.5	0.5–2.0	0.3–0.6	0.5–0.9	5.6–7.3	2–6
Riviera	96.5	2.0	1.5	0.5–2.0	0.6–1.0	0.9–1.5	4.5–6.5	2–6
Winder	85.0	6.0	9.0	1.0–3.0	0.7–1.2	1.1–1.8	5.6–7.8	14–18
SPODOSOLS								
Immokalee	98.5	1.0	0.5	1.0–2.0	0.4–0.8	0.6–1.2	3.6–6.0	2–6
Myakka	98.5	1.0	0.5	1.0–2.0	0.4–0.8	0.6–1.2	3.6–6.5	2–6
Oldsmar	98.0	1.5	0.5	1.0–2.0	0.3–0.6	0.5–0.9	3.6–7.3	2–6
Pomona	96.0	3.5	0.5	1.0–2.0	0.4–1.0	0.6–1.5	3.6–5.5	2–6
Smyrna	97.0	2.5	0.5	1.0–3.0	0.4–0.8	0.6–1.2	3.6–7.3	2–6
Wabasso	97.5	1.5	1.0	1.0–2.0	0.3–0.6	0.5–0.9	4.5–7.0	2–6

[1] Top 36 inches of soil for central Ridge Entisols and top 18 inches of soil for Flatwoods Alfisols, Spodosols, and Entisols.

Table 27. Physical and chemical properties of the subsurface diagnostic layers of typical Alfisols and Spodosols found in Florida Flatwoods citrus groves. These layers may reside in an undisturbed state beneath the root zone, or they may be partially excavated and mixed into the root zone soil during the bedding process.

Soil series	Layer	Physical properties					Chemical properties	
		Soil texture			Organic matter	Water-holding capacity	pH	Cation-exchange capacity
		Sand	Silt	Clay				
		%				inches per ft		meq/100 g
ALFISOLS								
Boca	Loamy	81.0	4.0	15.0	0.3–1.2	1.2–1.8	5.1–8.4	16–24
Holopaw	Loamy	80.0	7.0	13.0	0.2–0.4	1.8–2.4	5.1–8.4	11–22
Pineda	Loamy	77.0	3.5	19.5	0.1–0.3	1.2–1.8	5.1–8.4	4–18
Riviera	Loamy	77.0	4.5	18.5	0.2–0.3	1.4–1.8	6.1–8.4	9–24
Winder	Loamy	80.0	4.0	16.0	0.1–0.3	1.2–1.8	6.6–8.4	12–26
SPODOSOLS								
Immokalee	Organic	95.0	2.5	2.5	2.5–3.8	1.2–3.0	3.3–4.4	14–25
Myakka	Organic	90.5	5.0	4.5	2.8–4.5	1.2–2.4	4.0–4.7	13–18
Oldsmar	Organic	92.0	3.5	4.5	1.8–3.0	1.2–1.8	4.7–5.3	7–15
Pomona	Organic	93.0	5.5	1.5	1.0–1.5	1.2–1.8	4.0–4.7	5–15
Smyrna	Organic	90.5	5.0	4.5	3.3–3.9	1.2–1.8	4.3–4.7	19–21
Wabasso	Organic	93.0	2.0	5.0	1.8–2.1	1.2–1.8	4.7–5.2	5–12

Appendix B. Nutrient Concentrations of Component Fertilizer Materials

Table 28.

Material	Percentage composition							Availability
	N	P_2O_5	K_2O	Ca	Mg	S	Other	
Conventional sources								
Ammonium molybdate							54 Mo	Rapid
Ammonium nitrate	33							Rapid
Ammonium polyphosphate	10	34						Rapid
Ammonium sulfate	21					23		Rapid
Ammonium thiosulfate	12					26		Rapid
Borax							10–15 B	Rapid
Calcitic limestone				32				Slow
Calcium ammonium nitrate	27			6				Rapid
Calcium nitrate	15.5			20				Rapid
Calcium sulfate (gypsum)				23		18		Moderate
Copper sulfate						12	25–35 Cu	Rapid
Diammonium phosphate	18	46						Rapid
Dolomitic limestone						8–20	22 Ca	Slow
Iron (ferrous) sulfate							20 Fe	Rapid
Iron oxy-sulfate							45–50 Fe	Slow
Iron DTPA							10 Fe	Rapid
Iron EDTA							9–12 Fe	Rapid
Iron EDDHA							6 Fe	Rapid
Iron HEDTA							5–9 Fe	Rapid
Iron humate							25–28 Fe	Moderate
Iron sucrate							50 Fe	Moderate
Magnesium oxide					56			Moderate
Magnesium sulfate					10			Rapid
Manganese oxide							41–68 Mn	Moderate
Monoammonium phosphate	11	48				0–2		Rapid
Manganese sulfate						13	24 Mn	Moderate
Phosphoric acid		54						Rapid
Phosphorous acid		40–60						Moderate
Potassium chloride			60				44 Cl	Rapid
Potassium-magnesium sulfate			22		11	22		Moderate
Potassium nitrate	13		48					Rapid
Potassium phosphite		28	26					Moderate

Material	Percentage composition							Availability
	N	P_2O_5	K_2O	Ca	Mg	S	Other	
Potassium sulfate			46			18		Rapid
Potassium thiosulfate				25		17		Rapid
Sodium molybdate							39 Mo	Rapid
Sulfur, elemental						30–99		Moderate
Superphosphate, ordinary		20		20		10–14		Rapid
Superphosphate, concentrated		46		16		1–2		Rapid
Urea	46							Rapid
Urea-ammonium nitrate	28–32							Rapid
Zinc oxide							50–78 Zn	Moderate
Zinc sulfate						12	21–36 Zn	Moderate
Zinc EDTA							9–14 Zn	Rapid
Zinc HEDTA							9 Zn	Rapid
Slow-release sources								
Sulfur-coated urea	32–38							3–6 mo.
Urea formaldehyde	38–40							6–12 mo.
Isobutylidene diurea (IBDU)	31							3–6 mo.

Table 29. Organic sources

Material	Percentage composition							Availability
	N	P_2O_5	K_2O	Ca	Mg	S	Other	
Organic sources								
Organiform	30							Slow
Municipal biosolids	3–7	1–7	0.5–1					Moderate
Activated biosolids	6	2	0.5	2	1			Moderate
Blood meal	8–13	2	1					Rapid
Bone meal	1–4	18–34						Slow
Cottonseed meal	6	3	1					Medium
Fish meal	9	4–6						Rapid
Alfalfa meal	2.5	0.3	2					Medium
Soybean meal	7	1.5	2					Medium
Poultry manure	3	3						Rapid (depends on bedding)
Poultry litter pellets	4	2	2					Rapid
Poultry manure compost	5	3	2					Rapid
Cow manure	~3	~1	~2	~1	~0.2			Rapid (if fresh)

Appendix C. Salt Index of Fertilizer Materials

Table 30. Salt index of water-soluble fertilizers.

Material and analysis	Salt index	
	Per equal weights of materials (Basis: sodium nitrate = 100)	Per unit (20 lb) of plant nutrients
Nitrogen		
Ammonium nitrate, 34% N	104.0	3.059
Ammonium sulfate, 21% N, 24% S	68.3	3.252
Calcium nitrate,15.5% N	65.0	4.194
Sodium nitrate, 16% N	100.0	6.060
Urea	74.4	1.618
Urea-ammonium nitrate solution, 28% N	63.0	2.250
Urea-ammonium nitrate solution, 32% N	71.1	2.221
Phosphate		
Diammonium phosphate, 18% N, 46% P_2O_5	29.2	0.456
Superphosphate, ordinary, 20% P_2O_5	7.8	0.390
Superphosphate, concentrated, 45% P_2O_5	10.1	0.224
Ammonium polyphosphate, 10% N, 34% P_2O_5	20.0	0.455
Potassium		
Potassium chloride, 60% K_2O	116.2	1.936
Potassium hydroxide, 83% K_2O	---	1.015
Potassium nitrate, 13% N, 44% K_2O	69.5	1.219
Potassium sulfate, 50% K_2O, 18% S	42.6	0.852
Monopotassium phosphate, 52% P_2O_5, 34% K_2O	8.4	0.097
Potassium-magnesium sulfate, 22% K_2O, 11% Mg, 22% S	43.4	1.971

Table 31. Example salt index calculation for a dry fertilizer.

15-4-15 dry granular			Nutrient units			Salt index	
Material	Nutrient conc.	lb/ton	N	P_2O_5	K_2O	per unit (20 lb) (from table 30)	in the formula
Ammonium nitrate	34% N	882	15			3.059	45.9
Conc. superphosphate	45% P_2O_5	178		4		0.224	0.9
Potassium chloride	60% K_2O	500			15	1.936	29.0
Filler		440					
Total		2000	15	4	15		75.8

Table 32. Example salt index calculation for a solution fertilizer.

8-0-8 solution			Nutrient units			Salt index	
Material	% Nutrient	lb/ton	N	P_2O_5	K_2O	per unit (20 lb) (from table 30)	in the formula
Ammonium nitrate	34% N	329	5.6			3.059	17.1
Potassium nitrate	13% N 44% K_2O	364	2.4		8	1.219	9.8
Water		1307					
Total		2000	8	0	8		26.9

Appendix D. Solubility of Fertilizer Sources and Common Fertilizer Solutions

Table 33. Water solubility of fertilizer sources.

Material	Amount (lb) that will dissolve in 1 gallon of water	
	Cold water (32°F)[1]	Hot water (212°F)[1]
Ammonium nitrate, NH_4NO_3	9.8	72.7
Ammonium sulfate, $(NH_4)_2SO_4$	5.9	8.7
Borax, $Na_2B_4O_7•10H_2O$	0.17	14.2
Calcium carbonate (limestone), $CaCO_3$	0.00013 (77°F)	0.00016 (167°F)
Calcium nitrate, $Ca(NO_3)_2•4H_2O$	10.1 (64°F)	31.4
Calcium sulfate (gypsum), $CaSO_4•2H_2O$	0.020	0.019
Copper sulfate, $CuSO_4•5H_2O$	2.6	17.0
Diammonium phosphate, $(NH_4)_2HPO_4$	4.8 (50°F)	8.8 (158°F)
Ferric sulfate, $Fe_2(SO_4)_3•9H_2O$	36.7	Decomposes
Ferrous sulfate, $FeSO_4•7H_2O$	1.3	4.1 (122°F)
Magnesium sulfate, $MgSO_4•7H_2O$	5.9 (68°F)	7.6 (104°F)
Manganese sulfate, $MnSO_4•4H_2O$	8.8	9.3 (129°F)
Monocalcium phosphate, $Ca(H_2PO_4)_2•2H_2O$	0.15 (86°F)	Decomposes
Potassium chloride, KCl	2.9 (68°F)	4.7
Potassium nitrate, KNO_3	1.1	20.6
Potassium sulfate, K_2SO_4	1.0 (77°F)	2.0
Sodium molybdate, Na_2MoO_4	3.7	7.0
Sodium nitrate, $NaNO_3$	7.7 (77°F)	15.0
Urea, $CO(NH_2)_2$	6.5 (41°F)	62.8
Zinc sulfate, $ZnSO_4•7H_2O$	8.1 (68°F)	55.4

[1] Temperatures of cold and hot water are 32°F and 212°F, respectively, unless otherwise noted.

Table 34. Common fertilizer solutions.

Analysis N	P	K	Density	Materials and formulation	Additional nutrients
%			lb/gallon		
Component solutions					
21	0	0	10.8	Ammonium nitrate solution	
9	0	0	10.4	Ammonium sulfate solution	10 S
10	34	0	11.8	Ammonium polyphosphate	
12	0	0	11.0	Ammonium thiosulfate	26 S
17	0	0	12.6	Calcium ammonium nitrate solution	9 Ca
9	0	0	12.2	Calcium nitrate solution	11 Ca
32	0	0	11.1	Urea ammonium nitrate solution	
0	54	0	14.5	Phosphoric acid, merchant grade	
3	0	11	9.7	Potassium nitrate solution	
0	0	62	16.5	Potassium chloride solution	
7	0	0	11.3	Magnesium nitrate	6 Mg
7	0	0	13.4	Manganese nitrate	15 Mn
7	0	0	13.3	Zinc nitrate	17 Zn
Fertilizer solutions					
5	0	10	10.0	Ammonium nitrate, potassium chloride	
5	0	10	10.5	Ammonium nitrate, potassium chloride, magnesium nitrate	Micronutrients
8	0	8	9.8	Ammonium nitrate, potassium nitrate	
8	0	8	9.7	Ammonium nitrate, potassium chloride	
8	0	8	11.6	Calcium nitrate, potassium nitrate	
8	0	8	12.0	Calcium nitrate, potassium chloride	
8	0	8	10.2	Ammonium nitrate, potassium chloride, magnesium nitrate	1 Mg
8	2	8	10.3	Ammonium nitrate, potassium nitrate, phosphoric acid	
8	2	8	10.0	Ammonium nitrate, potassium chloride, phosphoric acid	
8	4	8	10.3	Ammonium nitrate, potassium nitrate, phosphoric acid	
8	4	8	10.0	Ammonium nitrate, potassium chloride, phosphoric acid	
9	0	9	10.2	Ammonium nitrate, potassium nitrate	
9	0	9	10.2	Ammonium nitrate, potassium chloride	
9	2	9	10.7	Ammonium nitrate, potassium nitrate, phosphoric acid	
9	2	9	10.6	Ammonium nitrate, potassium chloride, phosphoric acid	
9	4	9	10.7	Ammonium nitrate, potassium nitrate, phosphoric acid	
9	4	9	10.6	Ammonium nitrate, potassium chloride, phosphoric acid	
10	0	10	10.4	Ammonium nitrate, potassium nitrate	
10	0	10	10.3	Ammonium nitrate, potassium chloride	

Appendix E. Fertilizer Mixture Formulation Example

The following illustrates the procedure a bulk blending plant uses to formulate a fertilizer mixture. The formula is only an example and should not be regarded as a recommendation.

1. Assume that the annual fertilizer recommendation for a citrus grove is 160 lb of N, 40 lb of P_2O_5, 160 lb of K_2O, and 36 lb of Mg per acre, and that the yearly rate will be split into four applications.

2. The nutrients required per application are 40 lb of N, 10 lb of P_2O_5, 40 lb of K_2O, and 9 lb of Mg per acre. The fertilizer blend to be used contains 16% N, 4% P_2O_5, 16% K_2O, and 3.6% Mg.

3. The amount of this fertilizer needed is: (40 lb N per acre) ÷ (0.16) = 250 lb per acre. If the grove is 80 acres, then the amount of fertilizer to order is: (250 lb per acre) × (80 acres) = 20,000 lb = 10 tons.

4. One ton of this fertilizer contains 320 lb of N, 80 lb of P_2O_5, 320 lb of K_2O, and 72 lb of Mg. In this example, 1 ton will be blended using the following materials: Ammonium nitrate (34% N), diammonium phosphate, or DAP (18% N, 46% P_2O_5), potassium chloride (60% K_2O); and potassium-magnesium sulfate, or SPM (22% K_2O, 11% Mg).

5. The P fertilizer is supplied by only one source, DAP. The amount needed is: (80 lb P_2O_5) ÷ (0.46) = 174 lb DAP.

6. The Mg fertilizer is also supplied by only one source, SPM. The amount needed is: (72 lb Mg) ÷ (0.11) = 655 lb SPM.

7. In addition to supplying P, DAP also supplies some N: (174 lb DAP) × (0.18) = 31 lb N.

8. The balance of the N, to be obtained from ammonium nitrate, is: (320 lb N) – (31 lb N) = 289 lb N. Thus, the amount needed is: (289 lb N) ÷ (0.34) = 850 lb ammonium nitrate.

9. In addition to supplying Mg, SPM also supplies some K_2O: (655 lb SPM) × (0.22) = 144 lb K_2O.

10. The balance of the K_2O, to be obtained from potassium chloride, is: (320 lb K_2O) – (144 lb K_2O) = 176 lb K_2O. Thus, the amount needed is: (176 lb K_2O) ÷ (0.60) = 293 lb potassium chloride.

Table 35 summarizes the above calculations.

Table 35. Components of a fertilizer blend with 16-5-16-3.6 Mg nutrient ratio.

Material	Total material weight	N	P_2O_5	K_2O	Mg
	--------------------------- lb per ton ---------------------------				
Diammonium phosphate (18-46-0)	174	31	80		
Potassium-magnesium sulfate (0-0-22-11Mg)	655			144	72
Ammonium nitrate (34-0-0)	850	289			
Potassium chloride (0-0-60)	293			176	
Filler	28				
Totals	**2000**	**320**	**80**	**320**	**72**

Appendix F. Example Determination of the Fertilizer Requirement for Bearing Citrus Trees

We have a 40-acre block of 10-year-old Hamlin orange trees on Carrizo citrange rootstock with an average yield of 567 boxes/acre during the past 3 years. How much fertilizer should the grove receive this year? Assume that we want to apply dry fertilizer material in three equal split applications.

1. Determine the annual N fertilizer requirement from the recommendations in Chapter 8, which for this example is 180 lb/acre. The rate selection assumes healthy trees and optimum leaf N as indicated by leaf analysis.

2. Determine the annual K_2O requirement. The rate recommendation for K_2O in most cases will be the same as for N. Assuming trees in good condition and optimum leaf analysis for K, we will use 180 lb K_2O/acre/year.

3. Determine the need (if any) for P_2O_5 from Table 8.3. We will assume that our grove tests very low in Mehlich 1 P and a leaf test shows P in the low range. Therefore, we will supply P_2O_5 at 72 lb P_2O_5/acre/year based on the previous year's yield.

4. Determine if Mg is needed by inspecting leaves for deficiency symptoms, analyzing leaf tissue, and/or testing the soil. If tests reveal a deficiency, it could be corrected by including Mg in the fertilizer. If soil pH is below 5.3, dolomite should be applied to raise the pH to 6.0–6.5. We will assume that no Mg is needed.

5. Determine other nutritional deficiencies or excesses by inspecting leaves and confirming with leaf analysis. In this grove, corrections (if any) will be made by applying a foliar nutritional spray that is not part of the routine soil-applied fertilizer program.

6. Establish the ratio of the fertilizer mix to be used, assigning a value of 1 to the N rate. In this example, the relative values are N = 1, P_2O_5 = 0.4, and K_2O = 1, so the ratio is 1-0.4-1.

7. Choose a fertilizer analysis that will provide the desired ratio. Examples of analyses that will provide a 1-0.4-1 ratio would be 10-4-10, 15-6-15, or 20-8-20. In this example, we will use a 10-4-10 fertilizer.

8. Determine the application frequency and distribution of the fertilizer in each application. This publication recommends applying at least one-half of the annual fertilizer rate between January and June. In this example, we will fertilize three times during the year, applying one-third in February, one-third in May, and one-third in October. This schedule supplies two-thirds of the fertilizer during the January–June period.

9. Determine how many lb/acre of 10-4-10 fertilizer are needed for each application to deliver the required amounts of N, P_2O_5, and K_2O. Only the N value needs to be determined since P_2O_5 and K_2O will be present in the appropriate amounts in the 10-4-10 mixed fertilizer.

   The annual N fertilizer rate requirement is 180 lb/acre, divided as follows:

   February application (⅓) = 60 lb/acre.
   May application (⅓) = 60 lb/acre.
   October application (⅓) = 60 lb/acre.

10. Determine how much 10-4-10 fertilizer to apply to each acre to achieve the required N, P_2O_5, and K_2O rates.

    Divide 60 lb by 10%: (60 ÷ 0.10) = 600. Thus, we will apply 600 lb of 10-4-10 to each acre in February, May, and October.

11. Multiply the lb/acre of fertilizer needed by the number of acres in the grove to get amount needed per application.

    600 lb/acre of 10-4-10 × 40 acres = 24,000 lb = 12 tons/application

    Total amount of fertilizer needed for the year = 12 tons/application × 3 applications = 36 tons.

Appendix G. Key to Citrus Nutrient Deficiency Symptoms. (Excerpted with minor modification from the book *Nutrition of Fruit Crops*. 1966. Horticultural Publications, New Brunswick, NJ. Permission granted by the author of the article "Citrus Nutrition," P. F. Smith, and the editor of the book, N. F. Childers.)

Many citrus nutrient deficiency symptoms are distinctive and can be diagnosed by skillful observation without the benefit of leaf analysis. Initial symptoms of nutrient deficiencies can be transient. As they become more severe, symptoms begin to intensify and will become permanent until corrected. Severe deficiencies in most cases are not easily corrected on the current crop of leaves and fruit, and correction may not be possible until new growth starts. To the untrained eye, injury from residual herbicides or other soil-applied chemicals may be confused with nutritional disorders. Multiple deficiencies may be encountered where a distinctive pattern is not readily recognized. In such cases, leaf analysis is essential in interpreting the condition.

A1. Symptoms originate only on new growth, but they often persist in mature growth.

B1. Leaves uniform in color; growth reduced; internodes shortened, giving a bushy appearance.

C1. Leaves usually large and dark green. Shoots long and willowy in early stages, may have short and bushy secondary growth following dieback of long shoots; gum blisters may form along vigorous shoots at base of each petiole; multiple buds or sprouts may form at the nodes; fruit may show gum in tips of locules and brownish eruption on peel surface (exanthema)…**COPPER**

C2. New leaves pale green, turning yellow-green as they enlarge; growth is sparse…**NITROGEN**

C3. New growth is drab green, lusterless, sparse, with some misshapen leaves; fruit has gum deposits in the albedo peel layer…**BORON**

B2. Leaves with chlorosis patterns

C1. Leaves reduced in size, pointed, narrow, with sharply contrasting bright yellow mottling on a green background…**ZINC**

C2. Leaves approximately normal in size and shape.

D1. Pale green mottle over entire leaf; or, mottle may be a marbled pattern with dark green color following a crooked network of veins with light green color in between…**MANGANESE**

D2. Feather-like straight green veins on a light green or yellow background; in severe cases, leaves may be totally yellow, reduced in size, and twigs may die on the outer end of branches…**IRON**

A2. Symptoms originating on mature leaves, with young leaves appearing normal or nearly so.

B1. Pattern formed by fading of chlorophyll in localized areas, with gradual enlargement with time.

C1. Fading of chlorophyll starts in basal part of leaf between midrib and lateral leaf margin; spread is usually outward, leaving a green "wedge" pattern at the base of the leaf; however, it may be inward, causing a yellow wedge; entire leaf may fade to a golden bronze color…**MAGNESIUM**

C2. Fading of chlorophyll starts along lateral leaf margins and moves inward about halfway to midrib with an irregular front margin…**CALCIUM**

C3. Fading of chlorophyll starts as blotches in distal half of leaf; blotches are pale yellow at first, but deepen to bronze as they spread and coalesce; foliage is drab, fruit is greatly reduced in size but of good quality…**POTASSIUM**

C4. Chlorophyll fading in spots randomly distributed over the leaf blade; spots develop brown centers with a yellow or orange halo; spots range from one-quarter to one-half inch in diameter and appear only in the fall…**MOLYBDENUM**

B2. Fading of chlorophyll not localized.

C1. Fading of leaf to dull green and eventually to orange-yellow; in extreme cases, burned tips or spots may develop; fruit is coarse, spongy, and hollow-centered with thickened peel and above-normal acid…**PHOSPHORUS**

C2. General pale green to yellow foliage color with whitish veins; fruit is sparse and pale-colored both externally and internally; quality is good, but juice content is low…**NITROGEN**

Appendix H. Color Plates

Figure 47. Nitrogen deficiency. Top: Moderate leaf N deficiency. Center: Severe leaf N deficiency. Bottom: Severely N-deficient leaf at left compared with increasing N status to the right.
Credits: Mongi Zekri, UF/IFAS

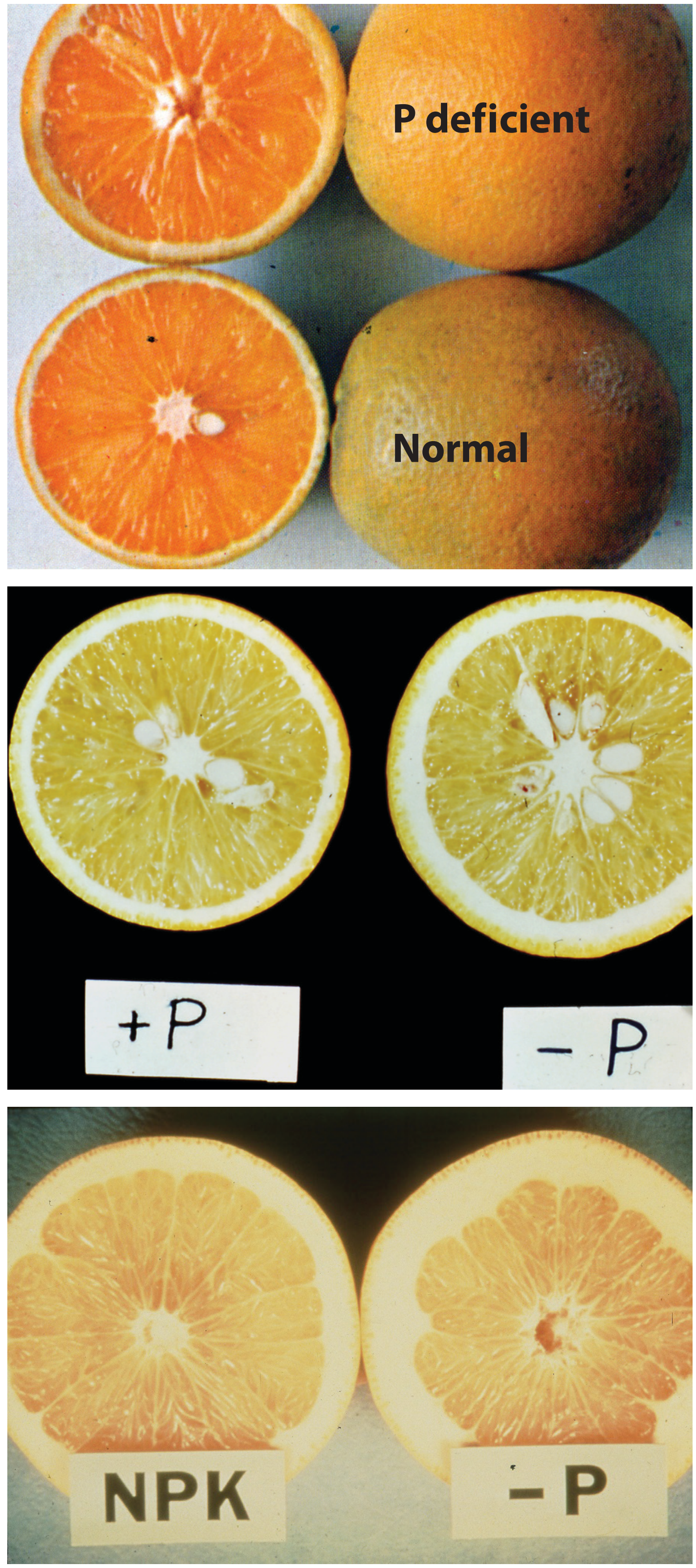

Figure 48. Phosphorus deficiency. Note the thicker peel and hollow core of P-deficient fruit compared with normal fruit.
Credits: IPNI

Figure 49. Potassium deficiency. Top: K deficiency produces smaller fruit with smoother peel and higher color compared with normal fruit. Center: Leaf chlorosis caused by K deficiency. Bottom: Severe K deficiency can cause leaf and twig death.
Credits: Top: Mongi Zekri, UF/IFAS; Bottom/Center: Thomas Obreza, UF/IFAS

Figure 50. Sulfur deficiency. General leaf chlorosis that looks similar to N deficiency.
Credits: Mongi Zekri, UF/IFAS

Figure 51. Magnesium deficiency. Chlorosis begins at the leaf margins and moves inward as the severity increases, producing a "Christmas tree" effect.
Credits: Mongi Zekri, UF/IFAS

Figure 52. Iron deficiency. Mild to severe from top to bottom. The major symptom is interveinal chlorosis. In severe cases, leaves are small and almost white, with twig dieback.
Credits: Top/Middle: Mongi Zekri, UF/IFAS; Bottom: Thomas Obreza, UF/IFAS

Figure 53. Zinc deficiency. The major symptoms are interveinal chlorosis and smaller-than-normal leaves.
Credits: Mongi Zekri, UF/IFAS

Figure 54. Manganese deficiency. The main symptom is interveinal chlorosis of normal-size leaves.
Credits: Mongi Zekri, UF/IFAS

Figure 55. Copper deficiency. Top: "Ammoniation" of fruit. Center: Gum pockets and twig dieback. Bottom: Vigorous, drooping branches and unusually dark green leaves with a "bowing up" of the midrib characterize Cu-N imbalance.
Credits: Mongi Zekri, UF/IFAS

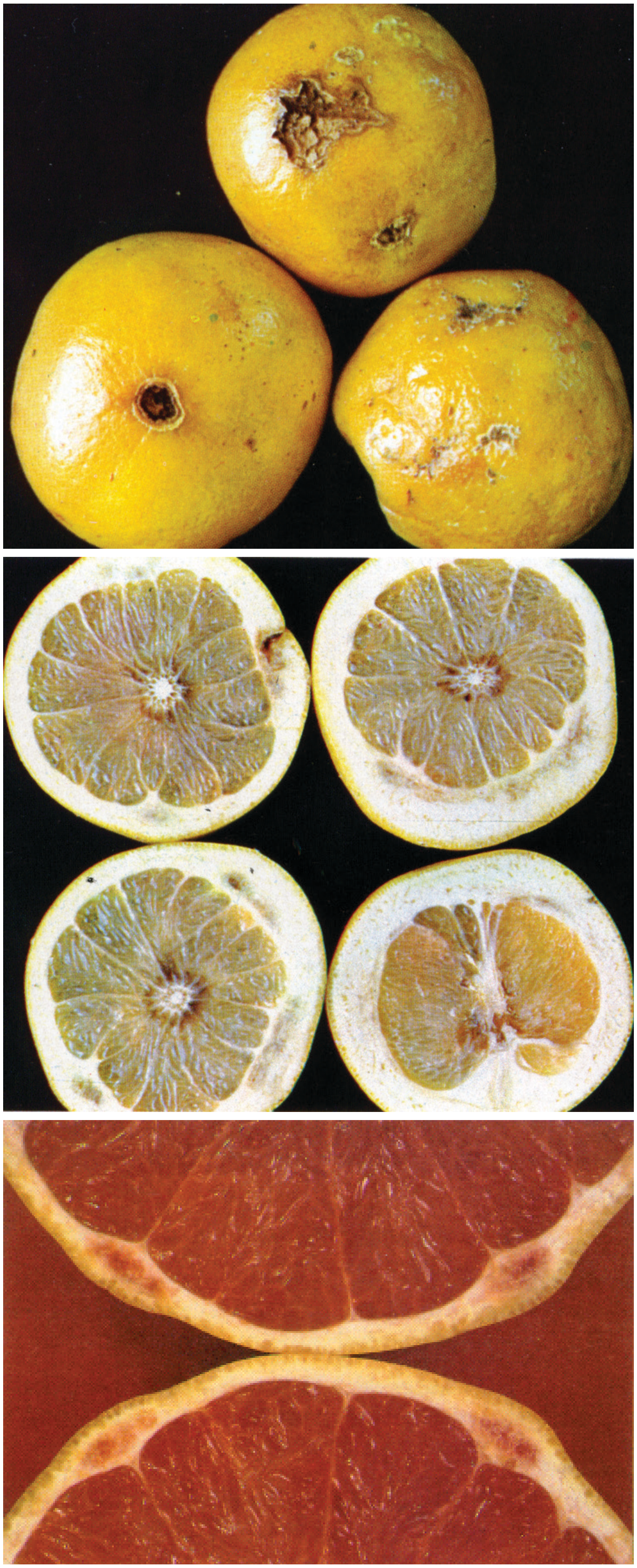

Figure 56. Boron deficiency. Top: External symptoms on grapefruit. Center: Internal symptoms on grapefruit (thick peel, gum pockets in peel, gumming around core). Bottom: Close-up of gum pockets in peel.

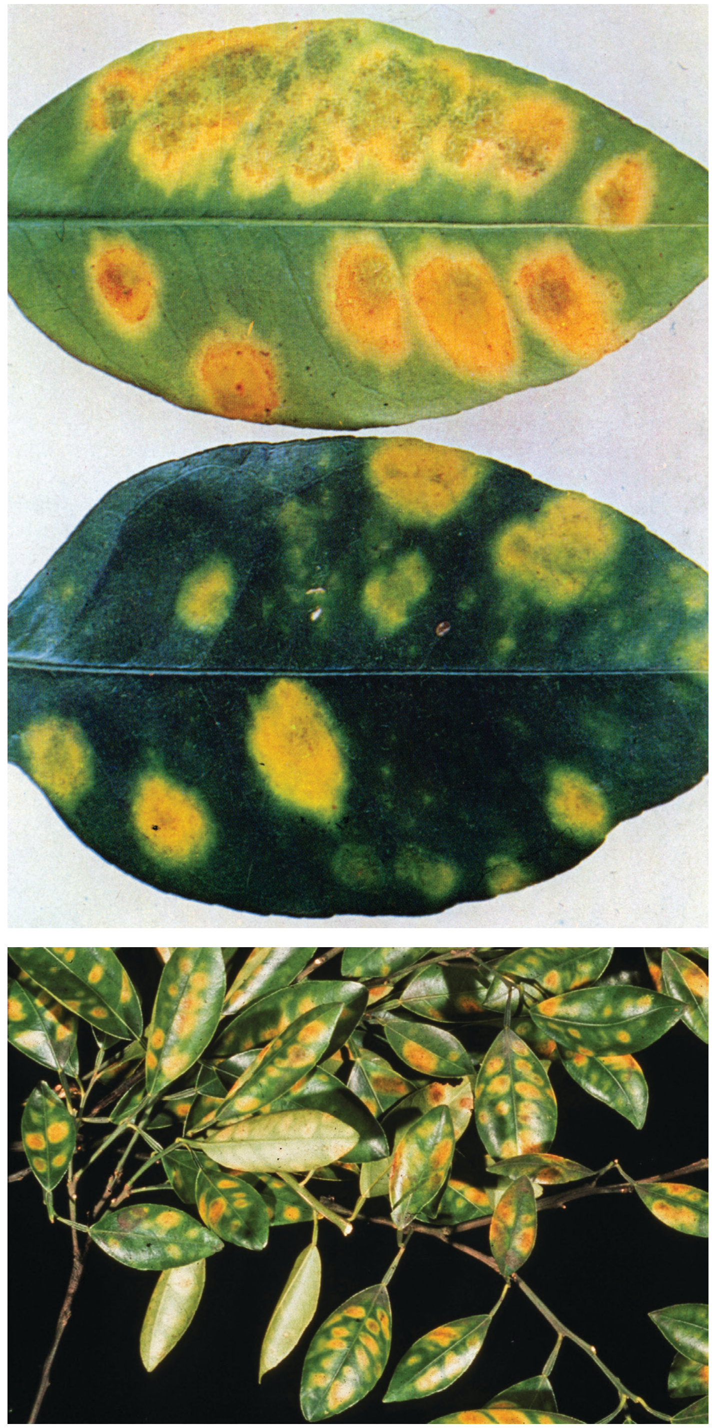

Figure 57. Molybdenum deficiency. The main symptom is large yellow spots.
Credits: Mongi Zekri, UF/IFAS

Figure 58. Salt damage. Top: Burn on leaf edges compared with normal leaf at right. Center: Salinity-induced chlorosis. Bottom: Severe leaf burn in the field.
Credits: Mongi Zekri, UF/IFAS

Figure 59. Biuret toxicity (top and center). Urea spray burn (bottom).
Credits: Mongi Zekri, UF/IFAS

Figure 60. Do not confuse the blotchy mottle (light and dark green patches) pattern of citrus greening disease with nutrient deficiency symptoms. The pattern is not symmetrical on opposite sides of the midvein. (Contrast with nutritional deficiencies that usually exhibit a symmetrical pattern in relation to the midrib.)
Credits: Top/Bottom: Mongi Zekri, UF/IFAS; Second from Top: Michael Rogers, UF/IFAS; Third from Top: J. M. Bove and M. Garnier, UF/IFAS