Citrus Nutrition Day

Tuesday, September 15, 2015

University of Florida, IFAS, Citrus Research and Education Center
700 Experiment Station Road, Lake Alfred, Florida
Ben Hill Griffin, Jr. Hall

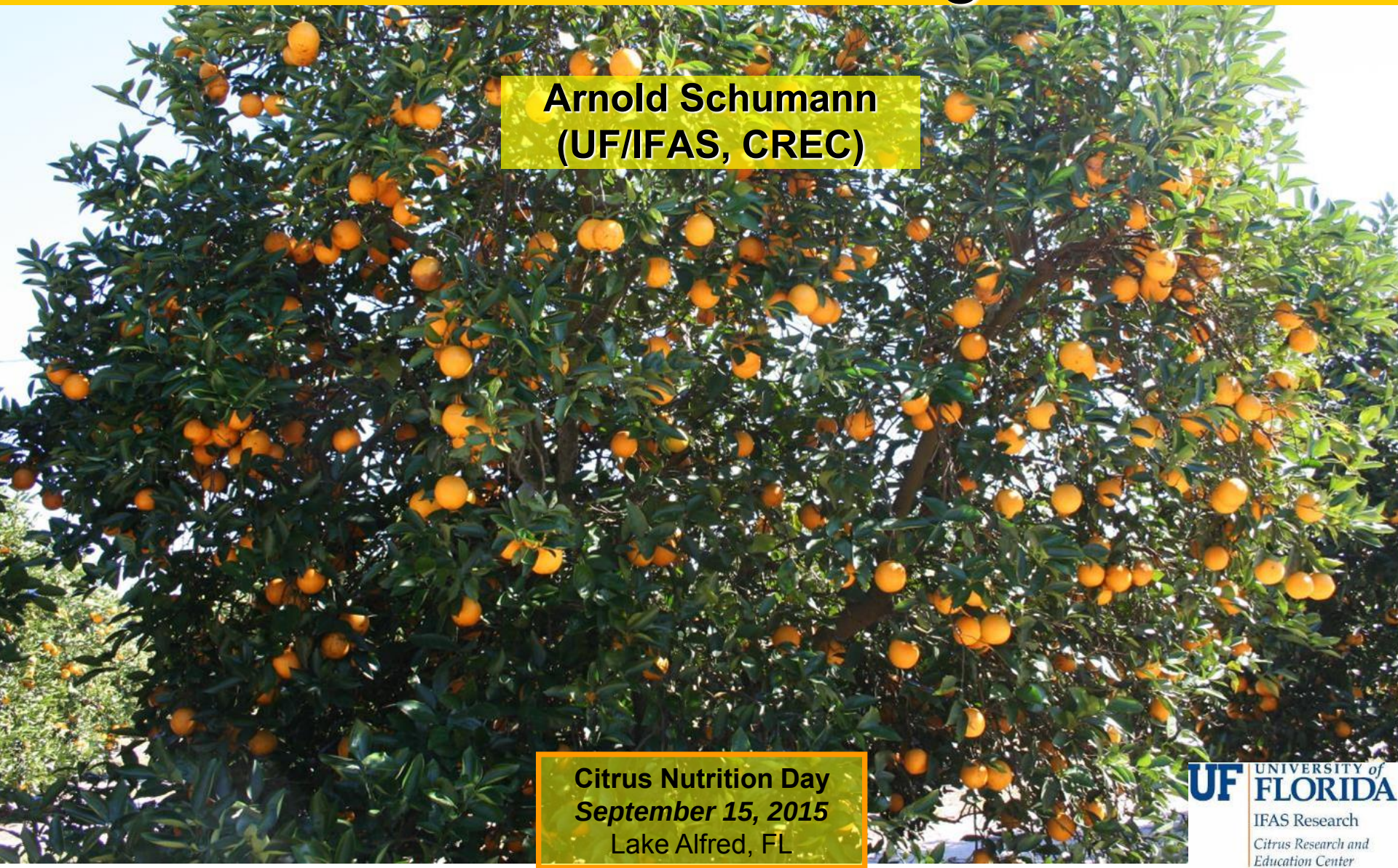
PROGRAM

9:00 am	Check-in begins
9:25 am	Welcome (Dr. Michael Rogers, UF/IFAS Citrus REC)
9:30 am	Citrus Nutrient Requirements and Fertilization Strategies (Dr. Arnold Schumann, UF/IFAS Citrus REC)
10:00 am	Important Fertilizer Chemistry in HLB Mitigation Programs (Dr. Arnold Schumann, UF/IFAS Citrus REC)
10:30 am	Break
10:45 am	Improved Citrus Nutrient Uptake by Modification of Irrigation Water Quality, Soil Water Content and Soil Conditions (Dr. Kelly Morgan, UF/IFAS Southwest Florida REC)
11:15 am	Rootstocks Performance Under Controlled Release Fertilizer (Dr. Jude Grosser, UF/IFAS Citrus REC)
11:45 am	Lunch at UF/IFAS Citrus Research and Education Center
1:00 pm	Young Tree Care in HLB Environment (Mr. Lee Jones)
1:15 pm	Observations on Improving Tree Health with Nutrition on Flatwood Soils (Mr. Tim Gast, Southern Gardens)
1:30 pm	Using Controlled Release Fertilizer and Soluble Fertilizer Blends in Mature Citrus (Mr. Joby Sherrod, Duda Farms)
1:45 pm	A Grower's Observations of Nutrient Management (Mr. Vic Story, Story Company)
2:00 pm	Break
2:15 pm	Field Trials (Dr. Tripti Vashisth, UF/IFAS Citrus REC)
2:45 pm	Discussion and Questions & Answers Session
3:15 pm	Concluding Remarks

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Please complete the evaluation form and place in the basket at the registration desk.

Citrus Nutrient Requirements and Fertilization Strategies



Arnold Schumann
(UF/IFAS, CREC)

Citrus Nutrition Day
September 15, 2015
Lake Alfred, FL

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IFAS Research
Citrus Research and Education Center

Citrus Nutrient Programs

- Nutrition is the most useful, practical defense against incurable citrus disease, particularly citrus greening (HLB)
- Citrus fertilization (foliar, soil) is the highest single production cost for FL citrus – due to HLB
- Optimizing nutrition programs to achieve highest efficacies AND efficiencies is crucial for sustaining fruit production and profitability of groves
- The presence of HLB and other diseases has elevated the traditional role of plant nutrition and nutritional programs in grove caretaking
- Mineral nutrition is not a cure for HLB; *C*Las bacteria remain; nutrition helps trees cope with infection; most often still adverse fruit symptoms and drop

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Citrus Nutrient Programs

The main nutritional program choices:

Higher cost /unit nutrient

1) granular soluble fertilizer

2) liquid fertilizer – fertigation

3) granular CRF fertilizer

4) liquid fertilizer – blended foliar sprays

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Citrus Nutrient Programs

An integrated program is most efficient:

1) granular soluble fertilizer {all trees}

(primary season fertilizer + variable rate)

2) liquid fertilizer – fertigation {all trees}

(primary/supplementary fertilizer but NO variable rate)

[Special case: some liquid fertilizer applied with herbicide]

3) granular CRF fertilizer {young trees}

(young tree / supplementary fertilizer + variable rate)

4) liquid fertilizer – foliar sprays {all trees}

(supplementary fertilizer + variable rate)

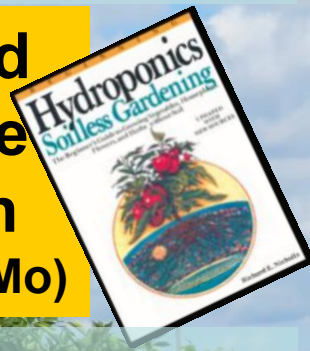
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The RIGHT Nutrient Programs
The 4 Rs of Nutrient Stewardship for Best Management Practices (BMPs)
Right Source
Right Rate
Right Time
Right Place
= HIGH EFFICIENCIES
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e.g. Advanced Citrus Production Systems: 1-yr 'Valencia'

Right Source

Balanced complete nutrition (N-P-K-Ca…Mo)



Right Place





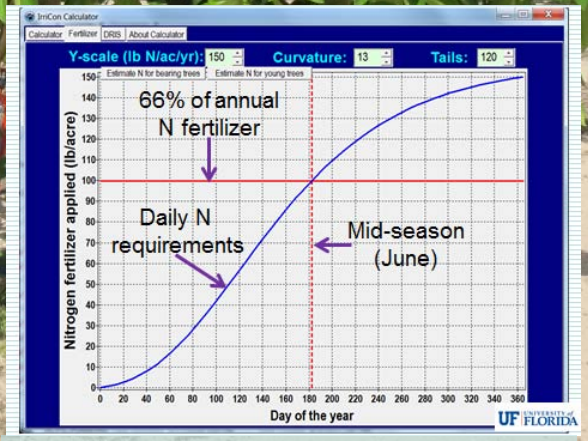
Higher planting density

Right Rate



Intensive fertigation (controller, sensors, models)





Right Time

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2.5 years (‘Valencia’)



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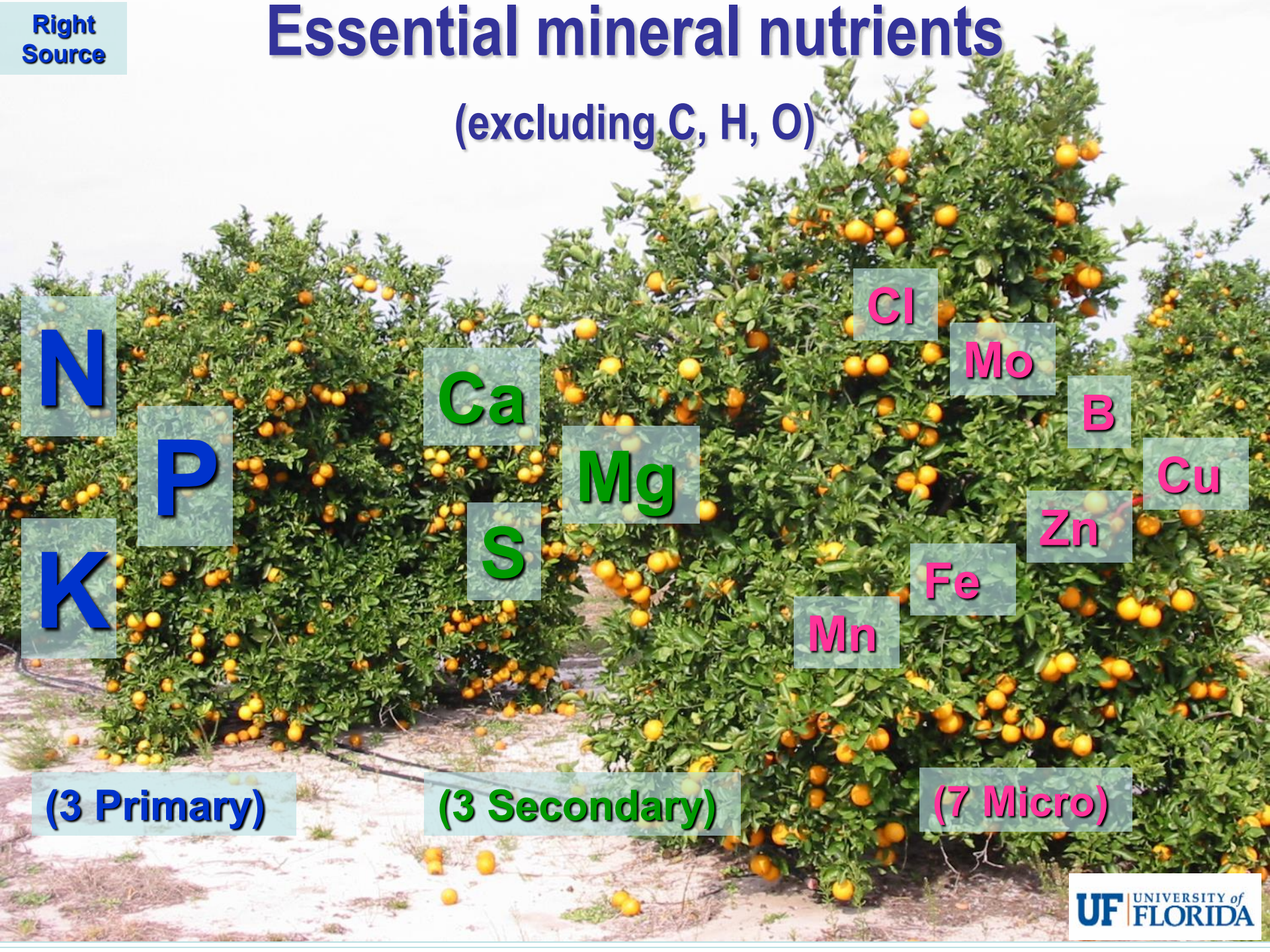


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Right Source

Essential mineral nutrients

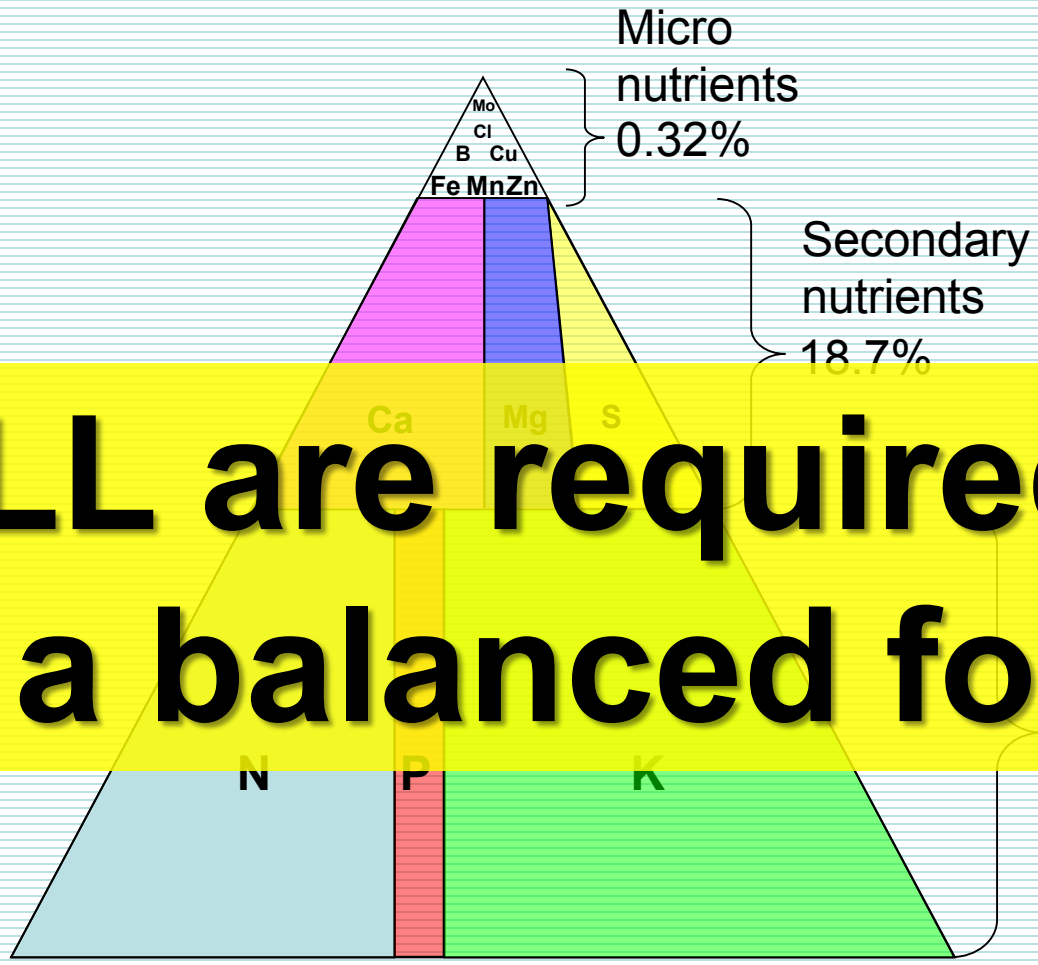
(excluding C, H, O)



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Relative abundance of the different nutrients

The essential nutrient pyramid for citrus



ALL are required - in a balanced form

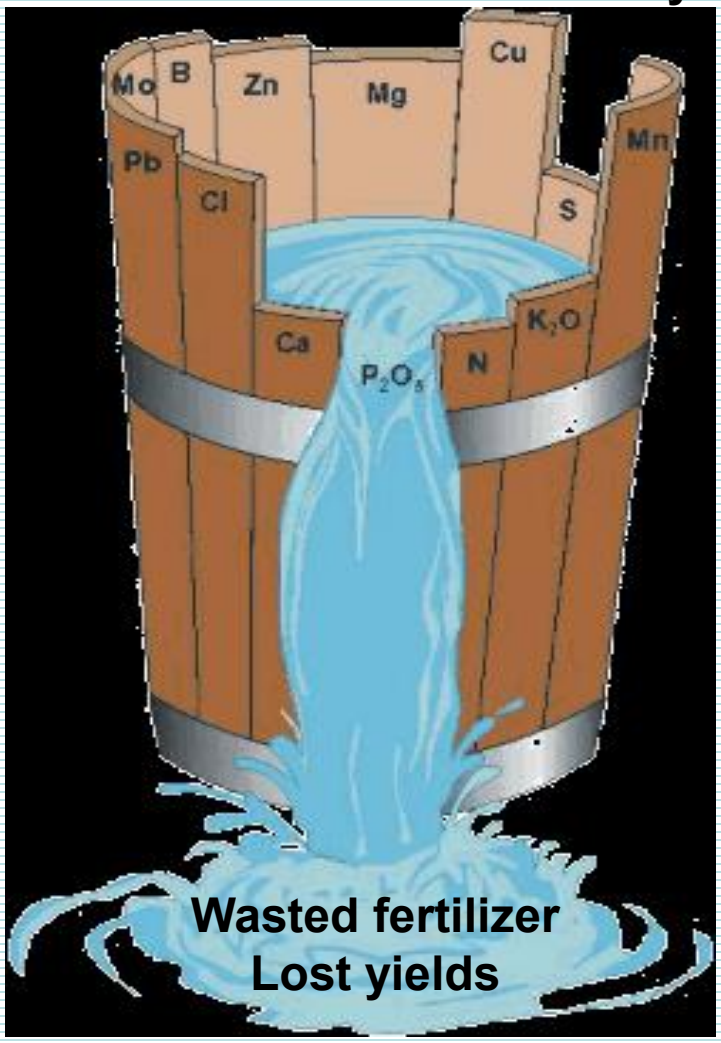
AWS, 2009

Right Source

Right Rate

BALANCED mineral nutrition is important: Liebig's Law of Minimum

"Yield is proportional to the amount of the most limiting nutrient, whichever nutrient it may be"



Imbalanced nutrition is wasteful and inefficient

Soil and leaf testing helps to maintain a balance

Proactive fertilization with a comprehensive formulation helps

Source: The Fertilizer Institute
WP graphic by Michelle Houlden

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Right Source

Comprehensive fertilizer formulations

e.g. minimal granular fertilizer

N-P_2O_5-K_2O:

19-00-23



More balanced fertilizer

N-P_2O_5-K_2O-Ca-Mg-S-Fe-B:

10-02-12-13-2.5-3.3-0.05-0.05

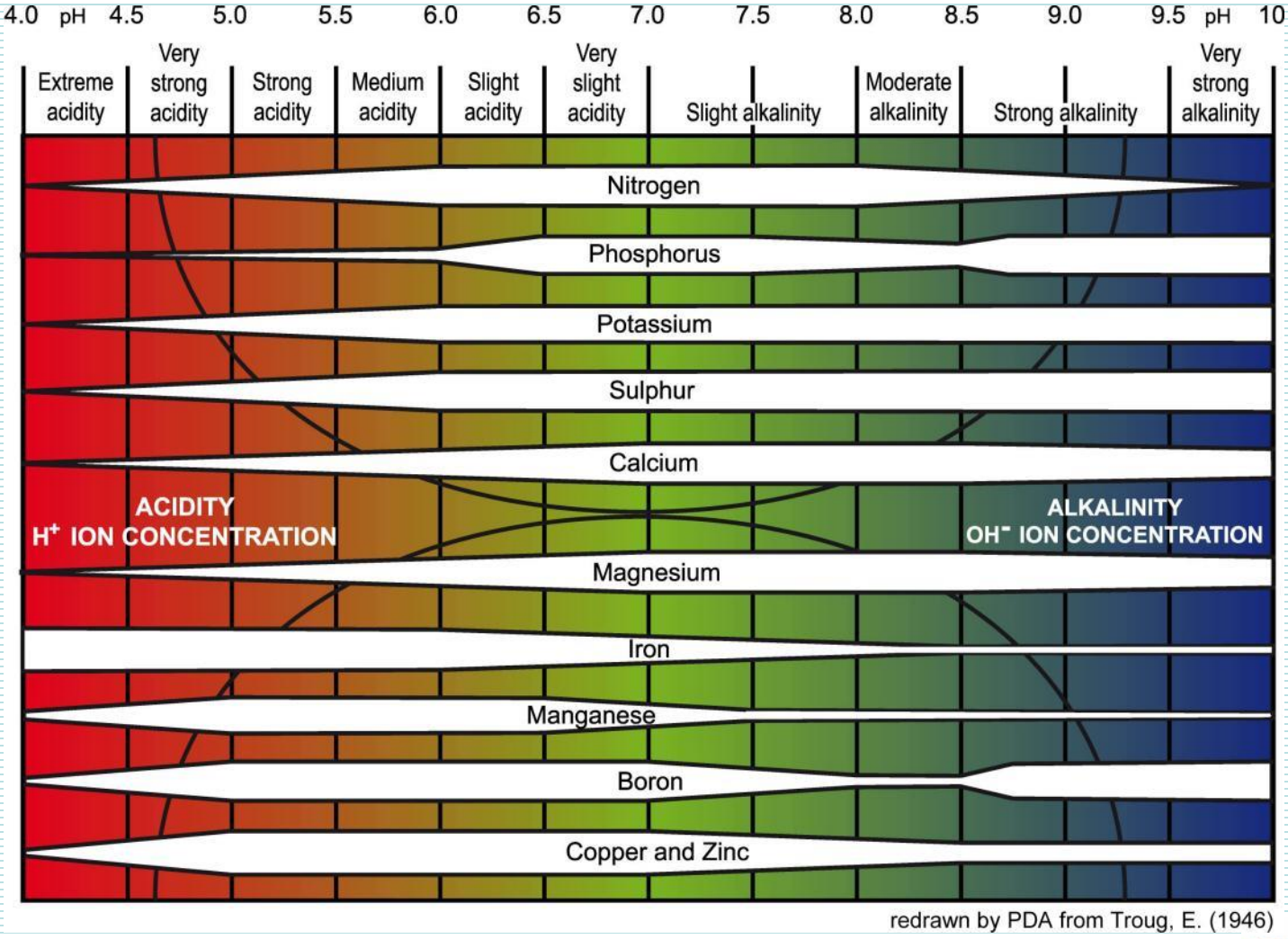
Remember that most nutrient mixtures can now be formulated as CRF

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Basic soil fertility concepts for Florida citrus: Soil pH and nutrient availability

Right Source

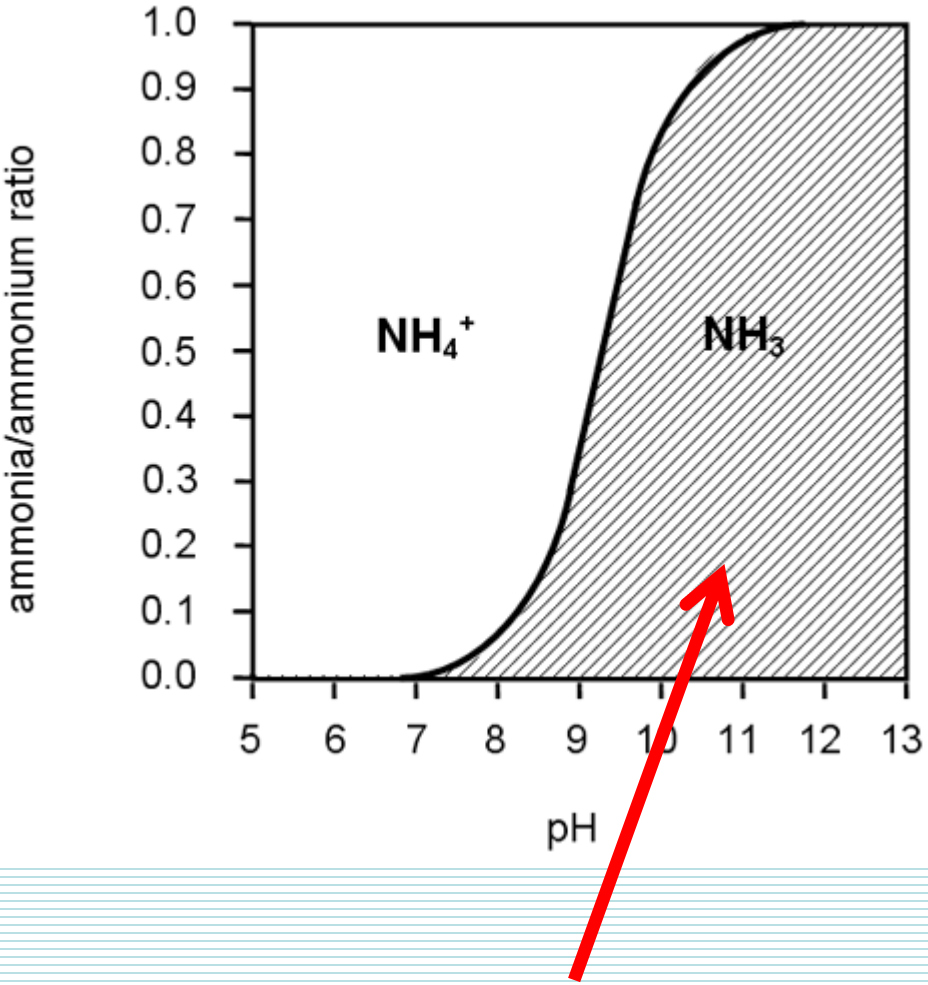
- **Optimum soil pH is in the range 6.0 to 7.0**

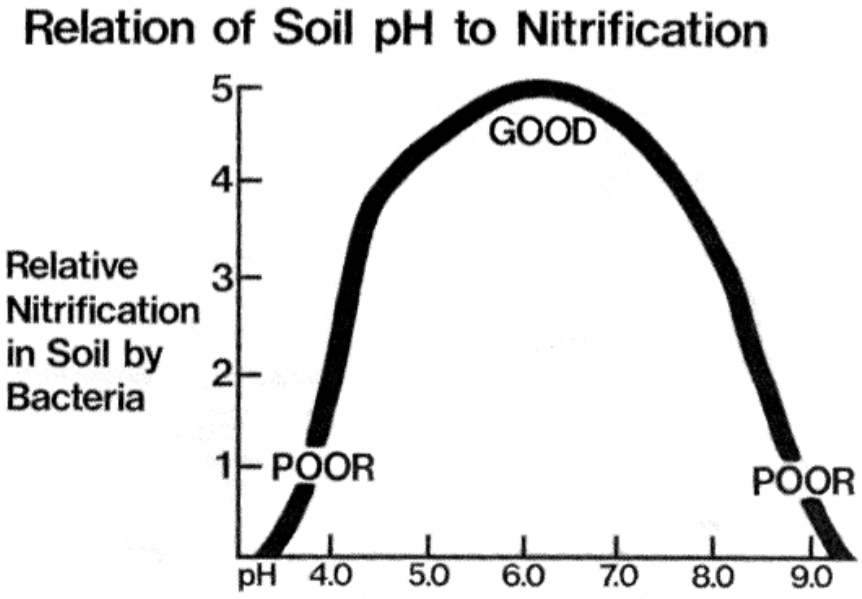


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Right Source

Soil pH and nitrogen forms, losses





- **Optimum soil pH is in the range 5.0 to 7.0**

Volatile form of surface-applied ammonium-N

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e.g. 4Rs of Foliar Spray Nutrition:

Right Source

- nutrients to correct deficiencies
- sulfates, nitrates, chlorides, chelates
- compatible in solution – acid pH
- adjuvants, adequate leaf wetting
- salt index

Right Rate

- calibrated, variable rate sprayer (corrects for tree size, ground speed)

Right Time

- target newly expanded leaf flush
- dry foliage, low wind, moderate temperature, no rain within 24-48h
- pre-bloom
- post-bloom (repeat if needed)

Right Place

- variable rate spray on canopies only
- directed sprays –abaxial leaf surface
- electrostatic droplet charging

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Rates of nutrient absorption into plant tissue

(Midwest Labs, Inc.)

Nutrient	Time for 50% Absorption
Nitrogen (as urea)	1/2 - 2 hours
Phosphorus	5 - 10 days
Potassium	10 - 24 hours
Calcium	1 - 2 days
Magnesium	2 - 5 hours
Sulfur	8 days
Zinc	1 - 2 days
Manganese	1 - 2 days
Iron	**10 - 20 days**
Molybdenum	10 - 20 days

Rainfall within 24 to 48 hours after a foliar application may reduce the application effectiveness

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Optimizing granular fertilizer application: Variable rate technology (VRT) for precision placement and rates



Only the healthy canopy should be fertilized - avoid fertilizing bare soil or weeds

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Essential equipment for VRT

CANOPY SENSORS





FERTILIZER SPREADER



CONTROL BOX

RATE CONTROLLER



SPRAYER

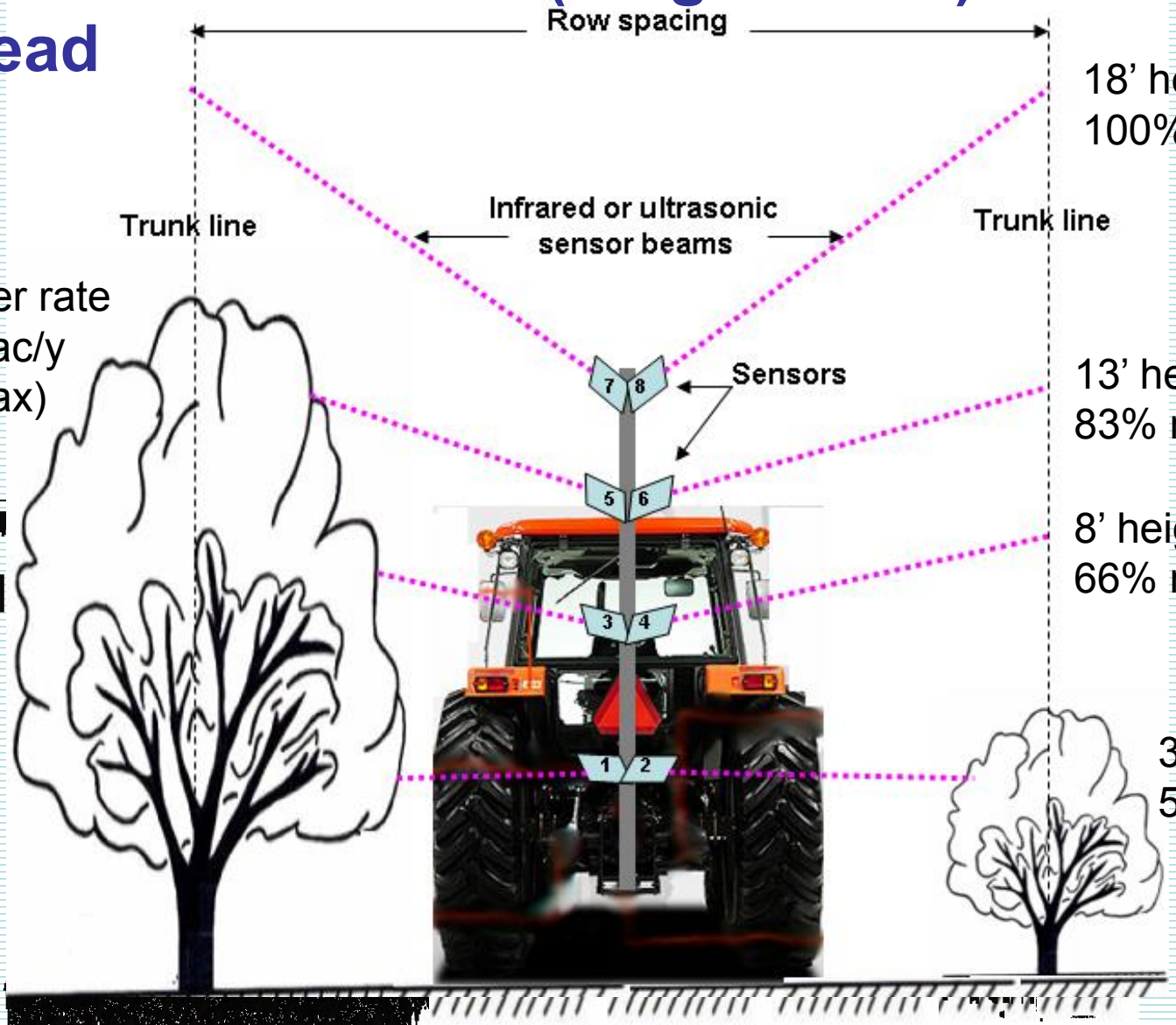


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Right Rate Right Place

Spinner-disk VRT spreader:

- Eight Banner® photoelectric diffuse reflectance sensors (range ~ 18 ft) with look-ahead



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Fertilizer spreader application: 4.5 mph

Right Rate

Right Place

(Video clip)



(Gapway Groves, Chemical Containers & IFAS)

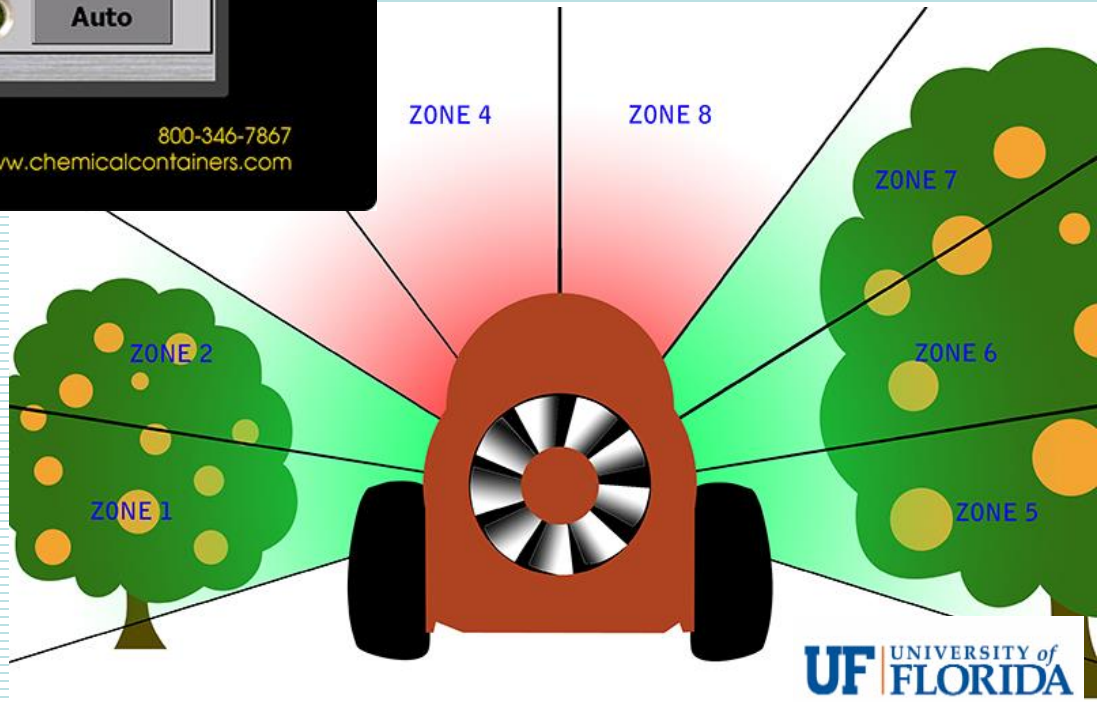
Two rows covered one sided; fertilizer savings: 25-30%

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Example: CC-Eye 8000 Tree Sense Control System

http://www.chemicalcontainers.com/cceye8000.aspx





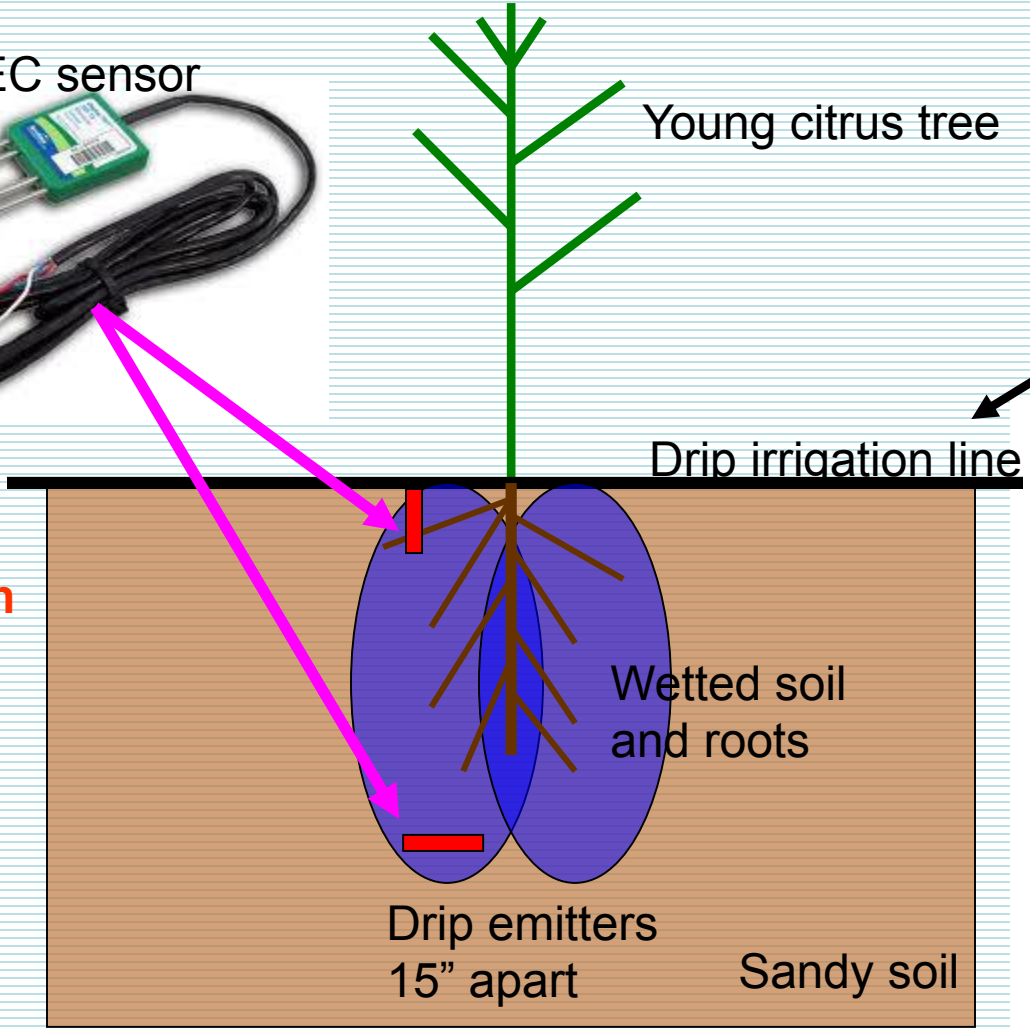
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Right Source | Right Rate | Right Time | Right Place

Optimizing liquid fertigation:

* sensors, computer automation,
* targeting root systems







Computer control



Profile moisture sensor

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Proper targeting of water and nutrients to the root zone ensures high efficiencies: drip emitters are ideal



Drip fertigation develops healthy, dense feeder roots



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Properly designed microsprinkler irrigation systems can achieve similar high efficiencies: target the root zones of trees appropriate for their size

e.g. inverted emitters for young trees

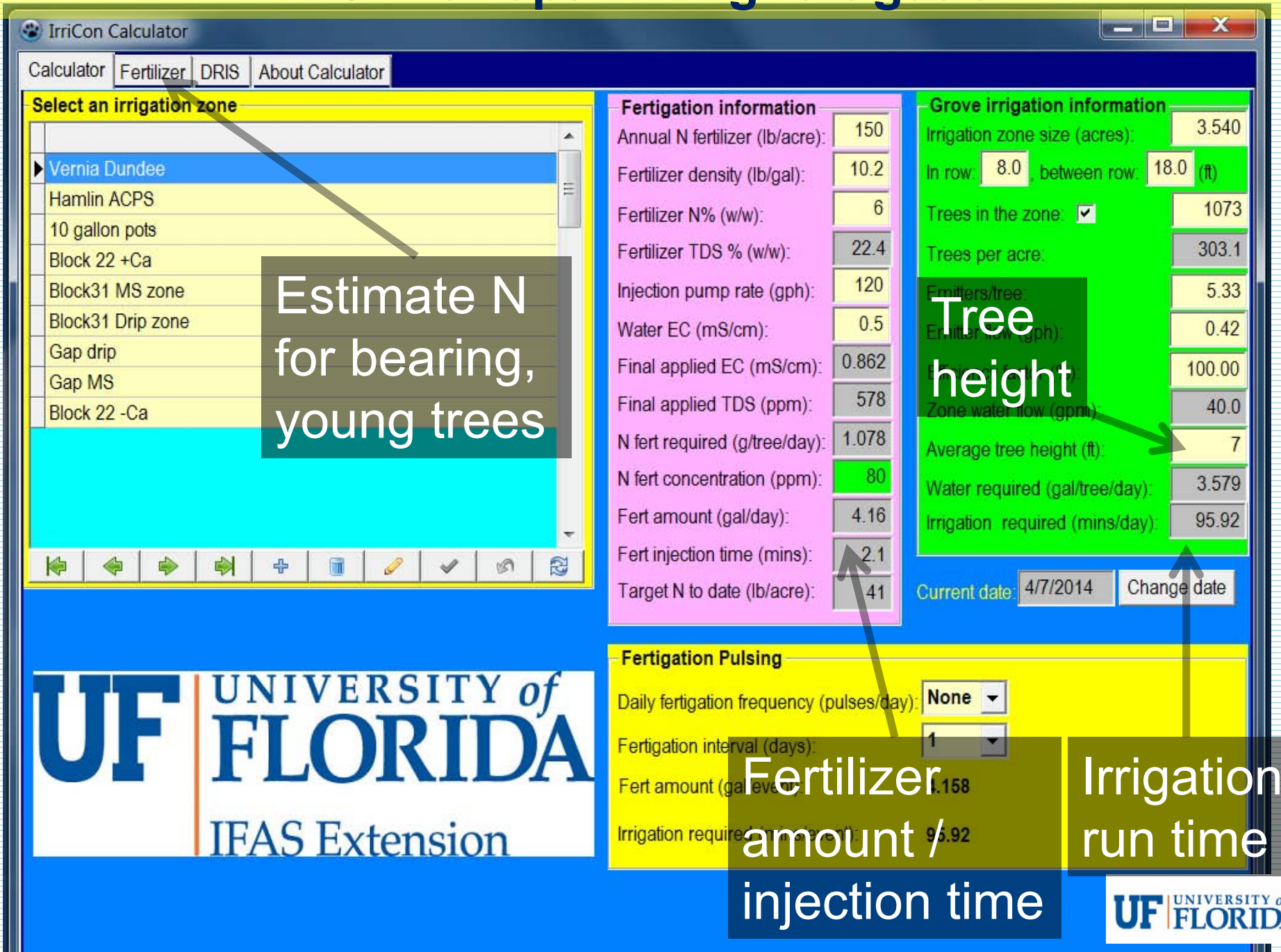


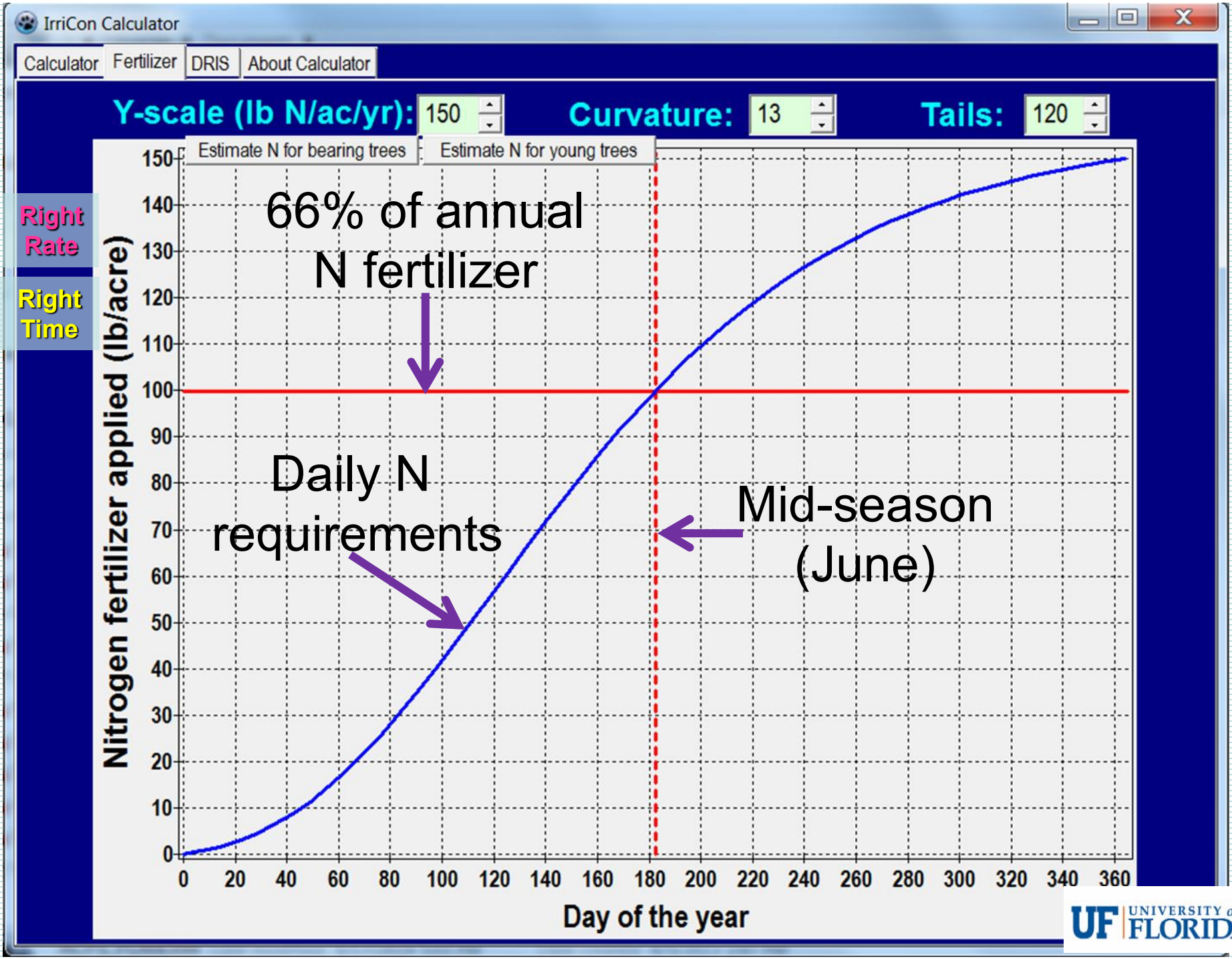
Wetted soil pattern: inverted emitter



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A DSP for optimizing fertigation




IrriCon Calculator
Calculator
Fertilizer
DRIS
About Calculator
Y-scale (lb N/ac/yr): 150
Curvature: 13
Tails: 120
Estimate N for bearing trees
Estimate N for young trees
Right Rate
Right Time
66% of annual N fertilizer
Daily N requirements
Mid-season (June)
Nitrogen fertilizer applied (lb/acre)
Day of the year
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
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Results of optimized ACPS fertigation:

ACPS: Early fruit production, early ripening, high quality after 2 years



Conventional methods



Advanced drip fertigation methods (OH)

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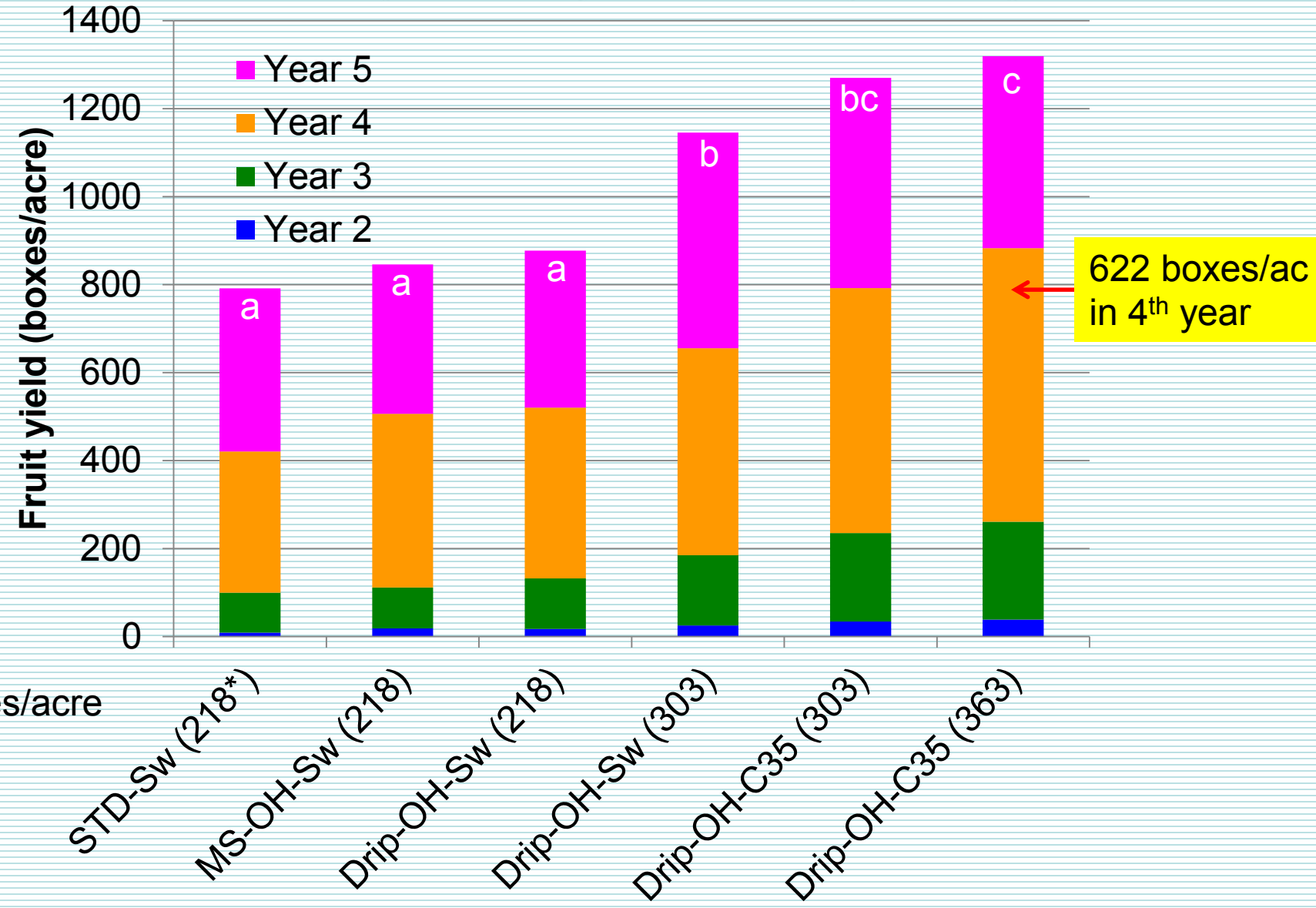
Gapway experiment: Drip OH, C35 rootstock, 3 years
222 boxes/acre with 363 trees/acre



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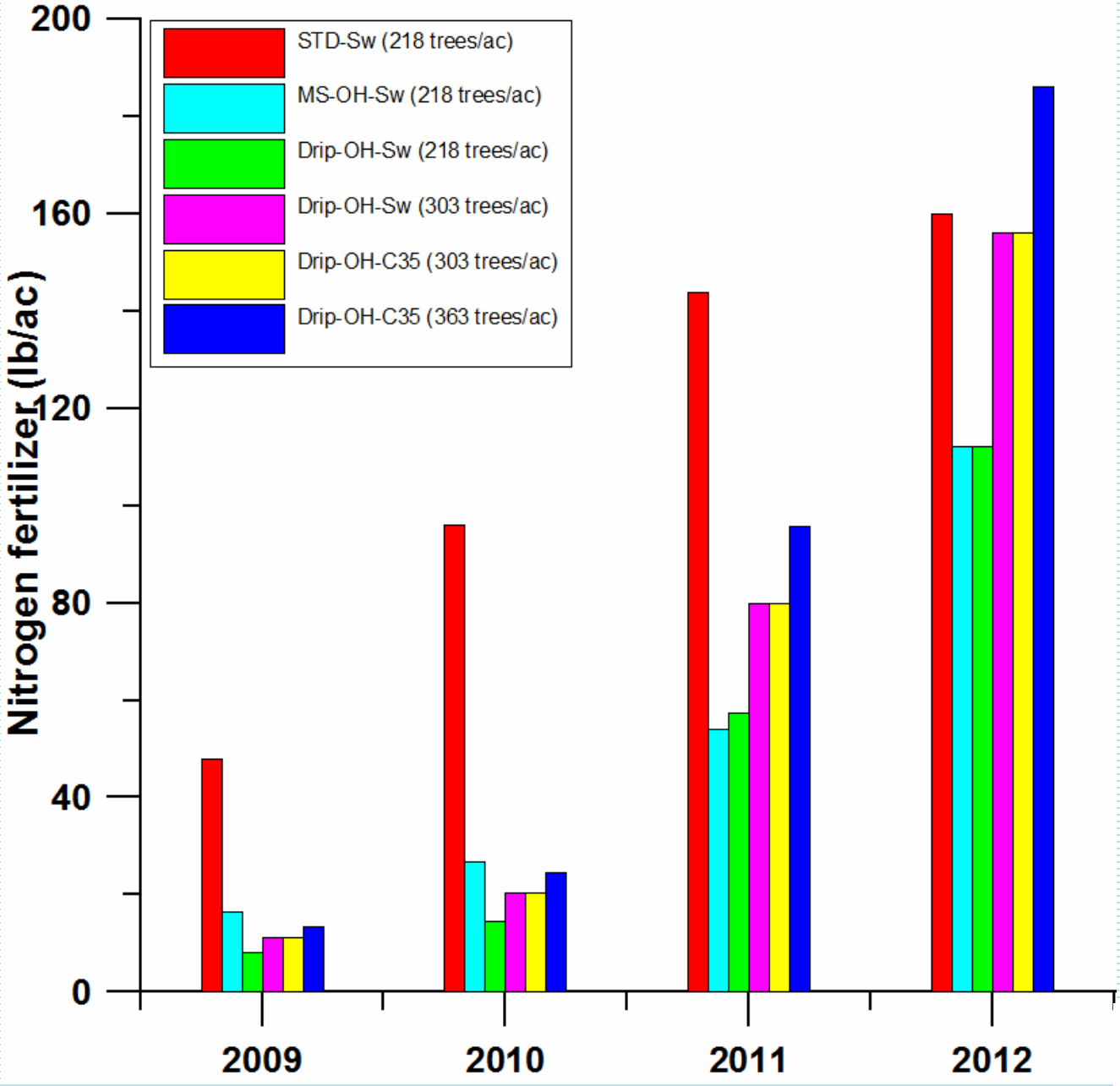
‘Hamlin’ fruit yields (boxes/ac) at 5 years



* trees/acre

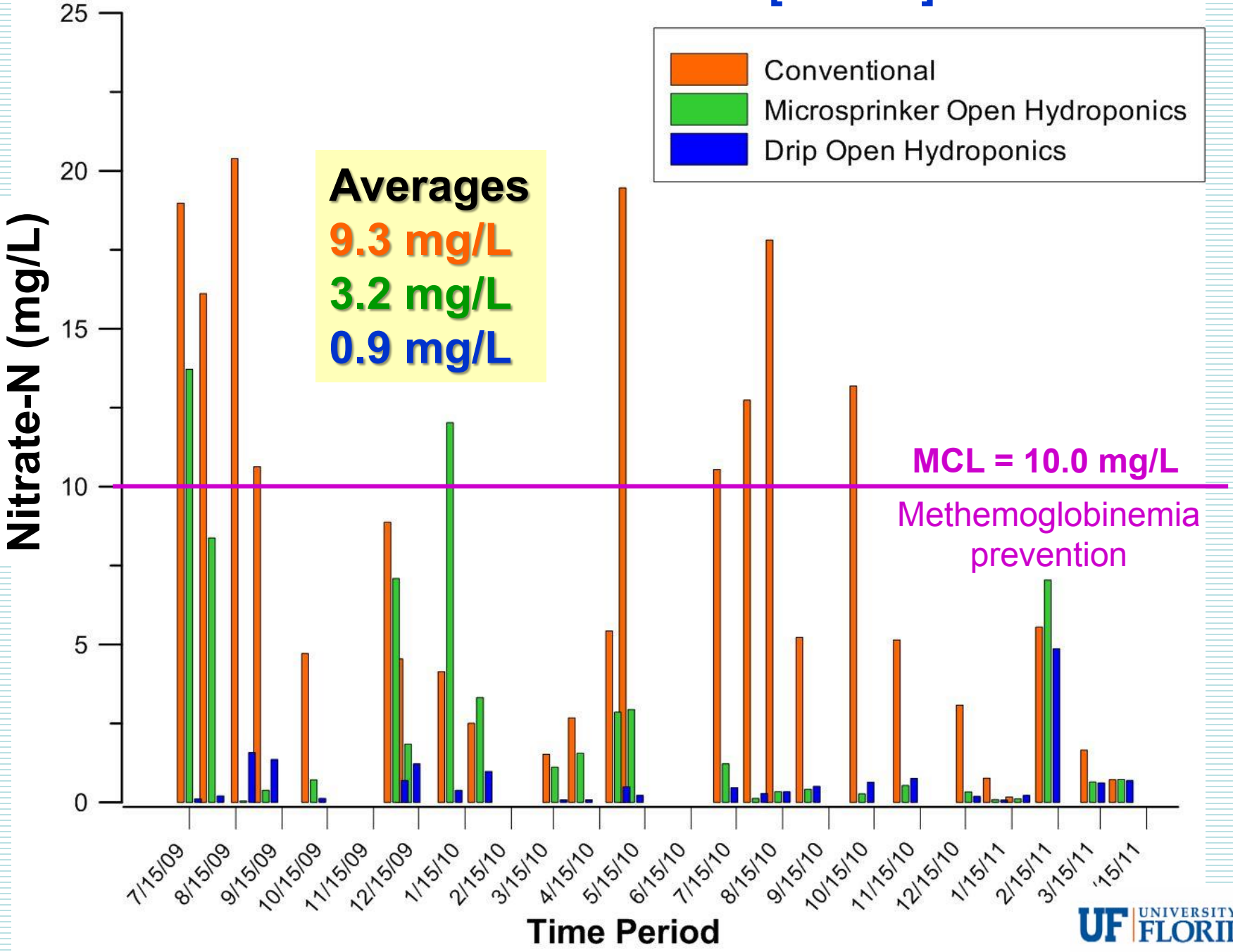
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ACPS / OHS uses ~80% less fertilizer in first 3 years



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Environmental benefits – reduced [nitrate] in leachate



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Optimizing foliar fertilization with precision VRT spraying

Hoop sprayer for young citrus trees

Ground speed: 3.4 mph;
Front and back buffers: 12 inches



Pesticide or foliar fertilizer savings: 50-80%

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Summary and Conclusions

- 4 Rs are the guiding principles for efficient nutrient programs and best management practices
- Granular soluble, CRF, liquid fertigation and foliar sprays are all important for fully integrated nutrient programs
- Balanced, comprehensive nutrition (especially hydroponics) applying Liebig's Law of Minimum are the basic building blocks
- Custom foliar nutrition, variable rate technology, DSPs and CRFs are refinements that enhance the performance of nutrient programs and help mitigate diseases

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Acknowledgements

Kevin Hostler, Laura Waldo, Dennys Cornelio

Gapway Grove Corp.

Contact: schumaw@ufl.edu

Griffin Fertilizer, Plant Food Systems, Tiger-Sul, Growers Fertilizer, Harrell's

IMPORTANT FERTILIZER CHEMISTRY IN HLB MITIGATION PROGRAMS

Arnold Schumann
UF/IFAS, Lake Alfred, FL



Citrus Nutrition Day
September 15, 2015
Lake Alfred, FL

Pest and disease sprays often involve tank mixes:



Can we safely add nutrient and SAR products?















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Sprayer tank mixtures: OBJECTIVES

SYNERGIES

- Improved leaf deposition, penetration, reduced drift
- Multiple pest / disease control





- Integrated Pest Management (IPM) with nutrients, SAR

ECONOMICS

- Reduced fuel and labor costs

OTHER

- Water saving
- Less grove traffic

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Sprayer tank mixtures: POTENTIAL PROBLEMS

PHYSICAL INCOMPATIBILITY

- Slowly soluble / insoluble products
- Layering (immiscible components)

} Ineffective delivery and low efficacy

CHEMICAL INCOMPATIBILITY

- Acid-base reactions & pH imbalance
- Reduction – Oxidation (RedOx) reactions
- Precipitation (preferential ion pairing)

} Ineffective delivery and low efficacy



BIOLOGICAL INCOMPATIBILITY

Some products use “live” cultures – vulnerable to chemicals

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Sprayer tank mixtures: POTENTIAL PROBLEMS

PHYSICAL, CHEMICAL, BIOLOGICAL incompatibilities can cause varying degrees of inefficiencies in the grove spraying operation and at worst, can cause

LOSS OF PRODUCT (and $$) by neutralization in the tank

PHYTOTOXICITY to the trees due to altered efficacy (e.g. copper toxicity at low spray mixture pH)

Product incompatibilities and phytotoxicities are also affected by

- concentration (**do not** mix concentrates; use HV sprays)
- temperature (e.g. phytotoxicity at higher temperatures)
- contact time (**do** mix just prior to use)
- water quality

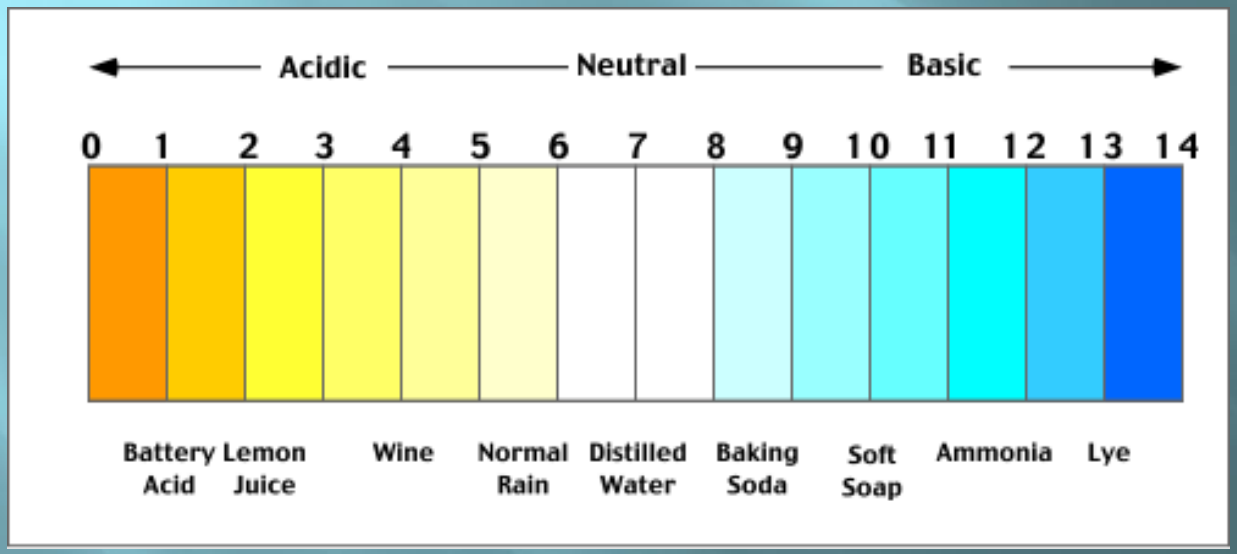
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Sprayer tank mixtures:

REAL EXAMPLES OF SPRAY MIXTURES

DEFINITIONS

pH is a measure of solution acidity or alkalinity
and represents the activity of hydrogen ions in solution





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DEFINITIONS

Oxidation Reduction Potential (ORP):
is a measure of an aqueous system's capacity to either release or gain electrons in chemical RedOx reactions. The process of oxidation involves losing electrons while reduction involves gaining electrons.

ORP is measured with a platinum electrode – reference electrode pair, in millivolts



Common examples:

Aquatic life: 300 to 400 mV
Properly chlorinated swimming pool: >700 mV
Tidal wetland sediment: -187 mV
"Oxidate" @ 1 gal / 500 gal / acre: 659 mV

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Example RedOx properties of spray chemicals

REDOX REACTIVE CHEMICALS

Hydrogen peroxide, “Oxidate” = strong inorganic oxidizer (659 mV)

Salicylic acid / salicylates, “SAver” etc = organic antioxidant

Phosphorous acid / phosphites, “K-Phite” etc = reduced P

Fe^{2+} <> Fe^{3+} transformations are RedOx reactions

REDOX UNREACTIVE CHEMICALS & PRODUCTS

- Organic pesticides / fungicides
- Nitrate-N, ammonium-N, phosphate, calcium, magnesium,
- Most micronutrients are relatively inert except Fe, Mn

Live bacterial culture products are vulnerable to extreme ORP (e.g. *Bacillus subtilis*)

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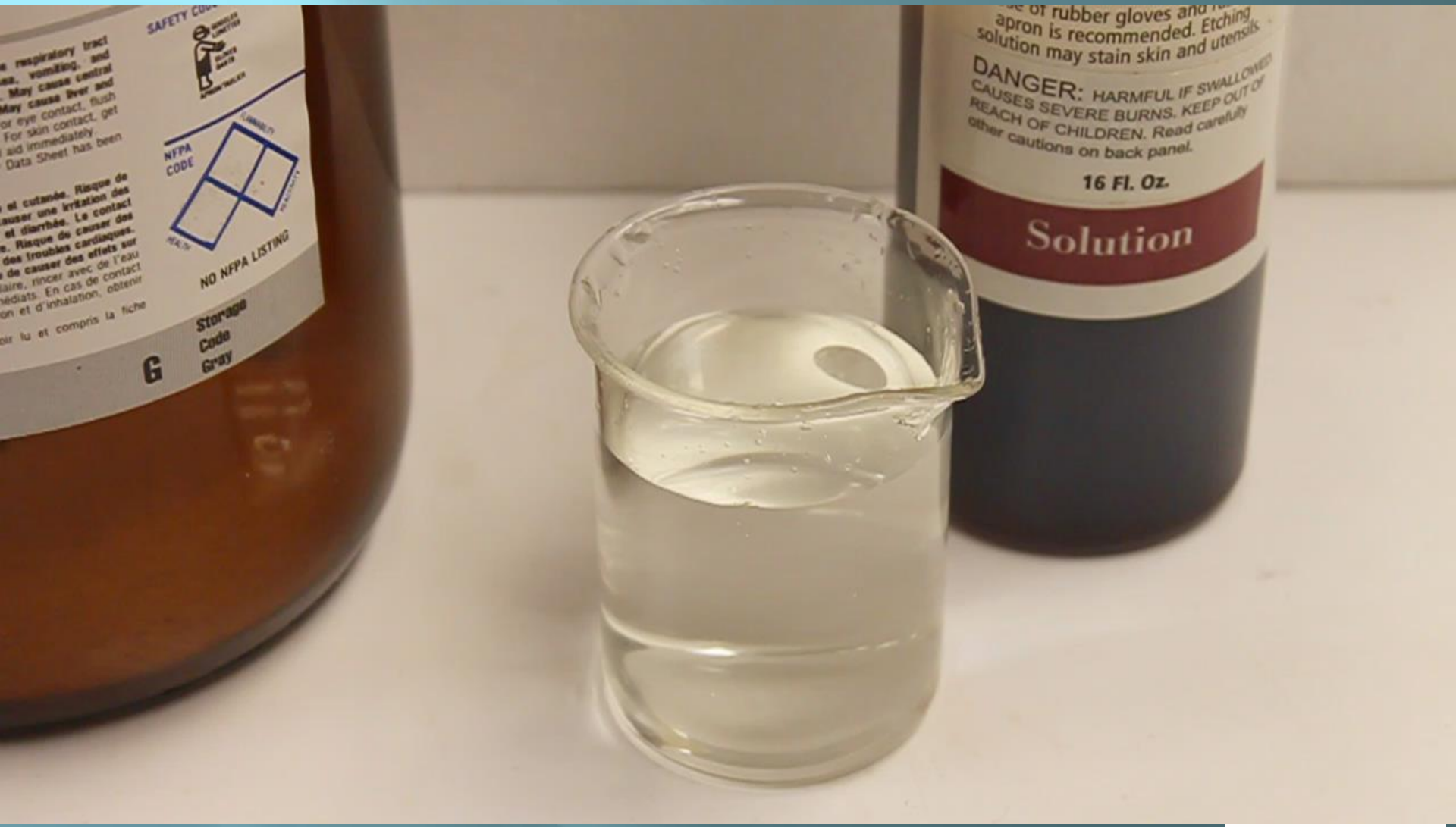
Example: colored complex formation: ferric iron salicylate



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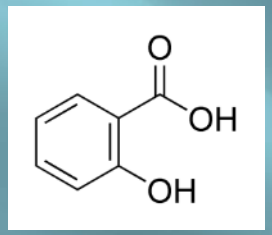
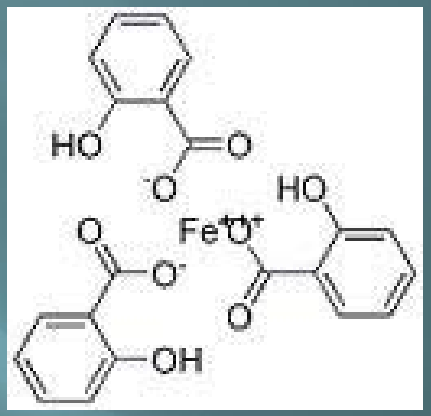
Example: colored complex formation: ferric iron salicylate

Demonstrates interaction between a nutrient and SAR chemical



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Example: colored complex formation: iron (III) salicylate (an iron chelate)

Fe^{3+} + 3  = 

Ferric iron

Salicylic acid

Ferric salicylate
(violet-colored complex)

This reaction can be used to quantify salicylate in solutions

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Sprayer tank mixtures: read the labels first

The “Oxidate” label states:

DIRECTIONS FOR USE

- OxiDate works best when diluted with water containing low levels of organic or inorganic materials, and with water having a neutral pH.

-that implies **DO NOT** mix with other spray chemicals

The “Delegate” label states:

Tank Mixing: When tank mixing Delegate WG with other materials, a compatibility test (jar test) using relative proportions of the tank mix ingredients should be conducted prior to mixing ingredients in the spray tank. If foliar fertilizers are used, the jar test should be repeated with each batch of fertilizer utilizing the mixing water source. Vigorous, continuous

Read and understand the list of active ingredients:
Avoid products with incomplete specifications

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Sprayer tank mixtures: read the labels first

TYPICAL TANK MIXING PROCEDURE: "Delegate"

- Fill tank to ¼ to ⅓ of the required spray volume
- Start agitation
- 1. Delegate WG and other dispersable granules
- 2. Wettable powders
- 3. Maintain agitation and fill to ¾
- 4. Emulsifiable concentrates and water-based products
- 5. Spray adjuvants, surfactants and oils
- 6. Foliar fertilizers
- 7. Maintain continuous agitation

✓ **MOST PESTICIDES ARE COMPATIBLE WITH THE ESSENTIAL PLANT NUTRIENTS**

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Sprayer tank mixtures: some combinations to avoid

DO NOT mix strong oxidizers with

- ferrous (II) iron or manganese (II)
- phosphites
- salicylic acid or other antioxidants
- biofungicides and other oxidizible organics

DO NOT mix Cu, Mn, Zn fungicides / bactericides

- with live biofungicides (e.g. *B. subtilis*)

DO NOT mix

- Fertilizer Ca, P, and sulfates – insoluble precipitates (e.g. calcium nitrate + magnesium sulfate produces insoluble gypsum)

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Solving sprayer tank mixture problems:

- Alternate different products at different times to keep compatible groups together and incompatible ones apart
- Use different delivery methods (aerial spray, ULV ground, air blast HV spray) to apply different components. Use HV for the most unstable mixtures
- Supply most macronutrients through fertigation and granular fertilizer application to the roots e.g.$Ca(NO_3)_2$; In general, micronutrients are more compatible with spray mixtures than macronutrients
- Spray nutrients during the active growing season

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Soil or water acidification with fertilizers:

- Soil acidification can be by direct addition of acidic chemicals OR by oxidation (conversion) of source chemicals in situ to release acid [H^+], usually with the help of soil microbes.
  EXAMPLES:
  Direct: sulfuric, nitric, or phosphoric acids via fertigation.
  Indirect: in-situ oxidation of sulfur, thiosulfate, ammonium fertilizers by soil bacteria (e.g. *Thiobacillus* spp.).
  sulfur → sulfate; thiosulfate → sulfate; ammonium → nitrate
  Direct soil acidification is very rapid, while indirect acidification occurs over a longer time (slow release, safer)

- Irrigation water is acidified by direct addition of acidic chemicals releasing [H^+]. EXAMPLES: sulfuric, nitric, or phosphoric acids. Sulfur can be used via a controlled combustion (oxidation) device to generate sulfuric acid in situ:
  $2S + 2H_2O + 3O_2 = 2H_2SO_4$ (Eq.1)

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Common misconceptions about fertilizer chemistry:

☒ Ammonium sulfate acidifies soil due to the sulfate content.
☑ The oxidation of NH_4^+ to NO_3^- causes acidification.

☒ Gypsum ($CaSO_4$) will acidify soil due to the sulfate content
☑ No part of the gypsum molecule can be further oxidized, and thus it releases no acidity. *HINT: fertilizer sulfates* (SO_4^{2-}), *phosphates* (PO_4^{3-}), *nitrates* (NO_3^-), *are fully oxidized states, and don't acidify soil, unless they already contain* $[H^+]$ *(acids).*

- NOTE that fertilizers with partially oxidized oxyanions like those containing nitrites (NO_2^-), sulfites (SO_3^{2-}), phosphites (PO_3^{3-}) can release some acidity upon further oxidation.

- NOTE that the capacity for different fertilizers to acidify soil or irrigation water varies greatly. Consult the product labels to obtain the correct application rates.

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Calcium (Ca) nutrition, HLB and roots

- Ca is taken up mainly behind the root tips
- Ca moves upward from the roots in the xylem – driven by transpiration
- Ca is not translocated in the phloem, so cannot move from one part of the canopy to another or to the roots
- Disruption of transpiration flow therefore leads to deficiencies of Ca: cloudy humid weather, cold, drought, flooding, over-irrigation, root injury, soil compaction and root disease
- Ca deficiencies cause rapid meristem death, including root tip dieback; This can trigger a “vicious cycle”
- HLB results in root damage, exacerbated by critical Ca deficiencies, root tip dieback and consequently even less Ca uptake - a self-perpetuating decline cycle begins. Recognized since the 1980s during HLB studies on Reunion Island.

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Calcium (Ca) nutrition, HLB and roots

What can be done to improve calcium nutrition in HLB-affected citrus trees? A neglected nutrient?

- Proactively include Ca in granular fertilizer blends; e.g. calcium nitrate {Orange Hammock program}
- Slow-release Ca from coated calcium nitrate in CRFs {Harrells-UF CRF blend}
- Gypsum ($CaSO_4$) applications to soil or as a constant feed through irrigation water
- Rock phosphate application (provides both Ca and P in a very slowly soluble natural form) – constant supply
- Foliar spray application of Ca is not effective – not translocated to roots, and amounts of Ca applied in spray coating on leaves is minimal and transient.

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Calcium (Ca) nutrition, HLB and roots

Additional fertilizer chemistries that are potentially critical to optimize Ca nutrition of HLB-affected trees, and are currently being researched:

- **Root hair** and root mycorrhizal development is suppressed by high P and low Ca concentrations in soil solution. Both root hairs and mycorrhizae are critically important for increasing the root surface area for uptake of all nutrients (70-80%).
- The **proportion** of soil CEC and soil solution occupied by Ca^{2+} relative to total cations is important for adequate uptake of Ca by plants. {60-80% Ca on CEC; >15% Ca in solution's ionic strength}. This has important implications for acid soils, where H^{+} and Al^{3+} compete with Ca^{2+}, or saline soils where Na^{+} competes with Ca^{2+} . Thresholds for HLB-affected trees are likely different, and being studied.

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Thank you

Contact: schumaw@ufl.edu



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Improved citrus nutrient uptake by modification of irrigation water quality, soil water content and soil

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Florida Without Oranges

A disease is decimating the citrus industry, leading some to wonder what's next for parts of the Sunshine State.



Sam Wimborne/Reuters

HLB Symptoms Similar to Nutrient Deficiency



Zinc Deficiency



Manganese Deficiency



Effects Fruit Size



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Function of Nutrients in Plants

- Seventeen elements are essential for the growth and functioning of green plants
- Carbon (C), hydrogen (H), and oxygen (O), from water and air make up about 95% of tree biomass
- Florida's sandy soils often do not contain a sufficient supply of many of these nutrients

Element	No. of atoms relative to Mo	% of total tree dry weight
Mo	1	0.00003
Cu	100	0.002
Mn	200	0.003
Zn	300	0.006
Fe	600	0.010
B	800	0.002
S	11,000	0.096
P	13,000	0.116
Mg	18,000	0.120
K	66,000	0.728
Ca	98,000	1.096
N	237,000	0.932

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Nutrient Uptake for Fruit Production

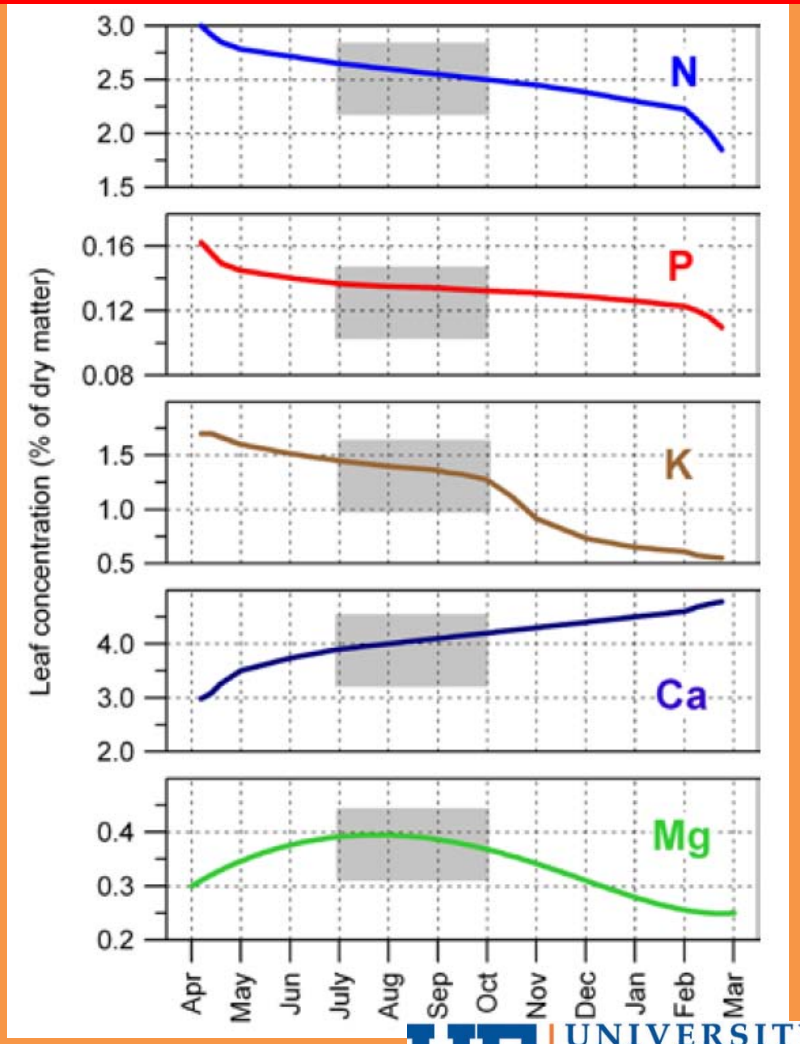
Nutrient	Hamlin[2]	Hamlin[3]	Hamlin[4]	Parson Brown[3]	Valencia[3]	Sunburst[3]	Average
	lbs nutrient/100 boxes of fruit						
N	12.5	10.6	10.8	11.3	13.5	13.6	12.1
P	1.4	1.5	1.7	1.5	2.0	1.8	1.7
K	17.6	13.6	13.9	13.3	14.4	14.0	14.5
Ca	4.5	4.0	5.2	4.9	4.3	3.4	4.4
Mg	1.9	1.1	1.0	1.2	1.2	1.0	1.2
S	1.1	---	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

- Nutrients removed with the harvested crop must be replaced from fertilizer sources
- Uptake efficiency is approximately 40% for healthy trees
- 200 pounds of N = approx. 80 pounds of N uptake = approx. 650 box of fruit not including growth and leaf replacement

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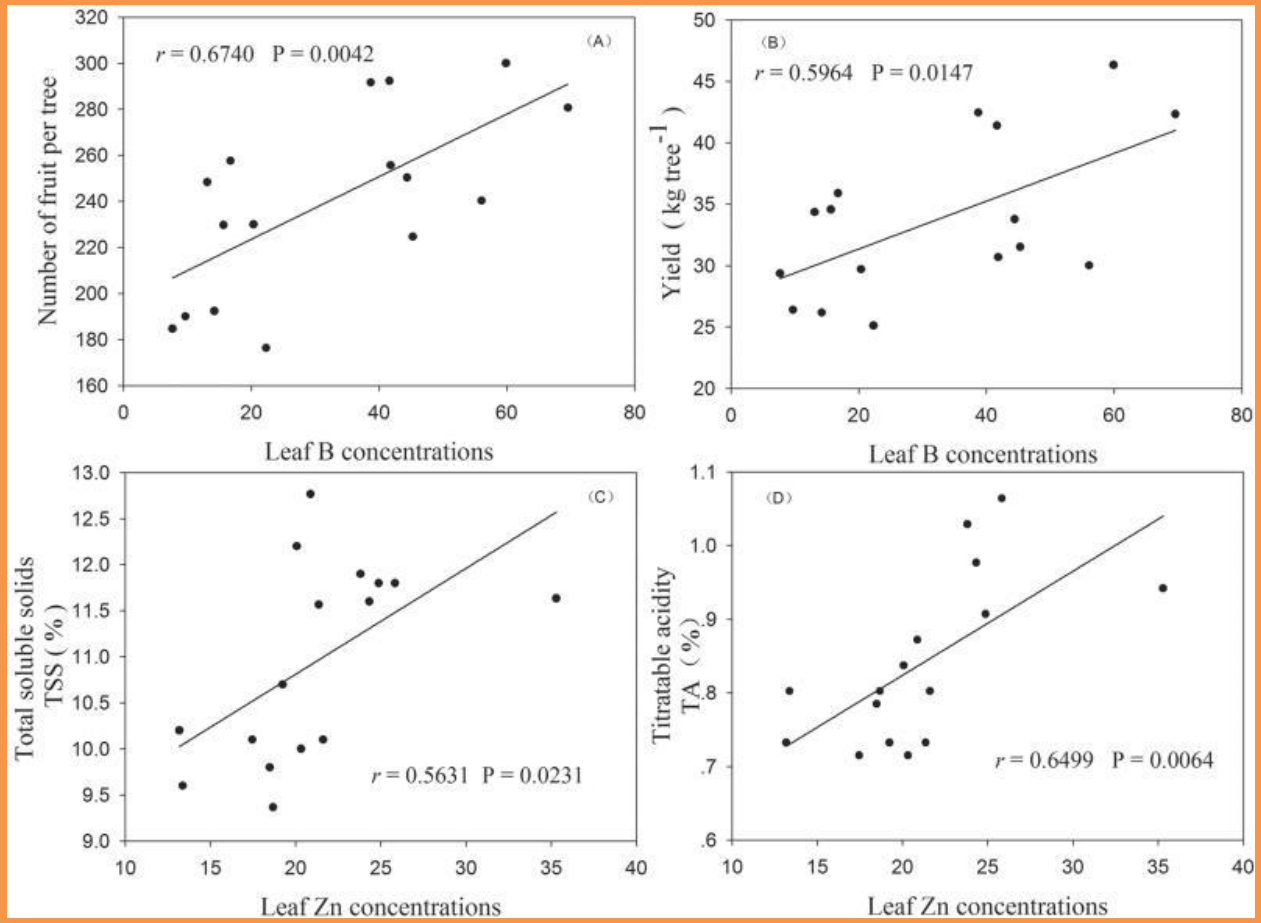
Leaf Nutrient Concentrations

- Leaf nutrient concentrations continuously change.
- As leaves age from spring through fall, N, P, and K concentrations decrease, Ca increases, and Mg first increases and then decreases
- Leaf mineral concentrations are relatively stable from 4 to 6 months after emergence in the spring
- Consider leaf age and time of year when interpreting analysis



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Leaf Nutrient Concentrations Affect Yield and Fruit Quality

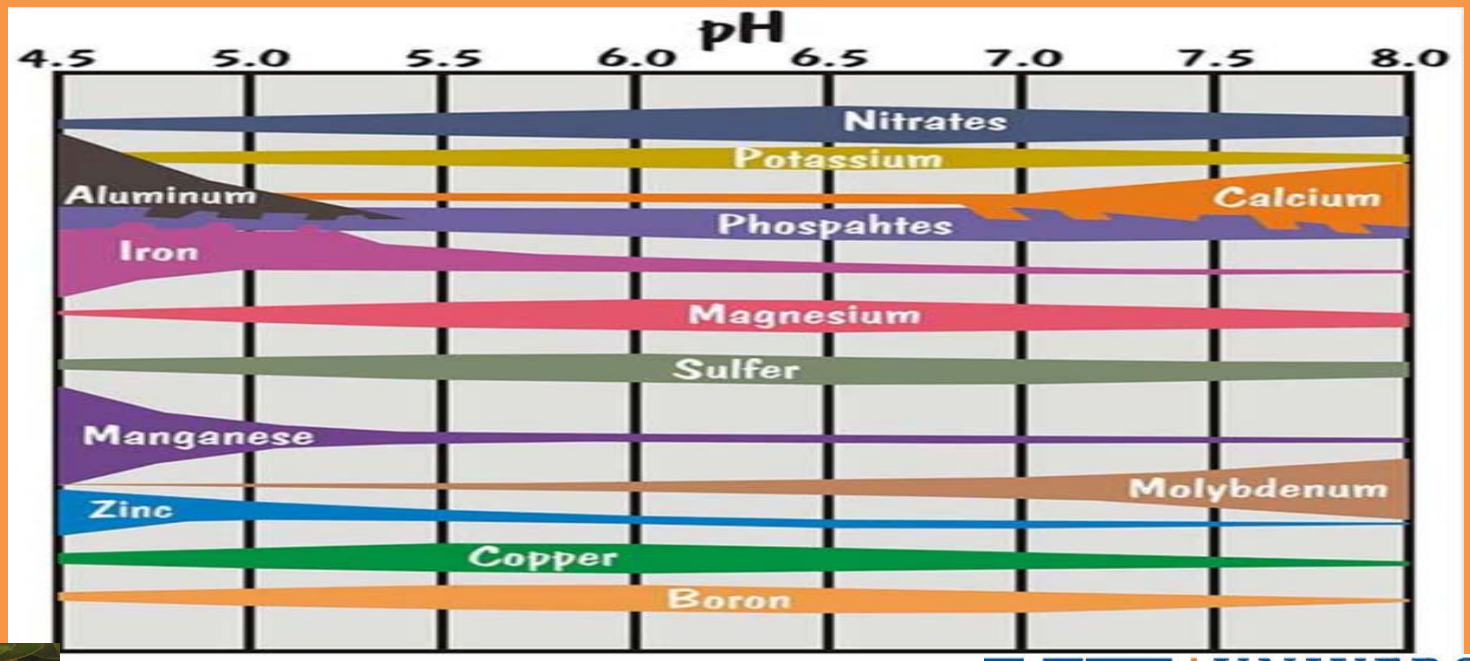


Zhan, Hu, Tan, Nie, Zheug, Gwi, Sun, Zhoa. 2014. Soil Application of Boron and Zinc Influence Fruit yields and Quality of Satsuma Mandarin. Agronomy J. 107:1-8.

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Micronutrient Availability

- Soil pH and bicarbonates effect nutrient availability and root uptake.





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ROOT DENSITY PRIOR TO AND AFTER HLB

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Root Density Change With Soil Depth

	Root zone section				
Depth	**R1**	**R2**	**M1**	**M2**	**M3**
in	**---------- in root in^{-3} soil ----------**				
0 – 6	**1.16**	**0.71**	**1.05**	**0.76**	**0.46**
6 – 12	**0.32**	**0.29**	**0.31**	**0.26**	**0.03**
12 – 18	**0.20**	**0.15**	**0.21**	**0.09**	**0.02**
18 – 36	**0.28**	**0.20**	**0.23**	**0.16**	**0.02**
	Proportion of total allocated root zone volume				
	---------- %			**----------**	
	22	**10**	**20**	**37**	**11**

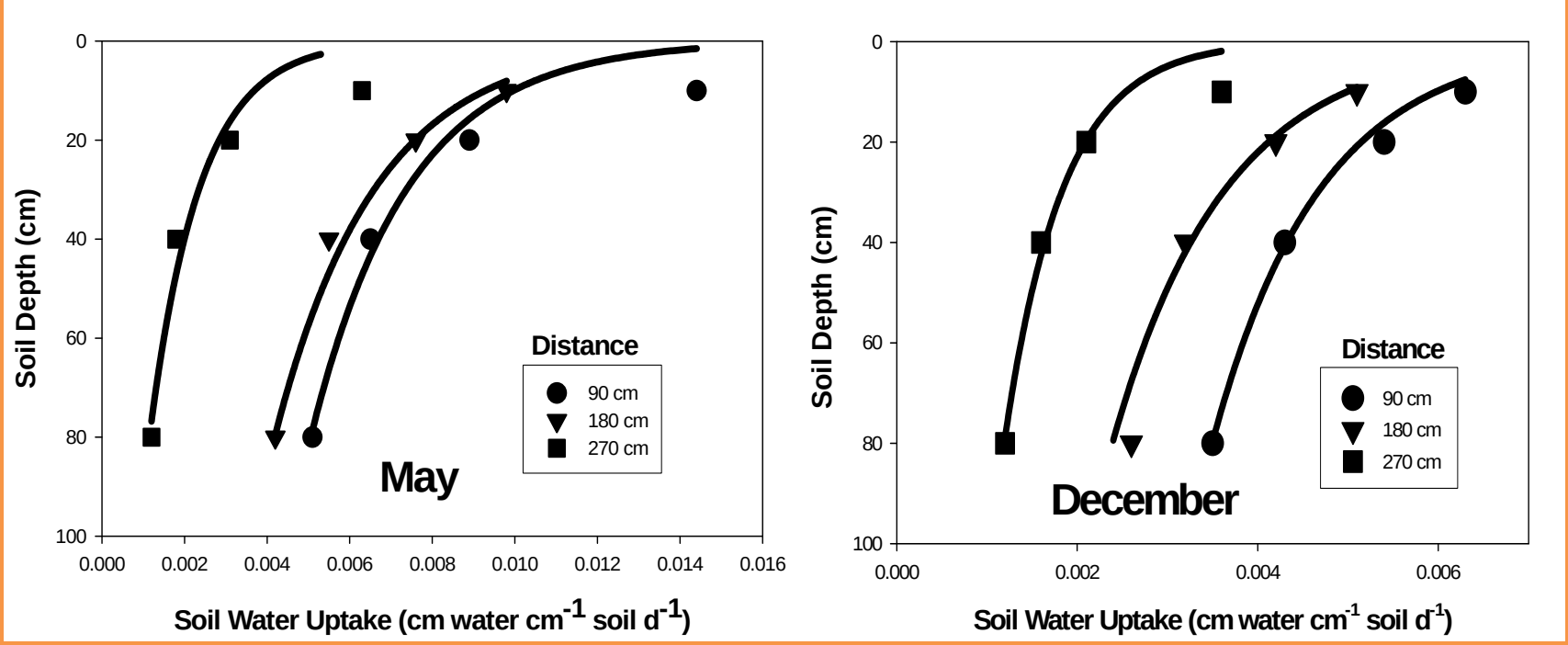
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Root Density Change With Distance From Tree

Soil depth (in)	Carrizo citrange			Swingle citrumelo		
	FRLD ($in \cdot in^3$)	Root length (yards)	Root length 0-90 cm (%)	FRLD ($in \cdot in^3$)	Root length yards)	Root length 0-90 cm (%)
0-6	0.84 A	432	38 A	1.39 A	620	53 A
6-12	0.27 B	143	13 B	0.35 B	150	13 B
12-18	0.16 B	82	7 C	0.16 B	85	7 C
18-24	0.28 B	155	14 B	0.19 B	88	8 C
24-30	0.32 B	176	16 B	0.21 B	118	10 B
30-36	0.28 B	149	12 B	0.25 B	107	9 BC

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Soil water Uptake Proportional to Root length Density



- Maximum water uptake varies with time of due to tree demand
- Higher demand in May compared to December
- Fibrous root length density decreases with distance from the tree
- Water uptake increases with increased root density

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Root Density Prior to HLB

- Root length densities varies among rootstocks
- Root length density decreases with soil depth and distance from the tree
- Approximately 60 % of roots in top 12 in
- Approximately 80 % under tree canopy
- Water uptake can be estimated from weather data
- Water uptake varies with root density
- Nutrient use efficiency dependent on root density and water uptake rate

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First Symptom – loss of feeder roots

- Johnson and Graham have reported upto 70% root loss after HLB infection



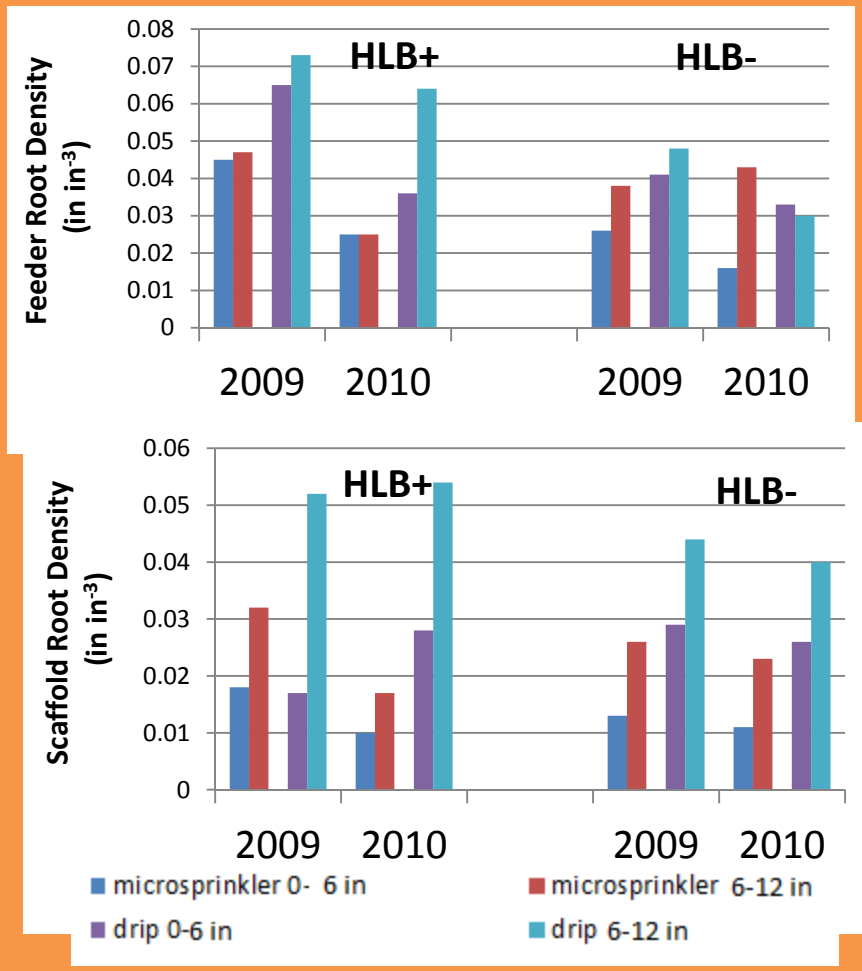
Citrus greening incubates in the tree's roots, making it difficult to detect infection. A healthy citrus root system is shown at left, and an infected one at right.

PHOTOGRAPH BY CRAIG CUTLER, NATIONAL GEOGRAPHIC

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Change in Root Density After HLB

- Feeder Roots of HLB+ trees decrease after infection
- Scaffold roots do not change with infection



Kadyampakeni et al. 2014. Effect of Irrigation Pattern and Timing on Root Density of Young Citrus Trees Infected With Huanglongbing Disease. HortTechnology 24(2) 209-221.

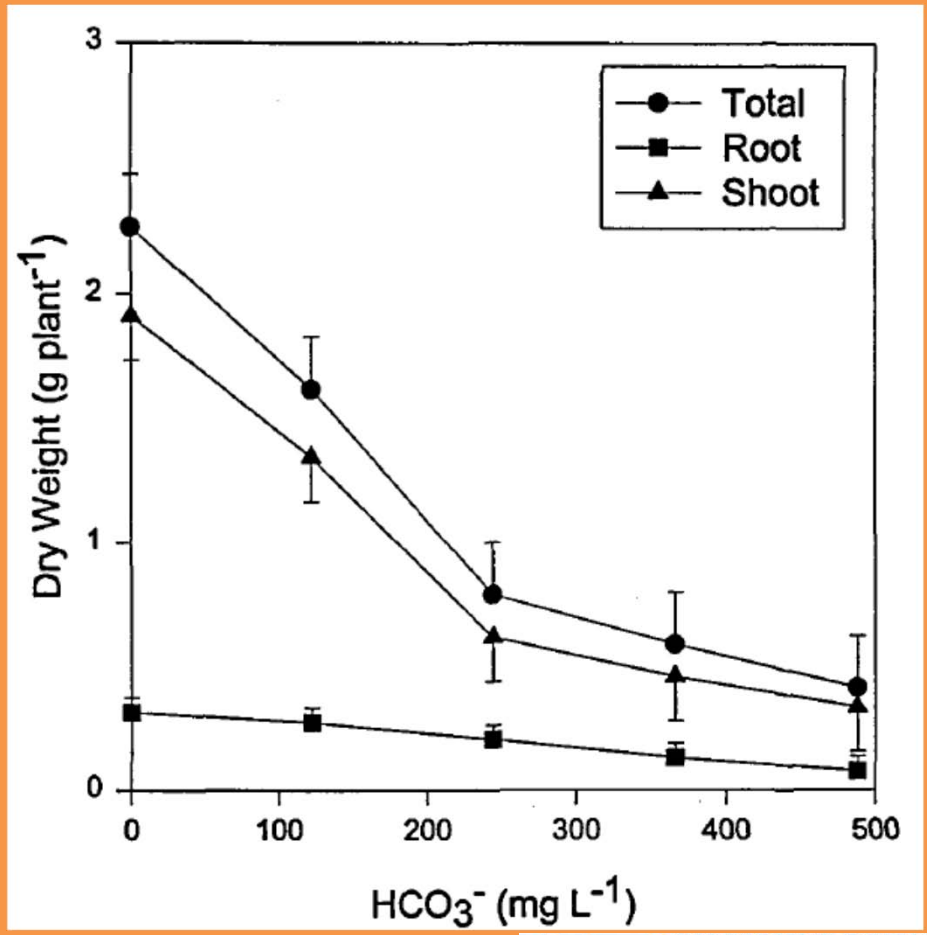
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WATER OR SOIL ACIDIFICATION

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Carbonate Impact on Plant Growth

- "Stunted plants appeared chlorotic with very little new leaf development"
- Root growth was adversely affected with brown root decreasing linearly with increasing HCO_3
- Growth inhibition has also been reported for tomatoes, celery, and flowering plants



Pearce, Li and Bush. 2015. Calcium and bicarbonate effects on the growth and nutrient uptake of burley tobacco seedlings. J. Plant Nutri. 22(7):1069-1078

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Impact of Bicarbonates on Citrus Rootstocks

- **Growth rate in soil amended with CaCO3**
  - ✓ **Cleo > sour orange > Volk. > Rangpur > Carrizo > Swingle**

Table 8. Plant growth and changes in leaf greenness (n = 6) among rootstocks in the Summer 1999 iron nutrition trial conducted in soil amended with $CaCO_3$.

Selection	Fresh wt (FW) (g) Initial		Fresh wt (FW) (g) Final		FW rel. growth rate ($g \cdot g^{-1}$)		HT rel. growth rate ($cm \cdot cm^{-1}$)		Leaf greenness ratio[z]	
Cleopatra mandarin	3.4	f[y]	87.2	de	24.4	a	6.7	a	1.1	c
Sour orange	5.8	cd	122.5	a	20.6	b	4.5	b	1.4	c
Sour orange + Carrizo citrange	6.5	bc	111.5	ab	16.5	c	3.7	bcd	1.4	c
Kinkoji	7.3	a	120.5	a	15.7	cd	4.5	b	1.0	c
Volkamer lemon	6.5	bc	105.9	abc	15.7	cd	4.4	b	1.4	c
Rangpur	5.8	cd	92.2	cde	15.0	cd	2.6	e	1.8	bc
Sunki × Benecke TF	5.1	d	78.4	e	14.5	cd	2.9	de	1.5	bc
Carrizo citrange	5.3	d	78.4	e	14.1	cd	3.0	cde	1.7	bc
Smooth Flat Seville	6.6	ab	95.5	bcd	13.8	cd	3.9	bc	1.7	bc
Cleo × Trifoliate orange	4.2	e	56.6	f	12.5	de	3.9	bc	2.0	bc
Swingle citrumelo	5.2	d	51.6	f	9.1	e	2.4	e	5.8	a
TF 50-7	5.6	d	33.8	g	5.1	f	1.1	f	2.5	b
$CaCO_3$ means										
0.4					15.6	a	3.8	ab	1.4	c
1.4					16.0	a	3.9	a	1.8	b
2.2					15.0	ab	3.7	ab	1.9	b
4.2					13.5	c	3.5	b	2.1	ab
5.9					13.9	bc	3.4	b	2.3	a
P values										
Rootstock	<0.0001		<0.0001		<0.0001		<0.0001		<0.000	
$CaCO_3$	0.5244		<0.0001		<0.002		0.0135		0.001	
Interaction	0.3816		0.5243		0.5688		0.086		0.099	

[z]Readings taken with a SPAD meter. Ratio of lower:upper leaves after 14 weeks. Ratios 1.0 or greater generally indicate decreasing greenness of the upper leaf relative to the lower leaf.
[y]Mean separation by Tukey's honestly significant difference test ($P \leq 0.05$).



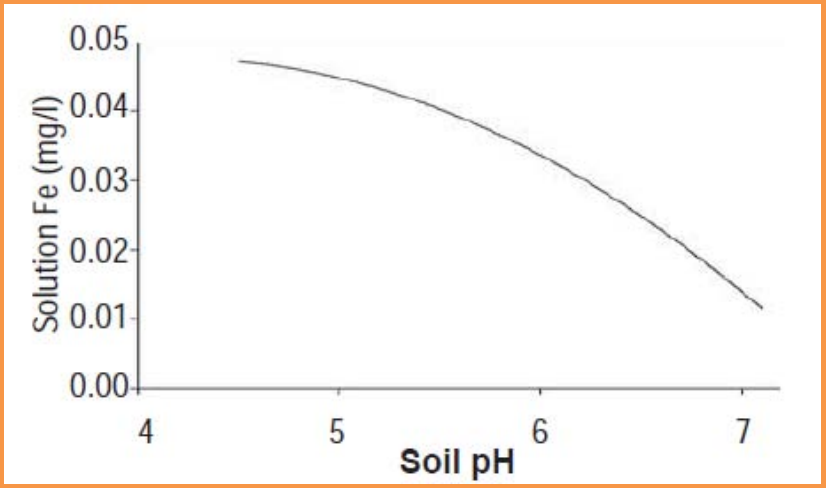
Source: Castle, W.S., J. Nunnallee, and J.A. Manthey. 2009. Screening Citrus Rootstocks and related Selections in Soil and Solution Culture for Tolerance to Low-iron Stress. HortScience 44(3):638-645.

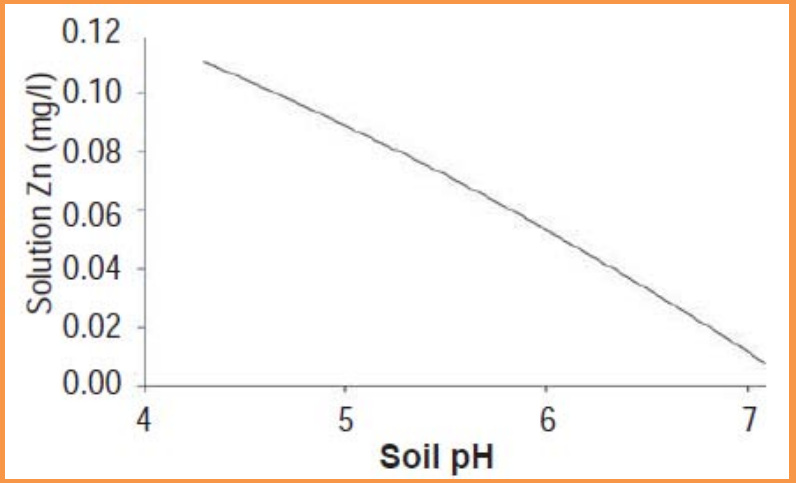
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Plant Uptake

- **Bicarbonate induced chlorosis is caused by transport of bicarbonate into the plant leading to reduced nutrient uptake.**
- **Lime-induced chlorosis effects many annual crops and perennial plants growing on calcareous soils.**

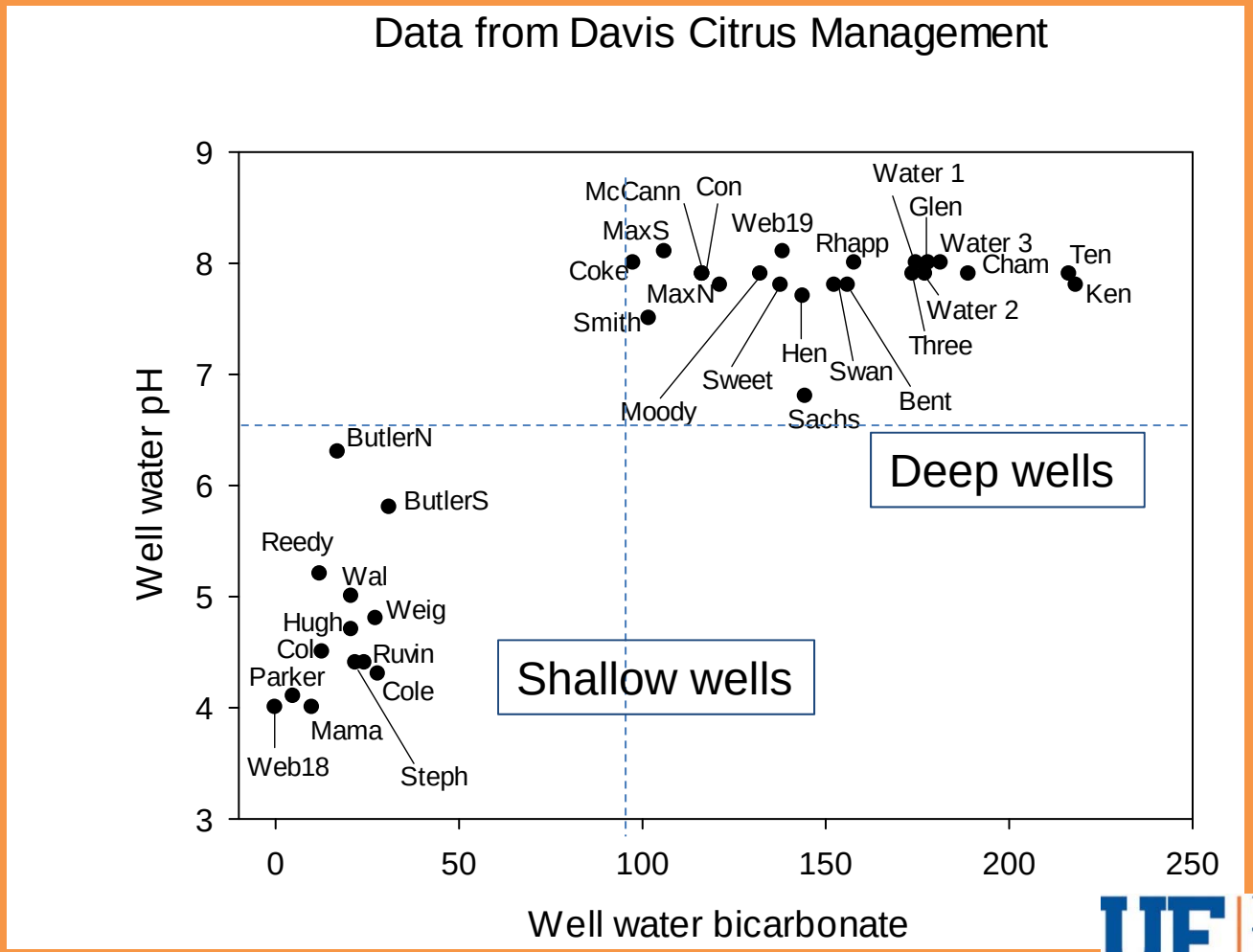




Horneck, D. 2006. Acidifying Soil for Crop Production East of the Cascades. Oregon State

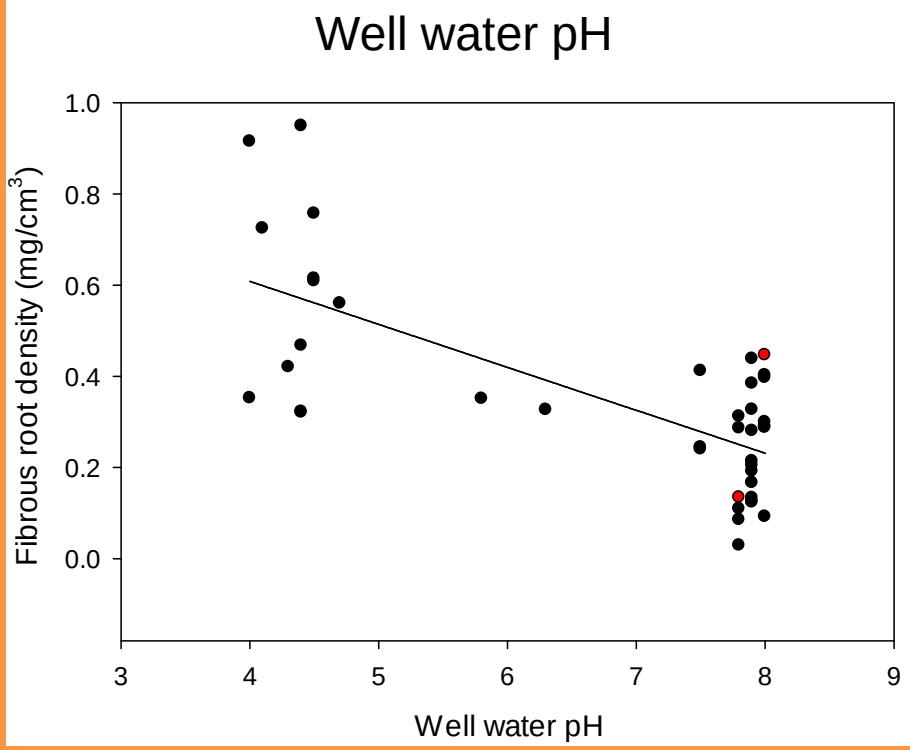
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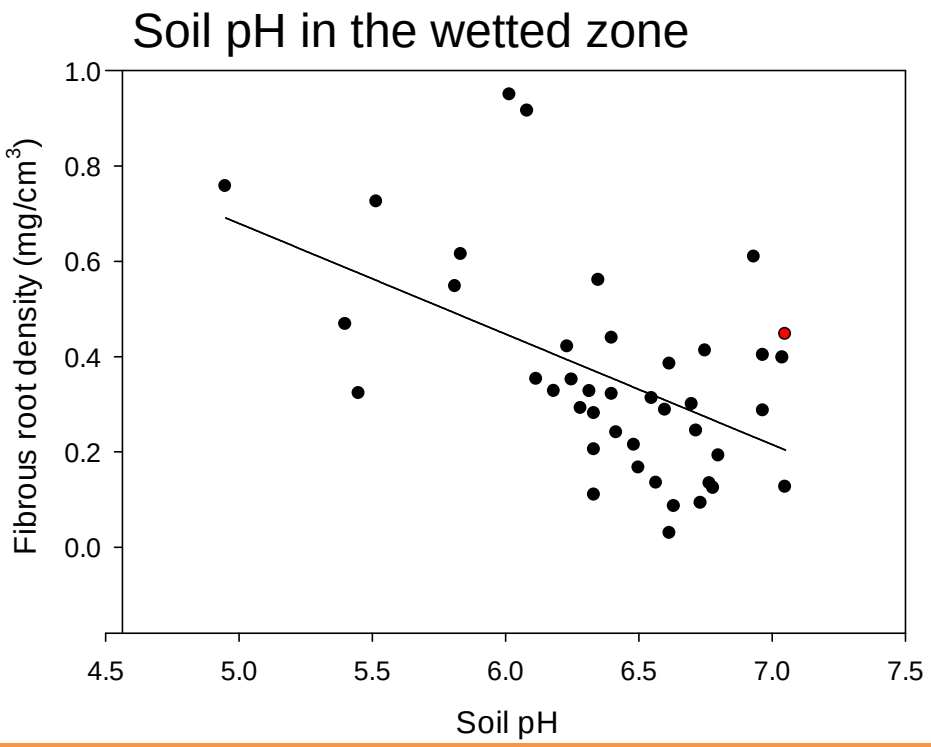
Survey of groves on Swingle and Carrizo



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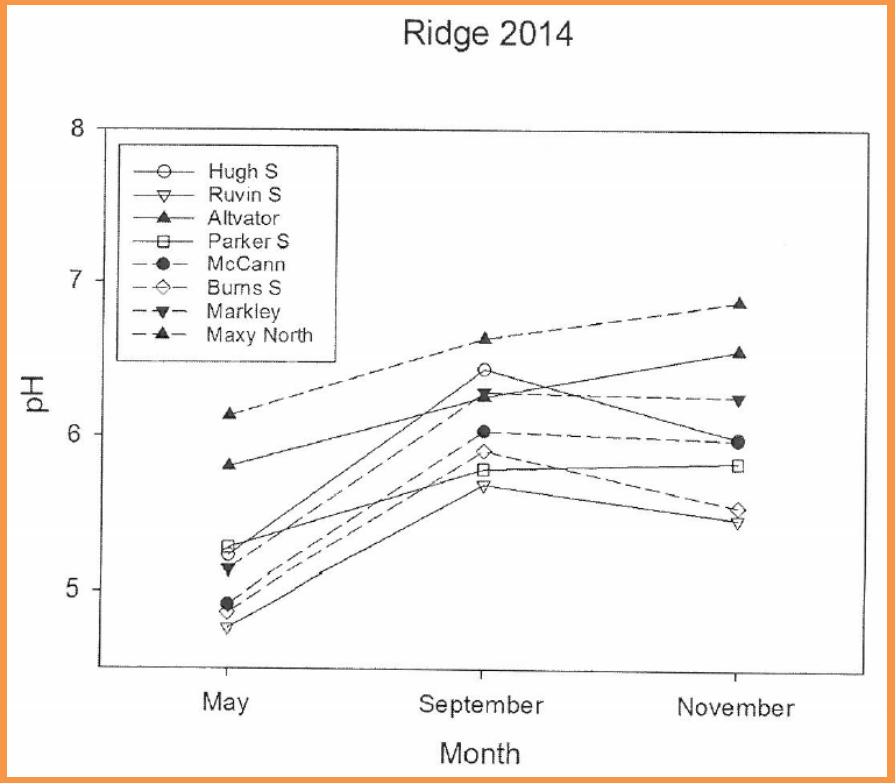
Lower Root Density is related to higher pH

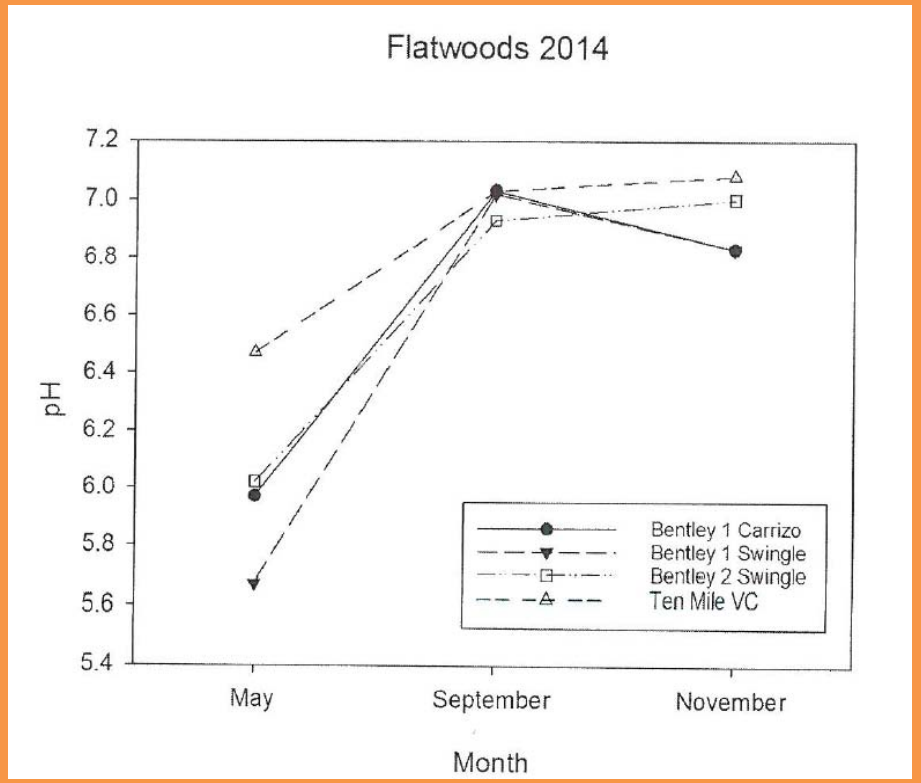




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Soil pH Rebounds During Rainy Season



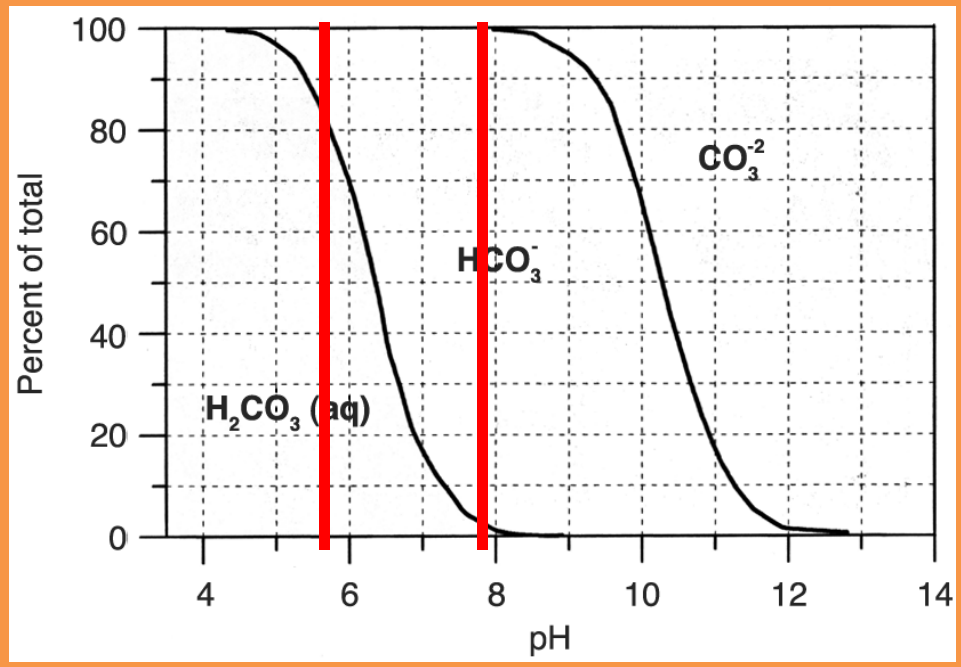


- Soil pH rebounds after injection ended at beginning of rainy season indicating the effect of irrigation water on soil if irrigation water acidification is not continued

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Irrigation Water pH and Bicarbonates

- **Injection of acidified water will reduce bicarbonate accumulation in the irrigated area**
- **Reducing water pH from 7.5 to 5.5 reduces bicarbonates from 100% to about 20% (80% reduction) releasing Ca or Mg**



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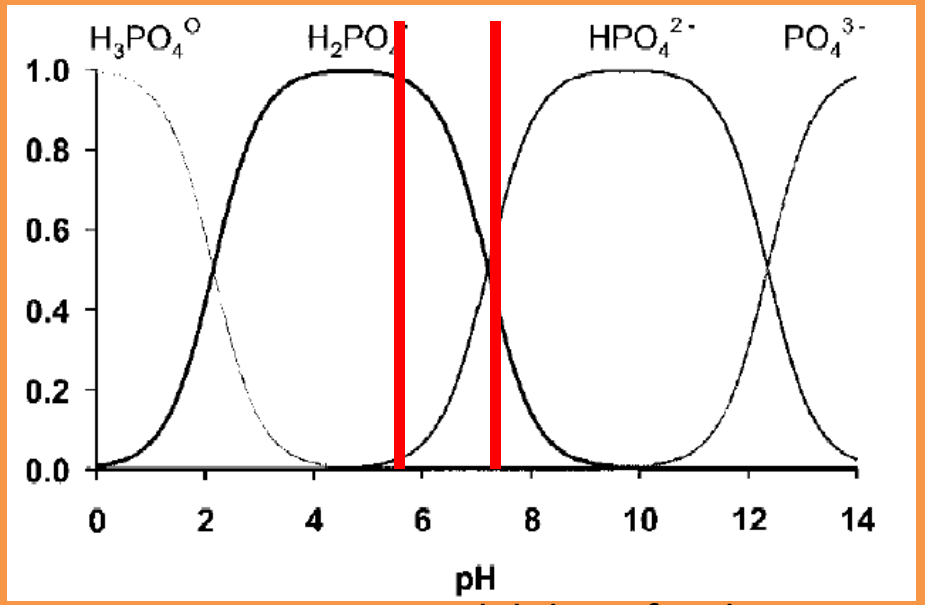
Example of Ca Release With Acidification

- Irrigation water = 200 ppm bicarbonates (assume 100% Calcium bicarbonate)
- 1 inch of irrigation water = 27154 gal. = 225378 pounds of water
- 200 ppm $CaCO_3$* 0.23 million pounds of water = 46 pounds of $CaCO_3$
- Release rate of 80% at 5.5 = 37 pounds $CaCO_3$
- $CaCO_3$ contains 40% Ca * 37 pounds $CaCO_3$ = 15 pounds Ca
- 15 inches of irrigation per year = 225 pounds Ca per year per acre

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P Transformations with Soil pH

- Distribution of P among various species in solution is first of all determined by solution pH
- H_2PO^{-4} and HPO_2^{-4} are the dominant orthophosphate ions, the latter being the major species at pH above 7.2
- In soil solution Ortho P has a strong tendency to form ion pairs with several metal cations (Ca, Mg, Fe and Al) depending on pH
- Acidification can release P as well as Ca



Hinsinger. 2001. Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. Plant and Soil 237:173-195.

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Results of Field Experiment

- Project funded by CRDF to determine the effect of soil pH on tree health and productivity
- Selected irrigation water pH with acid injection with and without soil application of slow release sulfur
- Study conducted on both young and mature trees

	Initial measurements (April 2014)		6 month measurements (December 2014)	
Treatments	Soil pH	Root length Density (mm cm^{-3})	Soil pH	Root length Density (mm cm^{-3})
control - no acid, no sulfur	7.45 A	1.2 A	7.42 A	1.3 B
no acid with sulfur	7.36 A	1.3 A	7.28 A	1.4 B
pH 6.0 without sulfur	7.21 A	1.4 A	6.37 AB	1.6 AB
pH 6.0 with sulfur	7.38 A	1.6 A	6.11 AB	1.7 A
pH 5.0 without sulfur	7.56 A	1.2 A	5.41B	1.8 A
ph 5.0 with sulfur	7.34 A	1.0 A	5.26 B	1.6 AB
pH 4.0 without sulfur	7.58 A	1.3 A	4.78 B	1.7 A
pH 4.0 with sulfur	7.62 A	1.7 A	4.46 B	1.8 A

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Acidification of the soil and water reduces pH, increase nutrient uptake

Water conditioning, Faster, lower soil bicarbonate

Injection of N-furic acid or sulfuric acid (40%) to adjust irrigation water to pH 6.5



Soil conditioning, Slower , high soil bicarbonate

300 lbs/treated acre of Tiger 90 sulfur lowered soil pH in 9 months

Valencia/Swingle - 10 yr old

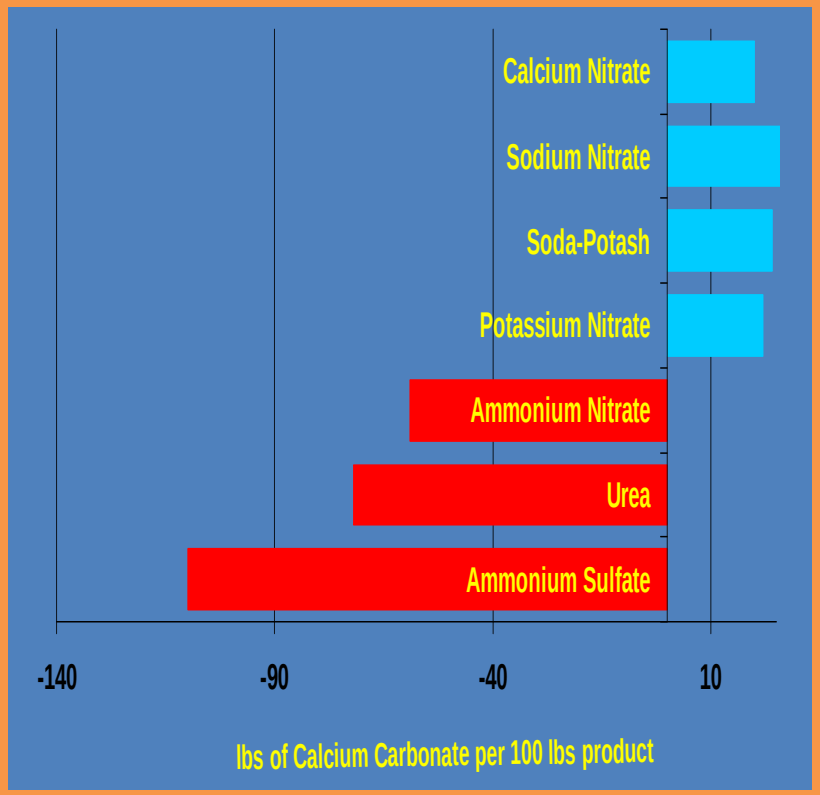
Sulfur	pH	Root density (mg/cm^3)
No	6.4	1.1
Yes	5.9*	1.4*

*Significant difference $P < 0.05$

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Acidifying Fertilizers

- **Alternative Acidifying methods**
  - **Formulations with acidifying materials**
    - **When ammonium is converted into nitrate in the soil $3H^+$ are released increasing soil pH**
    - **Ammonium thiosulfate is also acidifying because it supplies both ammonium and sulfur**
  - **Replace any filler with slow release forms of sulfur (e.g. Tiger 90)**



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Water Treatment

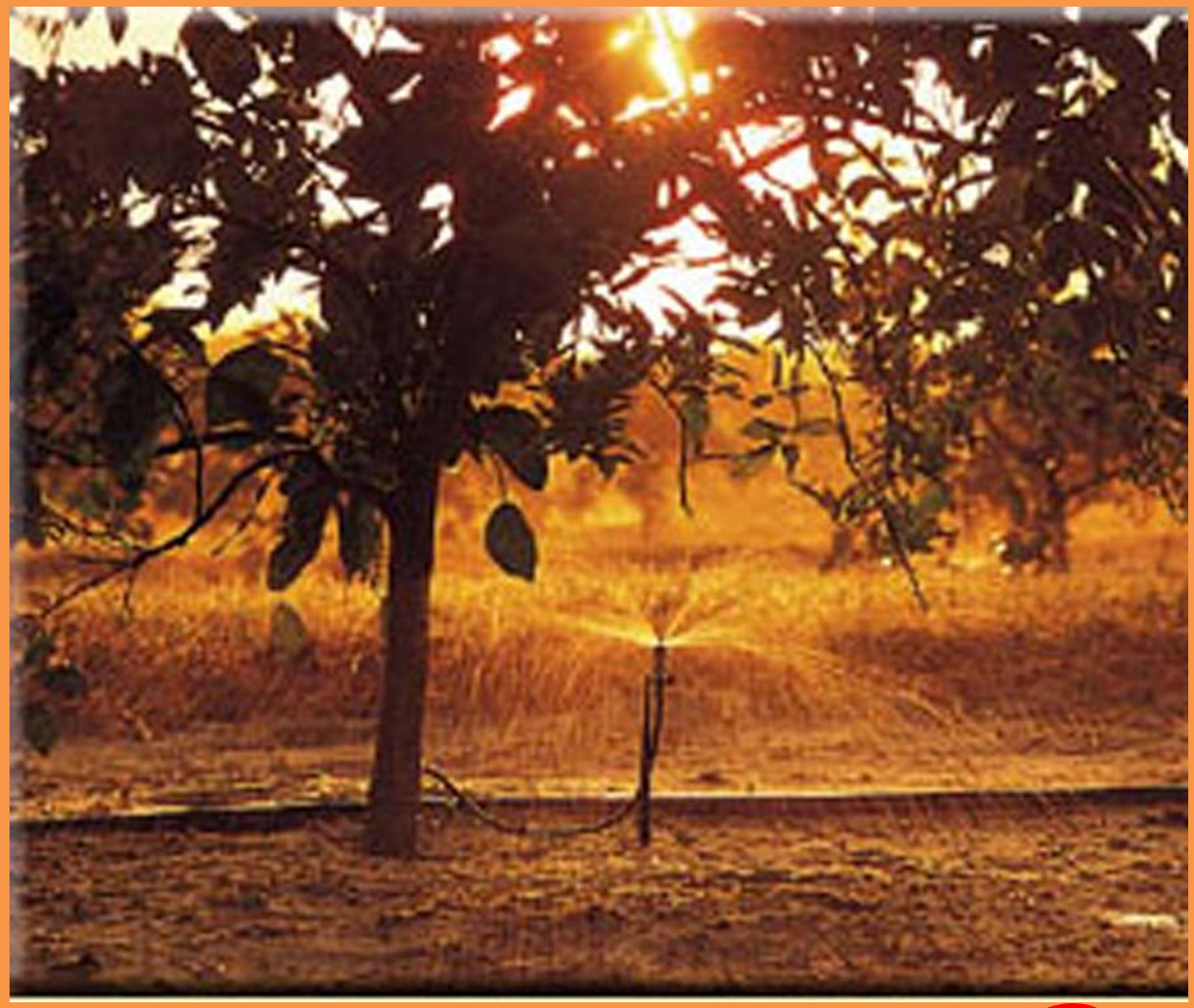
- Standard treatment is to lower the water's pH by adding an acid. Lowering the pH to 6.5 neutralizes about half the bicarbonate in the water.
- Injection of acidified water instead of a dry material to a wide area will reduce bicarbonate accumulation in the irrigated area where irrigation may cause to accumulation.
- Most common acids to inject are sulfuric acid, phosphoric acid.

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Conclusions

- Ca, Mg and micronutrient should be applied to reduce HLB symptoms and provide sufficient tree health, but leaf concentrations should be the same as past recommendations.
- Inability to sufficiently extract micronutrients, including Fe, Zn and Mn.
- Water and soil bicarbonates should be addressed to allow for proper nutrient uptake. This appears to not have been a problem prior to HLB except in extreme cases.

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Questions?

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Soil-applied controlled release fertilizer (CRF) treatments impact the health and growth of HLB-infected trees – Results from greenhouse and field experiments

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Citrus Research and Education Center

Jude Grosser, Gary Barthe, Jim Baldwin, Ahmad Omar and Tripti Vashisth



UF-CREC Citrus Genetic Improvement Team
2015

Why has the 'Maury Boyd Program' worked at some locations but not at others?

- Foliar only?
- Soil type?
- Soil Amendments? Sludge, compost, biochar???
- Calcium nitrate to soil?
- Availability of micronutrients in soil?

Minor element deficiencies are greater in HLB-impacted roots than in HLB-impacted leaves! Foliar sprays temporarily help the leaves, but don't get minors to the roots! What about xylem function ??? GROUND NUTRITION IS IMPORTANT! (quantity and type – constant supply is needed!)

Variety	Type of Sample	Tree Condition	Nitrogen	P	K	Mg	Ca	S	B	Zn	Mn	Fe	Cu
			%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm
CZO	Leaf	non-symptomatic	4.08	0.18	4.04	0.25	1.42	0.37	223.4	45.33	452.5	109.7	164.6
CZO	Leaf	Symptomatic	3.61	0.2	3.52	0.29	1.18	0.3	178.2	22.32	192.7	77.91	93.93
CZO	Root	non-symptomatic	2.67	0.21	1.57	0.32	1.33	0.97	29.65	1600	6913	2084	38.93
CZO	Root	Symptomatic	2.63	0.24	1.38	0.16	0.8	0.29	23.3	291	1308	496	16.46

Greenhouse Study

Effects of nutrient overdoses on HLB-infected Valencia trees on UFR-3 (Orange #15) rootstock- a one-year study

Trees were grown in an air-conditioned greenhouse that favors HLB disease expression. Overdoses were applied twice, 6-month intervals.

UF UNIVERSITY of FLORIDA
IFAS
Citrus Research and Education Center

UFR-3: Nova+HBPummelo x Cleo+Arg.trifoliate orange



UF-CREC Citrus Genetic Improvement Team
2015



Candidate for ACPS

Valquarius on Orange #15 tetrazyg rootstock – just < 5 years at St. Helena, Dundee FL – Fast-track released as UFR-3

Harrell's
Professional Fertilizer Solutions

16-5-10

Batch #:

12 Month.

NPK+ Minors

GUARANTEED ANALYSIS

* Total Nitrogen (N)	16.0000%
5.8630% Nitrate Nitrogen	
6.8750% Ammoniacal Nitrogen	
3.2620% Urea Nitrogen	
** Available Phosphate (P2O5)	5.0000%
*** Soluble Potash (K2O)	10.0000%
Magnesium (Mg)	1.0830%
1.0830% Soluble Magnesium (Mg)	
Copper (Cu)	0.0620%
0.0620% Soluble Copper (Cu)	
Iron (Fe)	0.2580%
0.2580% Iron (Chelated)	
Manganese (Mn)	0.1000%
0.1000% Soluble Manganese (Mn)	
Molybdenum (Mo)	0.0090%
Zinc (Zn)	0.0620%
0.0620% Soluble Zinc (Zn)	

Derived From: Polymer Coated Ammonium Nitrate, Polymer Coated Copper Sulfate, Polymer Coated EDTA Iron Chelate, Polymer Coated Magnesium Sulfate, Polymer Coated Manganese Sulfate, Polymer Coated Mono-Ammonium Phosphate, Polymer Coated Sodium Molybdate, Polymer Coated Sulfate of Potash, Polymer Coated Urea, Polymer Coated Zinc Sulfate, Polymer-Coated Potassium Nitrate

- * **Has 14.05% slow release NITROGEN derived from Polymer Coated Ammonium Nitrate, Polymer Coated Mono-Ammonium Phosphate, Polymer Coated Urea, Polymer-Coated Potassium Nitrate**
- ** **Has 4.5% slow release PHOSPHATE derived from Polymer Coated Mono-Ammonium Phosphate**
- *** **Has 8.916% slow release POTASH derived from Polymer Coated Sulfate of Potash, Polymer-Coated Potassium Nitrate**

Warning: — This fertilizer is to be used only on soils which respond to Molybdenum. Crops high in Molybdenum are toxic to ruminants.

Density - 61 lb./(cu. ft.)

CAUTION MAY CAUSE STAINS ON CONCRETE

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020804

NET WEIGHT 50 LBS

Liquid Fertilizer - Control

Harrell's Max 12-2-12 supplemented with Harrell's Max Minors

Total Nitrogen		12.0%
Nitrate Nitrogen	1.10%	
Ammoniacal Nitrogen		
Urea Nitrogen	10.9%	
Available Phosphate		2.00%
Soluble Potash		12.00%
Magnesium		1.00%
Boron		0.02%
Copper (chelated)	0.25%	
Iron		4.10%
Chelated Iron	4.10%	
Manganese (chelated)		1.00%
Molybdenum		0.0005%
Zinc (chelated)		0.60%
Sulfur		3.50%

Supplemental Nutrients in Controlled Release Forms

<u>Micronutrients – applied at 3x concentration</u>
Tiger-Sul Micronutrients Zinc 18% (18% Zn, 65% S)
Tiger-Sul Micronutrients Iron 22% (22% Fe, 55%S)
Tiger-Sul Micronutrients Manganese 15% (15%Mn, 65% S)
Tiger-Sul 'Arnolds mix' (3.85% Fe, 7.50% Mn, 5.85% Zn, 63% S)
Florikote Polymer Coated Sodium Borate (8.82% B)
Florikote Polymer Coated Magnesium Sulfate (13.9%)
Florikote Polymer Coated Triple Super Phosphate (40% P_2O_5)
Florikote $FeSO_4$ Polymer Coated Ferrous Sulfate (28% Fe, 17% S)
BioChar from Southern Yellow Pine (97%)

<u>Macaronutrients—applied at 2x concentration</u>
Florikote Polymer Coated Mini Ammonium Sulfate (19% N)
Florikote Polymer Coated Sulfate of Potash (47% K_2O)
Florikote Polymer Coated Urea (42% N)

Polycoated Florikote products kindly provided by Brian Patterson (Florikan Corp.)



Stick-graft method – Valencia budstick taken from heavily HLB-impacted field tree. Graft wrapped with budding tape, Budstick wrapped with parafilm. 10 trees per treatment.

Harrell's UF Mix
HLB-infected Valencia/Orange #15 rootstock



Harrell's UF Mix + Tiger-Sul Manganese (3X)
HLB-infected Valencia/Orange #15 rootstock



Parameters Measured

New Flush (Y or N)
HLB symptom (0-7)
Stem dia. (mm)
Tree Height (cm)
# of Leaves
PCR – roots (partially completed)
PCR – leaves (partially completed)
Nutritional analysis –leaves (samples submitted)
Nutritional analysis -roots (samples submitted)
Starch content – leaves
Spad Avg.
Scion Leaves Fr. wt. g
Rootstock Leaves Fr. Wt. g
Scion Leaves Surface Area
Rootstock Leaves Surface Area
Total Leaf Surface Area
Root FWt. g
Stems FWt. g
Soil pH
Young Scion Leaves Dry Wt.
Mature Scion Leaves Dry Wt.
Rootstock Leaves Dry Wt.
Total Leaf Dry Wt.
Stems Dry Wt.
Feeder Roots Dry Wt.
Tap and Scaffold Root Dry t.
Total Root Dry Wt.

HLB visual symptoms (7=no symptoms to 0=severe, stunted)

Treatment	N	Mean*	Tukey Grouping
Harrell's + 3X TigerSul-Arnold's + Biochar	9	3.89	A
Harrell's + 3X Tigersul Zinc	10	3.70	AB
Harrell's + 3X TigerSul Manganese	10	3.70	AB
Harrell's + 3X Tiger-Arnold's Mix (Mn, Fe, Zn)	9	3.56	ABC
Harrell's + 2X Florikan Urea	8	3.13	ABCD
Harrell's + 3X Florikan Iron	7	2.86	ABCDE
Harrell's + 3X Florikan Sodium Borate	10	2.80	ABCDE
Harrell's + Biochar	9	2.78	ABCDE
Liquid Fertilizer Only - Control	6	2.67	ABCDE
Harrell's - Control	8	2.50	BCDE
Harrell's + 3X Tigersul Fe	7	2.43	BCDE
Harrell's + 2X Florikan Ammonium Sulfate	8	2.38	CDE
Harrell's + 3X Magnesium Sulfate	8	2.25	DE
Harrell's + 3X Florikan Super Triple Phosphate	6	2.17	DE
Harrell's + 2X Florikan Potash	4	1.75	E

Least significant difference 1.28
Experiment mean 2.93
Pr > F 0.02

* Means with the same letter are not significantly different at 95% confidence

Tree height (cm)

Treatment	N	Mean*	Tukey Grouping
Harrell's + 3X TigerSul Manganese	10	110.75	A
Harrell's + 3X Tiger-Arnold's Mix (Mn, Fe, Zn)	9	102.11	AB
Harrell's + 3X Tigersul Zinc	10	91.45	ABC
Harrell's + 3X Florikan Sodium Borate	10	89.00	ABC
Harrell's - Control	8	87.56	BCD
Harrell's + 3X TigerSul-Arnold's + Biochar	9	86.67	BCD
Harrell's + 3X Magnesium Sulfate	8	84.88	BCD
Harrell's + 2X Florikan Ammonium Sulfate	8	83.75	BCD
Harrell's + 3X Florikan Iron Sulfate	7	82.86	BCD
Harrell's + Biochar	9	80.28	BCD
Harrell's + 3X Tigersul Fe	7	79.71	BCD
Harrell's + 2X Florikan Urea	8	78.56	CD
Liquid Fertilizer Only - Control	6	77.17	CD
Harrell's + 3X Florikan Super Triple Phosphate	6	77.17	CD
Harrell's + 2X Florikan Potash	4	65.00	D

Least significant difference 22.6 cm

Experiment mean 86.8 cm

Pr > F 0.04

* Means with the same letter are not significantly different at 95% confidence

Scion leaves fresh weight (grams)

Treatment	N	Mean*	Tukey Grouping
Harrell's + 3X TigerSul Manganese	10	29.63	A
Harrell's + 3X Tiger-Arnold's Mix (Mn, Fe, Zn)	9	24.55	AB
Harrell's - Control	8	23.77	AB
Harrell's + 3X TigerSul-Arnold's + Biochar	9	23.68	AB
Harrell's + 3X Tigersul Zinc Sulfur	10	23.49	AB
Harrell's + 3X Magnesium Sulfate	8	21.67	AB
Harrell's + 3X Florikan Sodium Borate	10	20.60	AB
Liquid Fertilizer Only - Control	6	20.44	AB
Harrell's + 3X Florikan Iron Sulfate	7	19.34	AB
Harrell's + 2X Florikan Urea	8	16.89	AB
Harrell's + 3X Tigersul Fe	7	16.10	B
Harrell's + 2X Florikan Ammonium Sulfate	8	16.06	B
Harrell's + Biochar	9	15.90	B
Harrell's + 3X Florikan Super Triple Phosphate	6	15.11	B
Harrell's + 2X Florikan Potash	4	14.13	B

Least significant difference 13.0 g

Experiment mean 20.7 g

Pr > F 0.48

* Means with the same letter are not significantly different at 95% confidence

Total leaf dry weight (grams)

Treatment	N	Mean*	Tukey Grouping
Harrell's + 3X TigerSul Manganese	10	12.73	A
Harrell's + 3X Tiger-Arnold's Mix (Mn, Fe, Zn)	9	10.93	AB
Harrell's + 3X Tigersul Zinc Sulfur	10	10.02	ABC
Harrell's + 3X TigerSul-Arnold's + Biochar	9	9.80	ABC
Harrell's + 3X Florikan Sodium Borate	10	9.74	ABC
Harrell's - Control	8	9.39	ABC
Harrell's + 3X Magnesium Sulfate	8	9.28	ABC
Harrell's + 3X Florikan Iron Sulfate	7	8.19	ABC
Liquid Fertilizer Only - Control	6	7.93	ABC
Harrell's + 2X Florikan Urea	8	7.21	BC
Harrell's + Biochar	9	6.98	BC
Harrell's + 2X Florikan Ammonium Sulfate	8	6.94	BC
Harrell's + 3X Tigersul Fe	7	6.58	BC
Harrell's + 3X Florikan Super Triple Phosphate	6	5.78	BC
Harrell's + 2X Florikan Potash	4	4.91	C

Least significant difference 5.32 g

Experiment mean 8.76 g

Pr > F 0.25

* Means with the same letter are not significantly different at 95% confidence

Feeder roots Dry weight (grams)

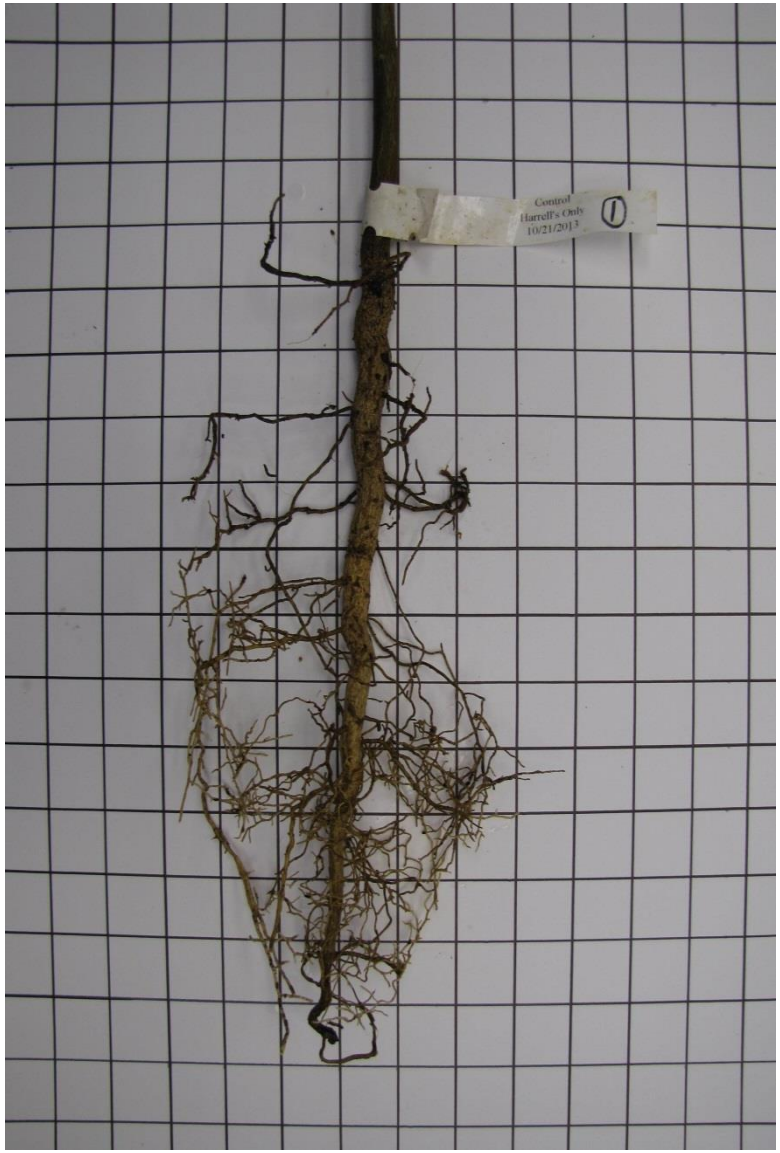
Treatment	N	Mean*	Tukey Grouping
Harrell's + 3X TigerSul Mn	10	3.49	A
Harrell's + 3X Florikan Sodium Borate	10	3.43	A
Harrell's - Control	8	3.36	A
Harrell's + 3X Tiger-Arnold's Mix (Mn, Fe, Zn)	9	3.36	A
Harrell's + 2X Florikan Ammonium Sulfate	8	3.11	A
Harrell's + 3X Magnesium Sulfate	8	3.08	A
Harrell's + 3X Tigersul Fe	7	2.86	A
Harrell's + Biochar	9	2.55	A
Liquid Fertilizer Only - Control	6	2.49	A
Harrell's + 3X TigerSul-Arnold's + Biochar	9	2.48	A
Harrell's + 3X Tigersul Zinc Sulfur	10	2.26	A
Harrell's + 2X Florikan Potash	4	2.00	A
Harrell's + 3X Florikan Iron Sulfate	7	1.83	A
Harrell's + 2X Florikan Urea	8	1.79	A
Harrell's + 3X Florikan Super Triple Phosphate	5	1.41	A

Least significant difference 2.18 g

Experiment mean 2.71 g

Pr > F 0.73

* Means with the same letter are not significantly different at 95% confidence



Harrell's CRF Control #1



Harrell's+TigerSul Mn #10

Greenhouse Study – Effects of nutrient overdoses on HLB-infected Valencia on UFR-3 (Orange #15) tetrazyg rootstock after 1 year. Total Root length (cm) , determined by winRhizo washed root image analysis.

Treatment	N	Mean*	Standard Deviations	Tukey Grouping
Harrell's + 3x TigerSul Mn	10	2361	848	A
Harrell's + 3x Tiger-Arnold's Mix (Mn, Fe, Zn)	9	2270	933	A
Harrell's + 3x TigerSul-Arnold's + Biochar	9	1955	1237	AB
Harrell's + 3x Tigersul Zinc Sulfur	10	1672	1039	AB
Harrell's - Control	8	1670	900	AB
Harrell's + 3x Florikan Sodium Borate	10	1554	1466	AB
Harrell's + 3x Tigersul Fe	7	1419	704	AB
Liquid Fertilizer Only - Control	6	1349	1273	AB
Harrell's + 3x Florikan Magnesium Sulfate	8	1315	1025	AB
Harrell's + 2x Florikan Ammonium Sulfate	8	1276	805	AB
Harrell's + 2x Florikan Urea	8	1173	766	AB
Harrell's + 3x Florikan Iron Sulfate	7	1032	544	AB
Harrell's + 3x Florikan Super triple Phosph	6	910	642	AB
Harrell's + 2x Florikan potash	4	902	226	AB
Harrell's + Biochar	9	559	403	B

* Means with the same letter are not significantly different at 95% confidence





Control liquid fertilizer Trees after one year.

Harrell’s CRF+TigerSul Mn

qPCR ct averages from greenhouse treatments

Treatment	Midrib	Root
Harrell's + PC Boron	34.86	33.66
Harrell's + PC Super Triple Phosphate	33.95	33.95
Harrell's + PC Ammonium Sulfate	33.89	33.78
Harrell's + PC Magnesium Sulfate	33.07	31.59
Harrell's Plus TigerSul Zinc	33.05	33.11
Harrell's + PC Potash	33.01*	35.57*
Harrell's Plus PC-Urea	32.92	33.00
Harrell's + biochar	32.80	32.48
Harrell's + Arnolds's mix/biochar	32.35	30.87
Harrell's Plus TigerSul manganese	31.91	35.18
Harrell's + PC Iron Sulfate	31.17	33.30
Harrell's Plus Arnold's mix	30.64	29.88
Liquid control	30.57	34.57
Harrell's control	29.78	32.75
Harrell's Plus TigerSul iron	29.75	30.79

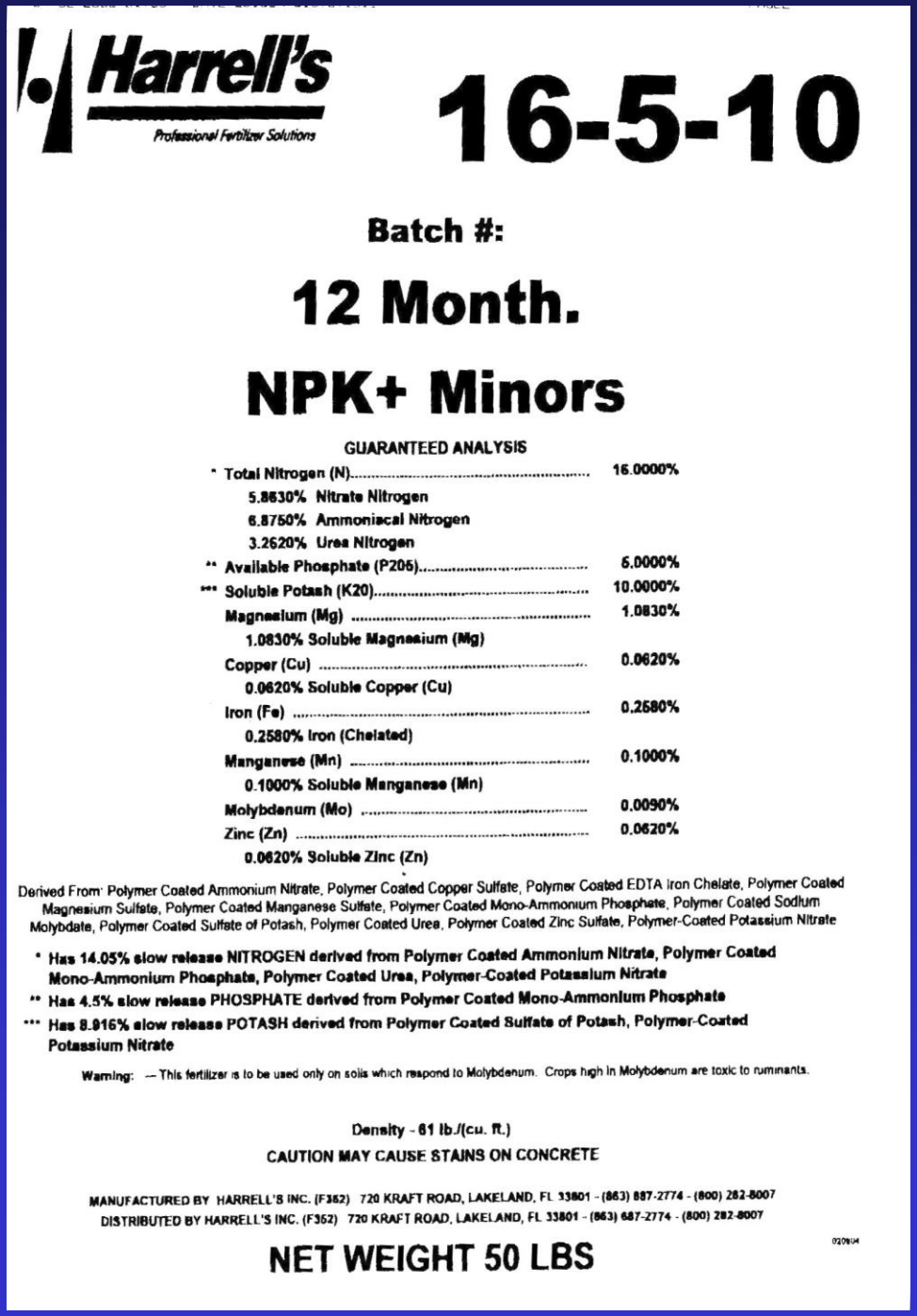
* Trees in very poor health



St. Helena Project c/o Mr. Orie Lee

8/9/12 photo, trees 4.5 years old

Bad neighbor effect - Rootstock effects on HLB emerging!



Harrell's
Professional Fertilizer Solutions

16-5-10

Batch #:

12 Month.

NPK+ Minors

GUARANTEED ANALYSIS

* Total Nitrogen (N)	16.0000%
5.8630% Nitrate Nitrogen	
6.8750% Ammoniacal Nitrogen	
3.2620% Urea Nitrogen	
** Available Phosphate (P2O5)	5.0000%
*** Soluble Potash (K2O)	10.0000%
Magnesium (Mg)	1.0830%
1.0830% Soluble Magnesium (Mg)	
Copper (Cu)	0.0620%
0.0620% Soluble Copper (Cu)	
Iron (Fe)	0.2580%
0.2580% Iron (Chelated)	
Manganese (Mn)	0.1000%
0.1000% Soluble Manganese (Mn)	
Molybdenum (Mo)	0.0090%
Zinc (Zn)	0.0620%
0.0620% Soluble Zinc (Zn)	

Derived From: Polymer Coated Ammonium Nitrate, Polymer Coated Copper Sulfate, Polymer Coated EDTA Iron Chelate, Polymer Coated Magnesium Sulfate, Polymer Coated Manganese Sulfate, Polymer Coated Mono-Ammonium Phosphate, Polymer Coated Sodium Molybdate, Polymer Coated Sulfate of Potash, Polymer Coated Urea, Polymer Coated Zinc Sulfate, Polymer-Coated Potassium Nitrate

* **Has 14.05% slow release NITROGEN derived from Polymer Coated Ammonium Nitrate, Polymer Coated Mono-Ammonium Phosphate, Polymer Coated Urea, Polymer-Coated Potassium Nitrate**
** **Has 4.5% slow release PHOSPHATE derived from Polymer Coated Mono-Ammonium Phosphate**
*** **Has 8.916% slow release POTASH derived from Polymer Coated Sulfate of Potash, Polymer-Coated Potassium Nitrate**

Warning: -- This fertilizer is to be used only on soils which respond to Molybdenum. Crops high in Molybdenum are toxic to ruminants.

Density - 61 lb./(cu. ft.)
CAUTION MAY CAUSE STAINS ON CONCRETE

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NET WEIGHT 50 LBS

St. Helena Project – c/o Mr. Orie Lee

-mimic principles of OHS to minimize tree stress

-two applications per year of Harrell's/UF mix slow-release fertilizer (January, July); thanks to Arnold Schumann for assistance in developing the formula

-daily irrigation unless adequate rainfall

-evaluation of >75 rootstocks, 19.9 acres

-bad neighbor issue – unsprayed grove on one side, organic grove on other side

Harrell's
Professional Fertilizer Solutions

13-4-9

Batch #: 1002-0646

FERTILIZER

UF Citrus Research Center

GUARANTEED ANALYSIS

*	Total Nitrogen (N)	13.0000%
	7.4900% Nitrate Nitrogen	
	5.0100% Ammoniacal Nitrogen	
	0.5000% Urea Nitrogen	
**	Available Phosphate (P205)	4.0000%
***	Soluble Potash (K20)	9.0000%
	Calcium (Ca)	4.2800%
	Magnesium (Mg)	1.0950%
	1.0950% Water Soluble Magnesium (Mg)	
	Boron (B)	0.0500%
	Copper (Cu)	0.0460%
	0.0460% Water Soluble Copper (Cu)	
	Iron (Fe)	0.9470%
	0.1580% Water Soluble Iron (Fe)	
	0.3170% Iron (Chelated)	
	Manganese (Mn)	0.1580%
	0.1580% Water Soluble Manganese (Mn)	
	Molybdenum (Mo)	0.0070%
	Zinc (Zn)	0.0460%
	0.0460% Water Soluble Zinc (Zn)	

Derived From: Calcium Nitrate, Polymer Coated Ammonium Nitrate, Polymer Coated Copper Sulfate, Polymer Coated EDTA Iron Chelate, Polymer Coated Magnesium Sulfate, Polymer Coated Manganese Sulfate, Polymer Coated Mono-Ammonium Phosphate, Polymer Coated Sodium Molybdate, Polymer Coated Sulfate of Potash, Polymer Coated Sulfate of Potash-Magnesia, Polymer Coated Sulphate of Potash, Polymer Coated Urea, Polymer Coated Zinc Sulfate, Iron Chelate, Iron EDTA, Iron Humate, Iron Oxide, Iron Sulfate, Iron Sucrate, Manganese Sulfate, Sodium and Calcium Borate

* **8.58% slow release NITROGEN derived from Polymer Coated Ammonium Nitrate, Polymer Coated Mono-Ammonium Phosphate, Polymer Coated Urea**

** **3.984% slow release PHOSPHATE derived from Polymer Coated Mono-Ammonium Phosphate**

*** **8.098% slow release POTASH derived from Polymer Coated Sulfate of Potash, Polymer Coated Sulfate of Potash-Magnesia, Polymer Coated Sulphate of Potash**

Warning: --- Some crops may be injured by Application of Boron.
--- This fertilizer is to be used only on soils which respond to Molybdenum. Crops high in Molybdenum are toxic to ruminants.

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Net Weight 50 LBS

Harrell's
Growing a Better World™

12-3-8

Batch #: 1407-0797

FERTILIZER ~ CREC Mix with Tiger micros

GUARANTEED ANALYSIS

* Total Nitrogen (N)	12.0000%
6.9400% Nitrate Nitrogen	
4.5500% Ammoniacal Nitrogen	
0.5100% Urea Nitrogen	
** Available Phosphate (P2O5)	3.0000%
*** Soluble Potash (K2O)	8.0000%
Calcium (Ca)	4.5270%
Magnesium (Mg)	0.9850%
0.9850% Water Soluble Magnesium (Mg)	
Boron (B)	0.0540%
Copper (Cu)	0.0400%
0.0400% Water Soluble Copper (Cu)	
Iron (Fe)	1.0980%
0.1100% Water Soluble Iron (Fe)	
0.2200% Chelated Iron (Fe)	
Manganese (Mn)	0.9160%
0.0690% Water Soluble Manganese (Mn)	
Molybdenum (Mo)	0.0060%
Zinc (Zn)	0.7150%
0.0400% Water Soluble Zinc (Zn)	

Derived From: Polymer Coated Ammonium Nitrate, Polymer Coated Calcium Nitrate, Polymer Coated Copper Sulfate, Polymer Coated Iron EDTA, Polymer Coated Magnesium Sulfate, Polymer Coated Manganese Sulfate, Polymer Coated Monoammonium Phosphate, Polymer Coated Sodium Molybdate, Polymer Coated Sulfate of Potash, Polymer Coated Sulfate of Potash-Magnesia, Polymer Coated Urea, Polymer Coated Zinc Sulfate, Elemental Sulfur, Ferrous Sulfate, Iron EDTA, Iron Humate, Iron Oxide, Iron Sucrate, Manganese Oxide, Sodium and Calcium Borate, Zinc Oxide

*** 11.46% slow release NITROGEN derived from Polymer Coated Ammonium Nitrate, Polymer Coated Calcium Nitrate, Polymer Coated Monoammonium Phosphate, Polymer Coated Urea**

**** 3.195% slow release PHOSPHATE derived from Polymer Coated Monoammonium Phosphate**

***** 8.01% slow release POTASH derived from Polymer Coated Sulfate of Potash, Polymer Coated Sulfate of Potash-Magnesia**

Warning: ---Some crops may be injured by Application of Boron.
---This fertilizer is to be used only on soils which respond to Molybdenum. Crops high in Molybdenum are toxic to ruminants.

Density - 46 lb./(cu. ft.)

CAUTION MAY CAUSE STAINS ON CONCRETE

Directions for Use

It is a violation of Federal Law to use this product in a manner inconsistent with its labeling.

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1407-0797 281407

Net Weight 50 LBS

Rootstock Data from 5-year old trees in the St. Helena trial - Dundee.

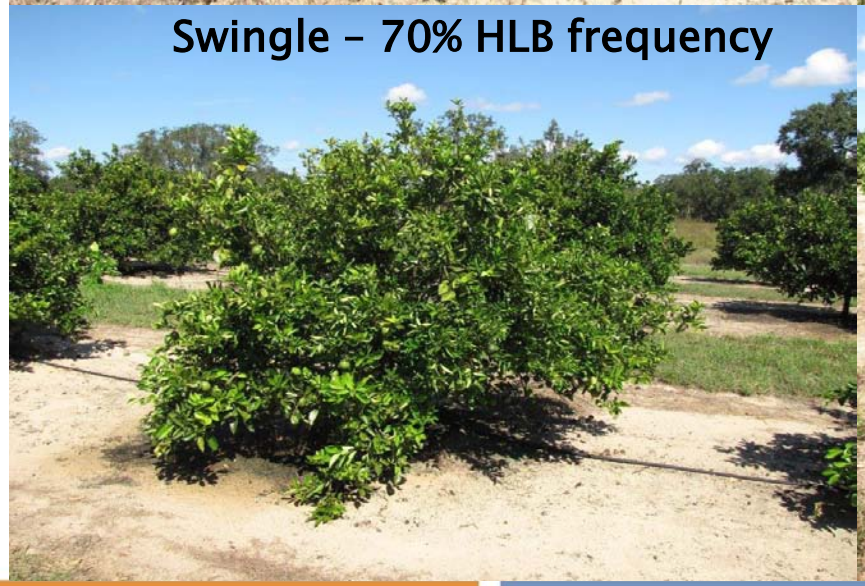
White = diploid; Orange = somatic hybrid; Blue = tetrazyg

NS = not significant fruit na = data not available * = control commercial rootstock Commercial control rootstocks in red

Scion	Rootstock	Lbs Solids/Box		Yield Boxes/Tree			Cumulative Yield (Boxes)	Tress With Symptoms as of March 2013	Number of Trees in Trial	Percentage with HLB as of March, 2013 (5 years)
		2012	2013	2011 (35 mo.)	2012 (47 mo.)	2013 (59 mo.)				
VALQUARIUS	**UFR-6** CH+50-7	5.64	5.43	0.5	0.78	1.94	3.22	25	60	42%
VERNIA	**UFR-6** CH+50-7	5.67	6.01	0.4	0.63	1.41	2.44			
VALQUARIUS	**UFR-1** ORANGE 3	5.5	4.87	NS	0.72	2.23	2.95	15	60	25%
VERNIA	**UFR-1** ORANGE 3	5.61	6.28	0.31	0.67	1.33	2.31			
VERNIA	**UFR-2** ORANGE 4	5.47	5.93	0.35	0.25	1.38	1.98	22	73	30%
VALQUARIUS	**UFR-2** ORANGE 4	4.57	5.37	NS	0.75	1.73	2.48			
VALQUARIUS	**UFR-3** ORANGE 15	4.84	5.05	NS	0.81	1.97	2.78	6	43	14%
VERNIA	**UFR-3** ORANGE 15	5.46	5.82	0.37	0.38	1.82	2.57			
VERNIA	**UFR-4** ORANGE 19	5.79	6.07	0.54	0.71	1.73	2.98	30	129	23%
VALQUARIUS	**UFR-4** ORANGE 19	4.65	5.07	NS	0.65	1.59	2.64			
VALQUARIUS	**UFR-5** WHITE 4	5.76	5.72	0.33	0.56	1.80	2.69	20	72	28%
VERNIA	**UFR-5** WHITE 4	5.89	5.34	0.42	0.25	1.93	2.60			
VALQUARIUS	**UFR-13** FG 1731	5.83	6.81	NS	0.68	2.20	2.88	1	5	20%
VALQUARIUS	**UFR-14** FG 1733	5.12	5.63	NS	0.67	2.77	3.44			
VERNIA	SWINGLE*	5.11	5.79	0.33	0.85	1.08	2.26	14	20	70%
VALQUARIUS	SWINGLE*	NS	5.61	NS	NS	1.50	1.50			
VERNIA	CLEO*	4.79	5.51	NS	0.50	0.83	1.33	6	16	38%
VALQUARIUS	CLEO*	NS	5.21	NS	NS	1.7	1.7			
VERNIA	R. LEMON*	3.67	na	NS	0.78	na	0.78	12	18	67%
VALQUARIUS	VOLK*	NS	4.12	NS	NS	2.58	2.58	18	20	90%
VERNIA	VOLK*	3.6	4.73	0.4	1.13	0.83	2.36			
VALQUARIUS	KUHARSKE*	NS	5.75	NS	NS	2.2	2.2	56	65	86%
VERNIA	KUHARSKE*	4.34	5.83	0.15	0.75	1.08	1.98			









HLB-infected trees in the St. Helena Project -differences in infection frequency & disease severity

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St. Helena Project, Dundee (C/) Orie Lee– Projected Cummulative PS/Acre – 2011-2015
Top 25 combinations. Trees 7-years old in April, 2015; now 95% infected with HLB.

Scion	Rootstock	Tree Width	OptimalTrees/ acre	Boxes/ acre 2014	Boxes/ acre 2015	PS / Acre 2014	PS / Acre 2015	Cumulative PS / Acre	% change in yield 2014-2015
Valquarius	UFR-13	8.3	264.0	528.0	628.3	3373.9	3795.1	12170.8	19.0
Vernia	Blue1	7.6	285.6	462.7	517.0	2461.8	2946.9	10311.2	11.7
Valquarius	Cleo+CZO	8.4	258.1	467.2	709.9	2280.0	4223.7	10107.9	51.9
Vernia	Chang+Bent	6.9	316.8	456.2	377.0	3015.4	2062.1	10072.2	-17.4
Valquarius	Org14	7.8	281.0	373.8	539.6	1767.9	3264.5	9804.3	44.4
Vernia	Cleo+CZO	7.8	281.0	368.2	359.7	2260.5	2305.8	9343.6	-2.3
Valquarius	UFR-1	8.9	243.7	441.1	750.6	2064.3	3662.8	9338.6	70.2
Valquarius	Org13	8.4	260.1	390.1	455.1	2305.4	2676.0	9296.4	16.7
Vernia	Aqua1803	10.3	211.2	329.5	528.0	2032.8	3231.4	9086.2	60.3
Valquarius	Aqua1803	9.1	238.7	496.5	386.7	2675.9	2026.1	8943.2	-22.1
Valquarius	UFR-14	10.0	217.8	326.7	435.6	1793.6	2940.3	8877.6	33.3
Valquarius	White1805	11.0	198.0	469.3	445.5	2266.5	2619.5	8854.0	-5.1
Valquarius	SO+50-7	5.8	378.8	424.2	473.5	2511.5	2528.4	8850.8	11.6
Valquarius	AMB+HBJL1	7.3	300.4	225.3	375.5	1198.7	1971.5	8637.7	66.7
Vernia	Purple4	7.0	311.1	448.0	348.5	2822.7	2317.4	8562.7	-22.2
Vernia	Blue2	7.4	292.8	348.5	421.7	2188.5	2715.7	8470.6	21.0
Vernia	Amb+HBJL-2B	7.9	274.4	332.0	354.0	2058.5	2297.3	8357.5	6.6
Vernia	WGFT+50-7	8.2	266.0	348.5	415.0	2272.1	2444.3	8231.5	19.1
Valquarius	FG1709	7.9	276.7	368.1	462.2	2248.9	2689.8	8189.9	25.6
Valquarius	Blue9	8.3	264.0	264.0	594.0	1380.7	3326.4	8171.5	125.0
Valquarius	UFR-5	8.5	256.0	350.7	384.0	1971.0	2185.0	8104.1	9.5
Valquarius	UFR-6	8.4	258.1	291.7	338.2	1636.4	1829.4	8048.2	15.9
Vernia	Blue4	7.5	292.0	274.5	341.7	1669.0	1875.7	8016.8	24.5
Valquarius	Org2	7.2	303.0	303.0	369.7	1875.7	2170.1	8013.2	22.0

St. Helena Project – Dundee, FL (C/O Orie Lee) – Comparison of UFR-Fast Track released Rootstocks versus Commercial Control Rootstocks after 7 years.

Scion	Rootstock	Tree Width	OptimalTrees/ acre	Boxes/ acre 2014	Boxes/ acre 2015	PS / Acre 2014	PS / Acre 2015	Cumulative PS / Acre	% change in yield 2014-2015
Valquarius	UFR-13	8.3	264.0	528.0	628.3	3373.9	3795.1	12170.8	19.0
Valquarius	UFR-1	8.9	243.7	441.1	750.6	2064.3	3662.8	9338.6	70.2
Valquarius	UFR-14	10.0	217.8	326.7	435.6	1793.6	2940.3	8877.6	33.3
Valquarius	UFR-5	8.5	256.0	350.7	384.0	1971.0	2185.0	8104.1	9.5
Valquarius	UFR-6	8.4	258.1	291.7	338.2	1636.4	1829.4	8048.2	15.9
Valquarius	UFR-2	9.7	225.3	338.0	500.2	1973.7	2881.1	7720.2	48.0
Vernia	UFR-4	9.8	222.0	290.8	319.6	1986.0	1796.3	7719.5	9.9
Vernia	UFR-6	8.0	274.0	274.0	298.7	1934.4	1717.3	7573.8	9.0
Vernia	UFR-5	9.4	230.8	302.3	403.9	1865.3	2366.7	7521.2	33.6
Valquarius	UFR-3	9.3	235.5	367.3	485.0	1961.5	2740.5	7503.7	32.1
Vernia	UFR-1	9.4	232.7	283.9	388.6	1876.5	2222.8	7322.1	36.9
Vernia	UFR-3	9.6	227.8	214.1	398.6	1393.8	2443.3	7182.4	86.2
Valquarius	Kuharske	11.4	191.6	216.5	478.9	1175.4	3237.3	6835.9	121.2
Valquarius	Volk	11.6	187.4	374.9	539.8	1237.1	2661.3	5890.7	44.0
Valquarius	Swingle	9.5	229.3	201.8	458.5	1246.8	2714.5	5890.6	127.3
Valquarius	Rough Lemon	10.2	213.8	239.4	395.5	1142.2	1965.7	5613.5	65.2
Vernia	UFR-2	8.8	247.1	215.0	232.3	1378.3	1226.6	5438.6	8.0
Valquarius	UFR-4	8.9	243.7	212.0	243.7	1257.2	1357.4	5315.6	14.9
Valquarius	Cleo	10.3	212.5	159.4	452.6	924.3	2507.4	5313.7	184.0
Vernia	Swingle	9.8	223.4	167.5	279.2	854.4	1549.7	5148.0	66.7
Vernia	Volk	12.3	177.8	200.9	467.6	721.3	2305.3	4703.9	132.7
Vernia	KCZ	9.8	223.4	111.7	252.4	577.4	1322.7	4178.5	126.0
Vernia	Cleo	10.8	202.6	178.3	228.9	939.6	1204.2	3555.7	28.4

Commercial Rootstocks at St.Helena – Yield Increase (all HLB-positive trees)

Scion	Rootstock	lbs. solids 2014	boxes/ tree 2014	lbs. solids 2015	boxes/ tree 2015	% increase in yield
Valquarius	Volkameriana	3.30	2	4.93	2.88	44.00
Valquarius	Swingle	6.18	0.88	5.92	2.00	127.27
Valquarius	Rough Lemon	4.77	1.12	4.97	1.85	65.18
Valquarius	Cleopatra	5.80	0.75	5.54	2.13	184.00
Vernia	Swingle	5.10	0.75	5.55	1.25	66.67
Vernia	Volkameriana	3.59	1.13	4.93	2.63	132.74
Vernia	Kuharske	5.17	0.50	5.24	1.13	126.00
Vernia	Cleopatra	5.27	0.88	5.26	1.13	28.41

Ground-Applied Nutrition Matters!

Bulk Yield Data – St. Helena Trial – Dundee, Florida
Valquarius and Vernia/>50 rootstocks

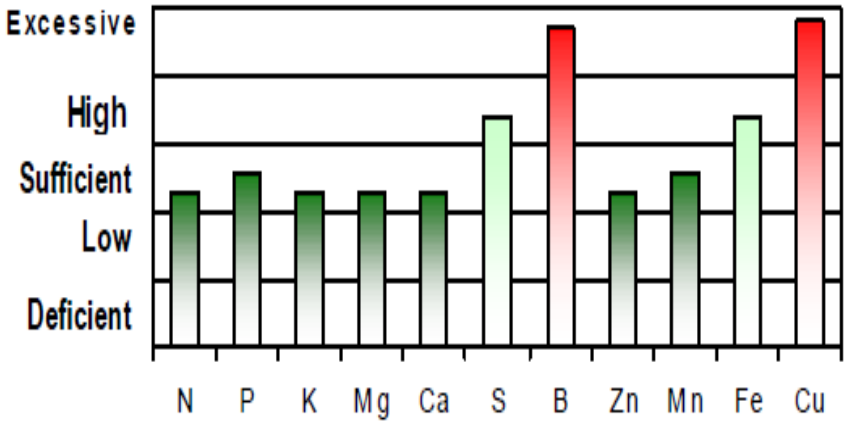
Year	%HLB	# Boxes	Ave. lbs. Solids	% change
2013	26%	2705	N/A	-
2014	59%	2218	5.44	-18%
2015	92%	3140	5.67	**+42%**

Probable reasons for 2015 yield increase:

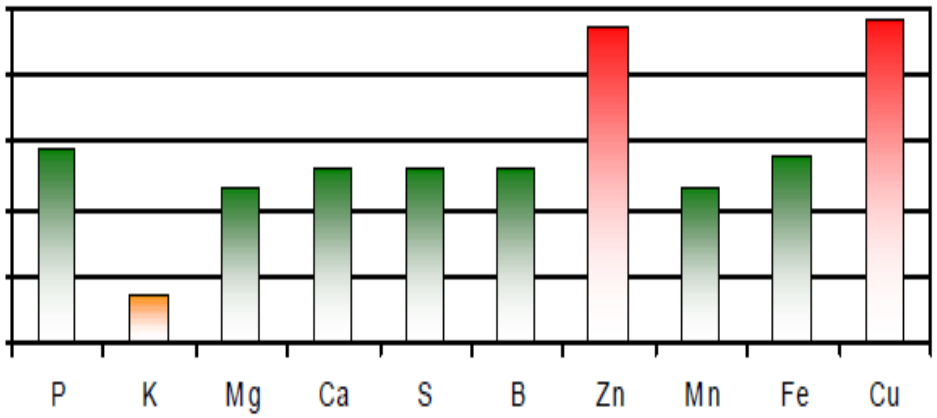
1. Addition of TigerSul Micros to UF Harrell's CRF + increased manganese and boron
2. Change to Rouse #7 foliar program
3. Alternate bearing effect
4. Earlier harvest

Nutritional Analysis – St. Helena – August 2015 – C/O Lykes Corp.

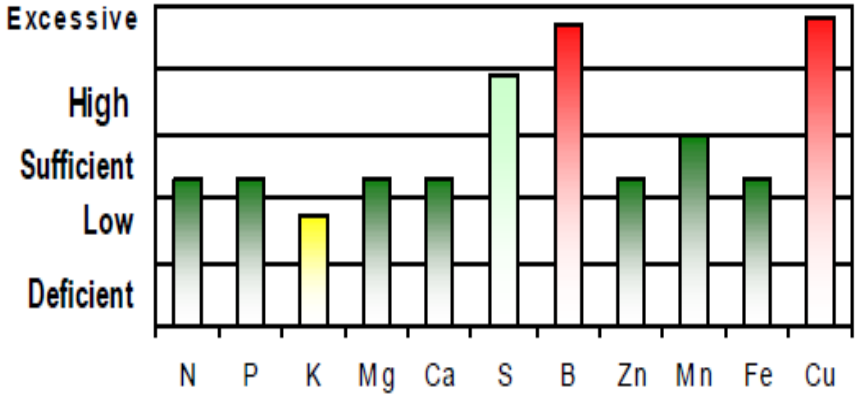
Plant Rating



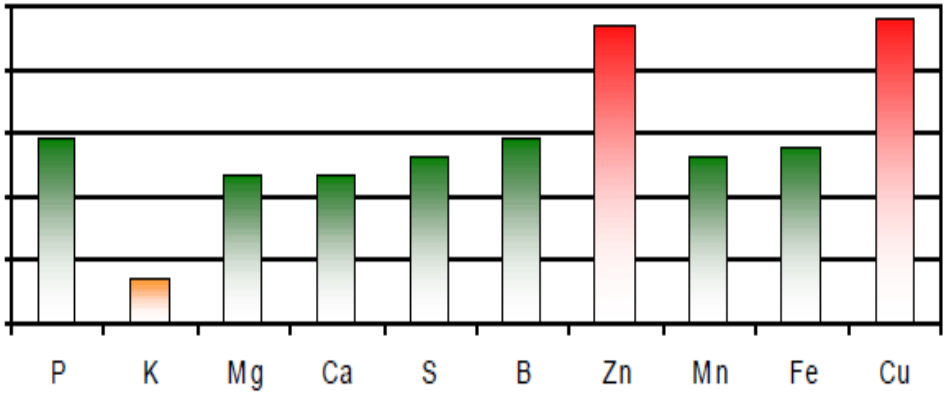
Soil Rating



Plant Rating



Soil Rating



My interpretation of the results:

1. Foliar nutrition of HLB trees is important, but providing proper nutrition to the roots may be more important. Recommended levels of micronutrients are probably incorrect for citrus trees in the HLB world.

2. Results from the greenhouse study indicate that overdoses of micronutrients in the TigerSul (clay prill) form increase feeder root density, and thus overall tree growth. Manganese appears to be the most important micronutrient in this regard.

3. There is an apparent synergy between the TigerSul products and the Harrell's CRF. Acidification of the root zone by the slow release of the sulfate could be increasing the efficiency of CRF nutrient uptake by the roots – leading to improved tree health.

4. In the field, the addition of TigerSul micros with increased manganese, zinc, iron and boron contributed to a 42% yield increase from 6.5 year old trees (92% HLB-infected) in the St. Helena rootstock trial.

5. There is clearly a tolerance/genetics/nutrition interaction.

Practical Considerations and Questions

1. A 100% CRF program on mature trees is quite expensive. Hybrid programs combining traditional dry fertilizer + CRF can improve the economics and are proving successful in some commercial operations (Duda, etc.). Significant improvements in tree health and cost efficiency are possible with additional fine-tuning.

2. Anecdotal evidence suggests that applications of CRF (**including overdoses of TigerSul micros and poly-coated sodium borate**) can 'freeze' the disease and allow for tree recovery in many cases.

3. An optimal CRF program should be tested with tree recovery following thermotherapy – this could bring trees back into production more quickly and extend their productivity.

4. Can such CRF programs slow the effects of HLB and improve overall tree health if implemented at the time of planting??? Research is underway to determine this.

5. WE STILL HAVE A LOT TO LEARN ABOUT HLB AND NUTRITION!



Typical fruit from young HLB-infected (3 years) LB8-9 SugarBelle™ trees treated with controlled release fertilizer containing extra manganese and boron, and Tiger-Sul micros.



Typical fruit from young HLB-infected (3 years) LB8-9 SugarBelle™ trees with standard fertilization regime.





February, 2015

August, 2015

OLL-7 sweet orange top-worked to HLB-compromised Valencia/Swingle, Grown back with Harrell's UF mix + TigerSul micros CRF and extra TigerSul manganese and Florikan polycoated sodium borate – 2.5 years. Alligator Grove , St. Cloud, FL, C/O Orie Lee

Take care of your ROOTS!

- Constant supply of nutrients – no gaps!

- Fertigation – good minor package; backup with CRF in case of flooding or breakdown

- Overdoses of specific micronutrients may be helpful i.e. manganese and boron in CRF form or frequent applications

- Do not overdose micronutrients in soluble forms – could lead to TOXICITY!

- This is not a one-time deal – it requires a commitment to a new way of doing business!

To HALL OF FAME CITRUS GROWER-RESEARCHER
and Outstanding Industry Collaborators: Mr. Orie Lee

Funding: Mr. Orie Lee, Citrus Variety Improvement Grants from the Citrus Research and Development Foundation (CRDF) , USDA/CSREES; and the Citrus Research and Education Foundation (CREF).

Thanks also to: Chuck Dunning, Mauricio Rubio, Ralph 'Chandler' Story, Paul Ling, Frank Rogers and especially Troy Gainey and the CREC Grove Crew (including our scouts!).

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Thanks!



UF-CREC Citrus Genetic Improvement Team
2015

Field Trials-Nutritional Products Evaluation

Tripti Vashisth, Arnold Schumann, Kelly Morgan

Mongi Zekri, Chris Oswalt, Steve Futch, Gary England, Cami McAvoy, Laurie Hurner, Parker Platts

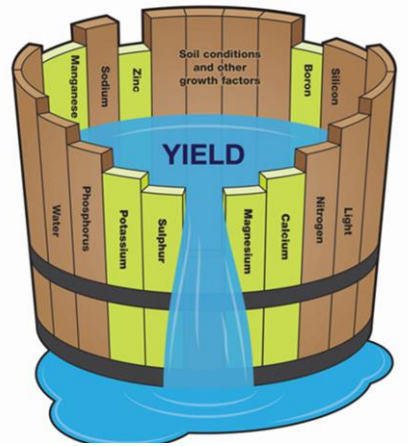
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Outline

- Fertilization –things to remember
- Suggestions for how to set up a product evaluation field trials
- Things to keep in mind
- NEW IFAS-Growers field trials
- Conclusion

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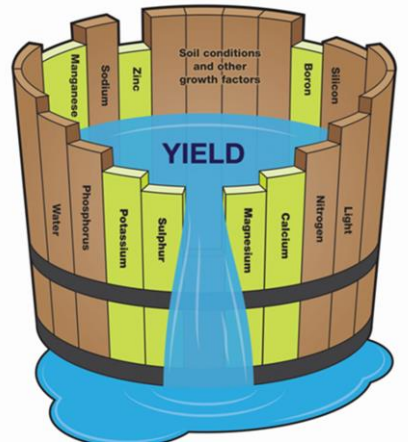
Fertilization- *ABC*



- Plant mineral nutrition is very important for a healthy and productive tree
- When considering a nutritional program, keep in mind:
  - ✓ *A- All*
  - ✓ B- Balance
  - ✓ C- Constant

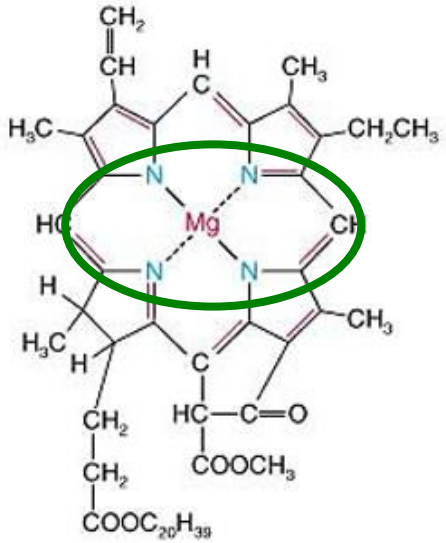
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Fertilization- ABC

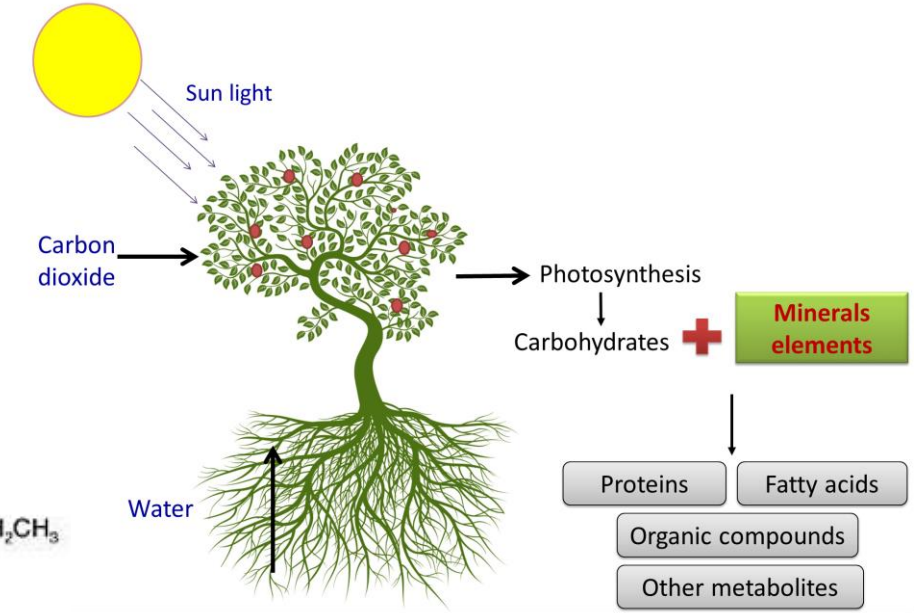


- ✓ All- 17 essential elements
- ✓ There are 14 mineral nutrients that are recognized as essential for normal plant growth and development

Example- Chlorophyll is critical for photosynthesis

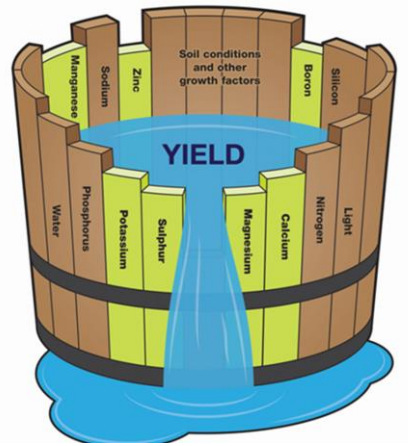


Structure of chlorophyll
Magnesium
Nitrogen



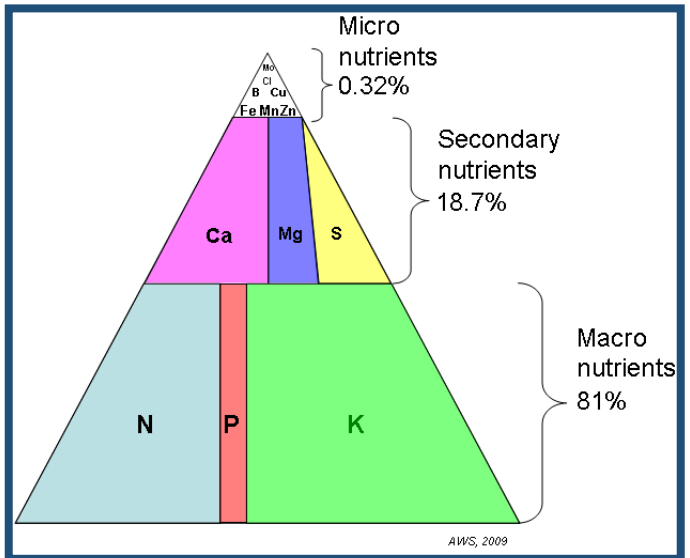
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Fertilization- ABC



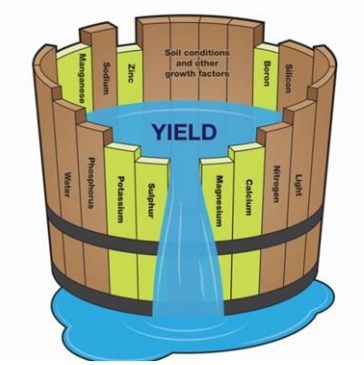
- ✓ All- 17 essential elements
- ✓ Balance is ESSENTIAL!!

Any nutritional deficiency or toxicity hinders plant metabolism and results in a weakened plant, which lowers disease resistance



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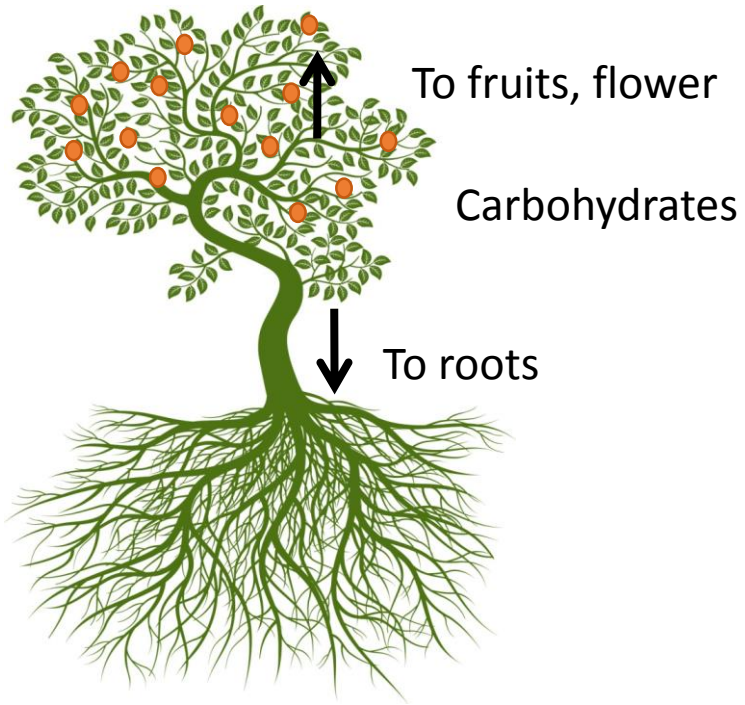
Fertilization- ABC

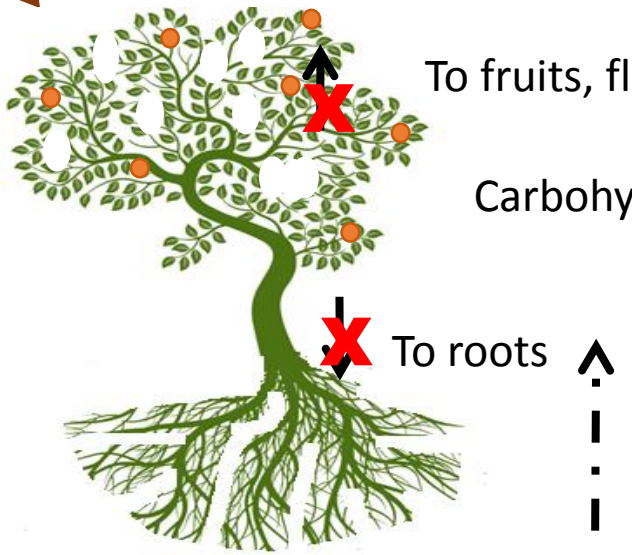


- ✓ All Balance
- ✓ **Constant** Reduced root & shoot system requires continuous supply of nutrient



Asian citrus psyllid feeds on leaf → Transmits bacteria → CLas thrives in phloem → Phloem plugging → Tree growth arrests and decline



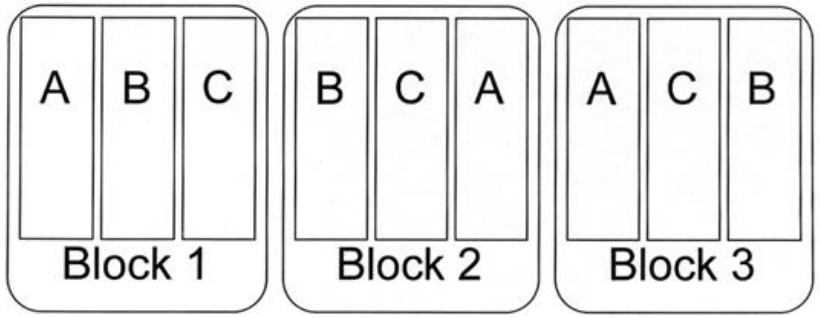


Root loss
Water
+
minerals uptake reduces

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Setting Up a Product Evaluation Field Trial

- Have a specific question. Why?
- Nutritional product or soil amendment?



- Check the complete formulation of products to be evaluated
- Always have a control, negative and positive
- The control & treatment blocks should be next to each other
- Replication is necessary because all test plots are not identical

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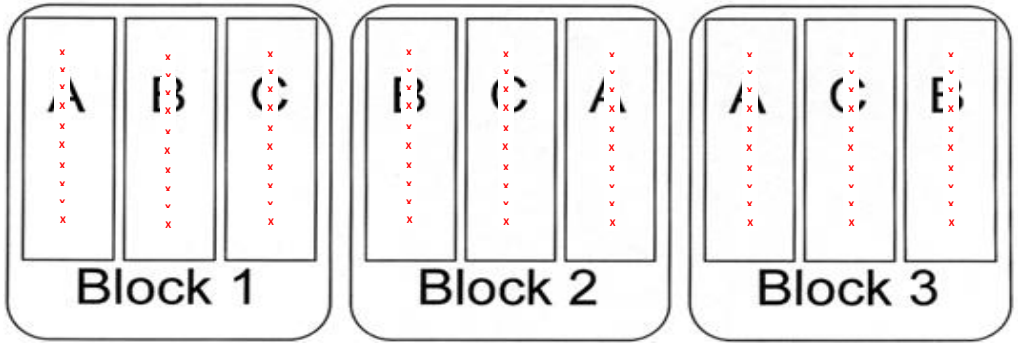
Things to Consider...

- Pre-treatment assessment is CRITICAL
- The overall block health should be comparable
- Tree age , Scion/Rootstock, Tree spacing/density
- Soil type and pH
- Irrigation scheduling and Water quality
- Nutrition program (foliar and soil applied)
- Psyllid and other pest control
- Check yields and quality from previous years

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Suggested Protocol for Evaluation

- Mark 10 trees in control & treatment for data collection
- Very important to collect data prior to treatments and possibly every 6 months
  - ✓ Visual Disease Index
  - ✓ Photographs
  - ✓ Leaf and Soil Nutrient Analysis
  - ✓ Trunk Diameter, Canopy Volume (height and diameter) and Density
  - ✓ Fruit Drop
  - ✓ Fruit Yield and Quality



http://citrusrdf.org/wp-content/uploads/2015/04/Field-Trial-Evaluation-Methods-for-Growers.pdf

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IFAS-Growers Field Trials: Goal

- To evaluate nutrition products with potential to improve tree health
- Establish field trails throughout the state, multiple sites to test the products in a broad range of conditions
- Develop a database of results to assist growers in decision making for nutritional program

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IFAS-Growers Field Trials: Objective

Evaluation of promising nutritional products at multiple sites with same evaluation protocol will help in scrutinizing the effectiveness of product in improving citrus tree health and productivity

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Products for Field Trials

1. Tiger Micronutrient Mix

   (Mn-Zn-Fe-B: 6-6-2-1)

2. Controlled Release Fertilizer- Harrell's & Everris

   (N-P-K- Ca-Mg-Fe:12-4-14-9.5-2.5-0.25)

3. Foliar Nutritional Sprays

   Sulfates vs Glucoheptonates (Chelated) vs Nitrates

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IFAS-Growers Field Trials

- Growers are encouraged to participate in the trials
- Potential sites characteristics
  - Scion/Rootstock: Valencia/Swingle or Hamlin/Swingle
  - Tree age: 10-15 year
  - Block size and experimental design will be customized for each site
- Control will be growers choice or standard grove program

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IFAS-Growers Field Trials

- Each site will be evaluated & experiment will be customized as per the site
- Same formulation at all sites throughout the state
- Trials will be evaluated for at least two years
- Growers will be responsible for obtaining the products & application
- IFAS will be responsible for data collection and cost associated with the analysis

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IFAS-Growers Field Trials

- Data will be collected prior to treatments & then at every 6 months after product application
- Data collected will be:
  - ✓ Visual Disease Index
  - ✓ Photographs
  - ✓ Leaf and Soil Nutrient Analysis
  - ✓ Trunk Diameter, Canopy Volume (height and diameter) and Density
  - ✓ Fruit Drop
  - ✓ Fruit Yield and Quality

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IFAS-Growers Field Trials: What to Expect?

- Trials will be setup at CREC groves at two locations- Central Ridge and Lake Placid groves
- All the data collected each site and trial will be updated on a website & accessible to everyone and anytime

  http://www.crec.ifas.ufl.edu/extension/horticulture/citrus_nutrition/
- Citrus nutrition day will be an annual event

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IFAS-Growers Field Trials: Benefits

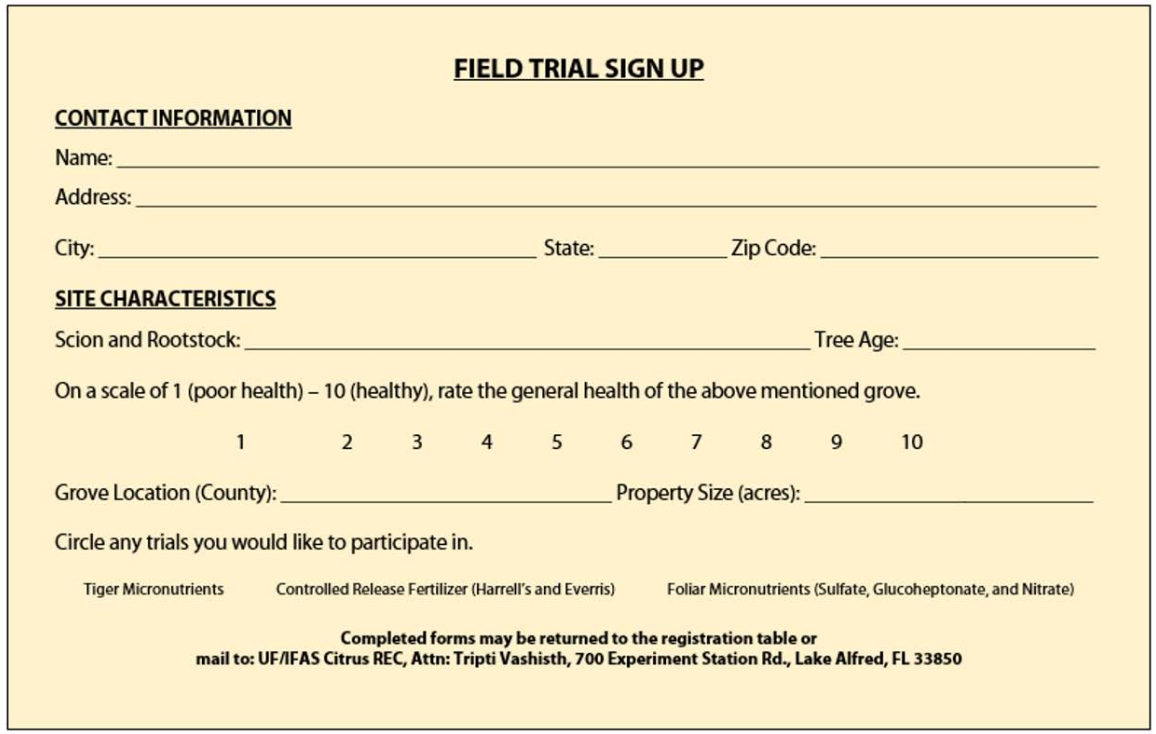
- TIME IS OF THE ESSENCE –Trials will help in collecting data fast
- Products evaluated at multiple sites by same protocol
- Trials will help to determine the promising products
- Data collected will be accessible to everyone and can be used for decision making

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Conclusion

- If interested in the field trials- Please sign up the yellow form provided
- We will contact you shortly
- The website will be updated soon
- Keep the evaluation protocol same

Questions, contact:
Dr. Tripti Vashisth
Assistant Professor, Horticultural Sciences
CREC, Lake Alfred
tvashisth@ufl.edu
863-956-8846



FIELD TRIAL SIGN UP

CONTACT INFORMATION

Name: _____

Address: _____

City: _____ State: _____ Zip Code: _____

SITE CHARACTERISTICS

Scion and Rootstock: _____ Tree Age: _____

On a scale of 1 (poor health) – 10 (healthy), rate the general health of the above mentioned grove.

1 2 3 4 5 6 7 8 9 10

Grove Location (County): _____ Property Size (acres): _____

Circle any trials you would like to participate in.

Tiger Micronutrients | Controlled Release Fertilizer (Harrell's and Everris) | Foliar Micronutrients (Sulfate, Glucoheptonate, and Nitrate)

Completed forms may be returned to the registration table or mail to: UF/IFAS Citrus REC, Attn: Tripti Vashisth, 700 Experiment Station Rd., Lake Alfred, FL 33850

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Thank you!!

- Dr. Michael Rogers
- Jamie Burrow
- Sarah White, Jen Dawson, Taylor Livingston, Brandon Page, Steve Futch, Andrew Persaud, Kathy Snyder, Cindy Basnaw, Jean Coggins
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SL 200

Plant Nutrients for Citrus Trees[1]

Mongi Zekri and Thomas A. Obreza[2]

Introduction

Seventeen elements are considered necessary for the growth of green plants: carbon (C), hydrogen (H), oxygen (O), 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). These elements are commonly referred to as essential plant nutrients. An element is considered essential if a plant cannot complete its life cycle without it, and if the problem that develops in its absence is curable only by its addition. Plants obtain C, H, and O from carbon dioxide and water. The remaining elements, called the "mineral nutrients," are obtained from the soil.

Mineral nutrients are classified as *macronutrients* and *micronutrients*. The term "macronutrients" refers to those elements that plants require in large amounts (N, P, K, Ca, Mg, S). The term "micronutrients" applies to plant nutrients that are essential to plants but are needed only in small amounts (Fe, Zn, Mn, B, Cu, Mo, Ni, Cl). The use of the terms "minor element" or "trace element" for some of the nutrients can be 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 "micronutrients" and "macronutrients" is more appropriate.

Macronutrient Functions in Plants

Nitrogen (N)

Nitrogen is of special importance because plants need it in large amounts. It is also easily lost from soil and fairly expensive to supply. A major factor in successful farming is the grower's ability to manage N efficiently. Nitrogen has numerous functions in plants, and essentially all life processes depend on it. Nitrogen occurs chiefly in amino acids, proteins, and sugars. The most active nitrogenous compounds occur largely in the protoplasm and nuclei of plant cells. Among them are the enzymes that speed up biological processes.

An abundant supply of essential N compounds is required in each plant cell for normal cell division, growth, and respiration. Even the green leaf pigment chlorophyll, which enables plants to use the energy of sunlight to form sugars from carbon dioxide and water, is a nitrogenous compound. A high concentration of N is found in young, tender parts of plant tissues like tips of shoots, buds, and new leaves. The N, present mostly as protein, is constantly moving and undergoing chemical changes. As new cells form, much of the protein moves from older cells to newer ones, especially when the total N content of the plant is low.

The proper functioning of N in plant nutrition requires that the other essential elements, particularly P, K, Ca, and Mg, be present in adequate supply. If the supply of one or more of them is inadequate, the addition of N to most common crops may not produce optimum growth. Such plants

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2. Mongi Zekri, multi-county citrus agent, Hendry County; and Thomas A. Obreza, professor, Soil and Water Science Department, UF/IFAS Extension, Gainesville, FL 32611.

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often are susceptible to disease, mature late, and produce poor-quality fruit. However, if the nutrient balance and total supply are adequate, significant growth of dark green foliage will occur. Nitrogen is the mineral element used most by citrus trees to produce leaves, flowers, and fruit, although Ca and K are also used in great amounts.

Nitrogen is the key component in mineral fertilizers applied to citrus groves; it has more influence on tree growth, appearance, and fruit production/quality than any other element. Nitrogen affects the absorption and distribution of practically all other elements and appears to be particularly important to the tree during flowering and fruit set.

For more information on N deficiency, see SL 201, Macronutrient Deficiencies in Citrus: Nitrogen, Phosporus, and Potassium.

Phosphorus (P)

Phosphorus is present in all living tissue. It is particularly concentrated in the younger parts of the plant, in the flowers, and in the seeds. Phosphorus is necessary for many life processes such as photosynthesis, synthesis and breakdown of carbohydrates, and the transfer of energy within the plant. It helps plants store and use energy from photosynthesis to form seeds, develop roots, speed maturity, and resist stresses. Phosphorus is involved in nutrient uptake and translocation. It is a major part of the cytoplasm and the nucleus of cells, where it is involved in the organization of cells and the transfer of heredity characteristics. Phosphorus is also important for cell division and enlargement, thus plant growth is reduced when the supply of P is too low.

For more information on P deficiency, see SL 201, Macronutrient Deficiencies in Citrus: Nitrogen, Phosporus, and Potassium.

Potassium (K)

Citrus fruits remove large amounts of K compared with other nutrients. Potassium moves from leaves to fruit and seeds as they develop. Potassium is necessary for several basic physiological functions like the formation of sugars and starch, synthesis of proteins, normal cell division and growth, and neutralization of organic acids. Potassium is important in fruit formation and enhances fruit size, flavor, and color. It helps reduce the influence of adverse weather conditions like drought, cold, and flooding.

Potassium is known to influence many enzymatic reactions and is associated with almost every major plant function. Potassium helps regulate the carbon dioxide supply to plants by controlling stomata opening and closing. It improves the efficiency of plant water and sugar use for maintenance and normal growth functions. It moves sugars from the site of photosynthesis to other storage sites. Potassium works with P to stimulate and maintain rapid root growth of plants. It stimulates the synthesis of protein from amino acids. Potassium improves plant health and resistance to disease and tolerance to nematodes and insects.

The rate of photosynthesis drops sharply when plants are K deficient. Too much N with too little K can result in a back-up of the protein building blocks, set the stage for disease problems, reduce production of carbohydrates, reduce fruiting, and increase fruit creasing, plugging and drop. A shortage of K can result in lost crop yield and quality. Moderately low plant K concentrations will cause a general reduction in growth without visual deficiency symptoms. The onset of visual deficiency symptoms means that production has already been seriously impaired.

For more information on K deficiency, see SL 201, Macronutrient Deficiencies in Citrus: Nitrogen, Phosporus, and Potassium.

Calcium (Ca)

Calcium resides mainly in plant leaves. Calcium is an important element for root development and functioning and is an important constituent of cell walls. It is required for chromosome stability and cell division. Calcium activates several enzyme systems and neutralizes organic acids in plants. Plant growth and fruit yield can be reduced by inadequate Ca supply long before deficiency symptoms become evident.

For more information on Ca deficiency, see SL 202, Macronutrient Deficiencies in Citrus: Calcium, Magnesium, and Sulfur.

Magnesium (Mg)

Magnesium is the center of the chlorophyll molecule. It is involved in photosynthesis and plays an important role as an activator of several enzymes. It is also involved in carbohydrate metabolism and synthesis of nucleic acids. Magnesium influences the movement of carbohydrates from the leaves to other parts of the tree and also stimulates P uptake and transport.

For more information on Mg deficiency, see SL 202, Macronutrient Deficiencies in Citrus: Calcium, Magnesium, and Sulfur.

Sulfur (S)

Many plants use about as much S as they do P. Sulfur is an essential constituent of many proteins. Sulfur is important for the production of amino acids, proteins, and chlorophyll, and is a constituent of vitamins and some plant hormones. Protein synthesis is retarded in S-deficient plants. Sulfur enhances the development of nodules and N fixation by legumes. It improves root growth and promotes vigor and hardiness. Sulfur also affects carbohydrate metabolism.

For more information on S deficiency, see SL 202, Macronutrient Deficiencies in Citrus: Calcium, Magnesium, and Sulfur.

Micronutrient Functions in Plants

Functions of iron (Fe)

- Catalyzes the production of chlorophyll.
- Involved in some respiratory and photosynthetic enzyme systems.
- Involved in the reduction of nitrates and sulfates.

For more information on Fe deficiency, see See SL 204, Micronutrient Deficiencies in Citrus: Iron, Zinc, and Manganese.

Functions of zinc (Zn)

- Involved in plant carbon metabolism.
- A necessary component of several enzyme systems that regulate various metabolic activities within plants.
- Part of an enzyme that regulates the equilibrium among carbon dioxide, water, and carbonic acid.
- Part of two enzymes that play a role in protein metabolism.
- Essential for the formation of chlorophyll and function of normal photosynthesis.
- Needed to form auxins, which are growth-promoting substances in plants.
- Associated with water relations in plants and improves water uptake.

For more information on Zn deficiency, see See SL 204, Micronutrient Deficiencies in Citrus: Iron, Zinc, and Manganese.

Functions of manganese (Mn)

- Involved in the production of amino acids and proteins.
- An activator of several enzymes.
- Plays an essential role in respiration and N metabolism.
- Necessary for the reduction of nitrates and helps make them usable by plants.
- Plays a role in photosynthesis and in the formation of chlorophyll.

For more information on Mn deficiency, see See SL 204, Micronutrient Deficiencies in Citrus: Iron, Zinc, and Manganese.

Functions of boron (B)

- Important in sugar translocation and carbohydrate metabolism.
- Particularly needed at the location of active cell division.
- Plays an important role in flowering, pollen-tube growth, fruiting processes, N metabolism, and hormone activity.
- Maintains Ca in a soluble form, thus insuring its proper utilization.
- Deficiencies may be aggravated by severe drought conditions, heavy lime applications, or irrigation with alkaline water.

For more information on B deficiency, see See SL 203, Micronutrient Deficiencies in Citrus: Boron, Copper, and Molybdenum.

Functions of copper (Cu)

- Part of several enzyme systems.
- Has a role in photosynthesis and chlorophyll formation.
- May have an important function in root metabolism. (Cu appears to be concentrated more in the rootlets of plants than in leaves or other tissues. Cu in citrus fibrous roots may be 5 to 10 times greater than in leaves.)
- Regulates several biochemical processes within the plant.
- Important in the utilization of proteins in the growth processes of plants. (The photosynthesis rate of Cu-deficient plants is abnormally low.)
- May also be involved in oxidation-reduction reactions in plants.
- Heavy fertilization with N tends to increase the severity of Cu deficiency.

For more information on Cu deficiency, see See SL 203, Micronutrient Deficiencies in Citrus: Boron, Copper, and Molybdenum.

Functions of molybdenum (Mo)

- Assists in the formation of plant proteins.
- Helps starch, amino acid, and vitamin formation.
- Considered a catalyst that aids the conversion of gaseous N to usable forms by nitrogen-fixing microorganisms.
- A constituent of the plant enzyme that converts nitrate to ammonia.

For more information on Mo deficiency, see See SL 203, Micronutrient Deficiencies in Citrus: Boron, Copper, and Molybdenum.

Functions of chlorine (Cl)

Although the essentiality of Cl has been established for most higher plants, its need for fruit crops has not yet been demonstrated. The plant requirement for Cl is quite high as compared with other micronutrients, but its exact role in plant metabolism is still obscure. Chlorine is:

- Associated with turgor in the guard cells through the osmotic pressure exerted by imported K ions.
- Involved with oxygen production in photosynthesis.
- Involved in chlorophyll and photosynthesis because its deficiency causes chlorosis, necrosis, unusual bronze discoloration of foliage, and reduction in growth.

Functions of nickel (Ni)

Within the last decade, Ni has been established as an essential element in higher plants. Although well-defined enzymatic functions are known to be associated with Ni in legumes, apparently the need for Ni exists in other plants as well. No one has ever seen a Ni deficiency in soil-grown plants.

Summary

Nutrient availability directly affects how well plants grow and produce. A sufficient supply of all nutrients is critical to nutrient management and sustainability. If a single essential element is below the critical level for availability, crop growth and yield will fall even if the other elements are in sufficient supply.

Concern for nutrient sufficiency is often confined to N, P, and K because they are needed in relatively large amounts by crops and are most often the limiting factors in crop production. However, nutrient insufficiency can go beyond N, P, and K. A balance of a sufficient supply of nutrients is a key component to profitability. Plant nutrients interact positively when properly balanced. For example, in the case of N fertilization, a shortage of another nutrient could decrease N uptake, reduce N use efficiency and returns on investment, and increase the potential for N loss.

Balanced nutrition of plants should be a high priority management objective for every citrus grower. Plants require a balanced nutrition program formulated to provide specific needs for maintenance and for expected production performance. Properly nourished fruit trees or plants grow stronger, produce more consistently, have better disease resistance, and are more tolerant to stresses.

For most macronutrients, soil application is still recommended because of the large quantities required. However, fertilizer applications to the soil are subject to various fates including leaching, runoff, and fixation to forms not available to plants. Therefore, foliar application should be considered as a possible supplement to soil application for some nutrients. Foliar application of N, K, Mg, Zn, Mn, and B has several positive attributes. It is of significant 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 growth. It is proven to be useful under prolonged spells of wet or dry soil conditions, calcareous soil, or cold weather, which decrease the plant's ability to take up nutrients when there is a demand. Foliar application can reduce overall fertilizer application rates and energy use, and can improve the uptake efficiency of micronutrients because they are directly absorbed into the leaves. Foliar application is the quickest method of getting nutrients into plants over the short term when a nutritional deficiency is diagnosed, but should not be relied upon for long-term tree nutrition. Foliar feeding may also become a best management practice that can help reduce groundwater contamination concerns.

It should be kept in mind that foliar feeding is not intended to completely replace soil-applied macronutrient fertilization. Furthermore, there is a perception that foliar spray of macronutrients is more expensive because several applications are required to satisfy plant needs and maintain high yield. On the other hand, foliar applications of micronutrients are more effective than soil applications with the exception of Fe. Foliar micronutrient (Zn, Mn, Cu, B) sprays provide a more rapid response and are easier to apply, but the effect does not last as long as that of soil

application. Soil applications of Fe chelates still offer the most effective means of correcting Fe deficiency.

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.

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SL378

Nitrogen (N) for Citrus Trees[1]

Mongi Zekri and Tom Obreza[2]

This publication is part of a series about understanding nutrient requirements for citrus trees. For the rest of the series, visit http://edis.ifas.ufl.edu/topic_series_citrus_tree_nutrients.

To maintain a viable citrus industry, Florida growers must consistently and economically produce large, high-quality fruit crops from year to year. Efficiently producing maximum yields of high-quality fruit is difficult without understanding soil and nutrient requirements of bearing citrus trees. Most Florida citrus is grown on soils inherently low in fertility with low cation exchange capacity (CEC) and low water-holding capacity, thus soils are unable to retain sufficient quantities of available plant nutrients against leaching caused by rainfall or excessive irrigation.

Seventeen elements are considered necessary for the growth of green plants: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), manganese (Mn), zinc (Zn), iron (Fe), copper (Cu), boron (B), chlorine (Cl), molybdenum (Mo), and nickel (Ni). Plants obtain C, H, and O from carbon dioxide and water. The remaining elements, called the "mineral nutrients," are obtained from the soil. Mineral nutrients are classified as *macronutrients* and *micronutrients*. The term "macronutrients" refers to those elements that plants require in large amounts (N, P, K, Mg, Ca, and S). The term "micronutrients" applies to plant nutrients that are essential to plants but are needed only in small amounts (Mn, Zn, Fe, Cu, B, Cl, Mo, and Ni). This publication reviews the nitrogen (N) requirements of citrus trees.

Introduction

Meeting the world's escalating food needs cannot be achieved without fertilizer input. Without fertilizer, the world would produce only about half as much food, and more forested and marginal lands would have to be put into production. Inorganic commercial fertilizer plays a critical role in the world's food security, and it is important from both yield and food quality perspectives. Intensifying production and increasing yield on limited arable land are clearly important to secure a sufficient food supply, and fertilizer plays a critical role in these goals. Intensifying production is increasingly essential to meet the challenge of future food demands. However, this intensification must be done while also minimizing environmental impacts. The 4R Nutrient Stewardship Framework (i.e., right fertilizer source, right rate, right time, and right place) is therefore very important.

Nitrogen Functions

Nitrogen (N) is of special importance because plants need this nutrient in large amounts. Nitrogen is also easily lost from soil and fairly expensive to supply. A major factor in successful farming is the grower's ability to manage N efficiently. Nitrogen has numerous functions in plants, and essentially all life processes depend on this nutrient. Nitrogen occurs chiefly in amino acids, proteins, and enzymes. The most active nitrogenous compounds occur largely in the protoplasm and nuclei of plant cells. Among them are the enzymes that speed up biochemical processes.

1. This document is SL378, one of a series of the Department of Soil and Water Science, UF/IFAS Extension. A version of this article was previously published in Citrus Industry magazine. Original publication date: July 2013. Visit the EDIS website at http://edis.ifas.ufl.edu.

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Table 1. Guidelines for interpretation of orange tree leaf N (%) analysis based on 4- to 6-month-old spring flush leaves from non-fruiting twigs.

	Deficient	Low	Optimum	High	Excessive
N	<2.2	2.2–2.4	2.5–2.7	2.8–3.0	>3.0

An abundant supply of essential N compounds is required in each plant cell for normal cell division, growth, and respiration. Even the green leaf pigment chlorophyll, which enables plants to use the energy of sunlight to form sugars from carbon dioxide and water, is a nitrogenous compound. A high concentration of N is found in young, tender plant tissues, including shoot tips, buds, and new leaves. This N is present mostly as protein, and it constantly moves and undergoes chemical changes. As new cells form, much of the protein moves from older cells to newer ones, especially when the total N content of the plant is low. While N moving to new tissue conserves N in the plant, the overall yield and quality can be at risk because of the reduced N supply to the plant.

Proper functioning of N in plant nutrition requires a sufficient supply of other essential elements, particularly phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). If one or more of these elements is in short supply, the addition of N may not produce optimum growth. Plants experiencing poor nutrition often are susceptible to disease, mature late, and produce poor-quality fruit. However, if the nutrient balance and total supply are sufficient, significant growth of dark green foliage occurs. Nitrogen is the mineral element most used by citrus trees to produce leaves, flowers, and fruit, although Ca and K are also used in great amounts.

Nitrogen is the key component in mineral fertilizers applied to citrus groves. N has more influence on tree growth, appearance, and fruit production/quality than any other mineral element. Nitrogen affects the absorption and distribution of practically all other elements, and it is particularly important to the tree during flowering and fruit set.

Nitrogen Deficiency

Trees grown where plant-available N is limited may appear normal but undersized. These stunted trees carry little fruit load and can be highly erratic in bearing habit. Affected trees bloom sparsely, flush irregularly, and produce limited twig and leaf growth. Severe N starvation causes a general yellowing of the foliage. This symptom can be observed particularly on well-nourished trees that have a sharp reduction in their N supply.

Nitrogen deficiency first appears on older leaves and then proceeds toward younger leaves. Deficiency symptoms are characterized by light yellowish-green leaves. The veins are only slightly lighter in color than tissue in between. New leaves are small, thin, fragile, and light green in color. Leaves on new flushes are greener than leaves on the old flushes. Mature green leaves slowly bleach to a mottled irregular green and yellow pattern, become entirely yellow, and then abscise. N-deficient trees are stunted with a thin canopy, and the crop is reduced as a result. The fruit peel tends to be smooth and pale in color, and the juice has lower soluble solids and acid concentrations. If N is deficient during the summer and fall when the fruit is expanding and maturing, some of the green leaves turn yellow and may abscise. Trees constantly short of N are stunted with irregular and very short twig growth. Twig dieback can occur, and crop production is greatly reduced.

Table 2. Effects of N on citrus fruit quality.

Variable	Rating
Juice Quality	
Juice Content	+
Soluble Solids (SS)	+
Acid (A)	+
SS/A Ratio	-
Juice Color	+
Solids/Box	+
Solids/Acre	+
External Fruit Quality	
Size	-
Weight	-
Green Fruit	+
Peel Thickness	+
Increase (+), Decrease (-)	

The ability to distinguish between N deficiency and the deficiency of other elements is very important. Symptoms of Mg deficiency at later stages can be confused with N deficiency. Growers must always remember that yellow leaves are not necessarily an indication of N deficiency. Nitrogen deficiency can be distinguished by the general nature of the yellowing of foliage throughout the entire tree with the absence of any distinctive leaf pattern. Nitrogen deficiency in Florida is most commonly observed after

flowering but before the summer rainy season begins. In many cases, the foliage of such trees becomes greener during the summer rainy season, particularly if a small crop has set. Magnesium deficiency develops in the summer and causes complete yellowing of the leaves in the fall or early winter with no possible re-greening unless Mg fertilizer is applied.



Figure 1. Nitrogen-deficient leaves.
Credits: M. Zekri



Figure 2. Magnesium-deficient leaves.
Credits: M. Zekri

The main cause of N deficiency is a lack of available N in the soil, which can be caused by a number of factors. Nitrogen leaching can occur because of heavy summer rainfall or over-irrigation on a highly porous soil or a combination of these factors. Water-logging of the soil can cause N loss through denitrification, which in turn may lead to a temporary N deficiency that is relieved by dry weather. N-deficient weak or old trees can be improved by frequently applying small doses of N fertilizer. Foliar sprays of N fertilizer sources such as low-biuret urea, calcium nitrate, or potassium nitrate are a very efficient and rapid way to correct N deficiency.

Conclusion

Supplying sufficient nutrition should be a high-priority management practice for every grower. An appropriate nutrient balance using fertilizer management is necessary to achieve sufficient plant nutrition for best fruit yield and quality. If an element is below the critical level, yield production falls even though the other elements are kept in good supply. Balanced use of plant nutrients corrects nutrient deficiencies and toxicities, improves soil fertility, increases nutrient- and water-use efficiency, enhances crop yields and fruit quality, develops tree tolerance to pests, diseases, and other stresses, and improves environmental quality.

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SL379

Phosphorus (P) for Citrus Trees[1]

Mongi Zekri and Tom Obreza[2]

This publication is part of a series about understanding nutrient requirements for citrus trees. For the rest of the series, visit http://edis.ifas.ufl.edu/topic_series_citrus_tree_nutrients.

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Introduction

Meeting the world's escalating food needs cannot be achieved without fertilizer input. Without fertilizer, the world would produce only about half as much food, and more forested and marginal lands would have to be put into production. Inorganic commercial fertilizer plays a critical role in the world's food security, and it is important from both yield and food quality perspectives. Intensifying production and increasing yield on limited arable land are clearly important to secure a sufficient food supply, and fertilizer plays a critical role in these goals.

Intensifying production is essential to meet the challenge of future food demands. However, this intensification must be done while minimizing environmental impacts. The 4R Nutrient Stewardship framework (i.e., right fertilizer source, right rate, right time, and right place) is therefore very important.

Phosphorus Functions

Phosphorus is present in all living tissue. It is particularly concentrated in younger plant parts, flowers, and seeds. Phosphorus is needed for photosynthesis, synthesis, and breakdown of carbohydrates, and the transfer of energy within the plant. It helps plants store and use energy from photosynthesis to form seeds, develop roots, speed maturity, and resist stress. Phosphorus is involved in nutrient uptake and translocation. It is a major part of the cytoplasm and the nucleus of cells, where it is involved in the organization of cells and the transfer of heredity characteristics.

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Table 1. Effects of P on citrus fruit quality

Variable	Rating
Juice Quality	
Juice Content	0
Soluble Solids (SS)	0
Acid (A)	-
SS/A Ratio	+
Juice Color	0
Solids/Box	0
Solids/Acre	+
External Fruit Quality	
Size	0
Weight	0
Green Fruit	+
Peel Thickness	-
Increase (+), Decrease (-), No change (0)	

Phosphorus is also important for cell division and enlargement. Thus, plant growth is reduced when the P supply is too low.

Excess P can affect fruit quality in the following ways:

- Reduced acid concentration, which increases the TSS/acid ratio
- Increased number of green fruit
- Reduced peel thickness
- Increased expression of wind scar

Phosphorus is listed on the fertilizer label as P_2O_5, where it is referred to as "available phosphoric acid." Phosphorus does not readily leach unless the soil is extremely sandy or low in organic matter. A citrus crop removes only approximately 2 lb. of P per 100 boxes of fruit. Most mature Florida citrus groves contain sufficient residual P accumulated from previous fertilizer applications, so regular P fertilizer applications are usually not necessary.

Some soils used for new citrus plantings are naturally low in P. These soils are commonly found in "sand-soaked" areas. In this situation, P fertilizer should be applied until a soil test P rating of medium to high is achieved. Phosphorus fertilizer should be applied each year in newly planted groves on previously non-fertilized soil until the groves begin to bear fruit. As the trees approach maturity, P applications may be reduced or omitted. Diagnostic information from leaf and soil testing can help determine if P fertilization is necessary.

Phosphorus Deficiency

Phosphorus deficiency is not common in Florida citrus groves. If it does occur, it is more difficult to diagnose than nitrogen (N) deficiency or other nutrient element deficiencies. Growth is reduced when P supply is too low. Phosphorus is highly mobile in plants, so when it is deficient, it may move from old leaves to young leaves and other actively growing areas where energy is needed to form seeds and fruit.

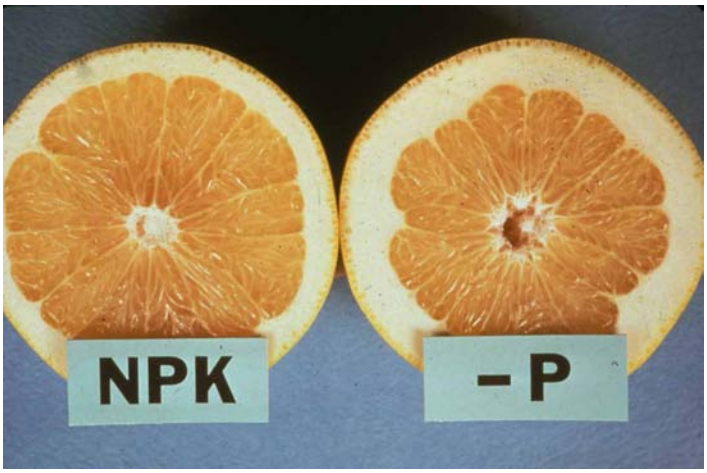


Figure 1. A thick rind and hollow core are both symptoms of P deficiency in citrus trees.
Credits: Dr. R.C.J. Roo

Because P moves from older to younger tissue, deficiency symptoms appear first on older leaves, which lose their deep green color. Leaves are small and narrow, with a lusterless purplish or bronze discoloration. Some leaves later develop necrotic areas, and young leaves show reduced growth rate. Leaves shed prematurely, and fruit can drop

before normal harvesting time. P deficiency symptoms are not strongly expressed on citrus foliage. Trees exhibit limited flower development with reduced fruit set and fruit yield. The fruit turns rough in texture with a coarse, thick rind and a hollow core (see Figure 1). The fruit has high acidity in proportion to total soluble solids. Thus, fruit maturity is delayed. Usually, roots are stunted and poorly branched.

The cause of P deficiency is a lack of available P in the soil. Phosphorus deficiency may occur because of leaching and erosion where soils are sandy and the climate is humid. Phosphorus may also react with clay, iron (Fe), aluminum (Al) or calcium (Ca) in the soil and become less available and less mobile. In strongly acidic soils, such as those found in Brazil, P can become quickly unavailable through fixation or immobilization by Fe and Al. Phosphorus availability can also be reduced in calcareous soils through Ca fixation.

When P fertilizer is added to a calcareous soil, it undergoes a series of chemical reactions with Ca. These reactions decrease P solubility through a process called P fixation. Consequently, long-term P availability to plants is controlled by the application rate of soluble P and the dissolution of fixed P. Applied P is available to replenish the soil solution for only a relatively short time before it converts to less soluble P forms. Phosphorus deficiency can be corrected by applying P fertilizer to the soil or foliage after confirming P deficiency using leaf and soil analysis.

Common solid sources of P applied to citrus groves include the following:

- Ordinary superphosphate
- Concentrated superphosphate
- Monoammonium phosphate (MAP)
- Diammonium phosphate (DAP)

The P source in both ordinary ("single" or "normal") and concentrated ("triple") superphosphate is mono-calcium phosphate, $Ca(H_2PO_4)_2$. The major difference between these two fertilizers is that ordinary superphosphate contains gypsum (calcium sulfate) and concentrated superphosphate does not. If the fertilizer program calls for dry material, using superphosphates may have the following advantages: they are relatively inexpensive; they are appropriate for application to soil of any pH (especially alkaline soil); and they supply sulfur to plants.

Although MAP and DAP are two products that sound nearly the same, their reactions in the soil are very different. High acidity forms around a dissolving MAP granule, while high alkalinity forms around a dissolving DAP granule. Therefore, do not apply DAP to an alkaline soil because P becomes unavailable due to tie-up by Ca and N is lost to the atmosphere by volatilization.

The following P nutrient sources are used to manufacture true solutions:

- Ammonium polyphosphate
- Phosphoric acid

Ammonium polyphosphate may be applied to the soil with a boom or injection wheel, but it should not be injected into a microirrigation system. Ammonium polyphosphate is not an acidic material, but has a slightly acidic reaction in the soil. Phosphoric acid is usually added to liquid fertilizers for application to soil or injected into irrigation water. If phosphoric acid is injected into a microirrigation system connected to a high-calcium water source, the emitters may clog because the calcium phosphate can precipitate.

These P nutrient sources are applied in foliar sprays:

- Potassium phosphite
- Ammonium phosphite
- Phosphorous acid

Phosphorus fertilizers are generally supplied to plants as salts of phosphoric acid (H_3PO_4). When phosphoric acid is neutralized by potassium hydroxide (KOH), it forms potassium phosphate (KH_2PO_4). However, if phosphorous acid (H_3PO_3) is neutralized with KOH, it forms potassium phosphite (KH_2PO_3), also known as phosphite or phosphonate. While the phosphate form of P is not easily absorbed by citrus leaves, the phosphite form is readily absorbed. Phosphite has been shown to accelerate foliar uptake of potassium, calcium, magnesium, and most micronutrients. Because phosphite has one less oxygen molecule than phosphate, a higher degree of solubility and mobility is achieved in the plant. This unique characteristic permits plant foliage and/or roots to rapidly absorb phosphites, and these play a nutritive role in crops, including citrus trees.

Table 2. Interpretation of soil analysis data for P (ppm) using the Mehlich 1 (double-acid) extractant

	Very Low	Low	Medium	High	Very High
Phosphorus	<10	10–15	16–30	31–60	>60

Table 3. Guidelines for interpretation of orange tree leaf P (%) analysis based on 4- to 6-month-old spring flush leaves from non-fruiting twigs

	Deficient	Low	Optimum	High	Excessive
Phosphorus	<0.09	0.09–0.11	0.12–0.16	0.17–0.30	>0.30

Table 4. Recommendations for P fertilization of bearing citrus trees based on leaf tissue and soil tests (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	Very High High Medium Low Very Low	Do not apply P fertilizer to the soil for 12 months following leaf and soil sampling, then sample again and re-evaluate.
Optimum	Very High High Medium	
Optimum	Low Very Low	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 re-evaluate.
Low	Low Very Low	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 re-evaluate.
Deficient	Low Very Low	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 re-evaluate.

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

The optimum range of P in citrus leaves is 0.12%–0.16%. Phosphorus is deficient if leaf P is less than 0.09%. Appropriate P management is important not only for higher crop yield but also for environmental protection. Slowing soil erosion can significantly decrease particulate and dissolved forms of P loss. Before deciding to apply P fertilizer to citrus, test the soil and leaves for P, and apply the results to Table 4 above.

Conclusion

Growers should be aware that the soil mineral fraction reacts quickly to remove dissolved P from solution. In order to maximize the availability of soil P, soil pH should be monitored and maintained in the range of 6.0–6.5. An appropriate nutrient balance is necessary to achieve optimum plant nutrition. Balanced use of plant nutrients corrects nutrient deficiencies and toxicities, improves soil fertility, increases nutrient- and water-use efficiency, enhances crop yields and fruit quality, develops tree tolerance to pests, diseases, and other stresses, and improves environmental quality.

UF UNIVERSITY of FLORIDA
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SL381

Potassium (K) for Citrus Trees[1]

Mongi Zekri and Tom Obreza[2]

This publication is part of a series about understanding nutrient requirements for citrus trees. For the rest of the series, visit http://edis.ifas.ufl.edu/topic_series_citrus_tree_nutrients.

To maintain a viable citrus industry, Florida growers must consistently and economically produce large, high-quality fruit crops from year to year. Efficiently producing maximum yields of high-quality fruit is difficult without understanding soil and nutrient requirements of bearing citrus trees. Most Florida citrus is grown on soils inherently low in fertility with low cation exchange capacity (CEC) and low water-holding capacity, thus soils are unable to retain sufficient quantities of available plant nutrients against leaching caused by rainfall or excessive irrigation.

Seventeen elements are considered necessary for the growth of green plants: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), manganese (Mn), zinc (Zn), iron (Fe), copper (Cu), boron (B), chlorine (Cl), molybdenum (Mo), and nickel (Ni). Plants obtain C, H, and O from carbon dioxide and water. The remaining elements, called the "mineral nutrients," are obtained from the soil. Mineral nutrients are classified as *macronutrients* and *micronutrients*. The term "macronutrients" refers to those elements that plants require in large amounts (N, P, K, Mg, Ca, and S). The term "micronutrients" applies to plant nutrients that are essential to plants but are needed only in small amounts (Mn, Zn, Fe, Cu, B, Cl, Mo, and Ni). This publication reviews the potassium (K) requirements of citrus trees.

Introduction

Potassium (K) is one of the most important nutrients applied as fertilizer in Florida citrus groves. Potassium (also called potash) is listed on the fertilizer label as K_2O. Potassium plays a key nutritional role in determining yield, fruit size, and quality. The sandy soils used to produce citrus in Florida are naturally low in K. Also, K is not fixed and does not accumulate in those sandy soils, even with repeated fertilizer applications. Thus, K fertilizer application is required every year in Florida citrus groves. Potassium deficiency is not common when a grove is fertilized normally, but deficiency can develop on high pH soils or when high N rates stimulate high fruit production.

If leaf K is consistently less than optimum from year to year, increase the K_2O rate by 25%. Low leaf K concentrations are common in groves planted on calcareous soils. If low yield, small fruit, fruit splitting, and/or creasing are observed, application of additional K fertilizer is justified. If trees do not respond to K soil application, an alternative approach to increasing leaf K is foliar sprays of potassium nitrate (KNO_3) or monopotassium phosphate (MKP), (KH_2PO_4). Take precautions to avoid foliar burn from high spray concentrations. Fruit burn was not observed when 25 lbs KNO_3/acre were applied in 125 gal of water/acre, 15 lbs MKP/acre were applied in 32.5 gal of water/acre, or when 15 lbs MKP/acre were applied in 10 gal of water/acre by airplane.

1. This document is SL381, one of a series of the Department of Soil and Water Science, UF/IFAS Extension. A version of this article was previously published in Citrus Industry magazine. Original publication date: July 2013. Visit the EDIS website at http://edis.ifas.ufl.edu.

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Table 1. Guidelines for interpretation of orange tree leaf K (%) analysis based on 4- to 6-month-old spring flush leaves from non-fruiting twigs

	Deficient	Low	Optimum	High	Excessive
Potassium	<0.7	0.7–1.1	1.2–1.7	1.8–2.4	>2.4

Table 2. Apply K fertilizer at a K_2O rate equal to the N rate.

Tree age	Pounds of K_2O/ tree/year (range)
1	0.15–0.30
2	0.30–0.60
3	0.45–0.90

Table 3. Apply K fertilizer at a K_2O rate equal to the N rate.

Tree age	Oranges	Grapefruit	Other cultivars
	Pounds of K_2O/acre/year (range)		
4–7	120–200	120–160	120–200
8 and up	140–250 Yield based	120–160	120–300 Yield based

Potassium Functions

Citrus fruits remove large amounts of K compared to other nutrients. Potassium moves from leaves to fruit and seeds as they develop. Potassium is necessary for several basic physiological functions such as the formation of sugars and starch, synthesis of proteins, normal cell division and growth, and neutralization of organic acids. Potassium is important in fruit formation and enhances fruit size, flavor, and color. This nutrient also helps to reduce the influence that adverse weather conditions (such as drought, cold, and flooding) have on citrus trees.

Table 4. Effects of K on citrus fruit quality

Variable	Rating
Juice Quality	
Juice Content	-
Soluble Solids (SS)	-
Acid (A)	+
SS/A Ratio	-
Juice Color	-
Solids/Box	-
Solids/Acre	+
External Fruit Quality	
Size	+
Weight	+
Green Fruit	+
Peel Thickness	+
Increase (+), Decrease (-)	

Potassium is known to influence many enzymatic reactions and is associated with almost every major plant function. Potassium helps to regulate the carbon dioxide supply to plants by controlling stomata opening and closing. It improves the efficiency of plant water and sugar use for maintenance and normal growth functions. Additionally, K moves sugars from the site of photosynthesis to other storage sites. Potassium works with phosphorus (P) to stimulate and maintain rapid root growth of plants and stimulates the synthesis of protein from amino acids. Potassium improves plant health, disease resistance, and tolerance to nematodes and insects. The rate of photosynthesis drops sharply when plants are K deficient.

Potassium Deficiency

The rate of photosynthesis drops sharply when plants are K deficient. Too much N with too little K can result in a backup of the protein building blocks, set the stage for disease problems, reduce production of carbohydrates, reduce fruiting, and increase fruit splitting, fruit creasing, plugging, and drop. K shortage can result in decreased yield and low fruit quality. Negative effects of low K generally occur on fruit yield and quality before leaf deficiency symptoms. Decreased yield and small fruit have been observed on trees with leaf K in the range of 0.5%–0.8%, while K concentrations of 1.2% or more have been associated with maximum yield of high-quality fruit. Moderately low concentrations of K in the tree cause a general reduction in growth without



Figure 1. One symptom of potassium deficiency is small fruit.
Credits: M. Zekri



Figure 2. This citrus tree shows chlorosis and necrotic spotting of leaves, both symptoms of a K deficiency. Credits: T. Obreza



Figure 3. These citrus leaves show K-deficiency symptoms, including chlorosis and necrotic spotting of leaves. Credits: T. Obreza

visual deficiency symptoms. The onset of visual deficiency symptoms means that production has already been seriously impaired.

In Florida, low K fertilization can lead to deficiency symptoms developing on the recently matured spring flush leaves in the late summer and fall. When K is low, the general leaf pattern begins as a yellowing of the tips and margins, which then gets broader. Necrotic areas and spotting can develop on the leaves. Symptoms appear first on older leaves because K tends to concentrate in the rapidly growing tissues. Potassium deficiency causes slow vegetative growth, small leaves, fine branches, thin canopy, increased susceptibility to drought and cold, reduced fruit size, very thin peel of smooth texture, premature shedding of fruit, and lower acid concentration in the fruit.

Potassium deficiency symptoms usually result from an insufficient K supply in the soil. Potassium deficiency may occur on acid sandy soils where leaching may be considerable. The supply of K to plants may be decreased by soils that have very high concentrations of Ca and Mg or by heavy N application. Decreased K uptake is typical on some calcareous soils. Lack of soil moisture also reduces K uptake and may lead to K deficiency. If the supply of N and P is high relative to that of K, growth may be rapid at first, but the K concentration in the plant may ultimately decrease to cause deficiency. Addition of K is necessary to maintain the nutrient balance required for uniform and continued growth. In situations where available K is high compared to the N or P supply, luxury consumption of K can occur.

Under most soil conditions, K deficiency can be corrected by applying potassium chloride (muriate of potash) or potassium sulfate to the soil. However, in fine-textured, saline, or calcareous soils, K applications to the soil are sometimes ineffective or slow to correct K deficiency. Foliar application of potassium nitrate or mono-potassium phosphate can be very effective and rapid to correct K deficiency. The recommended foliar K spray for mature citrus trees is 8 lbs K_2O/acre per application. Foliar spray application of K has been demonstrated to increase fruit size. Foliar-applied K has also corrected K deficiency of citrus on calcareous soil. Foliar application of potassium nitrate (KNO_3) increased leaf K more rapidly compared to soil-applied fertilizers because plant uptake was much faster, but the positive effect lasts for a shorter time.

Common solid sources of K applied to citrus groves include the following:

- Potassium chloride (muriate of potash)
- Potassium sulfate
- Potassium-magnesium sulfate
- Potassium nitrate

K nutrient sources used to manufacture true solutions include the following:

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

K nutrient sources applied in foliar sprays include the following:

- Potassium phosphite
- Potassium nitrate
- Potassium thiosulfate
- Monopotassium phosphate
- Dipotassium phosphate

Conclusion

Supplying sufficient nutrition should be a high-priority management practice for every grower. An appropriate nutrient balance is necessary to achieve optimum plant nutrition. Correct ratios of nutrients are critical to fertilizer management and sustainability. If an element is below the critical level, yield production falls even though the other elements are kept in sufficient supply. Too much N with too little K can reduce fruiting and results in lost crop yield and quality. High K with low N and P supply induces luxury consumption of K, delays fruit development, and reduces juice content. Balanced use of plant nutrients corrects nutrient deficiencies and toxicities, improves soil fertility, increases nutrient- and water-use efficiency, enhances crop yields and fruit quality, develops tolerance to pests, diseases and other stresses, and improves environmental quality.

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SL382

Calcium (Ca) and Sulfur (S) for Citrus Trees[1]

Mongi Zekri and Tom Obreza[2]

This publication is part of a series about understanding nutrient requirements for citrus trees. For the rest of the series, visit http://edis.ifas.ufl.edu/topic_series_citrus_tree_nutrients.

To maintain a viable citrus industry, Florida growers must consistently and economically produce large, high-quality fruit crops from year to year. Efficiently producing maximum yields of high-quality fruit is difficult without understanding soil and nutrient requirements of bearing citrus trees. Most Florida citrus is grown on soils inherently low in fertility with low cation exchange capacity (CEC) and low water-holding capacity, thus soils are unable to retain sufficient quantities of available plant nutrients against leaching caused by rainfall or excessive irrigation.

Seventeen elements are considered necessary for the growth of green plants: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), manganese (Mn), zinc (Zn), iron (Fe), copper (Cu), boron (B), chlorine (Cl), molybdenum (Mo), and nickel (Ni). Plants obtain C, H, and O from carbon dioxide and water. The remaining elements, called the "mineral nutrients," are obtained from the soil. Mineral nutrients are classified as *macronutrients* and *micronutrients*. The term "macronutrients" refers to those elements that plants require in large amounts (N, P, K, Mg, Ca, and S). The term "micronutrients" applies to plant nutrients that are essential to plants but are needed only in small amounts (Mn, Zn, Fe, Cu, B, Cl, Mo, and Ni). Previous EDIS articles in this series discussed the importance of N, P, K, and Mg in relation to citrus trees. This publication focuses on the importance of calcium (Ca) and sulfur (S) nutrition.

Calcium and sulfur are sometimes called secondary nutrients. This term does not mean that these nutrients play a secondary role in citrus plant growth and development. Ca and S are as essential as N, P, K, Mg, and other nutrients for healthy plant growth. An inadequate supply of Ca and/or S can be a major constraint to crop production and quality.

Functions and Importance of Ca and S

Calcium

Calcium is the most abundant mineral element by weight in citrus trees, accounting for approximately 1% of tree dry weight. Most Ca resides in the leaves, but fruit also contains Ca at a level of approximately 4.4 lb. per 100 boxes of oranges. Calcium is involved in cell division and cell elongation, is an important constituent of cell walls, and plays a major role in cell membrane integrity.

Calcium is also an important element for root development and functioning. Root growth is severely restricted in Ca-deficient plants, and the roots become more prone to bacteria and fungi infections. Calcium is required for chromosome stability and cell division. It activates several enzyme systems and neutralizes organic acids in plants. An inadequate Ca supply can reduce plant growth and fruit yield long before deficiency symptoms become evident. Soil Ca content is rarely low because occasional applications

1. This document is SL382, one of a series of the Department of Soil and Water Science, UF/IFAS Extension. A version of this article originally was published in Citrus Industry magazine. Original publication date: July 2013. Please visit the EDIS website at http://edis.ifas.ufl.edu.

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of lime (calcium carbonate, $CaCO_3$) 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 calcium carbonate (limestone). Despite the abundance of soil Ca, citrus trees can suffer from a range of Ca-deficiency disorders that affect plant tissue function. For example, the "creasing" disorder in navel and Valencia oranges may be caused by Ca deficiency in the albedo of the rind.

Sulfur

The S concentration in a citrus tree is approximately 10 times less than the Ca concentration, and it is about equal to the P concentration. The uptake and assimilation of S and N by plants are strongly interrelated and depend on each other because of their mutual occurrence in amino acids and proteins. Sulfur is an essential constituent of many proteins, vitamins, and some plant hormones. As a result, protein synthesis and amino acid and chlorophyll production are retarded in S-deficient plants. Sulfur is also known to enhance the development of nodules and N fixation by legumes, indicating its importance in root growth and development as well as in root vigor and hardiness. Sulfur also affects carbohydrate metabolism. Sulfur is a major component of soil organic matter and becomes available to plants as organic matter decomposes. Sulfur is also present in some irrigation water sources.

Many producers often forget sulfur as a needed element and critical nutrient. The problem of S deficiency may be widespread but not known because lab analysis does not target this nutrient. In general, plant tissue analyses are important to diagnose nutritional deficiency or sufficiency of all nutrients. Unfortunately, tissue analysis has not been routinely used to check the S status of citrus trees. The effects S nutritional status has on yield and quality are well documented for numerous crops, but not for citrus. Sulfur controls certain diseases and insect pests in many crops and improves plant tolerance to heavy metal toxicity. Currently, **sufficiency for Ca and S is defined as the optimum values in leaf tissue analysis and medium range for soil analysis.**

Calcium

If soil Ca level is less than sufficient, soil application of gypsum or soluble Ca fertilizer should be considered. If leaf Ca is less than the optimum level, calcium nitrate may be applied as a foliar spray.

Nutrient Behavior in Florida Soils

Calcium

- Ca exists 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 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 it is a divalent cation, Ca dominates on the cation exchange complex, limiting its 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 depends on organic matter quantity and decomposition rate. Organic S release combined with S from other sources such as rain and irrigation water may provide this nutrient to plants at a sufficient rate.
- The plant-available form of S is sulfate, a negative ion, which makes it prone to leaching. Sulfate can be adsorbed by soils but adsorption usually occurs much deeper in the soil profile than the majority of plant roots.
- Calcium sulfate (gypsum) is a sparingly soluble compound applied as a long-term source of available Ca, but it also supplies S to plants.

Calcium Deficiency

A Ca deficiency in citrus is expressed as a fading of the chlorophyll along the leaf margins and between the main veins during the winter months (Figure 1). Small necrotic (dead) spots can develop in the faded areas. Calcium deficiency produces small, thickened leaves and causes loss of vigor, thinning of foliage, and decreased fruit production. Severely deficient trees can develop twig dieback and multiple bud growth of new leaves. Trees with a Ca deficiency produce undersized and misshapen fruit with shriveled juice vesicles (Figure 2). Fruits from Ca-deficient trees are slightly lower in juice content but higher in soluble solids and acids.

Calcium deficiency usually occurs on acidic soils where native Ca has leached. Continuous use of ammonium-containing fertilizer, particularly ammonium sulfate, accelerates Ca loss from soils. Using muriate of potash and S causes similar losses of soil Ca. Soil testing is a widely used method of making liming recommendations. In the long term, liming is the most effective and economic practice to

supply Ca to crops in Ca-deficient acid soils because liming the soil neutralizes soil acidity and supplies available Ca. Calcium deficiency can also occur in highly saline soils because of the excessive sodium (Na) concentration. Under such a situation, gypsum can correct the deficiency and reduce the deleterious effect of Na. Short-term calcium deficiency can be addressed by foliar spraying with a water-soluble Ca source such as calcium nitrate. Calcium efficiency in crop production can also be improved by using farmland manures

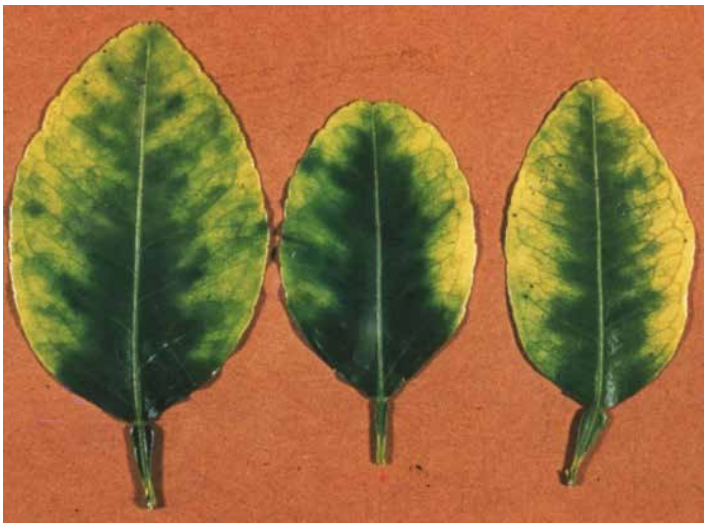


Figure 1. These leaves show calcium deficiency symptoms, including fading of the chlorophyll along the leaf margins and between the main veins during the winter months.
Credits: Dr. R. C. J. Koo

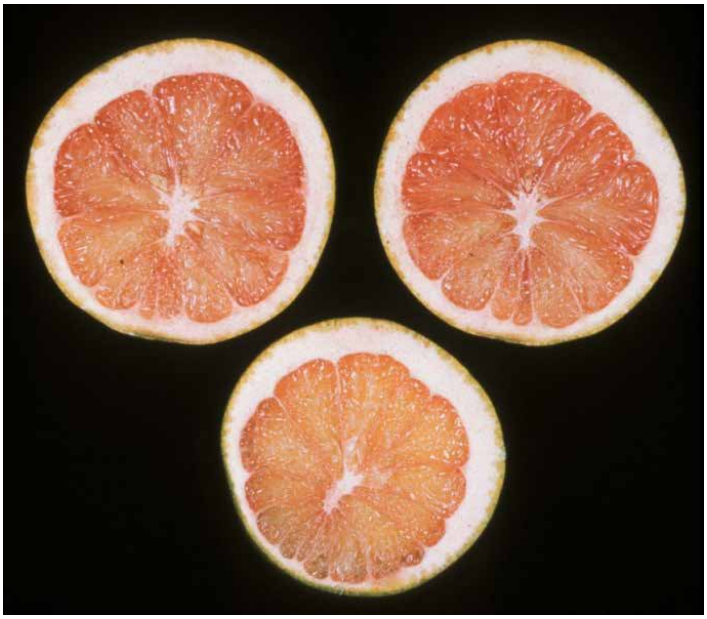


Figure 2. These fruit show calcium deficiency symptoms; they are undersized and misshapen with shriveled juice vesicles.
Credits: Dr. R. C. J. Koo

Sulfur Deficiency

Because S is associated with forming proteins and chlorophyll, deficiency symptoms resemble those of N deficiency, but the symptoms first appear on new growth (Figure 3). Such chlorosis in citrus is worse on new growth because S does not move readily from old to young leaves like N. Plants are stunted and pale green to yellow in color. Visual diagnosis of S deficiency is not easy to identify in citrus production. Accurate diagnosis should involve tissue analysis.



Figure 3. These leaves have sulfur deficiency symptoms because they show chlorosis (pale green to yellow in color) similar to N deficiency. S deficiency symptoms appear on new growth because S does not move readily from old to young leaves like N.
Credits: M. Zekri

Sulfur deficiency occurs most commonly with high N fertilizer rates. If the supply of N is not supplemented with adequate S, the N available for crop use may be excessive in relation to S. Under high N and low S conditions, plant growth processes are disrupted and plants develop symptoms of S deficiency. Sometimes total growth is reduced by fertilization with N alone, whereas combined applications of N and S provide normal growth and yield.

Sulfur deficiencies have become more common in the past few decades with the increased use of fertilizers lacking S, such as ammonium nitrate, potassium nitrate, urea, concentrated superphosphate, monoammonium phosphate (MAP), and diammonium phosphate (DAP). Decreased use of S-containing pesticides and fungicides may also contribute to the more common occurrence of S deficiency. Sulfur deficiency in citrus can easily be corrected by soil application of S-containing fertilizers such as ammonium sulfate, potassium sulfate, or magnesium sulfate. Applying gypsum is an inexpensive option that can also correct S

deficiency and supply Ca. Using manures may also be a good management strategy to increase S availability to citrus trees.

Common Solid Sources for Soil Application

Calcium

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

Sulfur

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

Conclusion

Citrus trees must have a sufficient supply of all essential plant nutrients to produce optimum fruit yields of good quality. If one or more nutrients are not supplied in adequate quantity, yield will be reduced. This effect is somewhat analogous to the saying that a wooden barrel holds no more water than its shortest stave. Growth and crop yield are limited by the element in shortest supply. An appropriate balance of nutrients in the soil is necessary to achieve optimum plant nutrition. A balanced use of plant nutrients corrects nutrient deficiencies and toxicities, improves soil fertility, increases nutrient- and water-use efficiency, enhances crop yields and fruit quality, develops tree tolerance to pests, diseases, and other stresses, and improves environmental quality. Unbalanced availability of nutrients can lead to mining soil reserves for nutrients in short supply and losing plant nutrients supplied in excess. Over- or under-fertilization is economically wasteful. Therefore, using proper rates, sources, and application methods is an important strategy to maximize nutritional efficiency and crop productivity and quality.

Table 1. Guidelines for interpretation of orange tree leaf Ca and S (%) analysis based on 4- to 6-month-old spring flush leaves from non-fruiting twigs

	Deficient	Low	**Optimum**	High	Excess
Ca	<1.5	1.5–2.9	3.0–4.9	5.0–7.0	>7.0
S	<0.14	0.14–0.19	0.20–0.40	0.41–0.60	>0.60

Table 2. Interpretation of soil aanalysis data for Ca (ppm)* using the Mehlich-1 (double-acid) extractant

	Medium	High
Ca	250	>250
*parts per million (ppm) x 2 = lbs./acre		

Table 3. Adjusting fertilization based on soil analysis

	When below sufficiency	When above sufficiency
Soil pH	Lime to pH 6.0.	1. Do nothing. 2. Use acid-forming N fertilizer. 3. Apply elemental sulfur. 4. Change rootstocks.
Ca	1. Check soil pH and adjust if needed. 2. Check leaf Ca status.	1. Do nothing. 2. Check leaf K and Mg status.

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SL380

Magnesium (Mg) for Citrus Trees[1]

Mongi Zekri and Tom Obreza[2]

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Seventeen elements are considered necessary for the growth of green plants: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), manganese (Mn), zinc (Zn), iron (Fe), copper (Cu), boron (B), chlorine (Cl), molybdenum (Mo), and nickel (Ni). Plants obtain C, H, and O from carbon dioxide and water. The remaining elements, called the "mineral nutrients," are obtained from the soil. Mineral nutrients are classified as *macronutrients* and *micronutrients*. The term "macronutrients" refers to those elements that plants require in large amounts (N, P, K, Mg, Ca, and S). The term "micronutrients" applies to plant nutrients that are essential to plants but are needed only in small amounts (Mn, Zn, Fe, Cu, B, Cl, Mo, and Ni).

Previous articles in this series of EDIS publications discussed the importance of avoiding deficiency of N, P, and K when managing nutrients in citrus trees. This publication discusses magnesium (Mg) requirements for citrus trees.

Functions and Importance of Mg

Magnesium is an essential constituent of chlorophyll; it is the center of the chlorophyll molecule. Magnesium is involved in photosynthesis, and it plays an important role as an activator of several enzymes. It is also involved in carbohydrate metabolism and synthesis of nucleic acids. Magnesium influences the movement of carbohydrates from leaves to other parts of the tree, and it also stimulates P uptake and transport. Seedy citrus varieties may need more Mg than seedless ones because seeds store a large amount of Mg. Dolomitic limestone is often used to correct acidity; this liming material supplies slowly available Mg as well as Ca. Calcium is abundant in alkaline soils, which can be antagonistic to Mg uptake.

1. This document is SL380, one of a series of the Department of Soil and Water Science, UF/IFAS Extension. A version of this article was previously published in Citrus Industry magazine. Original publication date: July 2013. Visit the EDIS website at http://edis.ifas.ufl.edu.

2. Mongi Zekri, multicounty citrus UF/IFAS Extension agent; and Tom Obreza, professor and interim associate dean for Extension; UF/IFAS Extension, Gainesville, FL 32611.

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Table 1. Guidelines for interpretation of orange tree leaf Mg (%) analysis based on 4- to 6-month-old spring flush leaves from non-fruiting twigs

	Deficient	Low	Optimum	High	Excessive
Mg	<0.20	0.20–0.29	0.30–0.49	0.50–0.70	>0.70

Table 2. Interpretation of soil analysis data for Mg (ppm)* using the Mehlich 1 (double-acid) extractant

	Low	Medium	High
Mg	<15	15–30	>30
*parts per million (ppm) x 2 = lbs/acre			

Table 3. Adjusting fertilization based on soil analysis

	When below sufficiency	When above sufficiency
Soil pH	Lime to pH 6.0	1. Do nothing. 2. Use acid-forming N fertilizer. 3. Apply elemental sulfur. 4. Use rootstocks tolerant to high pH.
Mg	1. Check soil pH and adjust with dolomitic lime if needed. 2. Check leaf Mg status.	1. Do nothing. 2. Check leaf K status.

Table 4. Effects of Mg on citrus fruit quality

Variable	Rating
Juice Quality	
Juice Content	0
Soluble Solids (SS)	+
Acid (A)	0
SS/A Ratio	+
Juice Color	?
Solids/Box	+
Solids/Acre	+
External Fruit Quality	
Size	+
Weight	+
Green Fruit	0
Peel Thickness	-
Increase (+), Decrease (-), No change (0), Unknown (?)	

If soil Mg level is low, apply Mg fertilizer at a rate equal to 20% of the N rate. Magnesium nitrate may also be applied as a foliar spray. Curtail Mg fertilizer application if a subsequent soil test shows Mg is in the high range.

Mg Behavior in Florida Soils

- Mg exists 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 Mg are sparingly soluble; they 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.
- Mg slightly increases total soluble solids per box and per acre, and soluble solid-acid ratio.
- Mg slightly increases fruit size and weight, but decreases rind thickness.

Magnesium Deficiency

Magnesium deficiency has been a major problem in citrus production. In Florida, Mg deficiency is commonly referred to as "bronzing." Trees with inadequate Mg may have no symptoms in the spring growth flush, but leaf symptoms develop as the leaves age and the fruit expand and mature in the summer and fall. Magnesium deficiency symptoms occur on mature leaves following the removal of Mg to satisfy fruit requirements.



Figure 1. These leaves show magnesium-deficiency symptoms, including disconnected yellow areas and midribs with an inverted V-shaped green area.
Credits: M. Zekri

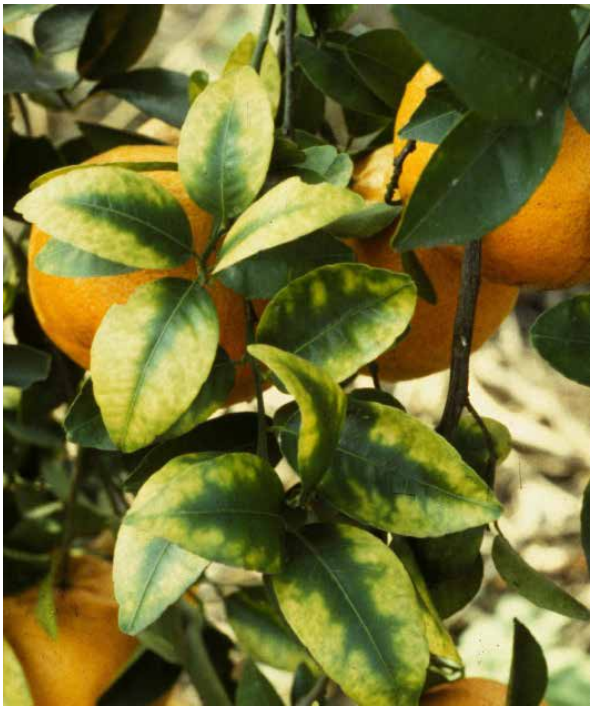


Figure 2. The leaves on this citrus tree show magnesium-deficiency symptoms. Notice how the leaves have an inverted V-shaped area pointed on the midrib.
Credits: M. Zekri

During the summer, when a rapid increase in fruit size occurs, the symptoms appear on leaves close to the developing fruit. Magnesium deficiency symptoms appear as a result of translocation of Mg from the leaves to the developing fruit, although there may also be a translocation from older leaves to young developing leaves on the same shoot. Disconnected yellow areas or irregular yellow blotches start near the base along the midribs of mature leaves close to fruit. These blotches become gradually larger and eventually coalesce to form a large area of yellow tissue on each side of the midrib. This yellow area enlarges until only the leaf tip and base are green, showing an inverted V-shaped area pointed on the midrib. In acute deficiency, the yellow area may gradually enlarge until the entire leaf becomes yellow or bronze in color.



Figure 3. These leaves show severe Mg-deficiency symptoms, including entire leaves yellowing and bronzing.
Credits: M. Zekri

Leaves that lose most of their green color drop freely during unfavorable conditions, including cold weather, water stress, or concentrated foliar sprays. Defoliated twigs are weak and usually die by the following spring, necessitating pruning of trees. There are neither primary twig symptoms nor striking fruit symptoms associated with Mg deficiency, but a secondary effect following defoliation may lead to the death of many twigs. Severe defoliation reduces the average size of individual fruit and causes a general decline in fruit production.

The mobility of Mg in the tree differentiates it from Fe, Zn, Mn, and Cu. Deficiency symptoms of these micronutrients develop on new growth, while Mg deficiency occurs only on mature leaves that were previously normal in appearance, usually on limbs bearing a heavy crop. Heavily fruited limbs develop extreme Mg deficiency symptoms and may

even become completely defoliated, while limbs with little or no fruit may not show deficiency symptoms.

Cultivars producing seedy fruit are more severely affected by Mg shortage than cultivars producing seedless fruit. Alternate bearing is common in seedy cultivars growing in an Mg-deficient condition. The loss of wood as a result of defoliation reduces the fruit-bearing wood for the following year. Magnesium deficiency can greatly reduce both fruit yield and fruit quality. Fruits from Mg-deficient trees are lower in soluble solids, acidity, and vitamin C. Magnesium-deficient trees are more susceptible to cold injury than non-deficient trees.

Mg deficiency in Florida is caused primarily by low soil Mg concentration. It is particularly severe on acidic sandy soils where Mg readily leaches. Leaching of added Mg is particularly serious and substantially rapid when soil pH is 4.5–5.0. Under such conditions, using dolomite to raise the pH to 6.0–6.5 furnishes Mg at the same time. Soil application of Mg sulfate or oxide can successfully correct Mg deficiency when soil pH is raised. Soil salinity, fertilizers high in potassium salts, and manures have induced or aggravated Mg deficiency. Magnesium deficiency can also be attributed to calcareous soils relatively low in Mg or to unbalanced conditions in the soil caused by excessive K or Ca. Under these conditions, the amount of Mg applied must be greater than that applied to soils lower in Ca or K.

In Florida, one foliar spray application of Mg is not always effective to correct Mg deficiency because the amount of Mg needed is often greater than the amount the leaves can absorb. Foliar sprays of Mg nitrate can be effective when applied to the spring and summer flush leaves that are two-thirds to fully expanded but not hardened off. Leaves that already developed a deficiency pattern will not completely recover when Mg is applied, but deficiency symptoms can be prevented the following season.

The following are common solid Mg sources for soil application:

- Magnesium carbonate (dolomitic lime)
- Potassium-magnesium sulfate (sul-po-mag)
- Magnesium sulfate
- Magnesium oxide

Mg nutrient sources used to manufacture fertilizer solutions or applied in foliar sprays include the following:

- Magnesium nitrate

Conclusion

Supplying sufficient nutrition should be a high-priority management practice for every grower. An appropriate nutrient balance using fertilizer management is necessary to achieve sufficient plant nutrition for best fruit yield and quality. If an element is below the critical level, yield production will fall even though the other elements are kept in good supply. Balanced use of plant nutrients corrects nutrient deficiencies and toxicities, improves soil fertility, increases nutrient- and water-use efficiency, enhances crop yields and fruit quality, develops tree tolerance to pests, diseases, and other stresses, and improves environmental quality.

UF IFAS Extension UNIVERSITY of FLORIDA

SL403

Manganese (Mn) and Zinc (Zn) for Citrus Trees[1]

Mongi Zekri and Tom Obreza[2]

This publication is part of a series about understanding nutrient requirements for citrus trees. For the rest of the series, visit http://edis.ifas.ufl.edu/topic_series_citrus_tree_nutrients.

To maintain a viable citrus industry, Florida growers must consistently and economically produce large, high-quality fruit crops year after year. Efficiently producing maximum yields of high-quality fruit is difficult without understanding soil and nutrient requirements of bearing citrus trees. Most Florida citrus is grown on soils inherently low in fertility with low-cation exchange capacity (CEC) and low water-holding capacity; thus, soils are unable to retain sufficient quantities of available plant nutrients against leaching caused by rainfall or excessive irrigation.

Seventeen elements are considered necessary for the growth of green plants:

1. Carbon (C)
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3. Oxygen (O)
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5. Phosphorus (P)
6. Potassium (K)
7. Magnesium (Mg)
8. Calcium (Ca)
9. Sulfur (S)
10. Mnganese (Mn)
11. Zinc (Zn)
12. Iron (Fe)
13. Copper (Cu)
14. Boron (B)
15. Chlorine (Cl)
16. Molybdenum (Mo)
17. Nickel (Ni)

Plants obtain C, H, and O from carbon dioxide and water. The remaining elements, which are called the "mineral nutrients," are obtained from the soil. Mineral nutrients are classified as *macronutrients* and *micronutrients*. The term "macronutrients" refers to the elements that plants require in large amounts (N, P, K, Mg, Ca, and S). The term "micronutrients" applies to plant nutrients that are essential to plants but are needed only in small amounts (Mn, Zn, Fe, Cu, B, Cl, Mo, and Ni).

When macronutrients are supplied in relatively higher proportions than micronutrients for growth stimulation of

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2. Mongi Zekri, Hendry County Extension agent; and Tom Obreza, senior associate dean and professor, Office of Dean for Extension and Florida Cooperative Extension Office, UF/IFAS Gainesville, FL 32611.

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newly planted citrus trees, extreme depletion of micronutrients can develop as a result of marked top growth, and micronutrient deficiencies can appear. Therefore, a balance between macronutrients and micronutrients is needed. Citrus micronutrient deficiencies are most commonly observed on previously uncultivated soils, shallow soils with high water table, extremely sandy areas, and calcareous soils.

Since mineral nutrition is a major factor in maximizing yield of high-quality fruit, understanding the functions of mineral elements, diagnosing nutrient deficiencies, and providing needed fertilizers are essential. This publication describes and discusses manganese (Mn) and zinc (Zn) deficiencies, functions, and recommended practices to alleviate nutritional problems.

Introduction

Meeting the world's escalating food needs cannot be achieved without fertilizer input. Without fertilizer, the world would produce only about half as much food, and more forested and marginal lands would have to be put into production. Inorganic commercial fertilizer plays a critical role in the world's food security, and it is important from both yield and food quality perspectives. Intensifying production and increasing yield on limited arable land secure a sufficient food supply, and fertilizer plays a critical role in these goals. Intensifying production is increasingly essential to meet the challenge of future food demands. However, this intensification must be done while also minimizing environmental impacts. The 4R Nutrient Stewardship Framework (i.e., right fertilizer source, right rate, right time, and right place) is therefore very important.

Manganese and Zinc Deficiencies

Manganese deficiency occurs commonly in Florida and in many other areas of the world. It is particularly evident in the spring after a cold winter. Recognizing Mn deficiency symptoms can be delayed due to masking by severe Zn or iron (Fe) deficiencies. Sometimes, the deficiency can be confused with symptoms of Fe and Zn deficiency or boron (B) toxicity. Manganese deficiency leads to a chlorosis in the interveinal tissue of leaves, but the veins remain dark green (Figure 1). Young leaves commonly show a fine pattern or network of green veins on a lighter green background but the pattern is not as distinct as with Zn or Fe deficiencies because the leaf is greener (Figure 2). By the time the leaves reach full size, the pattern becomes more distinct as a band of green along the midrib and principal lateral veins, with light green areas between the veins.



Figure 1. Manganese deficiency
Credits: Mongi Zekri



Figure 2. Manganese deficiency symptoms
Credits: Mongi Zekri

In more severe cases, the color of the leaf becomes dull green or yellowish-green along the midrib and main lateral veins, and it becomes pale and dull in the interveinal areas. White opaque spots may develop in the interveins, which give the leaf a whitish or gray appearance. The leaves are not reduced in size or changed in shape by Mn deficiency, but affected leaves prematurely fall from the tree. No particular twig symptoms are related to Mn deficiency. Growth is reduced in an acutely affected tree, giving it a weak appearance.

Manganese deficiency may greatly reduce crop volume and fruit color. The fruit may become smaller and softer than normal, and the rind may become pale in color. Manganese deficiency is frequently associated with Zn deficiency. A combination of the two deficiency symptoms on leaves is called "marl frenching" or "marl chlorosis," which is

characterized by dark green veins with dull white and green areas between the veins. In such combinations, the Mn deficiency is acute, and the Zn deficiency is relatively mild.

Due to leaching in the acid soils and to insolubility in the alkaline soils, Mn deficiency occurs on both acidic and alkaline soils in Florida. It can be associated with deficiencies of Zn, Fe, and copper (Cu) on both acid and alkaline soil and with magnesium (Mg) deficiency on acidic sandy soils.

Zinc deficiency has traditionally been the most widespread nutrient deficiency in citrus. Zinc deficiency is commonly known as "rosette" or "frenching" in Florida. Rosetting does not usually occur in citrus. Zinc deficiency symptoms are characterized by irregular green bands along the midrib and main veins on a yellow background (Figure 3). The relative amounts of green and yellow tissue vary from a condition of mild Zn deficiency in which only small yellow patches between the larger lateral veins are present to a condition in which only a basal portion of the midrib is green and the remainder of the leaf is light yellow to white (Figure 4). In less acute stages, the leaves are almost normal in size, while in severe cases the leaves are pointed, abnormally narrow with the tendency to stand upright, and extremely reduced in size.



Figure 3. Zinc deficiency symptoms
Credits: Mongi Zekri

In mild cases, Zn deficiency symptoms appear on weak twigs. Fruit formed on these twigs are drastically reduced in size and have an unusually smooth and light-colored thin skin and very low juice content. As Zn deficiency progresses, leaves are affected across the entire periphery of the tree, and twigs become thin and die back rapidly. A profuse development of "water sprouts" occurs on the



Figure 4. Zinc deficiency symptoms
Credits: Mongi Zekri

main branches and trunk with leaves free of deficiency symptoms. Fruit grown on these water sprouts are large, coarse, and woody.

The tree has dense growth in the center and a dying appearance across its periphery, which gives the tree a very bushy appearance. Affected leaves have irregular chlorotic areas between the leaf veins. As they develop, new leaves become progressively smaller. The number of blossoms and the fruit set is greatly reduced, and fruit produced have poor quality. Zinc deficiency symptoms can be so severe that they may mask or noticeably alter the symptoms of other deficiencies or disorders.

Deficiencies of Mg and Cu can also reduce Zn uptake through root injury, giving rise to characteristic symptoms of Zn deficiency, even though sufficient Zn is available in the soil. Zinc deficiency can develop due to soil depletion or formation of insoluble Zn compounds. Excessive phosphorus or nitrogen can also induce or aggravate Zn deficiency. Soils receiving large and frequent amounts of poultry manure often show Zn deficiency symptoms.

Functions of Mn

- Involved in the production of amino acids and proteins
- An activator of several enzymes
- Plays an essential role in respiration and nitrogen metabolism

• Necessary for the reduction of nitrate; helps make nitrate usable by plants

• Plays a role in photosynthesis and in the formation of chlorophyll

Functions of Zn

• Involved in plant carbon metabolism

• A necessary component of several enzyme systems that regulate various metabolic activities within plants

• Part of an enzyme that regulates the equilibrium among carbon dioxide, water, and carbonic acid

• Part of two enzymes that play a role in protein metabolism

• Essential for the formation of chlorophyll and function of normal photosynthesis

• Needed to form auxins, which are growth-promoting substances in plants

• Associated with water relations in plants; improves water uptake

Fertilizer Sources and Formulations for Soil Application

Manganese

Manganese sulfate

Manganese oxysulfate

Manganese oxide

Zinc

Zinc sulfate

Zinc oxide

Zinc EDTA and HEDTA

Recommended Rates and Timing

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 or alkaline soils where Mn deficiency is commonly encountered.

For groves on acidic soils that show persistent Mn deficiency symptoms on young foliage, Mn can be included in fertilizer applied to the soil. Soil application of 7–10 lb. of Mn as $MnSO_4$ per acre is recommended. On calcareous or heavily limed acid soils, foliar application of 3–5 lb. of Mn per acre, applied to two-thirds to fully expanded spring or summer flush leaves, is recommended. If nitrogen is needed, adding 7–10 lb. per acre of low biuret urea will increase foliar Mn uptake.

Foliar spray application quickly clears up the deficiency pattern on young leaves, but older leaves respond less rapidly and less completely. When Mn is sprayed on Mn-deficient citrus trees, fruit yield, total soluble solids in the juice, and pounds of solids per box of fruit will certainly increase. A special effort to prevent Mn deficiency symptoms should be made in groves being visually monitored for citrus greening disease symptoms.

Zinc. Soil pH is the most important factor regulating plant-available Zn. Zinc precipitates at alkaline pH, markedly decreasing availability. A soil pH less than 6.5 is the preferred situation. Although there are natural mechanisms in the soil-plant system that may increase the availability of Zn in alkaline soils, Zn deficiencies are common. Special consideration should be given to groves being visually monitored for citrus greening disease symptoms. Trees on Carrizo citrange rootstock tend to show Zn deficiency symptoms more readily than other rootstocks.

Application of foliar Zn fertilizer is usually combined with other micronutrients and with pesticide sprays scheduled in late spring, summer, or fall at 3– 5 lbs. of metallic Zn/acre using $ZnSO_4$, $Zn(NO_3)_2$, or ZnO. A number of other formulations are available for foliar application, including organically chelated forms using lignin sulfonate, glucoheptonate,

Table 1. Guidelines for Interpreting Orange Tree Leaf Mn and Zn (mg/kg or ppm)

	Deficient	Low	Optimum	High	Excess
Mn	< 18	18 – 24	25 – 100	101 – 300	> 300
Zn	< 18	18 – 24	25 – 100	101 – 300	> 300

**Analysis based on four- to six-month-old spring flush leaves from non-fruiting twigs collected from July—September.*

or alpha-keto acids. Under severe deficiency or persistent deficiency symptom conditions, a foliar Zn spray may be necessary on each major growth flush to keep the trees free of symptoms because Zn does not translocate readily to successive growth flushes. Maximum benefit is obtained if spray is applied to young leaves when they are two-thirds to nearly fully expanded, before hardening off.

Although practically speaking, Zn dusts are less effective than sprays, inorganic and organic Zn fertilizer sources are about equally effective with respect to foliar absorption. Application of Zn directly to acidic soils is rarely an economic or an effective practice, because of the massive rates required to correct a deficiency. Zinc should not be soil-applied to groves on calcareous soils, because the alkaline pH renders the Zn unavailable almost immediately.

Conclusion

Supplying sufficient nutrition should be a high-priority management practice for every grower. An appropriate nutrient balance using fertilizer management is necessary to achieve sufficient plant nutrition for best fruit yield and quality. If an element is below the critical level, yield production will fall—even though the other elements are kept in good supply. Balanced use of plant nutrients corrects nutrient deficiencies and toxicities; improves soil fertility, increases nutrient- and water-use efficiency; enhances crop yields and fruit quality; develops tree tolerance to pests, diseases, and other stresses; and improves environmental quality.

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When macronutrients are supplied in relatively high proportions to micronutrients for growth stimulation of newly planted citrus trees, extreme depletion of micronutrients can develop as a result of marked top growth, and micronutrient deficiencies can appear. Therefore, a balance between macronutrients and micronutrients is needed. Citrus micronutrient deficiencies are most commonly observed on previously uncultivated soils, shallow soils with high water table, extremely sandy areas, and calcareous soils.

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Since mineral nutrition is a major factor in maximizing yield of high-quality fruit, understanding the functions of mineral elements, diagnosing nutrient deficiencies, and providing needed fertilizers are essential. This publication describes and discusses iron (Fe) and copper (Cu) deficiencies, functions, and recommended practices to alleviate nutritional problems.

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Iron and Copper Deficiencies

Iron Deficiency

Iron deficiency is common on calcareous soils. A calcareous soil contains a high concentration of calcium carbonate and has a pH of about 8.3. These soils may contain appreciable amounts of Fe, but it exists in a form that is only slightly available to plants. Iron deficiency can also be attributed to low soil Fe concentration in white sandy areas near lakes or ponds and in places known locally as "sand-soaked areas." Iron deficiency can be induced by high phosphorus (P) or accumulation of heavy metals, primarily Cu, in the soil. Iron deficiency is commonly associated with zinc (Zn) and manganese (Mn) deficiencies.



Figure 1. Iron deficiency symptoms
Credits: Mongi Zekri

The symptom of Fe deficiency is known as "iron chlorosis" and is called "lime-induced chlorosis" when it occurs on calcareous soils. Deficiency symptoms occur on young leaves, which appear a light yellow to white in color, with the veins greener than the remainder of the leaf (Figure1). In acute cases, the leaves are reduced in size, and they are fragile, very thin, and can shed early. The trees die back severely on the periphery and especially at the top (Figure 2). Some trees may have a dead top with the lower limbs carrying almost normal foliage. Eventually, tree canopy volume decreases and fruit set and yield are reduced. The fruits tend to be small with reduced soluble solids and acidity in the juice. Sometimes, only a tree branch may be affected, or perhaps only a few trees in a grove will be chlorotic. In severe cases, the entire tree is affected. The tree loses some of its leaves, becomes unproductive, and dieback, or copper deficiency, results.



Figure 2. Iron deficiency symptoms
Credits: Mongi Zekri

Iron deficiency is usually associated with high soil alkalinity, but it is also associated with excessive irrigation, prolonged wet soil conditions, poor drainage, and low soil temperature. Some areas displaying Fe chlorosis have been substantially helped or completely cured by careful control of irrigation and drainage. Iron deficiency sometimes occurs where excess salts are present in the soil and in other situations that are not clearly understood.

Copper Deficiency

Copper deficiency is known as "dieback," "ammoniation," and "exanthema." These names are derived from the dying back of the twigs, the frequent association with heavy application of N (ammonia), and the exudates on twig and fruit surfaces. For years, excessive N fertilizer application has been considered a contributing cause of this problem, giving rise to the term "ammoniation." The cause might be an excessive N/Cu ratio in the plant. This condition is classified as Cu deficiency as opposed to excessive N, and the term "copper deficiency" is preferred in a practical sense because Cu application solves the problem.

The first symptom of Cu deficiency is formation of unusually vigorous, large, and dark green foliage with a "bowing up" of the midrib. Twigs are also unusually vigorous, long, soft, angular, frequently S-shaped, and somewhat drooping (Figure 3). As the deficiency becomes acute and the twigs start to die, some of the weak twigs will bear very small, yellowish-green leaves that drop quickly, leaving the twig defoliated.



Figure 3. Copper deficiency symptoms
Credits: Mongi Zekri

Fruit symptoms are most pronounced on oranges. Brown-stained areas of hardened gum on the fruit rind may precede the appearance of leaf and twig symptoms (Figure 4). Fruit splitting is common on the trees showing mild symptoms of Cu deficiency, with a part of the splitting beginning at the blossom end, which is normal, but some of it occurring across the axis or around the gum-stained areas. In severe cases, dieback of young twigs occurs, and reddish-brown droplets of gum cover the twigs. The brown-stained areas on the fruit darken and converge as time progresses and may become almost black by the time the fruit is half-grown. Most of this fruit will shed by summer.

Insufficient available Cu in the soil is believed to be the primary cause of the symptoms described. When Cu deficiency is combined with either Zn or Mg deficiency, leaf and twig symptoms may not be noticed due to reduction in growth, but the typical fruit symptoms will still show. Therefore, fruit symptoms are the most reliable indicator in routine observation.

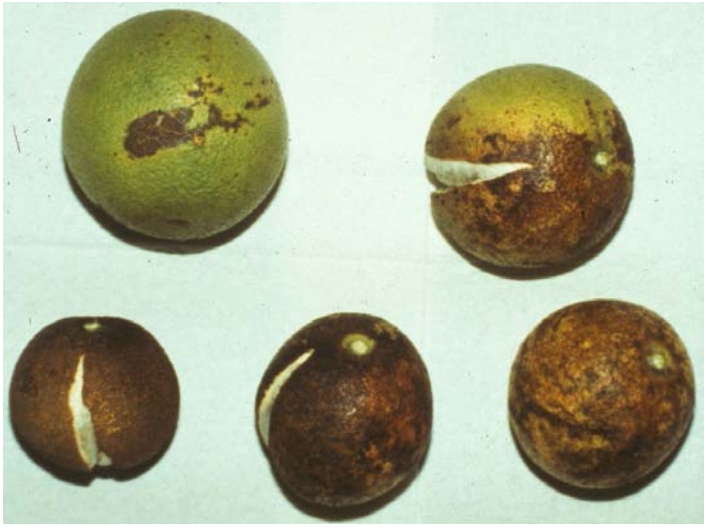


Figure 4. Copper deficiency symptoms
Credits: Mongi Zekri

Copper deficiency is more of a problem on newly planted flatwoods soils compared with deep sandy soils of the central Florida ridge. Copper deficiency can be a controlling factor in fruit production, and acute Cu deficiency may take trees entirely out of production.

FUNCTIONS OF FE

- Catalyzes the production of chlorophyll
- Involved in some respiratory and photosynthetic enzyme systems
- Involved in the reduction of nitrates and sulfates

FUNCTIONS OF CU

- Part of several enzyme systems
- Has a role in photosynthesis and chlorophyll formation
- May have an important function in root metabolism
- Regulates several biochemical processes within the plant
- Important in the utilization of proteins in growth processes
- Involved in oxidation-reduction reactions

Fertilizer Sources and Formulations for Soil Application

Iron

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

Copper

Copper sulfate

Recommended Rates and Timing

Iron

It is not easy to remedy iron chlorosis of citrus trees on susceptible rootstocks (Swingle citrumelo, trifoliate orange) planted on calcareous soils. Iron fertilizer formulations are available that can correct chlorosis, but the required application rate and frequency make the treatment expensive. Inorganic sources of Fe, such as ferrous sulfate ($FeSO_4$) or ferric sulfate [$Fe_2(SO_4)_3$], are not effective. Iron chlorosis should be addressed through soil application of Fe chelates. Chelates are superior Fe sources for plants because they supply sufficient Fe at much lower rates compared with inorganic Fe sources. The most popular synthetic organically chelated forms of Fe include Fe-EDTA, Fe-HEDTA, Fe-DTPA, and Fe-EDDHA. The effectiveness of these fertilizers varies greatly depending on soil pH (Table 2).

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

Foliar application of $FeSO_4$ or Fe chelates has not proven satisfactory on citrus trees because of poor translocation within the leaf. The use of foliar sprays also increases the possibility of fruit and/or leaf burn. For these reasons, foliar application of Fe is not recommended to correct Fe chlorosis of citrus.

Citrus rootstocks vary widely in their ability to overcome low Fe stress. Swingle citrumelo and trifoliate orange are among the most sensitive rootstocks to Fe-chlorosis. Using tolerant rootstocks is the easiest way to avoid alkaline-induced Fe chlorosis in citrus trees that are planted on calcareous soils.

Copper

Foliar sprays or soil applications of Cu fertilizer can prevent or cure Cu deficiency. Spraying a solution containing 2–3 lb. per acre of elemental Cu applied during flowering commonly results in near-immediate recovery followed by a normal fruit set. Foliar sprays are useful emergency treatments when symptoms of Cu deficiency are first observed.

Some central ridge and east coast grove soils contain 300–400 lb. of Cu/acre in the top 6 inches of soil. A moderate routine disease control spray program contributes an additional 3–4 lb. Cu/acre/year, so no soil application of Cu fertilizer is needed in this situation. Soil pH below 5.5 can solubilize enough soil Cu to be toxic to citrus trees. 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 non-cultivated Florida sandy soils are deficient in Cu. If a grove is developed on a virgin sandy soil, Cu should be included in the fertilizer blend at 2.5% of the nitrogen rate.

Conclusion

Supplying sufficient nutrition should be a high-priority management practice for every grower. An appropriate nutrient balance using fertilizer management is necessary to achieve sufficient plant nutrition for best fruit yield and quality. If an element is below the critical level, yield production will fall—even though the other elements are kept in good supply. Balanced use of plant nutrients corrects nutrient deficiencies and toxicities; improves soil fertility; increases nutrient- and water-use efficiency; enhances crop yields and fruit quality; develops tree tolerance to pests, diseases, and other stresses; and improves environmental quality.

Table 1. **Guidelines for Interpreting Orange Tree Leaf Fe and Cu (mg/kg or ppm)**

Element	Deficient	Low	Optimum	High	Excess
Fe	< 35	35 – 59	60 – 120	121 – 200	> 200
Cu	< 3	3 – 4	5 – 16	17 – 20	> 20
Analysis based on four to six-month-old spring flush leaves from non-fruiting twigs collected in July–September					

Table 2. Effective pH range of various Fe chelates

Fe Chelate	Effective pH Range
Fe-EDTA, Fe-HEDTA	4 to 6.5
Fe-DTPA	4 to 7.5
Fe-EDDHA	4 to 9

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SL406

Boron (B) and Chlorine (Cl) for Citrus Trees[1]

Mongi Zekri and Tom Obreza[2]

This publication is part of a series about understanding nutrient requirements for citrus trees. For the rest of the series, visit http://edis.ifas.ufl.edu/topic_series_citrus_tree_nutrients.

To maintain a viable citrus industry, Florida growers must consistently and economically produce large, high-quality fruit crops year after year. Efficiently producing maximum yields of high-quality fruit is difficult without understanding soil and nutrient requirements of bearing citrus trees. Most Florida citrus is grown on soils inherently low in fertility with low cation-exchange capacity (CEC) and low water-holding capacity; thus, soils are unable to retain sufficient quantities of available plant nutrients against leaching caused by rainfall or excessive irrigation.

Seventeen elements are considered necessary for the growth of green plants:

1. Carbon (C)
2. Hydrogen (H)
3. Oxygen (O)
4. Nitrogen (N)
5. Phosphorus (P)
6. Potassium (K)
7. Magnesium (Mg)
8. Calcium (Ca)
9. Sulfur (S)
10. Manganese (Mn)
11. Zinc (Zn)
12. Iron (Fe)
13. Copper (Cu)
14. Boron (B)
15. Chlorine (Cl)
16. Molybdenum (Mo)
17. Nickel (Ni)

Plants obtain C, H, and O from carbon dioxide and water. The remaining elements, which are called the "mineral nutrients," are obtained from the soil. Mineral nutrients are classified as *macronutrients* and *micronutrients*. The term "macronutrients" refers to those elements that plants require in large amounts (N, P, K, Mg, Ca, and S). The term "micronutrients" applies to plant nutrients that are essential to plants but are needed only in small amounts (Mn, Zn, Fe, Cu, B, Cl, Mo, and Ni).

When macronutrients are supplied in relatively high proportions to micronutrients for growth stimulation of newly planted citrus trees, extreme depletion of micronutrients can develop as a result of marked top growth, and micronutrient deficiencies can appear. Therefore, a balance between macronutrients and micronutrients is needed. Citrus micronutrient deficiencies are most commonly observed on previously uncultivated soils, shallow soils with high water table, extremely sandy areas, and calcareous soils.

1. This document is SL406, one of a series of the Soil and Water Science Department, UF/IFAS Extension. Original publication date March 2014. Visit the EDIS website at http://edis.ifas.ufl.edu.

2. Mongi Zekri, Hendry County Extension agent; and Tom Obreza, senior associate dean and professor, Office of Dean for Extension and Florida Cooperative Extension Office, UF/IFAS Gainesville, FL 32611.

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Since mineral nutrition is a major factor in maximizing yield of high-quality fruit, understanding the functions of mineral elements, diagnosing nutrient deficiencies, and providing needed fertilizers are essential. This publication describes and discusses boron (B) and chlorine (Cl) deficiencies, functions, and recommended practices to alleviate nutritional problems.

Introduction

Meeting the world's escalating food needs cannot be achieved without fertilizer input. Without fertilizer, the world would produce only about half as much food, and more forested and marginal lands would have to be put into production. Inorganic commercial fertilizer plays a critical role in the world's food security, and it is important from both yield and food-quality perspectives. Intensifying production and increasing yield on limited arable land secure a sufficient food supply, and fertilizer plays a critical role in these goals. Intensifying production is increasingly essential to meet the challenge of future food demands. However, this intensification must be done while also minimizing environmental impacts. The 4R Nutrient Stewardship Framework (i.e., right fertilizer source, right rate, right time, and right place) is therefore very important.

Boron Functions

- Important in sugar translocation and carbohydrate metabolism
- Particularly needed at the location of active cell division
- Plays an important role in flowering, pollen-tube growth, fruiting processes, N metabolism, and hormone activity
- Maintains Ca in a soluble form; thus, ensuring its proper utilization

Chlorine Functions

Although the essentiality of Cl has been established for many higher plants, its need for fruit crops has not yet been demonstrated, and its importance in citrus tree metabolism is unclear. The plant requirement for Cl is quite high as compared with other micronutrients, but its exact role in plant metabolism is still obscure.

Chlorine is

- associated with turgor in the stomata's guard cells through the osmotic pressure exerted by imported K ions;
- involved with oxygen production in photosynthesis; and
- involved in chlorophyll and photosynthesis because its deficiency causes chlorosis, unusual bronze discoloration of foliage, and reduction in growth.

Boron Deficiency

Native Florida soils are low in B, and a deficiency of this element occasionally occurs in field conditions. In acidic soil, B is more water-soluble, very mobile in the sandy soil profiles, and readily leaches by rainfall or excessive irrigation. Boron deficiency may be aggravated by severe drought, excessive lime applications, or irrigation with alkaline water that can result in reduced B availability and uptake.

Boron deficiency is known as "hard fruit," because the fruit is hard and dry because of lumps in the rind caused by gum impregnations. The chief fruit symptoms include premature shedding of young fruits. Such fruit have brownish discolorations in the white portion of the rind (albedo), which are described as gum pockets or impregnations of the tissue with gum and unusually thick albedo. Older fruit are undersized, lumpy, and misshapen with an unusually thick albedo containing gum deposits. Seeds fail to develop, and gum deposits are common around the axis of the fruit (Figure 1). Boron is relatively immobile in plants. The first visual symptoms of B deficiency are typically the death of the terminal growing point of the main stem. Further symptoms include brittle and slightly thickened leaves, vein splitting, a tendency for the leaf blade to curl downward,

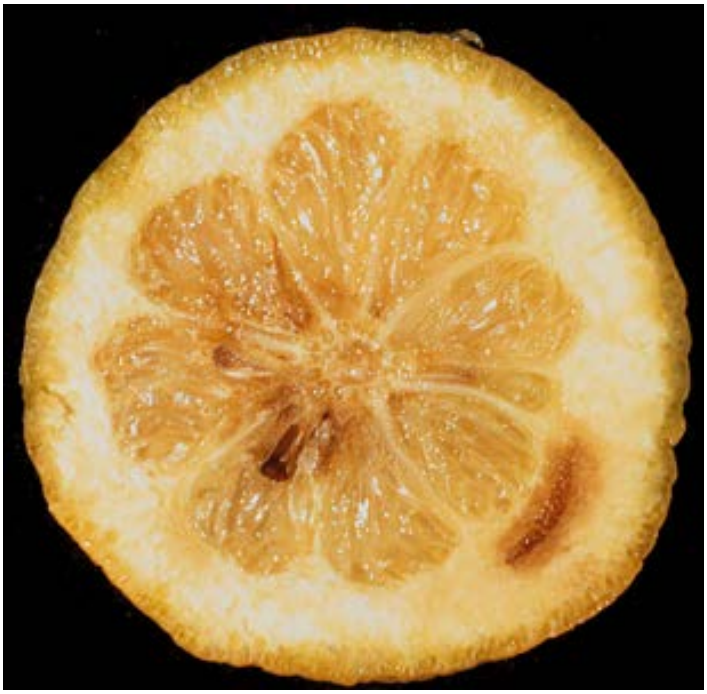


Figure 1. Boron deficiency—Small size and misshapen fruit, thick albedo containing gum pockets, and aborted seeds with gum deposits around the axis of the fruit.
Credits: Jack Whiteside, UF/IFAS retired faculty member

and at times chlorosis (Figure 2). Boron deficiency also tends to cause corking and enlargement of the upper surface of the main veins (Figure 3). A premature shedding of leaves beginning at the treetop that soon renders the tree almost completely defoliated is also associated with this symptom. Fruit symptoms are the most consistent and reliable tool to diagnose B deficiency. Boron deficiency is associated with citrus greening (HLB) disease. It is likely caused by restrictions of nutrient uptake and/or transport.



Figure 2. Boron deficiency—Thickening of the leaves, vein splitting, a tendency for the leaves to curl downward, and chlorosis.
Credits: Mongi Zekri



Figure 3. Boron deficiency—Corking and enlargement of the upper surface of the main veins and leaf chlorosis.
Credits: Mongi Zekri

Chlorine Deficiency

Deficiency symptoms of Cl are not commonly observed in most crops growing in the field. Chlorine deficiency has not been seen on citrus. On other plant species, the most commonly described symptom of Cl deficiency is wilting of leaves, especially at the margins. As the deficiency progresses and becomes more severe, the leaves exhibit curling, bronzing, chlorosis, and necrosis.

Deficiency Correction

Borax (sodium borate) is commonly used to treat B-deficient citrus. This source can be applied either to the foliage or to the soil. Because of its greater solubility, boric acid might be preferred more than borax for foliar spray application. Foliar spray applications are safer and more efficient than soil applications. Foliar sprays may be applied throughout the dormant and post-bloom period but preferably during early flower development. Treating at this growth stage is important because B does not move readily from other parts of the tree to the buds. Applying B at this time will also assist in flower initiation and pollen production, satisfy the needs for pollen tube growth, and enhance fruit set. For maintenance spray applications, 0.25 lb./ac. of B may be used. Where deficiency symptoms are present, double the amount suggested. Use care not to apply more than the recommended amount, because the margin between B sufficiency and toxicity is narrow. During dry weather, applying B to the soil frequently fails to give satisfactory results. If applied during the summer rainy season, then soil application may result in toxicity problems. As a maintenance program, apply B in the fertilizer at an annual rate equivalent to 1/300 of the N rate. If trees are irrigated with reclaimed water, B fertilization may not be necessary.

Boron Toxicity

In Florida, boron toxicity of citrus usually results from the addition of excess borax or similar B materials. The first symptom of B toxicity in the leaves begins with yellowing and death of the leaf tip. These chlorotic areas gradually expand and extend along the leaf margins, creating a mottling effect (Figure 4). Similar symptoms can be caused by urea spray burn and biuret toxicity. Dead areas may develop along the margins near the tips, and leaf drop

Table 1. Leaf analysis standard for assessing Cl and B nutrient status of citrus trees in 4- to 6-month-old spring-cycle leaves from non-fruiting terminals

Element	Deficient less than	Low	Satisfactory	High	Excess more than
Chlorine (Cl) (%)	—	—	less than 0.5	0.5–0.7	0.7
Boron (B) (ppm)	20	20–35	36–100	101–200	250

occurs. The new growth flush following partial defoliation will also show symptoms if toxic levels of B are still present. In severe cases, leaf drop can be extensive, leading to total defoliation, dieback, reduced cropping, and tree death. Because B accumulates progressively as citrus leaves age, the apical mottling is usually more pronounced in late summer and fall. Toxicity due to high B levels in the soil can be reduced by leaching the root zone with low-B irrigation water. Liming of acid soils has also been found to be effective. Boron toxicity can be prevented by exercising care to apply no more than the recommended fertilizer rate.



Figure 4. Boron toxicity—Chlorotic areas from the tip expand and extend along the leaf margins.
Credits: Mongi Zekri

Chlorine Toxicity

The most common source of chlorine toxicity is from chloride in irrigation water. Chloride moves readily with soil water. It can be absorbed by the crop, move in the transpiration stream, and accumulate in the leaves. If the chloride concentration in the leaves exceeds the tolerance of the crop, leaf burn will develop, and leaves can abscise. Normally, plant injury occurs first at the leaf tips and progresses from the tip down along the edges as severity increases (Figure 5). Excessive necrosis (dead tissue) is often accompanied by leaf drop. Many sensitive tree crops begin to show injury with more than 0.3% chloride (dry weight basis). In case of severe defoliation, dieback, and even tree death can result. Older leaves usually show the symptoms first. Similar symptoms can be caused by drought and fertilizer salt burn.

Alleviation of Chlorine/Salt Toxicity

- Frequent irrigation intervals help maintain a low soil-water tension and reduce salt accumulation within the irrigated zone. The volume of irrigation water should be great enough so any accumulated salts are leached below the root zone.
- Split fertilizer applications, and use nutritional materials with low salt index. Avoid the addition of chloride from the application of muriate of potash (potassium chloride).
- Well-managed fertigation with dilute weekly applications at low rates is probably the best solution.



Figure 5. Chloride toxicity—Leaf burn progresses from the tip down along the edges as severity increases.
Credits: Mongi Zekri

Conclusion

Supplying sufficient nutrition should be a high-priority management practice for every grower. An appropriate nutrient balance using fertilizer management is necessary to achieve sufficient plant nutrition for best fruit yield and quality. If an element is below the critical level, yield production will fall—even though the other elements are kept in good supply. Balanced use of plant nutrients corrects nutrient deficiencies and toxicities; improves soil fertility; increases nutrient- and water-use efficiency; enhances crop yields and fruit quality; develops tree tolerance to pests, diseases, and other stresses; and improves environmental quality.

Molybdenum (Mo) and Nickel (Ni) for Citrus Trees[1]

Mongi Zekri and Tom Obreza[2]

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Since mineral nutrition is a major factor in maximizing yield of high quality fruit, understanding the functions of mineral elements, diagnosing nutrient deficiencies, and providing needed fertilizers are essential. This publication describes and discusses molybdenum (Mo) and nickel (Ni)

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2. Mongi Zekri, Hendry County Extension agent; and Tom Obreza, senior associate dean and professor, Office of Dean for Extension and Florida Cooperative Extension Office, UF/IFAS Gainesville, FL 32611.

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deficiencies, functions, and recommended practices to alleviate nutritional problems.

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Functions of Molybdenum

- Assists in the formation of plant proteins
- Helps starch, amino acid, and vitamin formation
- Acts as a catalyst that aids the conversion of gaseous N to usable forms by nitrogen-fixing microorganisms
- Aids in conversion of nitrate to ammonium as a constituent of the plant enzyme nitrogenase

Functions of Nickel

- Critical constituent of the plant enzyme urease for conversion of urea to ammonia
- Chemically related to iron and cobalt
- Stimulates proline biosynthesis in plants, which is responsible for osmotic balance in plant tissues
- Foliar sprays of Ni were noted to increase yields of many plants
- Has well-defined enzymatic functions in legumes

Molybdenum Deficiency and Correction

In Florida, Mo deficiency in citrus is commonly called "yellow spot." The deficiency occurs when trees are unable to absorb sufficient Mo from an acidic soil. Deficiency symptoms appear on the leaves as large, interveinal chlorotic spots in early summer (Figure 1). As the leaves age, the yellow spots develop deposits of brown gum on the lower leaf surfaces, which may eventually turn black. In many cases, an infection of anthracnose causes the areas covered by the spots to die and drop out, leaving small holes in the leaves. When the deficiency is severe, the necrotic yellow spots enlarge and extend to the margins. Affected leaves eventually drop, and trees become almost defoliated during the winter.

Symptoms are seldom observed on fruit except when the deficiency is severe. In severely deficient conditions, large irregular brown spots surrounded with yellow discoloration may develop on the fruit. The discoloration goes only into the peel and does not affect the albedo. Symptoms of Mo deficiency appear more common in late summer on the sunny side of the trees. Since molybdenum deficiency usually occurs in acidic soils, the most common cure is to lime the soil to a pH of 6.0–6.5, after which Mo deficiency often disappears. If liming did not fix the deficiency or if the soil pH was already around 6.5, Mo deficiency can be easily corrected with a sodium molybdate or ammonium molybdate foliar spray. For example, spraying trees showing mild yellow spot leaf symptoms with 5 oz. of sodium molybdate per acre should take care of the problem. In severe cases, spray with 10 oz./ac. If the spray is applied between summer and early fall, the leaves will re-green, and the yellow spots will disappear from the upper surface. Most of the gum will also disappear from the lower surfaces of the leaves. However, black spots consisting primarily of cork cells will remain. One spray is usually sufficient for three years or more. Soil applications are not satisfactory.



Figure 1. Molybdenum deficiency—Large interveinal chlorotic spots
Credits: Mongi Zekri

Table 1. Leaf analysis standard for assessing Mo status of citrus trees in 4- to 6-month-old-spring-cycle leaves from non-fruiting terminals

Element	Deficient less than	Low	Satisfactory	High	Excess more than
Molybdenum (Mo) (ppm)	0.06	0.06–0.09	0.1–1.0	2–50	50

Molybdenum Sources

- Ammonium molybdate
- Sodium molybdate

Nickel Deficiency

Many researchers have demonstrated that plant growth is severely impacted by Ni deficiency when urea is the sole N source. Nickel-deficient plants accumulate toxic levels of urea in leaf tips because of reduced urease activity. Nickel deficiency causes severe disruption in N metabolism, and other metabolic processes exhibited as leaf tip necrosis, marginal chlorosis of leaves, and premature leaf drop. Nickel is mobile in plants. Hence, deficiency symptoms first appear in the older leaves. Nickel deficiency has not been seen in soil-grown plants. Nickel is abundant in the soil with concentrations varying from 5 to 500 mg Ni per kg (ppm). At pH <6.5, most Ni compounds are relatively soluble. Nickel is absorbed as Ni^{2+} and competes with other divalent cations, such as Ca, Mg, Fe, Zn, and Mn. Nickel toxicity can be associated with biosolids application or industrial pollution, and toxicity is more common in acid soils. Application of biosolids to horticultural crops is the most common cause of Ni accumulation in the soil. Soil concentrations can range from 24,000 to 53,000 ppm Ni in soil near metal refineries or in dried biosolids, respectively. Optimum concentration in leaf dry matter of most crops ranges between 0.08–0.22 ppm.



Figure 2. Leaf burn through foliar spray of urea mimics Ni deficiency symptoms
Credits: Mongi Zekri



Figure 3. Leaf burn through foliar spray of urea and biuret toxicity mimics Ni deficiency symptoms
Credits: Mongi Zekri

Conclusion

Supplying sufficient nutrition should be a high-priority management practice for every grower. An appropriate nutrient balance using fertilizer management is necessary to achieve sufficient plant nutrition for best fruit yield and quality. If an element is below the critical level, yield production will fall—even though the other elements are kept in good supply. Balanced use of plant nutrients corrects nutrient deficiencies and toxicities; improves soil fertility; increases nutrient- and water-use efficiency; enhances crop yields and fruit quality; develops tree tolerance to pests, diseases, and other stresses; and improves environmental quality.

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HS-797

A Guide to Citrus Nutritional Deficiency and Toxicity Identification[1]

Stephen H. Futch and David P.H. Tucker[2]

Citrus trees in commercial and dooryard plantings can exhibit a host of symptoms reflecting various disorders that can impact their health, vigor, and productivity to varying degrees. Identifying symptoms correctly is an important aspect of management, as inappropriate remedial applications or other actions can be costly and sometimes detrimental. Nutritional disorders addressed in this publication are an important aspect of citrus tree symptomology. Symptoms of deficiency or toxicity may have different forms of expression on foliage, stems, roots, and fruit, and may not in all cases resemble those illustrated in various publications. Symptoms can vary considerably from mild/incipient to chronic, particularly on foliage, and can also be expressed in leaf size. Because availability of some micronutrients like Zn, Mn, and Fe are soil-pH related, deficiency symptoms of these three elements may often occur simultaneously within a tree canopy and sometimes mask each other within a single leaf. To the untrained eye, nutritional disorders may be confused with herbicide, fungicide, physiological, and stress-related toxicities and physiological disorders. When in doubt, seek advice before committing to costly and perhaps inappropriate corrective measures.

Nitrogen Deficiency

Deficiency is expressed by light green to yellow foliage over the entire tree in the absence of any distinctive leaf patterns. With mild deficiency, foliage will be light green progressing to yellow as conditions intensify (Fig. 1). New growth usually emerges pale green in color, but darkens as foliage expands and hardens. With yellow vein chlorosis, the midribs and lateral veins turn yellow while the rest of the leaf remains a normal green color (Fig. 2). This chlorosis is frequently attributed to girdling of individual branches or the tree trunk. It may also occur with the onset of cooler weather in the fall and winter due to reduced nitrogen uptake by the plant from the soil. Nitrogen deficiency is also associated with senescing foliage which can develop a yellow-bronze appearance prior to leaf abscission (Fig. 3). Nitrogen deficiency will limit tree growth and fruit production, while high nitrogen applications produce excessive vegetative growth at the expense of fruit production, reducing fruit quality and threatening groundwater, particularly on vulnerable soil types.

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2. S.H. Futch, Extension Agent IV; and D.P.H. Tucker, professor, emeritus; Citrus REC, Lake Alfred, Florida, Horticultural Sciences Department, UF/IFAS Extension, Gainesville, 32611.

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Figure 1. Nitrogen deficiency (Dark green leaf is normal; the other two leaves are deficient.)



Figure 2. Yellow vein chlorosis



Figure 3. Nitrogen deficiency (Aging, senescing leaves.)

Phosphorus Deficiency

Fruit are rather coarse with thick rinds (Fig. 4) and have lower juice content which is higher in acid. Although rarely observed, foliage may exhibit a bronze appearance. Phosphorus deficiency is unlikely to occur in groves that have received regular P applications in the past. However, new plantings on previously uncropped land usually require substantial initial phosphorus applications.

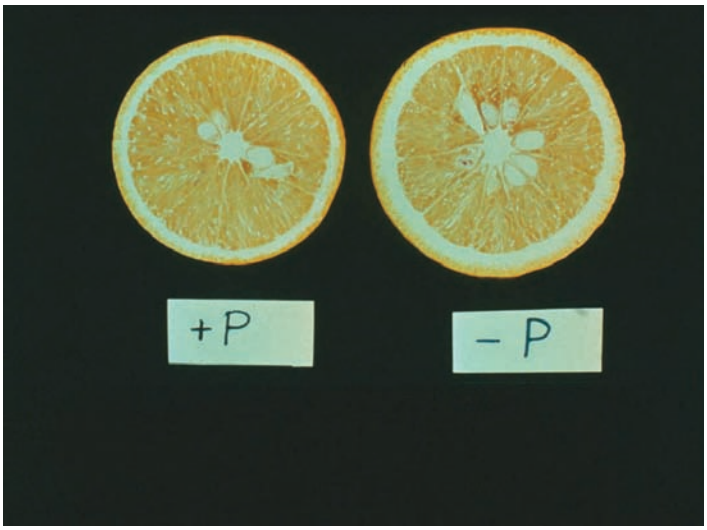


Figure 4. Phosphorus deficiency

Potassium Deficiency

Fruit are smaller, have smoother, thinner rinds and may be subject to splitting and/or drop (Fig. 5). Potassium deficiency is likely to occur on calcareous soils due to elemental antagonism, and where large crops of fruit are produced with high nitrogen rates. A rarely observed bronzing of foliage may sometimes be observed, particularly on lemons.

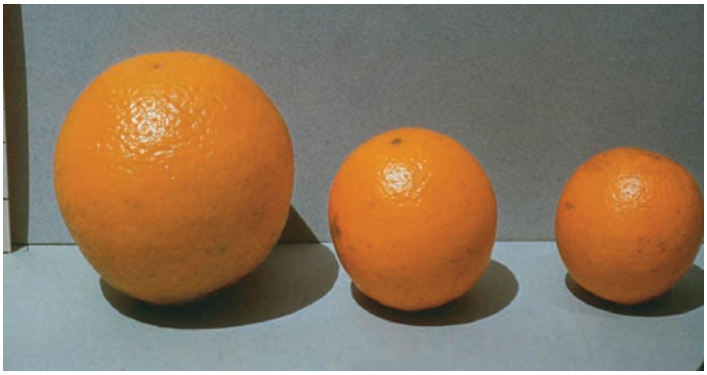


Figure 5. Potassium deficiency (3 levels of K deficiency with the smallest fruit being the most deficient.)

Magnesium Deficiency

The first symptom is a yellowish green blotch near the base of the leaf between the midrib and the outer edge. The yellow area enlarges until the only green remaining is at the tip and base of the leaf as an inverted V-shaped area on the midrib (Fig. 6). With acute deficiency, leaves may become entirely yellow-bronze and eventually drop. Dolomite will correct mild foliage symptoms in soils with low to neutral pH. Magnesium deficiency occurring in calcareous soil may have to be corrected with foliar applications.



Figure 6. Magnesium deficiency

Manganese Deficiency

Deficiency appears as dark green bands along the midrib and main veins surrounded by light green interveinal areas giving a mottled appearance (Fig. 7). As severity increases, the light green interveinal areas give way to a yellow-bronze coloration. Both manganese and zinc deficiencies may occur on calcareous soil and may be more severe on trees with highly pH-sensitive rootstocks. Incipient manganese symptoms may sometimes disappear as the season progresses, so leaves should be observed several times before remedial action is taken. Soil and foliar applications may be effective in correction of manganese deficiency.



Figure 7. Manganese deficiency

Zinc Deficiency

Early stages appear as small blotches of yellow between green veins on the leaf. With severe deficiency, leaves may become increasingly yellow except for the green veinal areas (Fig. 8). Under severe deficiency conditions, leaves will also be small with narrow pointed tips on terminal growth. Foliar fertilizer applications are usually recommended for correcting zinc deficiency. Trees with citrus blight will also show leaf symptoms of zinc deficiency.



Figure 8. Zinc deficiency

Iron Deficiency

In mild cases, leaf veins are slightly darker green than interveinal areas with symptoms appearing first on new foliage (Fig. 9). In severe cases, interveinal areas become increasingly yellow with entire area eventually becoming ivory in color with emerging foliage, which is smaller. Trees may become partially defoliated with eventual twig and canopy dieback. Iron deficiency is usually an indication of calcareous soil condition and is more likely to be expressed on high pH-sensitive rootstocks like Swingle citrumelo. An early expression of flooding damage to roots and of copper toxicity may be iron deficiency symptoms.



Figure 9. Iron deficiency

Copper Deficiency

Mild copper deficiency is usually associated with large, dark green leaves on long soft angular shoots. Young shoots may develop into branches which appear curved or "S-shaped," referred to as "ammoniation" usually resulting from excessive nitrogen fertilization (Fig. 10). Twigs can develop blister-like pockets of clear gum at nodes (Fig. 11). As twigs mature, reddish brown eruptions may occur in the outer portion of the wood. Severely affected twigs commonly die back from the tip with new growth appearing as multiple

buds or "witches broom". Necrotic-corky areas on the fruit surface may sometimes occur in extreme situations. Copper deficiency is more likely to occur in new plantings on previously uncropped soils, which are usually deficient or totally lacking in copper.



Figure 10. Copper deficiency (ammoniation)



Figure 11. Copper deficiency showing gum pocket at node

Copper Toxicity

Symptoms can include thinning tree canopies, retarded growth and foliage with iron deficiency symptoms. Feeder roots may also become darkened, and show restricted growth. When extractable copper exceeds 100 pounds per acre, trees may begin to decline. Old citrus land should be checked for soil copper before replanting. High soil copper levels may be ameliorated by liming to pH 6.5. The root-stock Swingle citrumelo is known to be quite susceptible to high soil copper.

Boron Deficiency

Fruit symptoms most indicative of boron deficiency include darkish-colored spots in the white albedo of fruit and sometimes in the central core (Fig. 12). Fruit may be somewhat misshapen with a lumpy surface. Unlike other micronutrient deficiencies, boron can impact fruit quality and should therefore not be allowed to occur. Slight excess can cause toxicity, so maintenance or correctional applications should involve ground or foliage applications, but not both.



Figure 12. Boron deficiency

Boron Toxicity

Early stages of boron toxicity usually appear as a leaf tip yellowing or mottling. In severe cases, gum spots occur on lower leaf surfaces (Fig. 13) with leaf drop occurring prematurely. Severe symptoms can include twig dieback.



Figure 13. Boron toxicity (Gumming on underside of leaf.)

Molybdenum Deficiency

Rarely observed, it can occur under acidic soil conditions. The most characteristic field symptoms are large yellow spots on the leaves that appear first as less defined water-soaked areas in spring (Fig. 14), later developing into distinct larger interveinal yellow spots.

Biuret Toxicity

Biuret is an impurity in urea fertilizer which may be avoided using only guaranteed low biuret urea products, particularly for foliar sprays. Leaf symptoms appear as irregular, yellowish-green interveinal chlorotic areas appearing first at leaf tips and spreading over the entire area

of the leaf surface (Fig. 15). As severity increases, only the midribs and parts of the major veins remain green.



Figure 14. Molybdenum deficiency



Figure 15. Biuret toxicity

Salt Injury

Many salinity-induced symptoms are similar to drought stress symptoms, including reduced root growth, decreased flowering, smaller leaf size, and impaired shoot growth. These can occur prior to more easily observed ion toxicity symptoms on foliage. Chloride toxicity, consisting of burned necrotic or dry appearing edges of leaves, is one of the most common visible salt injury symptoms. Actual sodium toxicity symptoms can seldom be identified, but may be associated with the overall leaf "bronzing" (Fig. 16) and leaf drop characteristic of salt injury. Slightly different symptomology may occur depending on whether injury is due to root uptake or foliage contact. Excessive fertilizer applications, highly saline irrigation water, and storm-driven ocean sprays can all result in salinity-induced phytotoxic symptoms.



Figure 16. Salt injury

UF IFAS Extension UNIVERSITY of FLORIDA

SL-243

Advancements with Controlled-Release Fertilizers for Florida Citrus Production: 1996 - 2006[1]

T.A. Obreza, R. Rouse, and E.A. Hanlon[2]

Introduction

Advances in fertilizer technology have resulted in a series of products that slowly release nutrients into the root zone using a number of different strategies. The intent is to minimize the amount of fertilizer nutrient that is exposed to potential loss from the root zone and to maximize the amount that is taken up by the plant. Controlled-release fertilizers (CRF) may have a place in cropping systems in Florida, especially in perennial crops such as citrus.

This document addresses citrus nutrition and its relationship to controlled-release fertilizers. The objectives are:

1. To describe CRF sources and their potential beneficial uses in citrus production;

2. To report the findings from a series of experiments in commercial citrus groves using both traditional and CRF sources relating to observed effects on tree growth and fruit yield.

The target audience for this document dealing with citrus nutrition and CRF sources includes Certified Crop Advisers, fertilizer dealers, citrus producers, and other parties interested in citrus fertilization practices.

Overview of Florida's Citrus Industry

In 2004, Florida's citrus industry consisted of more than 97 million trees on 748,555 acres (Figure 1). The industry produced 12.6 million tons of fruit with a farm gate value of $746 million. Florida's citrus industry comprised 73% of the total citrus production in the United States, and 18% of world production.



Figure 1. Citrus production areas of Florida.

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The citrus industry is a valuable, relatively environmentally friendly neighbor to Florida's growing population (Figure 2). Much of Florida's citrus is grown on prime land for urban expansion. This fact, coupled with additional pressures from the spread of diseases such as citrus canker and citrus greening, is prompting the industry to improve production efficiency, including an effective means of supplying nutrients with proper timing to satisfy crop nutrient requirements while avoiding inappropriate environmental consequences.

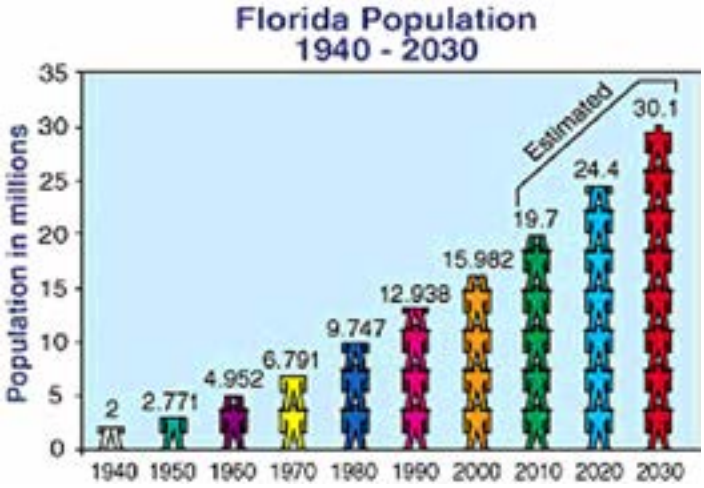


Figure 2. Florida human population growth from 1940 to 2000 and projected through 2030.

Soils in Florida's Citrus Growing Areas and Related Environmental Issues

Ridge Soils

Florida's Lake Wales ridge, running generally north and south through the center of the peninsula, is characterized by deep, well drained soils comprised mostly of sand (Figure 3). These soils permit rapid infiltration of rain and irrigation water, setting the scene for nutrient movement out of the citrus root zone. When nutrients are leached downward, they are no longer available to the plant, and may become an environmental concern.

Evidence supporting this concern is reflected in water quality measurements on the ridge. Of 3,949 statewide drinking water wells surveyed by the Florida Department of Agriculture and Consumer Services in the late 1980s, 584 wells (15% of all tested wells) contained nitrate-nitrogen concentrations greater than the regulatory maximum of 10 mg nitrate-nitrogen per liter. The majority of these wells (520) were located in Lake, Polk, and Highlands counties (Figure 3). Although it has never been proven that groundwater nitrate contamination beneath the Lake Wales ridge was caused by citrus fertilization, groves within these three counties are receiving considerable scrutiny because of the deep, well drained soils on which they have been planted.

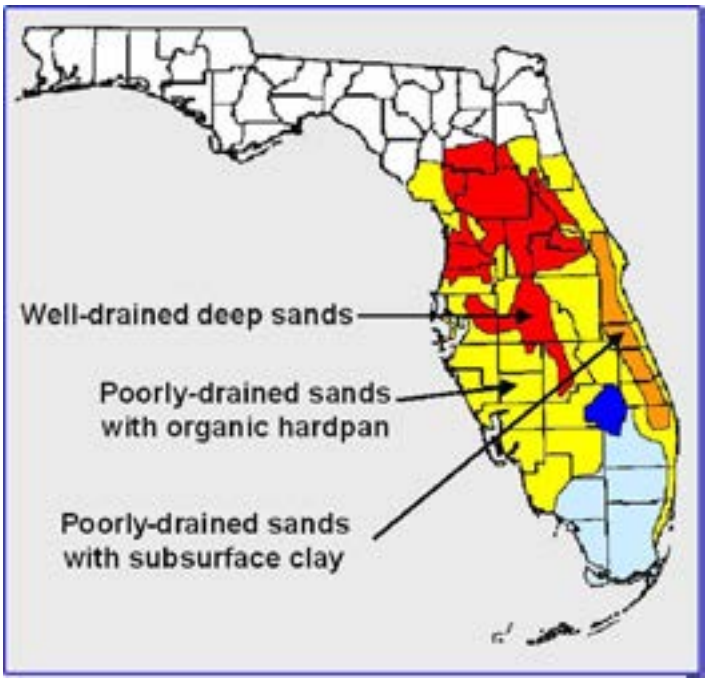


Figure 3. Soils in citrus production areas of Florida.

Flatwoods Soils

The so-called flatwoods soils are located on both the east and west sides of the Florida peninsula (Figure 3). These soils are characterized by poorly drained conditions, often requiring bedding and other field drainage structures to permit economical yields and quality citrus fruit juice. The striking differences in drainage and depth to a water table between ridge soils and flatwoods create entirely different conditions for the fate of soluble nitrogen fertilizers. While the potential for nitrate leaching does exist in these soils, conditions in these regions often reduce this potential substantially. "Nitrate concentrations were below the drinking-water standard (10 mg/L) in 108 south Florida wells (Biscayne and other surficial aquifers), except for two shallow wells in the unnamed surficial aquifer of the citrus area." (McPherson et al., 2000). Low nitrate-N concentrations found in well water beneath the flatwoods were most likely due to:

1) Denitrification in the shallow water table a few feet below the soil surface; and 2) Drainage water most likely ending up in surface water bodies as opposed to groundwater due to intensive artificial surface drainage of agricultural land.

General Citrus Nutrient Management

Fertilizers are important for commercially viable citrus production in both the ridge and flatwoods areas. By far, nitrogen is the most used nutrient in citrus production (Table 1) based upon Florida fertilizer use in the 2002-through-2003 production season. However, Florida's citrus industry consumes a relatively small amount of the total fertilizer sales in the United States (Table 1), utilizing a number of different nitrogen-containing fertilizer sources to satisfy the crop nutrient requirements for commercial citrus production. Traditional water-soluble nitrogen sources are made up of dry granular fertilizers and solution fertilizers. Dry granular fertilizers include the two most popular sources: ammonium nitrate and ammonium sulfate. Urea is by far the most popular solution fertilizer.

Table 1. General citrus nutrient management in Florida, 2002 through 2003.

Nutrient	Tons	% of North American consumption
N	194,363	1.5
P_2O_5	8,792	0.2
K_2O	43,867	0.9

Controlled-release fertilizers (CRF)

Controlled-release fertilizers are relative newcomers, both to national and Florida fertilizer markets. An older, but synonymous term for these types of fertilizers is slow-release fertilizers. While some of these compounds have been available since the 1950s, most of the advances have been made in the 1980s and 1990s. The first CRF sources to become commercially available were strictly nitrogen sources. The CRF technology has expanded to include potassium, phosphorus, and other nutrients including micronutrients (known as such because they are required by the plant in small amounts).

Slow-and controlled-release fertilizers employ several mechanisms to reduce the amount of nutrient that is available from the fertilizer at any one time.

Isobutylidene diurea (**IBDU**), which contains 31% nitrogen, was developed in the 1970s. This compound undergoes hydrolysis, splitting the IBDU molecule, to form urea. This hydrolysis process does not require microbial decomposition.

Sulfur-coated urea (**SCU**, 30 to 40% nitrogen) is designed to allow water from the soil solution to penetrate the sulfur coating, slowly dissolving the encapsulated urea. Some SCU sources contain a wax sealant to further retard urea release; however, microbes are required to degrade this wax sealant. Additionally, a number of earlier CRF products (methylene urea, nitroform, and ureaform) require microbial decomposition to provide nitrogen for plant uptake.

Other CRF products use **polymer-coated** nitrogen sources, and go by brand names such as Osmocote, Meister, Multicoat, and Polyon. These products all contain a semi-permeable membrane surrounding the water-soluble fertilizer. Water passes through the outer membrane dissolving the fertilizer, which, in turn, diffuses into the soil solution and subsequently is taken up by the plant.

Examples of current CRF uses are found that relate to tree age. Young-tree fertilizers often contain IBDU or methylene urea in combination with additional water-soluble nitrogen. Bearing-tree fertilizer blends may contain some SCU to extend the period within which nitrogen is available to the trees. In some citrus-growing areas, polymer-coated materials are added to the planting hole during reset operations.

Current Nitrogen Recommendations for Citrus

Recently, a nitrogen rate Best Management Practice (BMP) has been established for citrus production in Florida (Table 2). These fertilizer application rates are based on field studies that contain a water-quality and a yield component, most of which have used traditional dry or solution nitrogen fertilizer sources.

Table 2. Nitrogen rate (citrus trees greater than seven years old: BMP).

NITROGEN	lbs N/acre
Max. yearly N rate	240
Max. single dry app., dry season	65
Max. single dry app., wet season	40
Max. single fertigation, dry season	15
Max. single fertigation, wet season	10
POTASSIUM	
Apply K_2O at 100 to 125% of the N rate	

Reasons (for and against) Use of Controlled-release Fertilizers

Positive Aspects of CRF Use

Managers should be interested in CRF products because of their potential efficiency in delivering nutrients. The citrus industry as a whole has shown a preference for the use and

application of dry fertilizer sources. Most CRF products are also produced as a dry product, and would fit into current fertilizer application methods. These products have demonstrated higher nitrogen fertilizer efficiency compared with more soluble fertilizer sources resulting in equal or better citrus production, sometimes at a lower nitrogen rate. Because of the persistence (controlled release), the number of fertilizer applications is reduced compared with traditional fertilizer sources. This advantage is especially important when the grove manager must fertilize a considerable number of re-plants within the grove. In addition to the environmental advantage of maintaining nutrients within the root zone, there may eventually be a cost-sharing BMP to encourage the use of CRF sources.

Negative Aspects of CRF Use

As with any new technology, the cost per ton of CRF products is higher than traditional water-soluble fertilizer sources. This apparent disadvantage is offset somewhat by the potential for adding less CRF material to satisfy the crop nutrient requirements, as well as the potential BMP cost-sharing mentioned above. Because the body of research is small concerning CRF sources, grove managers are justified in questioning CRF performance, compared with traditional fertilizer sources. Many CRF sources need only be applied once per year, which is unheard of in the citrus industry. The common practice is three to four applications per year of standard soluble fertilizers. A common question about CRF products is: "Can I really apply fertilizer only once or twice a year and provide all of the necessary nutrition required for maximum production?" To address that important question, a series of experiments were conducted in commercial citrus groves using both traditional and CRF sources.

Experiments with CRF on Citrus in Central Florida

In 1996 (Wang and Alva, 1996), several CRF sources were tested in a simulated rainfall experiment, applying 40 inches of water in a 30-day period (Table 3). Findings indicated that for both a ridge Entisol and a flatwoods Spodosol, both CRF sources reduced nitrogen leaching considerably compared with the traditional ammonium nitrate source.

Selected CRF products were tested in 1998 on 20-year-old Hamlin/Cleo citrus in Highlands county (Alva and Paramavisam, 1998). The CRF source (added once per year) compared favorably with either the dry granular or the fertigation sources when rates were similar (Figure 4). In this study, the expected benefits of lower CRF rates were not demonstrated. However, the CRF source showed an advantage when considering the number of applications in the growing season.

Table 3. Leaching of water-soluble and controlled-release N following 40 inches of simulated rainfall in 30 days (Wang and Alva, 1996).

N source	Percentage of applied N fertilizer that leached	
	Candler sand	Wabasso sand
Amm. Nit.	100	88
IBDU	32	27
Meister coated	12	12

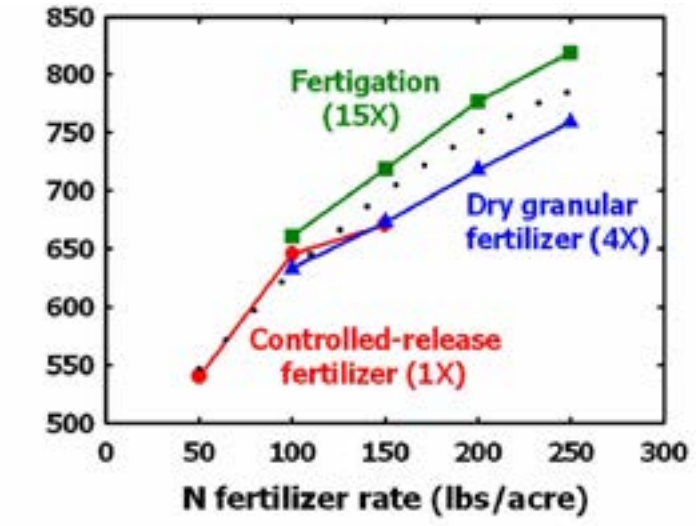


Figure 4. Orange yield (Hamlin) with nitrogen fertilizer rate from CRF applied once per year, dry granular applied in four equal amounts per year, and fertigation applied in 15 equal increments per year.

The amount of nitrogen leached below the root zone was studied in groves in 2001 (Paramasivam et al., 2001). Higher leaching of N applied by fertigation compared with dry granular fertilizer was explained by multiple instances of high rainfall events immediately following fertigations (Table 4). Much less nitrogen was leached from the CRF source compared with either the dry granular fertilizer or the fertigation practice. This finding indicates that the CRF source was effective in maintaining nitrogen within the root zone and/or it incurred more N losses by volatilization.

Table 4. Estimated N leached below the root zone (Paramasivam et al., 2001).

N rate	Dry granular fertilizer lbs/acre	Fertigation	CRF
		lbs N/acre/year	
50	---	---	0.8
100	11.1	16.3	2.9
150	11.8	21.5	7.1
200	12.2	27.1	---
250	19.0	31.3	---

Controlled-release Experiments in Southwest Florida

To further address CRF effects on citrus production and nitrogen fertilizer efficiency, three experiments were conducted in southwest Florida. The objectives of these experiments were to evaluate citrus tree growth and yield response to fertilizer programs containing both water-soluble nitrogen and controlled-release nitrogen, and to analyze the economics of using controlled-release fertilizers for citrus.

These experiments were conducted using young, healthy, irrigated, solid-set blocks of orange trees in commercial groves. Fertilizers, regardless of source, were hand applied to 3- to 5-trees per plot. Both orange yield and juice quality were measured, and used to calculate the pounds solids (sugars) yield per tree. Regression analyses included the generation of a quadratic plateau yield-response model to estimate the critical nitrogen application rate. The critical nitrogen application rate was defined as that rate above which citrus yield did not increase. In other words, adding additional nitrogen above the critical rate did not increase yields, but did increase cost of production. The cost of using CRF was compared with the traditional water soluble nitrogen program costs.

Experiment 1

In Experiment 1, Hamlin orange trees on Carrizo citrange rootstock were planted on a flatwoods soil in 1989 at 194 trees per acre. This grove received sub-surface irrigation. Water-soluble phosphorus and potassium fertilizers were applied at the same time as the nitrogen. A randomized complete block design using four trees per plot was used for 4 years (1992 through 1995), and juice quality and yield data were collected. Treatments (Table 5) included blends of ammonium nitrate, IBDU, and/or methylene urea. Rates were 0, 40, 80, 160, and 280 pounds of nitrogen per acre.

Table 5. Experiment 1.

Treatment	No. of applications in 7 years
100% Ammonium nitrate	31
50% Ammonium nitrate 50% IBDU	16
60% Ammonium nitrate 40% Methylene urea	14

Statistical analyses identified a mathematical nitrogen response between 230 and 250 pounds of nitrogen per acre; however, a practical response was found at approximately 200 pounds of nitrogen per acre (Figure 5). Up to that point, additional rate increased the boxes of fruit per acre, which in turn increased the pounds solids (sugars in the juice) per tree. There was a slight production advantage for the ammonium nitrate/IBDU combination compared with either ammonium nitrate alone or the ammonium nitrate/methylene urea combination. Perhaps the most significant finding was that CRF-containing materials resulted in similar nitrogen responses, but with approximately half the number of applications. Reducing the number of applications also reduces production costs.

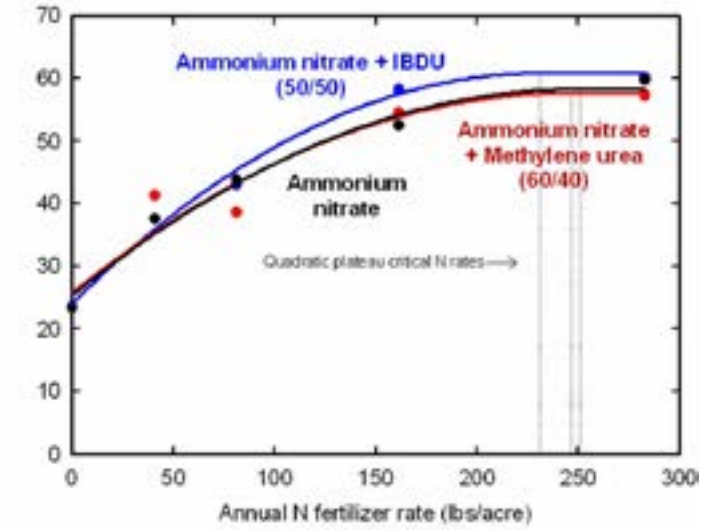


Figure 5. Mixtures of ammonium nitrate and either IBDU or Methylene urea rates used to produce 4-year cumulative pound-solids per tree.

Experiment 2

This experiment used valencia orange trees on Swingle citrumelo rootstock planted on a flatwoods soil in 1991 at 151 trees per acre. The grove was irrigated with micro-sprinklers. As with Experiment 1, this experiment used a randomized complete block design with three trees per plot. Production costs were calculated for 6 years starting at planting (1991 through 1996). Yield and juice quality were measured for 4 years (1993 through 1996). Treatments included a conventional fertilizer and five CRF products (Table 6). Rates were 0, 20, 40, 80, and 160 pounds of nitrogen per acre. Fertilizer applications during the 6-year experiment are shown in Table 7.

Findings included the fact that similar yield results, as measured by the 4-year average pound solids per tree, were obtained with the CRF products with fewer number of fertilizer applications (Figure 6). The conventional ammonium nitrate source achieved the highest pound solids per tree value at only 76% of the full nitrogen rate (Figure 6). The quadratic plateau critical nitrogen rates (Figure 7) show a range from approximately 120 pounds per acre for the

ammonium nitrate source up to a maximum of 150 pounds per acre for the Escote source.

Prokote and Sierra produced higher pounds solids yield and subsequent dollar return compared with the traditional ammonium nitrate source (Table 8). Based upon the economics measured in this experiment, using coated CRF sources exclusively to fertilize citrus was not economically feasible.

Table 6. Experiment 2, Treatments and number of applications, placecountry-regionValencia on Swingle citrumelo, 1993 through 1996.

Treatment (Trade name and analysis)	No. of applications in 6 years
Conventional (8-4-8)	24
Prokote Plus (20-3-10)	6
Nutricote 360 (17-6-8)	6
Sierra (16-6-10)	6
Meister (17-6-12)	6
Escote (19-6-12)	6

Table 7. Experiment 2 nitrogen applications by year for both traditional and CRF fertilizer sources.

Year	Ammonium nitrate	Coated fertilizers
1991	6	1
1992	5	1
1993	4	1
1994	3	1
1995	3	1
1996	3	1
Total	24	6

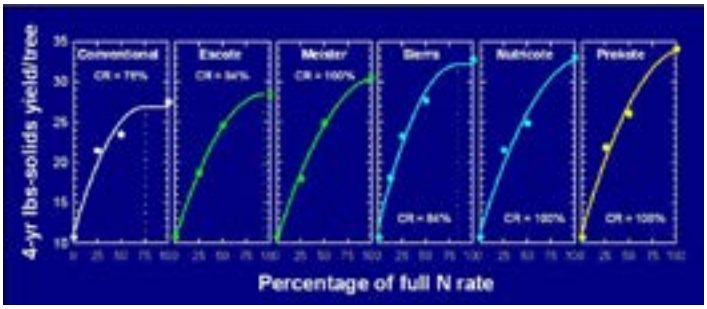


Figure 6. Comparison of five controlled-release fertilizer sources with conventional fertilization showing resulting 4-year pound-solids per tree responses.

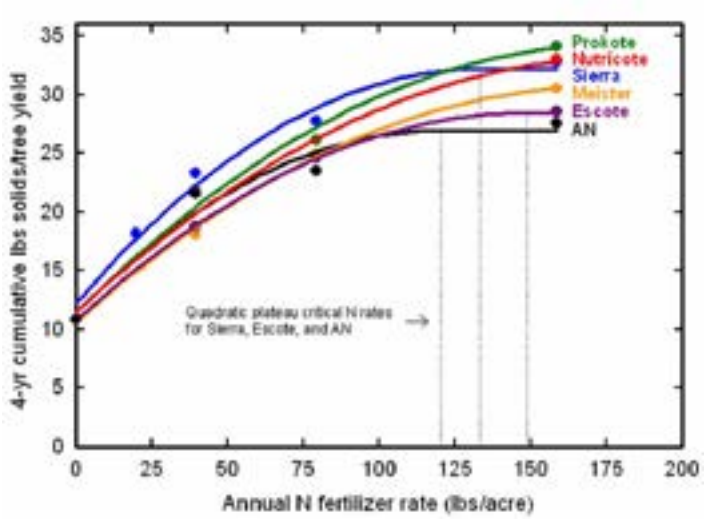


Figure 7. 4-year pound solids/tree as a function of annual nitrogen fertilizer rate. Regression analysis shows practical range of response to annual nitrogen fertilizer rate. Note that ammonium nitrate (AN) has the lowest critical nitrogen rate (120 pounds nitrogen per acre).

Table 8. Experiment 2, production cost analysis by nitrogen fertilizer source, 1991 through 1996.

Fertilizer	6-yr fert cost ($/tree)	Cumulative lbs solid/tree	Gross return ($/tree)
Prokote	15.49	27.7	28.90
Sierra	19.20	27.0	28.25
Nutricote	19.85	26.5	27.47
Meister	15.81	25.8	26.41
Escote	14.90	24.9	25.98
Conventional	5.06	24.2	25.40
None	0.00	10.8	11.23

Experiment 3

In a third experiment using Hamlin orange trees on Swingle citrumelo rootstock planted in 1990 at 151 trees per acre, yield and juice quality was measured for five years (1996 through 2000). As with the other two experiments, a randomized complete block was used, and in this case five trees per plot. Trees in this grove were irrigated using micro-sprinkler technology. Treatments (Table 9) included water soluble ammonium nitrate and several new technology CRF sources.

In 1999, leaf tissue samples were collected and analyzed for nitrogen, phosphorus, and potassium concentrations (Table 10). All nitrogen sources/treatments provided sufficient nitrogen to satisfy the crop nutrient requirements (Table 10). Phosphorus was also found to be at or above the sufficiency range; however, in all cases potassium was at or below the sufficiency range.

Yield response (Table 11) showed that CRF technology has been improving with time. In this experiment, citrus

responded more positively to fertilizer rate from CRF sources than from the water-soluble nitrogen source (Figure 8). This experiment also identified the difference in performance between the two CRF technologies. CRF sources applied once per year were more efficient nutrient sources for citrus than water-soluble fertilizer applied three times per year. When applied at 90 pounds of nitrogen per acre, the CRF source was as effective as water-soluble nitrogen applied at 180 pounds of nitrogen per acre (Figure 8).

Table 9. Treatments used in Experiment 3.

Fertilizer	Analysis	(lbs N/ac/yr)	App./yr
No nitrogen	0-5-16	0	3
Water-soluble N ("WSN")	16-5-16	45	3
	16-5-16	90	3
	16-5-16	180	3
Scotts AGROCOTE® (Resin-coated, "Tech 1")	16-5-16	45	1
	16-5-16	90	1
Scotts AGROCOTE® (Poly-S-coated, "Tech 2")	16-5-16	45	1
	16-5-16	90	1
	16-5-16	90	2
AGROCOTE® 50/50 combo of "Tech 1" and "Tech 2"	16-5-16	90	1

Table 10. Experiment 3, leaf tissue values from the 1999 and growing season by treatment.

Fertilizer source	N rate lb/acre	N (%)	P (%)	K (%)
Desirable ranges	=	2.5-2.7	0.12-0.16	1.2-1.7
None	0	2.6 ab*	0.26 a	1.44 a
WSN	45	2.6 ab	0.18 bc	0.64 c
WSN	90	2.4 ab	0.18 bc	0.84 bc
WSN	180	2.6 ab	0.20 b	0.87 bc
Tech 1	45	2.3 b	0.18 bc.	0.71 bc
Tech 1	90	2.5 ab	0.17 c	0.88 bc
Tech 2	45	2.5 ab	0.18 bc	0.76 bc
Tech 2	90	2.7 a	0.18 bc	0.91 bc
Tech 2 split	90	2.6 ab	0.17 bc	0.87 bc
Tech 1/Tech 2	90	2.5 ab	0.17 bc	0.97 bc
WSN/Tech 2	90	2.5 ab	0.16 c	0.83 bc

* Letters within the same column reflect statistical differences (P=0.05).

Table 11. 5-year pound solids per tree production from fertilizer sources at the indicated annual rates, Experiment 3.

Fertilizer	N rate lbs/acre	1996-2000 lbs solids/tree
Standard without N	0	65.7
WSN	90	74.8
Scotts Tech 1	90	89.3
WSN + Tech 2	90	81.6
Tech 1 + Tech 2	90	81.2
Tech 2	90	76.9
Tech 2 split app.	90	75.6
WSN	180	77.3

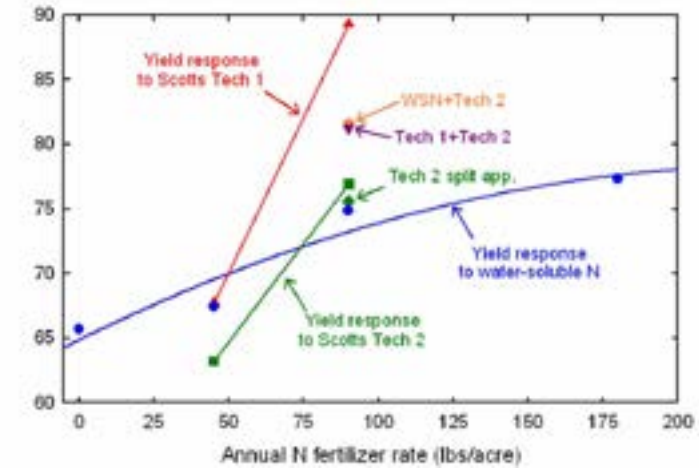


Figure 8. Experiment 3, showing a 5-year cumulative pounds solids per tree average as a function of the annual nitrogen fertilizer rate from water-soluble nitrogen, CRF sources, and the combination of these sources.

Current research

As of 2004, several field trials with commercial growers were underway. Studies involve the release rate of CRF sources in field conditions (Figure 9) as well as in the more controlled laboratory environment (Figure 10). Findings of these experiments will be reported in future documents and presentations to the citrus industry.



Figure 9. Current research showing porous bags containing CRF nutrient sources. Materials within the bag are exposed to both rainfall and irrigation. Contents of the bags are analyzed at selected time intervals to indicate the nutrient release rates of the CRF sources.

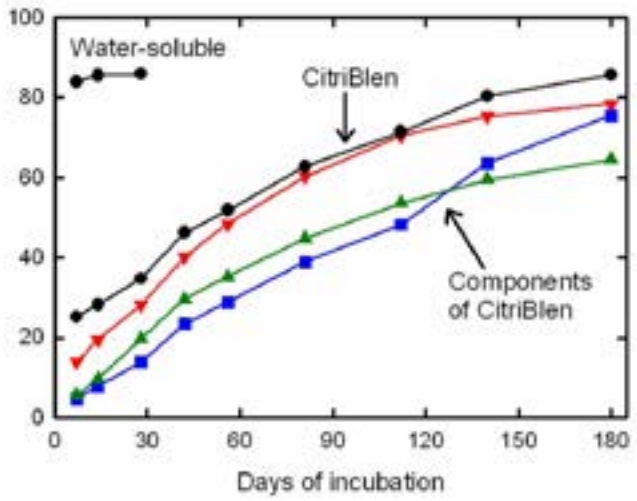


Figure 10. Current research showing results from a controlled laboratory experiment involving nutrient release from selected CRF sources with time.

Summary

The Florida citrus industry remains viable despite the pressures of disease, pests, and developmental land-use opportunities. Many citrus growers are interested in ways to improve production efficiency and at the same time address application of best management practices in their groves. Growers know that nitrogen and potassium are the top two mineral nutrients affecting citrus yield and quality, primarily because Florida's sandy soils hold both water and nutrients poorly. Research findings generated in commercial groves summarized in this document indicate that modern CRF sources are both horticulturally and environmentally effective but not economically viable. The reduced number of nitrogen fertilizer applications using CRF technology does reduce application costs; however, this technology must be implemented by a larger number of growers to reduce manufacturing costs incurred by CRF producers.

Acknowledgements

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UF IFAS Extension UNIVERSITY of FLORIDA

SL253.04

Soil and Leaf Tissue Testing for Commercial Citrus Production[1]

Thomas A. Obreza, Mongi Zekri, Edward A. Hanlon, Kelly Morgan, Arnold Schumann, and Robert Rouse[2]

Introduction

Nutrient deficiency or excess will cause citrus trees to grow poorly and produce sub-optimal 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 when adjusting a fertilizer program (Fig. 1).



Figure 1. Proper soil and leaf tissue sampling and analysis can accurately gauge citrus grove nutrition and help improve fertilizer programs. (Photograph by Mongi Zekri.)

This document, which is adapted from Chapter 4 of *Nutrition of Florida Citrus Trees, 2nd Edition* (http://edis.ifas.ufl.edu/ss478), explains the value of leaf and soil testing when choosing fertilizer programs to increase fertilizer efficiency while maintaining maximum yield and desirable fruit quality. Soil testing and leaf tissue analysis do not asses all of the same factors, so care must be taken to choose the correct test when diagnosing citrus nutrition (Table 1).

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 nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), zinc (Zn), copper (Cu), iron (Fe), and boron (B). Chlorine (Cl) concentration is usually sufficient in most field conditions, but Cl may become excessive if soil or irrigation water is saline. Molybdenum (Mo) deficiency or toxicity is rare. The goal in tissue analysis is to adjust fertilization programs so 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

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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.

Leaf 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 tissue analysis tests 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 be from a lack of K in the soil or from excessive Ca, Mg, and/or sodium (Na). Similarly, adding N when K is low may result in K deficiency since the increased growth caused by N 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 the procedures are done correctly, chemical analysis reliability, data interpretation, fertilization recommendations, and fertilizer program adjustments 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 (Fig. 2). However, leaf mineral concentrations are relatively stable from four to six months after leaf emergence in the spring.
- The best time to collect four- to six-month-old spring flush leaves is July and August (Fig. 3). If leaves are sampled later in the season, summer leaf growth easily can be confused with spring growth.

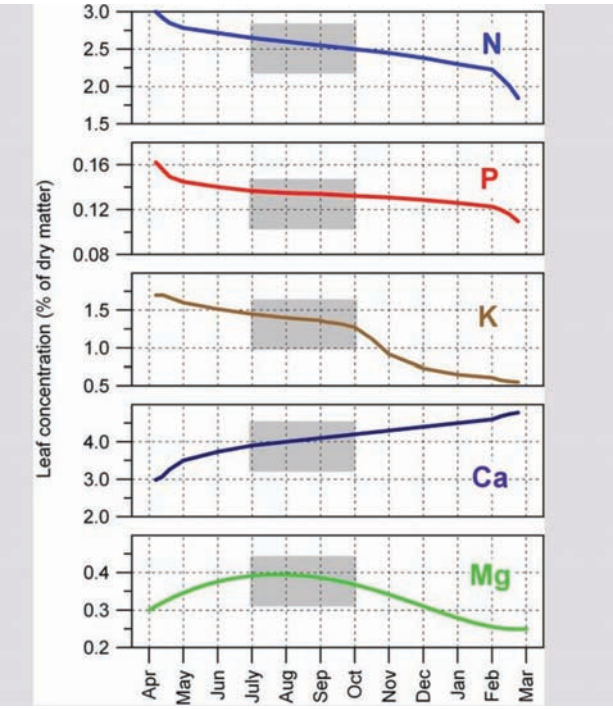


Figure 2. Changes in concentration of N, P, K, Ca, and Mg in citrus leaves with age. The shaded areas denote the recommended sampling period and the optimum concentration range for each element.

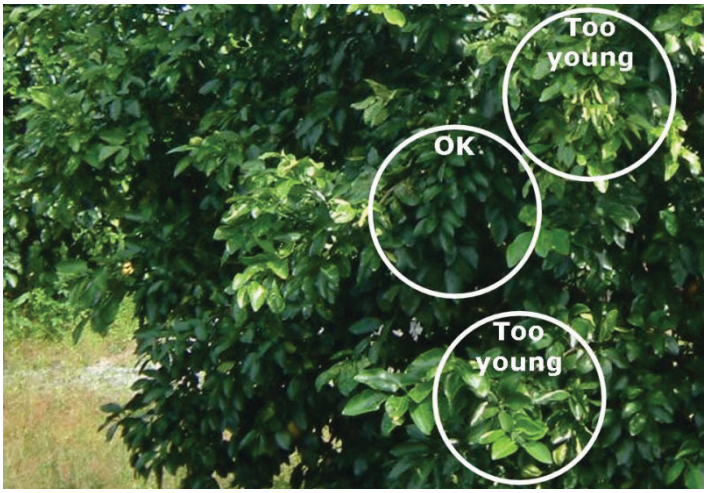


Figure 3. Sample four- to six-month-old spring flush leaves from nonfruiting twigs. (Photograph by Thomas Obreza.)

Leaf Sampling Technique

- A sampled citrus grove block or management unit should be no larger than 20 acres. The sampler should make sure the selected leaves represent the block being sampled. Management unit sampling strategies using grid sampling for variable rate application and other,

similar technologies are provided in the "Traditional vs. alternative sampling strategies" section of this document. Samples taken in a grid pattern are analyzed and interpreted similarly to those taken for a management unit.

- 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. Also, trees at the block's edge or at the end of rows should not be sampled as 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 in close proximity 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. Macronutrients include N, P, K, Ca, and Mg.
- If accurate micronutrient analysis is desired, the leaves will need to be washed (see below). Micronutrients include Cu, Zn, Mn, Fe, B, and Mo.
- 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, B, or other micronutrient determinations, leaf samples should be washed by hand soon after collection and before the leaves dehydrate.
- For micronutrient determinations, leaves should be rubbed between the thumb and forefinger while soaking them in a mild detergent solution and then thoroughly rinsed 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. Since **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. The tabulated standards 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 every year (Table 2). If the level of a particular nutrient is not optimum, various strategies can be used to address the situation (Table 3).

Benefits of Soil Analysis

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

Similar to leaf analysis, organic matter and soil pH determination methods 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 use extractants varying in strength and remove different amounts of nutrients from the soil. To draw useful information from soil tests, consistency using a single extraction procedure each year is necessary to avoid confusion when interpreting nutrient data.

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. The value of a soil testing procedure depends on how closely the extractable values from the soil 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 (Fig. 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 (Fig. 5).

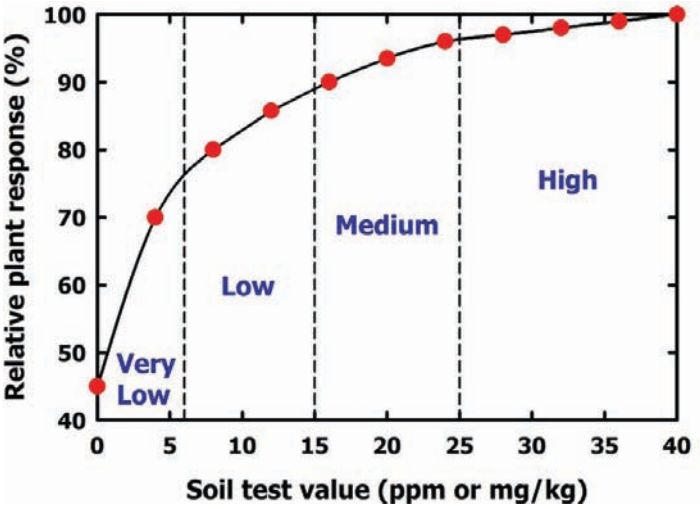


Figure 4. Ideal soil test calibration curve.

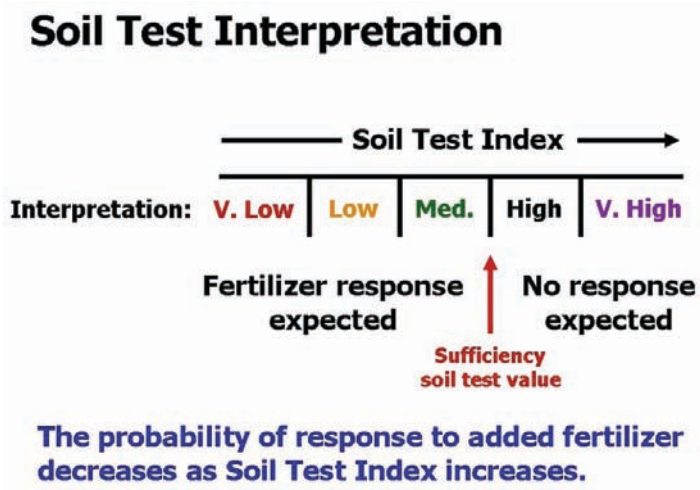


Figure 5. Soil test interpretation categories and their relationship to expected fertilizer response.

In Florida, soil testing for mobile, readily leached elements like N and K has no practical value. However, soil testing is used for P, Mg, Ca, Cu, organic matter, and pH. The University of Florida 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.

University of Florida 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. For Ca and Mg, other extractants 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. 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 six 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 a 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. Leaf 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 eight 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 (Fig 6).

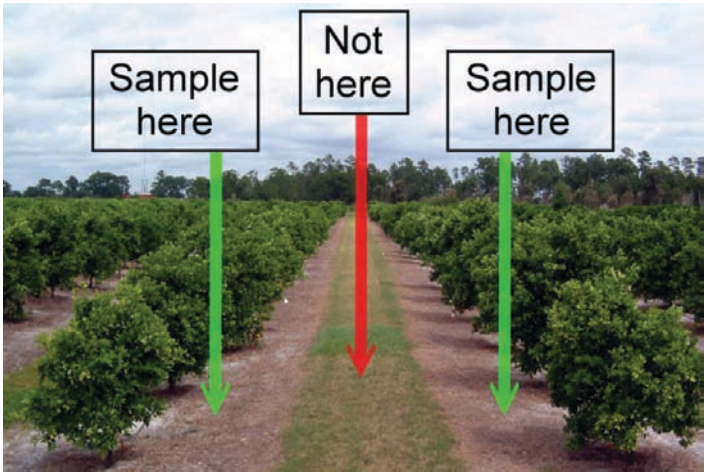


Figure 6. Sample soil near the dripline of the trees, not in the middle of the row. (Photograph by Thomas Obreza.)

- 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.
- Since **extractable** nutrients are measured, the magnitude of soil test values may differ between different laboratories. 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 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. This is 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, 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 one- to five-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 (Fig. 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).

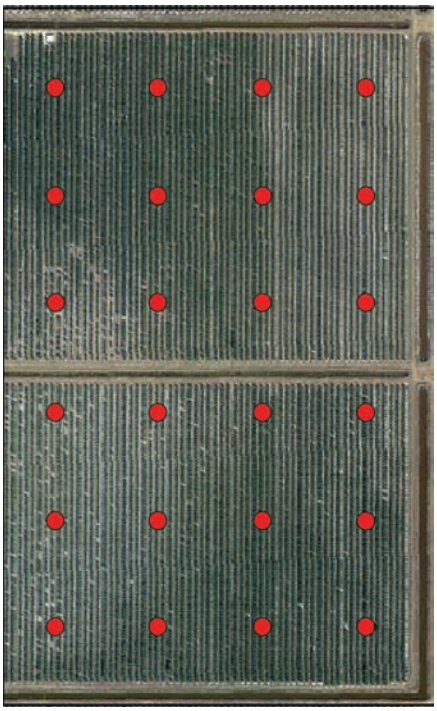


Figure 7. Example of the grid sampling strategy for selecting soil and leaf sampling locations. The red dots show predetermined sampling locations that will be recorded with GPS equipment and used to construct variability maps.

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 (Fig. 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.

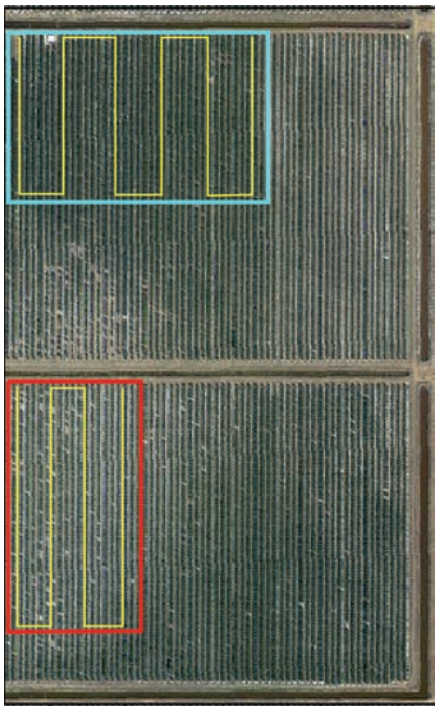


Figure 8. Example of soil and leaf tissue sampling locations using the management zone method. The grove zone area delineated by the blue rectangle is a productive area, while the one delineated by the red rectangle is a weak area. The yellow zigzag line denotes the sampling pattern within each management 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, soil maps, aerial photographs, and satellite images into nutrient management decision making.

By combining grid sampling, soil mapping, aerial photographs, and citrus yields (for example, based upon real-time harvesting data), growers are able to use new technologies such as on-the-fly tree canopy sensors and variable rate fertilizer applications (Fig. 9). These technologies reduce production costs and improve yield and quality while exercising prudent nutrient management to protect the environment.

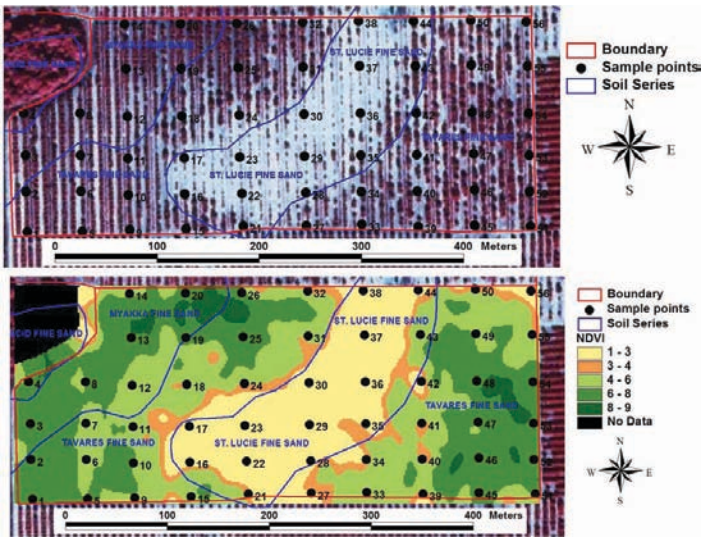


Figure 9. Example of grid sampling coupled with a soil map and resulting citrus yield map. Integration of these components can lead to effective sampling and better management decisions to optimize yield and quality. These strategies also qualify as Best Management Practices. (Image by Arnold Schumann.)

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 document.
- 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.

For More Information

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

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

[1]An "x" indicates the factor is assessed by the test.

Table 2. Guidelines for interpreting orange tree leaf analysis based on four- to six-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	%	---	---	< 0.20	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	< 0.06	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		1.Check soil organic matter. 2.Review N fertilizer rate.
P	1.Apply P fertilizer. (see Chapter 8, SL 253).	1.Do nothing.
K	1.Increase K fertilizer rate. (see Chapter 8, SL 253). 2.Apply foliar K fertilizer.	1.Decrease K fertilizer rate.
Ca	1.Check soil pH. 2.Check soil test Ca status. 3.Consider applying lime or soluble Ca fertilizer depending on soil pH.	1.Do nothing.
Mg	1.Check soil test Mg status. 2.Check soil pH. 3.Consider applying dolomitic lime or soluble Mg fertilizer depending on pH.	1.Do nothing.
Micronutrients	1.Check soil pH and adjust if needed. 2.Apply foliar micronutrients. 3.Include micronutrients in soil-applied fertilizer.	1.Check for spray residue on tested leaves. 2.Do nothing.

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

Element	Soil test interpretation				
	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 = lbs/acre.
[2]A Ca-to-Mg ratio greater than 10 may induce Mg deficiency.
[3]The University of Florida Extension Soil Testing Laboratory does not interpret extractable Ca. Work with Florida citrus trees suggests that a Mehlich 1 soil test with 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	
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	
Ammonium acetate pH 7.0[3]		≤50			> 50	
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 = lbs/acre.
[2] Estimated from unpublished correlation data (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]	1.Lime to pH 6.0.	1.Do nothing. 2.Use acid-forming N fertilizer. 3.Apply elemental sulfur. 4.Change rootstocks.
Organic matter[2]	1.Do nothing (live with it). 2.Apply organic material.	1.Do nothing.
P	1.Check leaf P status. 2.Apply P fertilizer if leaf P is below optimum (see Chapter 8, SL 253).	1.Do nothing.
K	1.Apply K fertilizer (see Chapter 8, SL 253).	1.Lower K fertilizer rate.
Ca	1.Check soil pH and adjust if needed. 2.Check leaf Ca status.	1.Do nothing. 2.Check leaf K and Mg status.
Mg	1.Check soil pH and adjust with dolomitic lime if needed. 2.Check leaf Mg status.	1.Do nothing.
Cu	1.Do nothing.	1.Lime to pH 6.5.

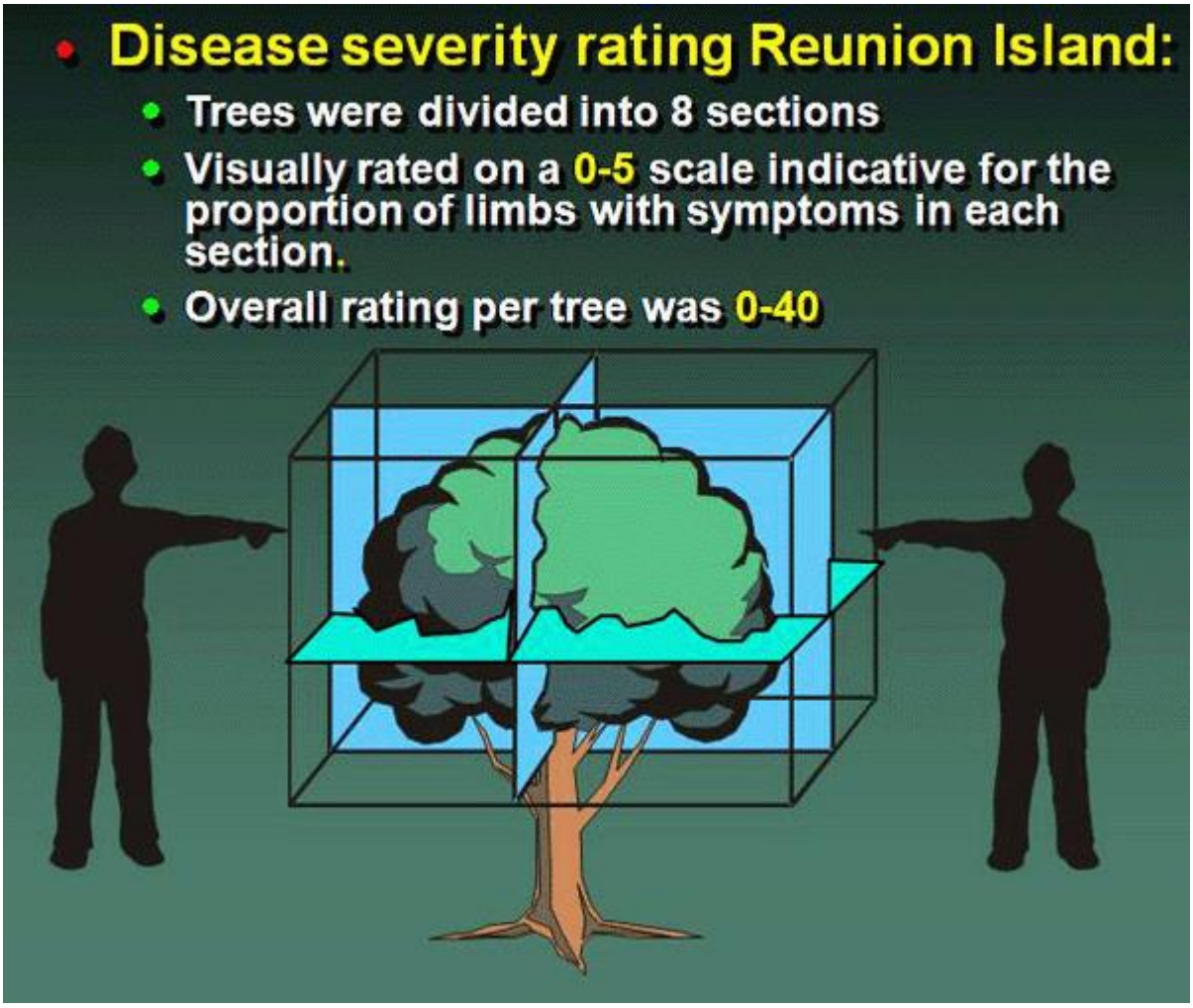
[1]The sufficiency value for soil pH is 6.0.
[2]There is no established sufficiency value for soil organic matter.

Field Trial Tree Evaluation Methods

This field evaluation protocol has been developed by CRDF project managers to evaluate CRDF field trials. This evaluation should provide valid information on the impact of various treatments on tree health, as well as the impact of treatments on bacterial infection and HLB disease. Methods are intended to be straightforward and easily adaptable to different locations and treatments.

The most basic field trial evaluation could include a visual disease index (DI, see below) rating before and after treatment and twice a year thereafter. DI ratings could be done on 12 treated trees and 12 control trees in about 1 hour. This rating plus yield data will provide sufficient information to compare the treated trees with the untreated control trees. It is important to include untreated control trees or standard practices or treatments in a field trial to serve as a basis for comparison of results. Additional potential tree evaluations follow.

Gottwald, T. R., Aubert, B., and Xue-Yuan, Z. 1989. Preliminary analysis of citrus greening (Huanglungbin) epidemics in the People's Republic of China and French Reunion Island. Phytopathology 79:687-693.



Tree canopy decline index (DI) score: Each canopy hemisphere will be subdivided into four equal quadrants by two imaginary perpendicular planes (vertical and horizontal at mid canopy height) passing through the axis of the tree trunk. The resulting eight sections (4 on each side of the canopy) are scored individually on a 0-5 scale indicative of the proportion of limbs expressing HLB disease symptoms within each section (0 = no limbs, 5 = all limbs). The summation of the eight scores for each tree will result in a severity rating of 0-40 for each tree on each survey date. For example, trees with a DI score of 32, have an average DI of 4 x 8 sections = 80% declined with symptoms.

A set of more complete evaluations which are used in CRDF field trials, includes a number of other measures. Some details are provided below; questions should be directed to the CRDF Project Managers.

Pre-treatment tree evaluation: It is important to collect measures of tree health and disease status prior to treatments to establish a baseline for comparisons of treatments.

Pre-treatment tree and grove documentation should include tree age, tree spacing/density, scion, rootstock, soil type, soil pH, general moisture status, and cultural practices including irrigation scheduling, water quality (salinity, bicarbonates), fertility programs, previous leaf nutrition, pest/psyllid control, yield records and fruit quality. Good horticultural care should continue uniformly in the entire trial area. At each site, there should be at least 12 replicate trees of each treatment plus 12 similar untreated control trees. 3-4 replicates of these 24 tree sets are desirable. Tree evaluations should focus on the middle 10 trees (excluding end buffer trees) of each of the treated and untreated trees for a total of 20 measurement trees in each replicate per site. Each of the 20 trees in each group should be assigned a unique treatment and replicate number. Treatment and control trees could be in rows of trees or in blocks with buffer trees on the borders.

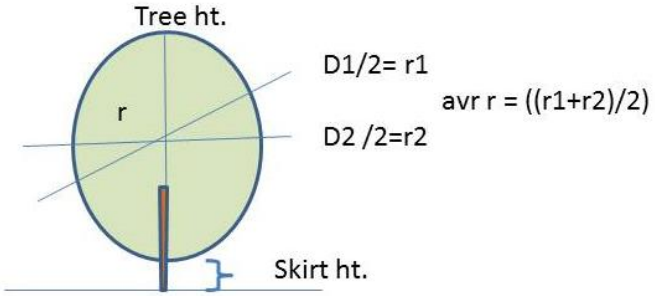
Photographs of each of the 20 measurement trees at a standard distance, direction and size, should be taken just prior to the treatment for comparison with later photos.

Disease Index (DI) is a visible estimator of HLB disease developed by Gottwald et al., 1989, and detailed above. The DI numerical scale of 0-40 will be evaluated prior to treatment on each of the 20 measurement trees using 8 canopy sectors (4 on each side; maximum DI = 40) in trees greater than 3 years old. Smaller trees that are 1-2 yr-old, can be evaluated using only 4 sectors, 2 on each side (maximum DI =20).

Leaves for PCR. Please contact the US Sugar Diagnostic Lab to make arrangements prior to sampling leaves for PCR. The lab requires the completion of a Disclaimer, Indemnification and Hold Harmless Agreement prior to any samples being sent to the lab. All sampled leaves should be accompanied by the site information and their sample form from http://www.flcitrusmutual.com/content/docs/issues/canker/sg_samplingform.pdf .
Six-8 mature leaves (with petioles attached) should be sampled from around the canopy before treatments from the 20 measurement trees. If visible blotchy mottle symptoms are present, sampled leaves should be mature symptomatic leaves and placed into a sealable (e.g. zip lock) plastic bag, labeled with the tree unique ID code (as above) for each measurement tree and GPS coordinates if available. Sealed sample bags should kept cool and out of the sunlight (eg., in ice chests) and immediately transported to the US Sugar Diagnostic Lab.

Trunk diameter. Two perpendicular trunk diameters (D) can be measured with calipers and averaged to get D on each of the 20 measurement trees before treatment and annually thereafter. Diameters can be measured at exactly 8 to 12 inches above the ground (or above the graft union) depending on tree size. It is important to be consistent so you can return to the same spot on the trunk next year. You can also use a tape measure to measure trunk circumference (C) as trunk diameter can come from C/π; $C=\pi D$. The trunk cross sectional area (CSA) can be calculated geometrically from the trunk radius (r=D/2) using the formula πr^2 (where $\pi = 3.14$).

Canopy volume. Canopy volumes (in cu ft or cu m) can be calculated using a geometric prolate spheroid formula: $[(4 / 3)(\pi)(\text{tree height}/2)(\text{average canopy radius})^2]$. π=3.14, D = average diameter, r = radius, and ht. = height. Canopy dimensions can be sighted using a pre-measured



marked pole. Tree height is the distance from the ground surface to canopy top ignoring any escaped branches. If there is no skirt height, then subtract about 10 % from the canopy volume for the flat bottom. Estimated volume corrections can be made for raised skirt heights. An average canopy radius can be calculated from ½ of the average diameter width.

Canopy density can be qualitatively estimated by visually classifying overall tree canopy density into 3 classes: **Healthy** = thick green canopy, few visible woody branches, good crop load. **Moderate** = some yellow leaves, some leaf loss, woody branches visible, a few fruit dropped. **Declined** = some die back, visible leaf loss, obvious fruit drop and an open declined canopy.

Fruit drop. All fruit on the ground of the 20 trees can be raked out prior to treatment and fruit drop counts can be made approximately every 2 weeks after treatment. Percentage fruit drop can be calculated by dividing the number of total fruit dropped by the (total fruit dropped + fruit harvested).

<u>Post-treatment tree evaluations</u>:

Post-treatment tree evaluations can begin 1 week after treatments to evaluate any incidental short-term tree injury from treatments.

Photographs of the 20 measurement trees at a standard distance, direction and size, will be taken 1 week after treatment, 3 months later and annually thereafter.

Disease Index. Depending on tree condition, DI can be evaluated again from 6 to 12 months after treatment on each of the 20 trees using, 4 canopy sectors per side, in trees greater than 3 years old and on 2 sectors on each side of the canopy for trees 1-2 years-old as described above.

Leaves for PCR test. 6-8 mature leaves on the 20 trees will be sampled as above 1 week after treatment, and either 3 months later or annually thereafter (winter season preferable) and submitted to the US Sugar Diagnostic Lab as above after prior arrangements have been made.

Trunk diameter. Two perpendicular trunk diameters or a trunk circumference can be measured on each of the 20 trees annually in December. Diameters will be measured at exactly the same height as described above.

Canopy volume. Canopy volumes can be evaluated twice per year using the prolate spheroid formula from measurements of average canopy radius, tree height and skirt height as in the tree canopy volume illustration above.

Canopy density can be rated twice per year and rated as **Healthy, Moderate** or **Declined** as defined above.

Fruit drop. All fruit on the ground of the 20 trees will be raked out prior to treatment and fruit drop counts will be made approximately 1 week after heart treatment every 2 weeks thereafter until harvest.

Leaves for nutrient analysis. 12 mature, 6 month old spring flush leaves from each of the 20 measurement trees (10 treated and 10 untreated controls) will be sampled during July-August for nutrition analyses and submitted to labs for routine analysis of major and minor elements.

Fruit. At the first harvest after treatment, 50-fruit samples will be sampled from each of the 20 trees and put into labeled net bags for fruit quality analyses and will be delivered to a testing lab after prior arrangements have been made. Total yield and remaining fruit counts will be collected from the 20 measurement trees. Weight of the 50-fruit quality samples will be added to calculate total yield per measurement tree. Fruit counts will be used to calculate percentage fruit drop (total fruit drop / (total fruit drop + remaining on-tree fruit) for each of the 20 trees.

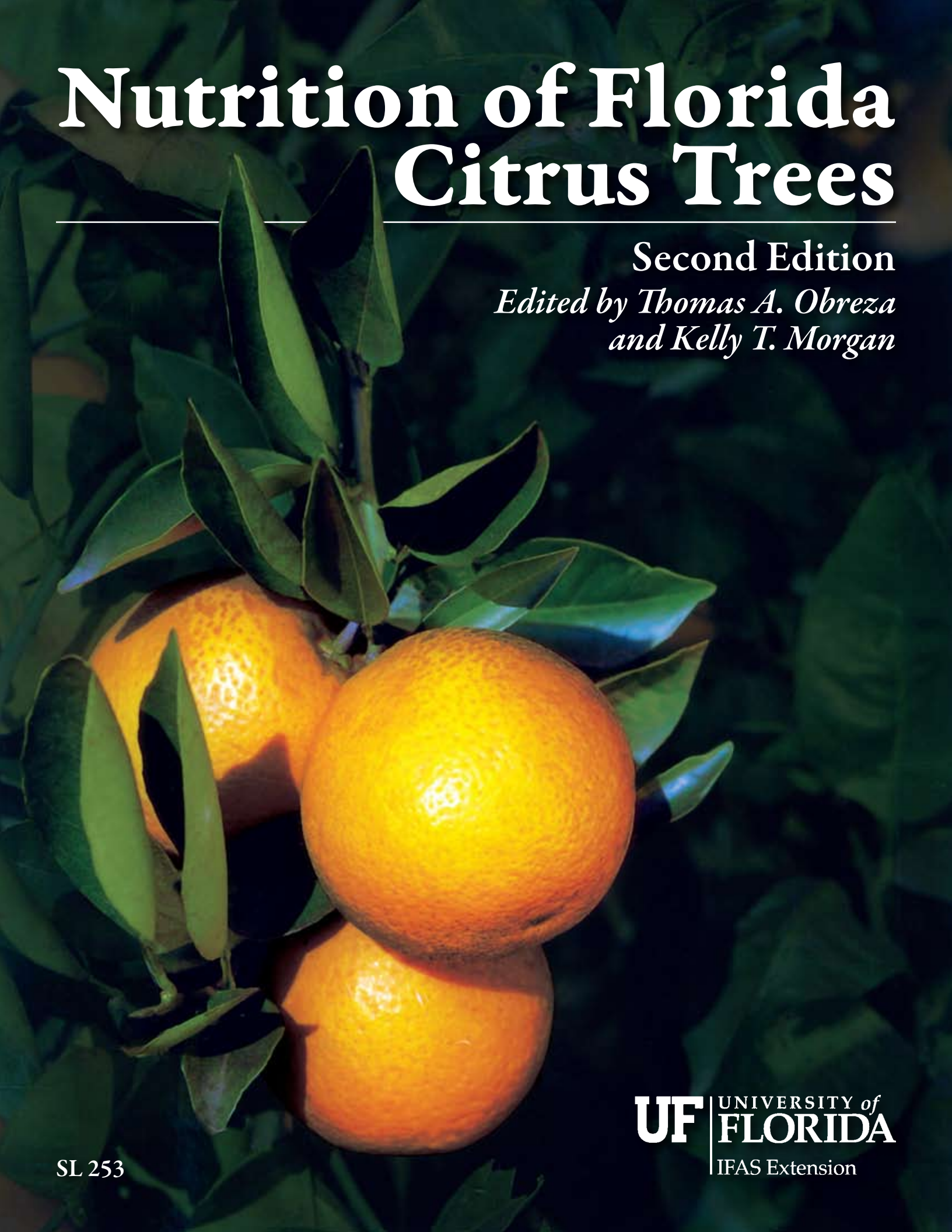
Data interpretation and analysis: Comparisons can be made between the 10 treated trees and 10 control trees. Tree photographs, DI ratings, trunk diameter, fruit drop and PCR data can be used as covariates in data analyses and collectively illustrate the effects of treatments.

Please contact Dr. Jim Syvertsen, jmsn@ufl.edu with any questions or comments.

Nutrition of Florida Citrus Trees

Second Edition

Edited by Thomas A. Obreza and Kelly T. Morgan



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IFAS Extension

SL 253

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Nutrition of Florida Citrus Trees 2nd Edition[1]

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

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Edited by Thomas A. Obreza and Kelly T. Morgan.
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COOPERATIVE EXTENSION SERVICE, UNIVERSITY OF FLORIDA, INSTITUTE OF FOOD AND AGRICULTURAL SCIENCES, Larry R. Arrington, 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 January 2008 as SL 253, Florida Cooperative Extension Service.

Dedication

The first edition of this publication was dedicated to emeritus citrus research scientists Drs. Robert C. J. Koo, Ivan Stewart, and Herman Reitz, Univ. of Florida, Citrus Research and Education Center (CREC), Lake Alfred and Paul Smith, USDA-Agricultural Research Service (ARS), 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, CREC-Lake Alfred; Dr. David V. Calvert, Indian River Research and Education Center, Ft. Pierce; and Dr. Heinz Wutscher, USDA-ARS, Orlando. Their many years of devoted service furthered our knowledge of nutrient management as the Florida citrus industry entered the era of Best Management Practices.

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Table of Contents

1. Introduction – *Thomas A. Obreza and Kelly T. Morgan* 7
- 1.1. Preface 7
- 1.2. Nutrition of Florida citrus trees – A historical perspective 7
- 1.3. Florida enters the BMP era 8

2. Production Areas, Soils, and Land Preparation – *Thomas A. Obreza and Mary E. Collins* 9
- 2.1. General information 9
- 2.2. Characteristics of soil orders important to Florida citrus production 9
- 2.3. Soil series typically found in citrus groves 9
- 2.4. Soil physical and chemical properties important to citrus nutrient management 11
- 2.5. Vulnerable soils 12
- 2.6. Grove site selection and land preparation 12
- 2.7. Effects of leveling and bedding on soil fertility in flatwoods citrus groves 14
- 2.8. Soil pH and liming 14
- 2.9. Organic matter 15

3. General Soil Fertility and Citrus Tree Nutrition – *Thomas A. Obreza, Mongi Zekri, and Stephen H. Futch* 16
- 3.1. Essential nutrients 16
- 3.2. Macronutrients and citrus production 16
- 3.3. Micronutrients and citrus production 17
- 3.4. Supplying nutrients to citrus trees 18
- 3.5. Nutrient behavior in Florida soils 18
- 3.6. Citrus nutrient requirements 20
- 3.7. Nutrition, irrigation, and fruit quality 21
- 3.8. Grove management practices 22
- 3.9. Interactions of nutrition with other grove practices 22

4. Soil and Leaf Tissue Testing – *Thomas A. Obreza, Mongi Zekri, and Edward A. Hanlon* 24
- 4.1. Introduction 24
- 4.2. Benefits of leaf analysis 24
- 4.3. Steps in leaf sampling 25
- 4.4. Benefits of soil analysis 26
- 4.5. Steps in soil sampling 28
- 4.6. Traditional vs. alternative sampling strategies 30
- 4.7. Summary 32
- 4.8. Soil and leaf tissue analysis checklist 32

5. Precision Agriculture for Citrus Nutrient Management – *Arnold W. Schumann and Edward A. Hanlon* 33
- 5.1. Common elements of precision agriculture 33
- 5.2. Objectives of precision agriculture for nutrient management 33
- 5.3. Remote sensing 33
  - 5.3.1. Field measurements of soil electrical conductivity 33
  - 5.3.2. Ultrasonic canopy measurements 34
  - 5.3.3. Citrus yield mapping 35
- 5.4. Precision nutrient application – Variable rate fertilization 35
- 5.5. Summary 37

6. Fertilizer Sources and Formulations – *Thomas A. Obreza and Brian J. Boman* 38
6.1. Introduction 38
6.2. Solid sources for soil application 38
6.3. Solid N fertilizer sources and ammonia volatilization 39
6.4. Solution sources – Fertigation 39
6.5. Solution fertilizer salt-out 40
6.6. Solution sources – Foliar sprays 40
6.7. Suspension sources 41
6.8. Slow-release sources 41
6.9. Controlled-release sources 41
6.10. Formulating fertilizer products 42
6.11. Nutrient sources for organic citrus production 42

7. Methods of Fertilizer Application – *Thomas A. Obreza, Brian J. Boman, Mongi Zekri, and Stephen H. Futch* 43
7.1. Applying dry fertilizers 43
7.2. Fertigation 43
7.3. Applying suspension fertilizers 46
7.4. Applying foliar fertilizers 46

8. Recommended Fertilizer Rates and Timing –
Thomas A. Obreza, Kelly T. Morgan, L. Gene Albrigo, and Brian J. Boman 48
8.1. Fertilizer rates, application frequency, and timing for non-bearing trees (first 3 years in the grove) 48
8.1.1. Solid plantings 48
8.1.2. Resets in established groves 50
8.1.3. Example fertilizer program for non-bearing trees 50
8.2. Fertilizer rates for bearing trees (4+ years in grove) 50
8.3. Timing and frequency of fertilizer application for bearing trees 56
8.4. Slow-release and controlled-release fertilizers 56
8.5. Foliar application of N, P, and K 57

9. Irrigation Management to Improve Nutrient Uptake – *Kelly T. Morgan and Thomas A. Obreza* 60
9.1. Water supply 60
9.2. Production region characteristics important to irrigation management 60
9.3. Nutrient uptake efficiency 60
9.4. Allowable soil water depletion 60
9.5. Irrigation scheduling 60
9.5.1. Soil moisture measurement 60
9.5.2. Water budgeting 61
9.6. Irrigation strategies to improve nutrient uptake and reduce leaching 61

10. Environmental Issues and Best Management Practices (BMPs) –
Brian J. Boman, Thomas A. Obreza, and Kelly T. Morgan 64
10.1. Environmental nutrient issues related to Florida citrus production 64
10.2. The BMP era 64
10.3. General nutrient BMPs for citrus production 65

11. Special Situations – *Thomas A. Obreza, Brian J. Boman, Mongi Zekri, Stephen H. Futch, Lawrence R. Parsons, and James J. Ferguson* 67
11.1. Scions and rootstocks 67
11.2. Rootstock/nutrition interaction 67
11.3. Soils high in copper 67
11.4. Calcareous soils 68
11.5. Saline soils and water 69
11.6. Using reclaimed water for irrigation 70
11.7. Fertilization strategies for damaged trees 71
11.7.1. Wind damage 71
11.7.2. Freeze damage 72
11.8. Nutritional deficiencies enhanced by environmental or pathological factors 72
11.9. Organic citrus production 72
11.9.1. General information 72
11.9.2. Soil fertility and crop nutrient management guidelines 73

12. References and Further Reading 74
12.1. Refereed journal articles 74
12.2. Non-refereed journal articles 75
12.3. Extension publications, articles, and books 75
12.4. Historical documents 75

13. Glossary 76

14. Appendices 79
A. Physical and chemical properties of typical Florida citrus soils 81
B. Nutrient concentrations of fertilizer materials 82
C. Salt index of fertilizer materials 84
D. Solubility of fertilizer sources and common fertilizer solutions 85
E. Fertilizer mixture formulation example 87
F. Example determination of the fertilizer requirement for bearing citrus trees 88
G. Key to citrus nutrient deficiency symptoms 89

15. Color plates 90

1. Introduction

Thomas A. Obreza and Kelly T. Morgan
(Includes contributions by David P. H. Tucker and Larry K. Jackson)

1.1. Preface

"Nutrition of Florida Citrus Trees, 2nd Edition" is an update of Univ. of Florida-IFAS Bulletin SP169, which 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 optimizes financial returns while sustaining yields and maintaining soil and water quality. The second edition maintains that objective as it incorporates the findings of numerous citrus nutrition research projects conducted since the mid-1990s.

Updated guidelines presented herein 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 adds 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 appear 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.

1.2. 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 Univ. of Florida-IFAS and USDA-ARS research programs, high production was not possible because citrus nutritional requirements were poorly understood. For example, 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.

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

Meanwhile, worldwide studies demonstrated that plants needed elements in addition to nitrogen, phosphorus, and potassium 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, zinc, manganese, magnesium, boron, and iron. They indicated how each of the above element deficiencies could be corrected with the exception of iron. 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 that this problem was due to molybdenum deficiency that could be corrected by a spray application of as little as 1 oz of sodium molybdate/acre.

Calcium 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 Citrus Research and Education Center) in Lake Alfred, they did not add calcium to some of the plots, which resulted in stunted trees that showed leaf symptoms specific to calcium deficiency.

Copper deficiency of citrus limited growth and fruit production in many early Florida groves. Following discovery of this problem, high rates of copper were applied to trees in both foliar sprays and soil applications. Later, I. W. Wander and co-investigators found that copper 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 iron 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 iron (iron-EDTA) was applied to the soil, yellow leaves on iron-deficient trees re-greened.

While sulfur 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 Citrus Experiment Station 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, 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 costs were reduced. Further reductions in costs were made when Spencer and Stewart reported that phosphorus applied to established groves had not leached, but had accumulated in an available form, resulting in reduced phosphorus application rates to established groves. Finally, the use of micronutrients was recommended only when deficiency symptoms persisted.

Numerous nitrogen fertilizer rate and timing studies were conducted by Univ. of Florida 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 lbs/acre were justified only for very productive groves. In addition, Stewart and Leonard demonstrated that excess nitrogen could reduce yield. Maximum production may vary greatly depending on other limiting conditions, but nitrogen fertilizer requirements remain similar for a range of production levels and conditions. As a result of these findings, Bulletin SP 169 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 nitrogen fertilizer rates in favor of a maximum rate of 200 lbs/acre for typical groves and 240 lbs/acre for "exceptional" groves (defined as groves producing 700 or more boxes/acre annually).

1.3. Florida enters the BMP era

In the late 1980s, the Florida Dept. of Environmental Protection (FDEP) surveyed drinking water quality across the state and detected the nitrate form of nitrogen 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 mg/L. 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 nitrogen fertilization on groundwater nitrate concentration was unknown, the combined circumstances of large citrus acreage, relatively high annual fertilization rates, high annual rainfall, and extremely inert, porous soils led the Florida Dept. of Agriculture and Consumer Services (FDACS) to implement a set of voluntary BMPs for nitrogen fertilization of ridge citrus trees designed to protect water quality. These were the first official nutrient BMPs for Florida citrus production. In exchange for implementing the BMP program, FDACS provides citrus producers with a presumption of compliance with water quality standards.

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.

2. Production Areas, Soils, and Land Preparation

Thomas A. Obreza and Mary E. Collins
(Includes contributions by Larry K. Jackson, Ashok K. Alva, David P. H. Tucker, and David V. Calvert)

2.1. General information

Florida's sandy soils are not particularly favorable for management of water and agrichemicals. Most Florida citrus is grown on naturally infertile sands 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 (Fig. 2.1). The root zone of these soils are dominated by sand and contain only minor quantities of silt, clay, and organic matter. This condition makes the management of water and nutrients a challenging task for grove managers.

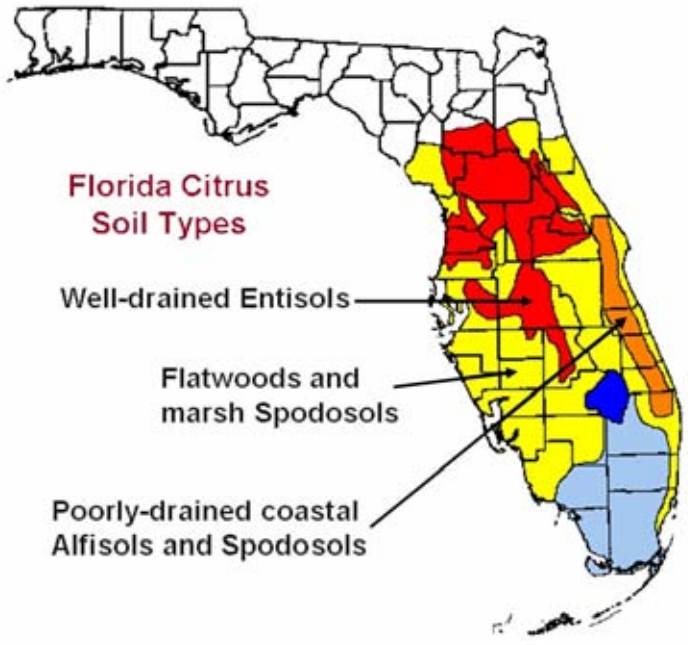


Fig. 2.1. Distribution of soil types planted to citrus in Florida.

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 a 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 topsoil due to deposition of subsurface materials over the natural surface during the bedding process.

2.2. Characteristics of soil orders important to Florida citrus production

A soil order is the most basic category of soil classification. The order provides a general idea about basic physical and chemical characteristics of a soil. Characteristics important to production on Florida citrus soil orders are as follows:

- Entisols are sandy mineral soils low in organic matter, natural fertility, and water-holding capacity (Fig. 2.2). They have weak or no diagnostic subsurface layers and are well to excessively well-drained.
- Spodosols are sandy mineral soils low in organic matter and natural fertility in the surface layer (Fig. 2.3). They contain an acidic subsurface restrictive layer composed of aluminum and iron cemented together with organic matter.
- Alfisols are sandy mineral soils low in organic matter in the surface layer but higher in relative natural fertility compared with Spodosols (Fig. 2.4). 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.

2.3. 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 2.1). Entisols (other than Basinger) occur on high ridges and upland plains at an elevation greater than 100 ft above mean sea level (MSL) in the central ridge production area. Alfisols, Spodosols, and the Basinger series occur on broad,

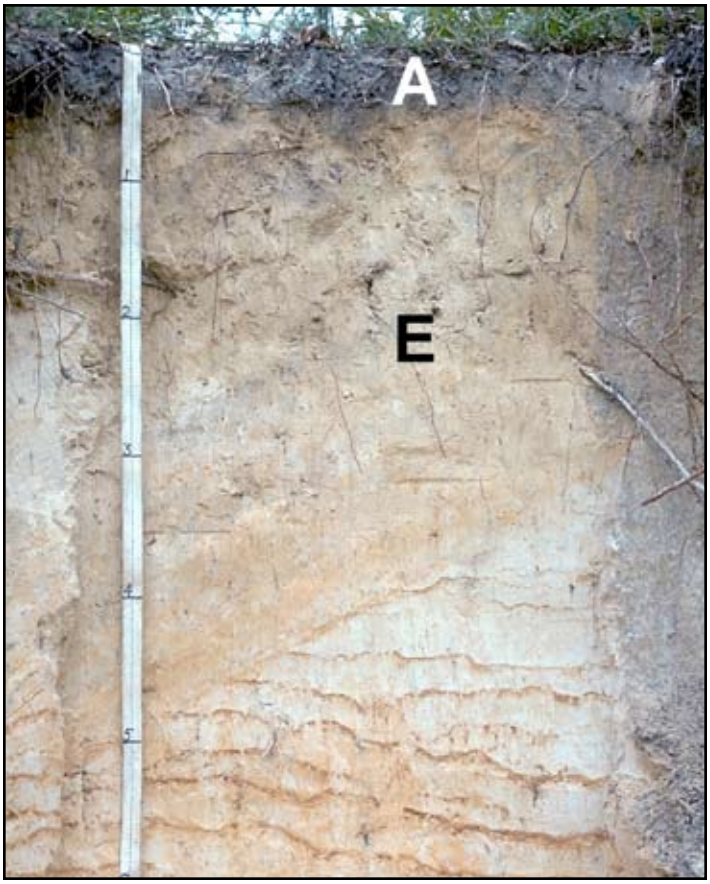


Fig. 2.2. Candler sand, an Entisol, with surface (A) and subsurface (E) horizons. (Mary Collins)

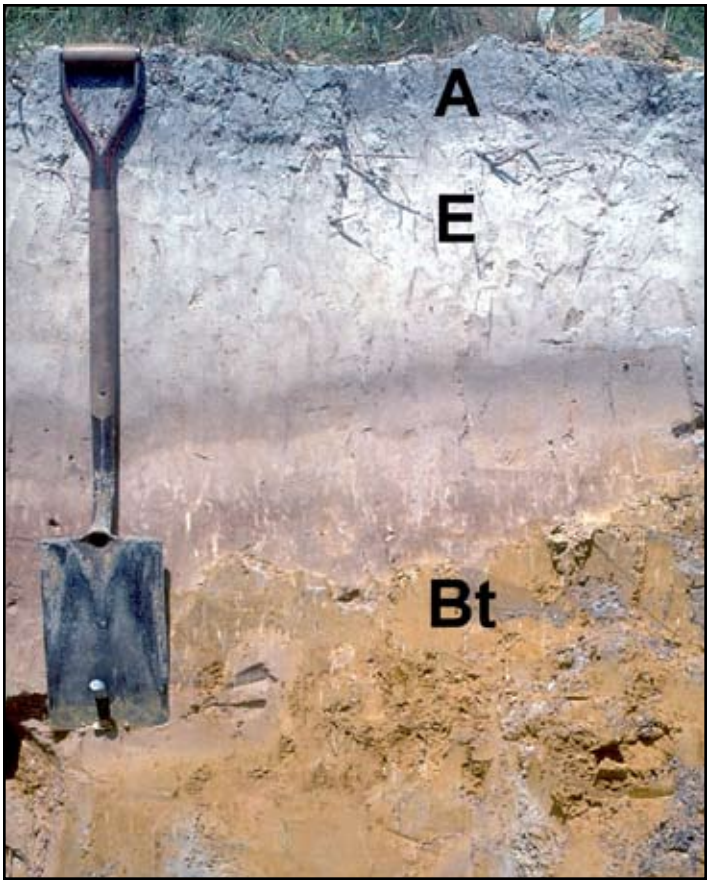


Fig. 2.4. Riviera sand, an Alfisol, with surface (A), leached (E), and restrictive (Bt) horizons. (Mary Collins)

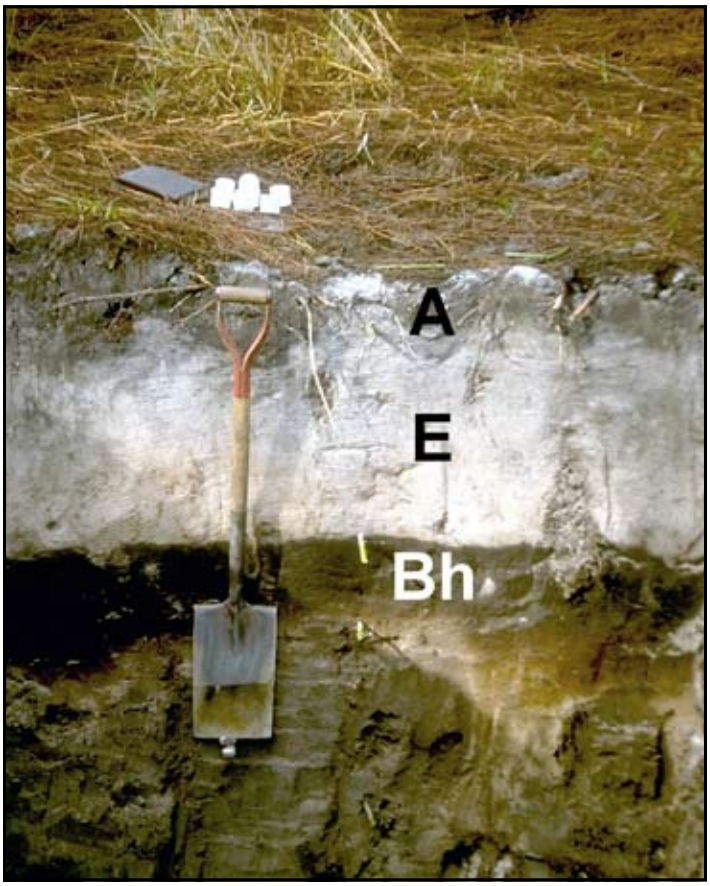


Fig. 2.3. Myakka sand, a Spodosol, with surface (A), leached (E), and restrictive (Bh) horizons. (Mary Collins)

Table 2.1. 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
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
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

low flat areas or in sloughs at elevations from 10 to 40 ft above MSL in the Gulf and Indian River production areas, and 35 to 100 ft above MSL 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.

2.4. 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 (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. Since 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 phosphorus (P), calcium (Ca), magnesium (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 principle is a calcareous soil. Some of the Alfisols in Table 2.1 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, potassium (K), and ammonium (NH_4^+) against leaching (Fig. 2.5). 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 nitrogen (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.

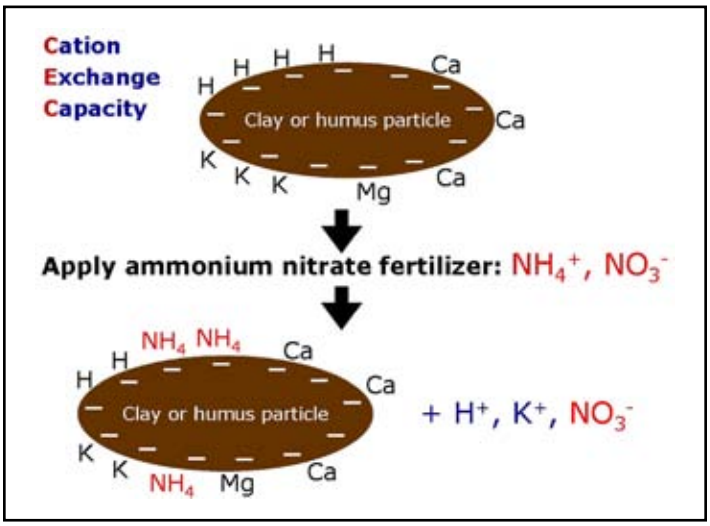


Fig. 2.5. Example of the cation exchange reaction that occurs when a soil is fertilized with ammonium nitrate.

- Coated and non-coated sands relate to the P fixation capacity of Florida soils. Fixation 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 (Fig. 2.6). Yellow, orange, or brown colored sand is more likely to be coated, while beige or white sand is not. Therefore, citrus groves on soils containing coated sands have the ability to build 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 non-coated 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.

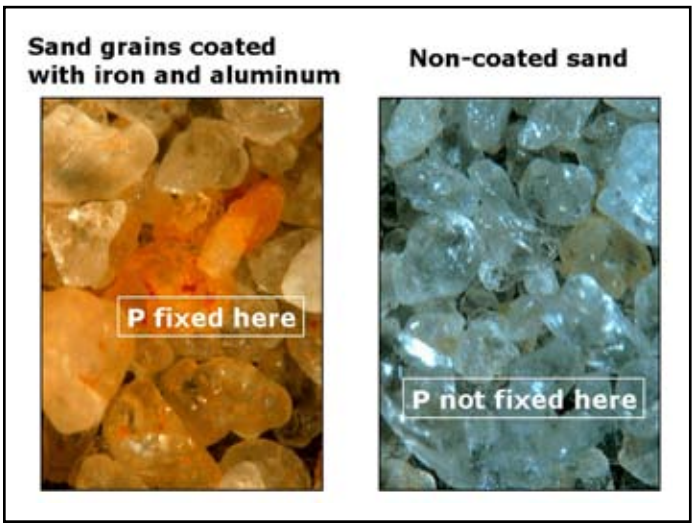


Fig. 2.6. Coated and non-coated sand grains.

2.5. 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 rely 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 since it may come in contact with soluble nutrients, pesticides, or 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** (Fig. 2.7). 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.

Table 2.2. 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	

The soils in Table 2.2 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. Thus, they are 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. Producers should consult the 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 internet web site at: http://websoilsurvey.nrcs.usda.gov/.

2.6. 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 copper (Cu) concentration should also be checked.

If the soil is found to be acidic (pH 5.5 or less), the pH should be raised to the 6.0 to 6.5 range by adding lime. The higher target pH should be used for soils with Me-

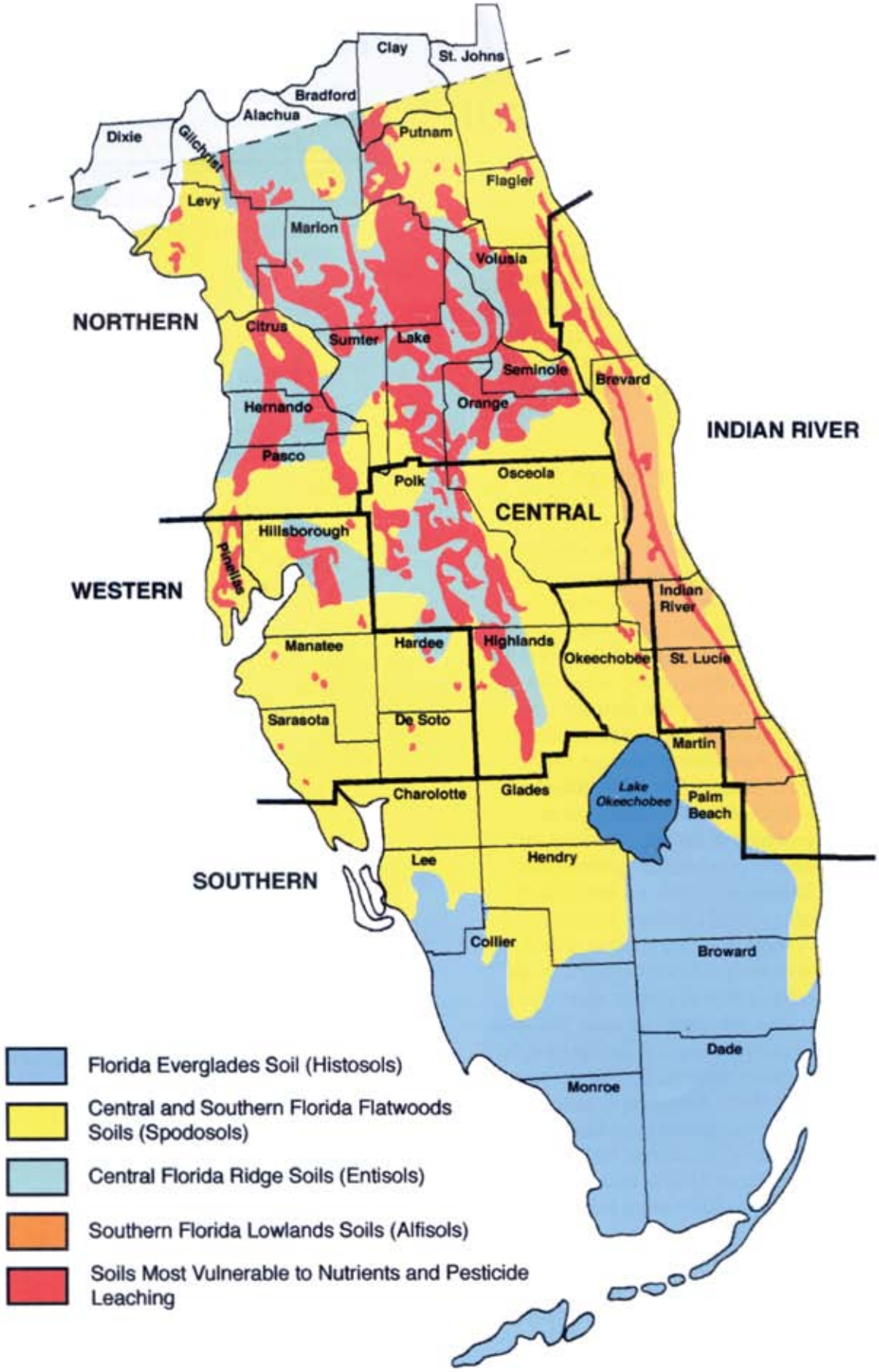


Fig. 2.7. Approximate location of vulnerable soils in citrus production regions. (Courtesy of James Turk and Juan Vega, USDA-NRCS, Gainesville.) See table 2.2 for a list of vulnerable soil series.

hlich 1-extractable Cu greater than 25 mg/kg (ppm). If the soil is calcareous (contains free calcium carbonate, with pH around 8.2), no attempt to lower the pH should be made. If planted to citrus, improving the fertility of highly calcareous soils and white sandy soils ("sand soaks") devoid of organic matter will be extremely difficult. Additional production costs associated with management of trees on such soils can make the difference between profit and loss, particularly during periods of low fruit returns.

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 is brought up into the rooting zone.

2.7. 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 a 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 (Fig. 2.8). Citrus tree growth and production in these areas (commonly referred to by flatwoods citrus growers as scraped areas or sand soaks) is usually poor.

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 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 12 to 18 inches of soil due to the effect of the restrictive layer.

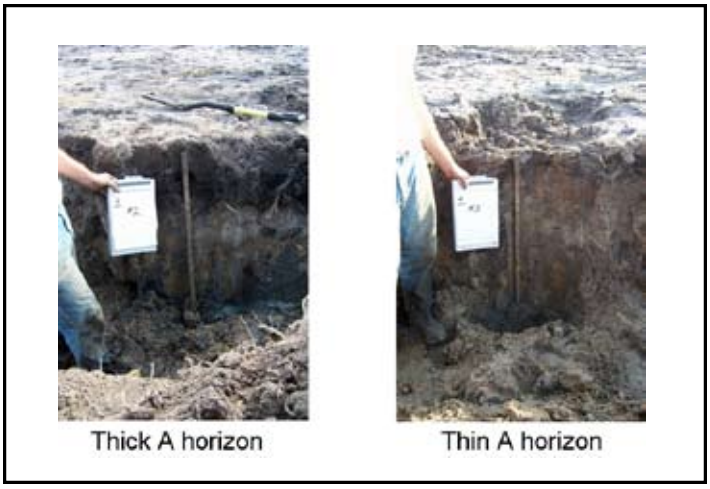


Fig. 2.8. Effect of leveling a flatwoods citrus site on topsoil (A horizon) thickness. Note the thick, dark topsoil on the left and lack of same on the right. (Mace Bauer)

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 amount of material that was excavated and mixed in during bedding.

2.8. 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 those that are toxic to plants are affected by it.

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 to 6.5 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 levels. Therefore, if a soil test does not show excessive copper 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 build-up of copper because this element becomes toxic at low soil pH.

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 or a more soluble fertilizer like calcium nitrate can be used as a source of available Ca. In most bearing groves, soil pH is generally above 6.0, so liming is not required. Gypsum is a source of moderately-available Ca with no effect on soil pH, while calcium nitrate is a rapidly-available Ca and N fertilizer with a slightly alkaline reaction in the soil.

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 recommendation for non-bearing and bearing citrus takes into account: 1) higher pH soils now in production, 2) the high pH of groundwater used for irrigation, and 3) greater use of rootstocks like Swingle citrumelo that grow poorly in high pH soils.

2.9. 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 adding organic matter from outside sources, so it is not 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 plus transportation, spreading, and incorporation costs. 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 lbs/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.

3. General Soil Fertility and Citrus Tree Nutrition

Thomas A. Obreza, Mongi Zekri, and Stephen H. Futch
(Includes contributions by Larry K. Jackson, Ashok K. Alva, David P. H. Tucker, and David V. Calvert)

3.1. 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. 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 many of these nutrients, so growers may need to provide some of 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. 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 3.1). 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.

Table 3.1. 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	% of total tree dry weight
Mo	1	0.00003
Cu	100	0.002
Mn	200	0.003
Zn	300	0.006
Fe	600	0.010
B	800	0.002
S	11,000	0.096
P	13,000	0.116
Mg	18,000	0.120
K	66,000	0.728
Ca	98,000	1.096
N	237,000	0.932

3.2. 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 yellow. 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 (Fig 3.1) 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 the optimum N rate. A sufficient N concentration in the tree is required for maxi-

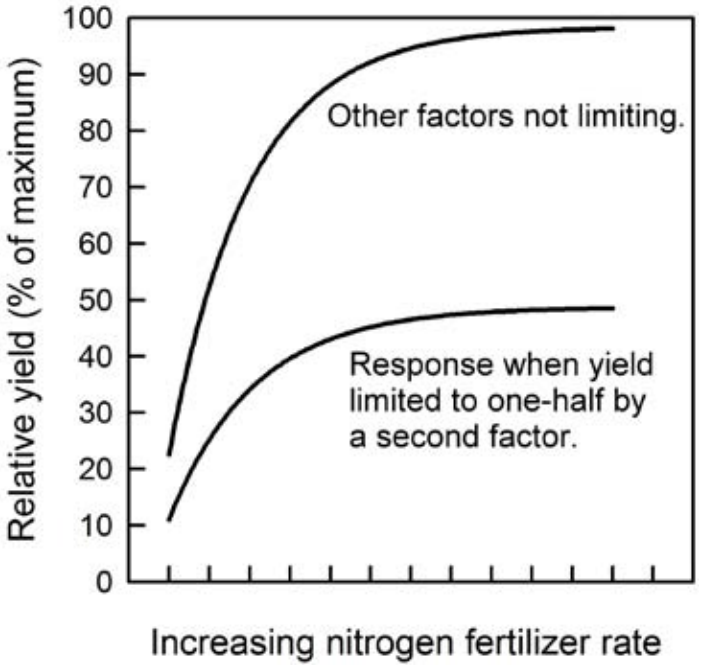


Fig. 3.1. Generic response of citrus yield to N fertilizer rate.

mum vegetative growth, flowering, and fruit yield. A high N concentration increases tree growth and may require increased applications of other elements, particularly K. Luxury (excessive) consumption of N can lead to excessive vegetative growth at the expense of fruit yield.

Phosphorus (P) is listed on a fertilizer label as P_2O_5 and is referred to as available phosphoric acid. Phosphorus does not readily leach if the soil pH is 6.0 or higher, and removal by a citrus crop is only around 2 lbs of elemental P/100 boxes of fruit. Most mature Florida citrus groves contain sufficient residual P that accumulated from previous fertilizer applications, so regular P fertilizer application is usually not necessary. Most previously non-cultivated soils used for new citrus plantings are naturally low in P, so fertilizer application may be needed for the first few years until P accumulates in the root zone.

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 when a grove is fertilized normally, but it can develop on high pH soils or when high N rates stimulate high fruit production. Too little K can slow vegetative growth and result in thinning of the topmost foliage. Potassium deficiency reduces fruit number and size, increases fruit creasing, plugging and drop, and decreases juice soluble solids, acid, and vitamin C content. High K fertilizer rates do not increase cold hardiness of citrus trees.

Calcium (Ca) is the most abundant mineral element by weight in citrus trees, residing mainly in the leaves. Ca is rarely deficient since 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 dissolved calcium carbonate (limestone).

Magnesium (Mg) is an essential constituent of chlorophyll. A deficiency produces a characteristic chlorotic pattern and may cause premature defoliation. Seedy citrus 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. It is supplied with fertilizers like 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.

3.3. Micronutrients and citrus production

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

Copper (Cu) deficiency causes fruit corking, ammoniation (curved branching), inter-nodal stem gumming, and twig dieback. The deficiency 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 (Chapter 4). For new plantings on previously non-cultivated flatwoods soils, Cu should be included in the fertilizer for the first 2 or 3 years.

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 interveinal chlorosis on acidic, sandy soils. The "marl chlorosis" found on calcareous soils is the result of com-

bined deficiencies of Mn and Zn, and sometimes Fe. Temporary mild deficiency patterns on new shoots are 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 fruit drop, gum pockets in the peel, gumming around the core, 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. Foliar application to correct a deficiency is advantageous due to rapid tree uptake. Boron fertilization may not be needed at all if trees are irrigated with reclaimed water.

Molybdenum (Mo) deficiency produces a symptom described as "yellow spot." Unlike other nutrients, Mo is less available in acidic than in slightly alkaline soils. Mo deficiency is rare in Florida. If it occurs, the soil usually has become too acidic with time. Liming the soil effectively relieves the deficiency, but more rapid response is obtained if sodium molybdate is applied as a foliar spray.

The exact roles of **chlorine (Cl)** and **nickel (Ni)** in citrus tree metabolism are not clear.

3.4. 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 penetrate leaves. Foliar fertilizer application may be considered for the nutrients 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 taken up in low amounts (Table 3.1). Foliar application is the fastest method of promoting micronutrient uptake by plants in the short term when a nutritional deficiency is diagnosed, but should not be relied upon for long-term tree nutrition unless the soil is calcareous (Chapter 11).

Fertilization represents about 20% of total citrus production costs, but it can have a large effect on potential profitability at extreme highs or lows. Visual evaluation of nutritional status, soil and plant analysis, field history, production experience and economics are all important guidelines for making fertilizer rate and source decisions.

3.5. 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 rapidly 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 accumulate in citrus grove soils over the long term. 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 (Fig. 2.5), or in the soil solution. The ionic nutrient forms that plants use (Table 3.2) 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 groves 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 is too slow for intensive agricultural production on sandy soils.
- Biological ammonification converts organic N to mineral N (ammonium, NH_4^+). Ammonium is also a component of some mineral N fertilizers. Nitrification, which also depends on microbial activity, converts NH_4^+ to nitrate (NO_3^-) in days to weeks. Thus, soil solution N is dominated by negatively-charged nitrate. 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 loading of the soil from fertilizer or animal waste application, followed by N leaching 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 soil pH or Ca at high soil pH. The best P availability in these soils occurs around pH 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 non-coated sand cannot (Fig. 2.6). If a soil is dominated by non-coated 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 (Fig. 2.5), which delays leaching. However, Florida soils planted to citrus have naturally low cation exchange capacity in the root zone (Appendix A, Table A.1), 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, limiting 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 depends on organic matter quantity and decomposition rate. Organic S release combined with S from other sources like rain or irrigation water usually provides this nutrient to plants at a sufficient rate 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 adsorption usually occurs much deeper in the soil profile than the majority of plant roots.
- 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 (Fig. 3.2), so it is important to not over-lime a soil. At

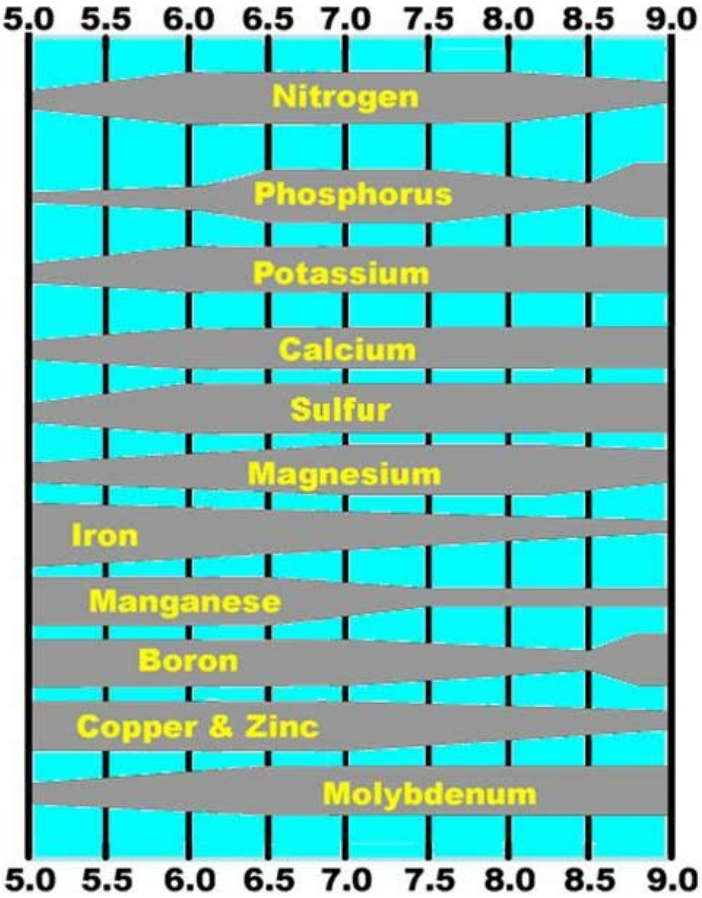


Fig. 3.2. Effect of soil pH on nutrient availability as expressed by relative bar width.

alkaline pH, some plants suffer micronutrient deficiencies due to almost total insolubility.

- 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 fertilizer should be regularly applied to Florida citrus groves, but there is a narrow range between deficiency and toxicity.

Molybdenum

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

Nutrient movement in Florida's sandy soils is summarized in Table 3.2.

Table 3.2. Qualitative assessment of nutrient movement in Florida's sandy soils based on ionic form in the soil solution and ability to precipitate or be adsorbed by the soil.

Nutrient	Ionic form taken up by plants	Nutrient subject to precipitation or adsorption?	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).**

3.6. 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 non-bearing 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 Fig. 3.1 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 Fig. 3.1 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.

The yield response curves shown never completely flatten out, indicating that ever higher N rates theoretically will

Table 3.3. 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
	lbs 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 lbs. [2]A. K. Alva, unpublished data. [3]Paramasivam et al. (2000). [4]Mattos et al. (2003).

produce small additional yield increases. Because fertilizer cost was a small portion of total production cost in the past, 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 lbs/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 lbs/acre of N or K from a high-producing grove (Table 3.3). For oranges, approximately 0.12 lbs N/box is removed with the harvest. Therefore, crop removal ranges from 12 lbs N/acre for a 100 box/acre yield to around 100 lbs 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 lbs N removed by the crop divided by lbs 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 lbs 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.

3.7. Nutrition, irrigation, 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 high quality fruit. On the other hand, excessive or deficient irrigation or fertilization may result in reduced fruit quality.

The most important management practices influencing fruit quality are irrigation and N, P, and K 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 may 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/box and TSS/per acre. However, excessive N, particularly with inadequate irrigation, can result in lower yields with lower TSS/acre.
- Decreases fruit size and weight.
- Increases green fruit at harvest. High N may delay color break and increase re-greening of Valencia oranges.
- Increases creasing and scab on susceptible varieties, 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 peel thickness.
- Increases blemish from wind scar, scab and *Alternaria* brown spot (overhead irrigation only), 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 3.4 are based on numerous field experiments conducted for 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.

3.8. Grove management practices

Management practices that improve fertilizer nutrient-use efficiency include:

- Using a leaf and soil testing program (Chapter 4).
- Using precision fertilizer application (Chapter 5).
- Selecting fertilizer materials and rates 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).
- Applying N fertilizer at a rate consistent with historical or expected production (Chapter 8).
- Irrigation management to maximize production and minimize leaching (Chapter 9).

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.

3.9. 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 pest control

Luxuriant growth caused by excessive fertilization or irrigation may increase incidence of foliar diseases like citrus canker and fungal diseases like scab, *Alternaria* brown spot, and post-bloom 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 (Chapter 8). However, if a grove is being visually monitored for greening symptoms, it is important to minimize signs of micronutrient (Zn, Mn, Fe) deficiencies 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 should be minimized.

Table 3.4. Increasing levels of nutrients within recommended ranges result in the responses shown, whereas excess nutrition can reduce fruit yield and quality (Koo, 1988). Key to symbols: Increase (+), Decrease (–), No change (o), No information (?).

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	+	–	+	o	–	o	o	o	o	o	–
Peel blemishes											
Wind scar	–	+	o	?	?	?	?	?	?	?	+
Russet	–	–	o	?	o	o	o	o	o	o	o
Creasing	+	+	–	?	?	?	?	?	?	?	o
Plugging	–	o	–	?	?	?	?	?	?	?	–
Scab	+	o	o	?	?	?	?	?	?	?	+
Storage decay											
Stem-end rot	–	o	–	?	?	?	?	?	?	?	–
Green mold	–	o	o	?	?	?	?	?	?	?	+
Sour rot	o	o	o	?	?	?	?	?	?	?	o

4. Soil and Leaf Tissue Testing

Thomas A. Obreza, Mongi Zekri, and Edward A. Hanlon

4.1. Introduction

Nutrient deficiency or excess will cause citrus trees to grow poorly and produce sub-optimal 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 (Fig. 4.1).



Fig. 4.1. Proper soil and leaf tissue sampling and analysis can accurately gauge citrus grove nutrition and help improve fertilizer programs. (Mongi Zekri)

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 4.1).

4.2. 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 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.

Table 4.1. 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		√

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 insure 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.

4.3. 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 (Fig. 4.2). 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 (Fig. 4.3). If leaves are sampled later in the season, summer leaf growth can easily be confused with spring growth.

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 non-fruiting 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).

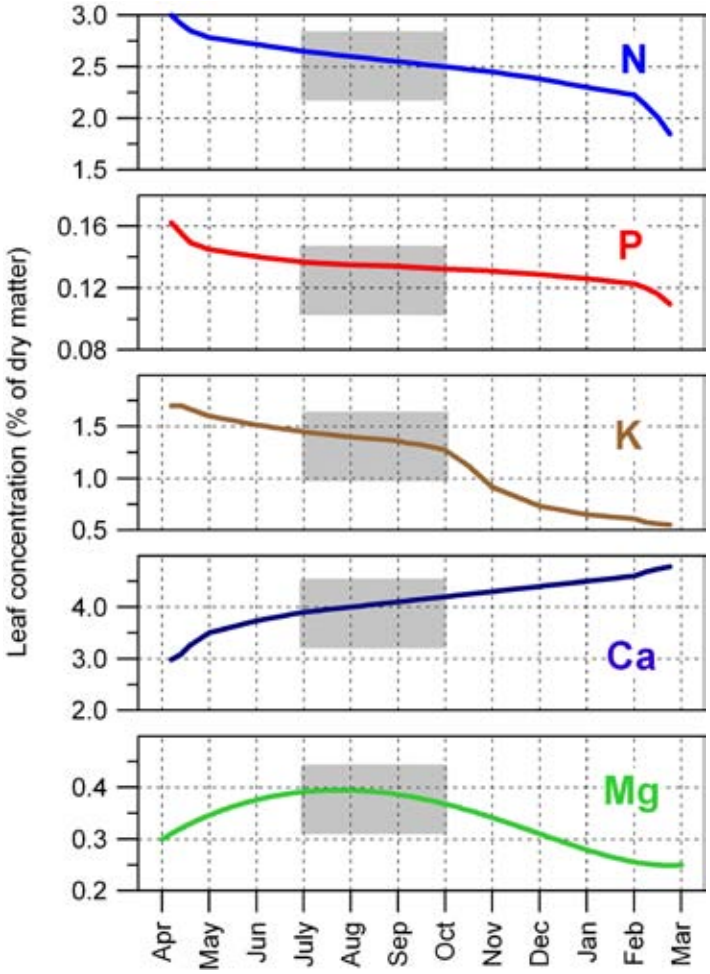


Fig. 4.2. Changes in concentration of N, P, K, Ca, and Mg in citrus leaves with age. The shaded areas denote the recommended sampling period and the optimum concentration range for each element.



Fig. 4.3. Sample 4 to 6-month-old spring flush leaves from non-fruiting twigs. (Thomas Obreza)

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 that 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. Since **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 4.2. These standards are based on long-term field observations and experiments conducted in different countries with different citrus varieties, rootstocks, and management practices, and 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 4.2) every year. If the interpretation for a particular nutrient is not optimum, various strategies can be used to address the situation (Table 4.3).

4.4. 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 (Fig. 4.4). 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 non-response is called the **critical** or **sufficiency** soil test value (Fig. 4.5).

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 Univ. of Florida Extension Soil Testing Laboratory (ESTL) has used the Mehlich 1 (double acid) extrac-

Table 4.2. Guidelines for interpretation of orange tree leaf analysis based on 4 to 6-month-old spring flush leaves from non-fruiting 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 4.3. 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	**1.** Check yield. **2.** Check tree health. **3.** Review water management. **4.** Review N fertilizer rate.	**1.** Check soil organic matter. **2.** Review N fertilizer rate.
P	**1.** Apply P fertilizer (see Chapter 8).	**1.** Do nothing.
K	**1.** Increase K fertilizer rate (see Chapter 8). **2.** Apply foliar K fertilizer.	**1.** Decrease K fertilizer rate.
Ca	**1.** Check soil pH. **2.** Check soil test Ca status. **3.** Consider applying lime or soluble Ca fertilizer depending on soil pH.	**1.** Do nothing.
Mg	**1.** Check soil test Mg status. **2.** Check soil pH. **3.** Consider applying dolomitic lime or soluble Mg fertilizer depending on pH.	**1.** Do nothing.
Micronutrients	**1.** Check soil pH and adjust if needed. **2.** Apply foliar micronutrients. **3.** Include micronutrients in soil-applied fertilizer.	**1.** Check for spray residue on tested leaves. **2.** Do nothing.

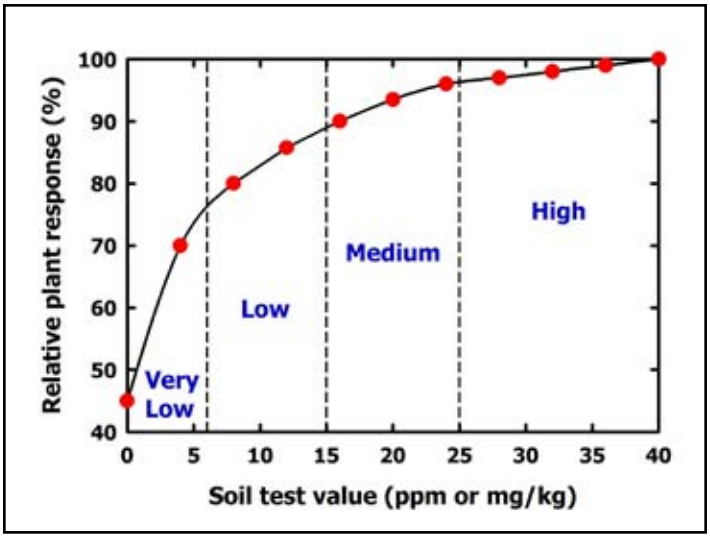


Fig. 4.4. Ideal soil test calibration curve.

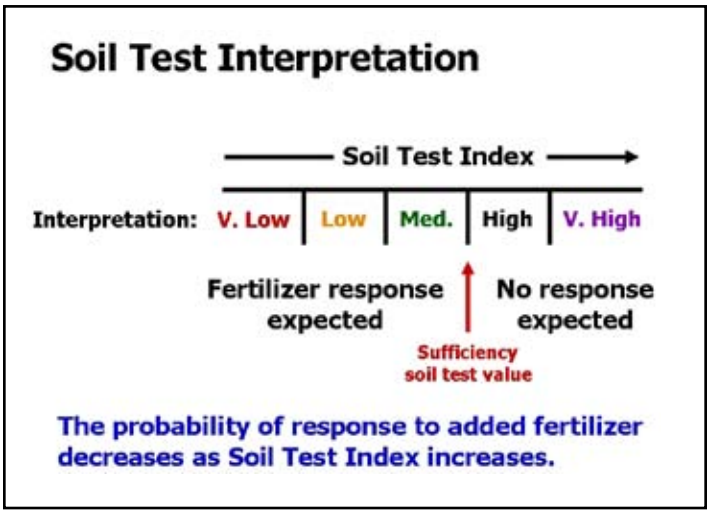


Fig. 4.5. Soil test interpretation categories and their relationship to expected fertilizer response.

tion 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.

Univ. of Florida soil test interpretations for P, K, and Mg (Table 4.4) 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 4.4 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 4.5). 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 (Fig. 3.2). 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 need 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.

4.5. 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.

Table 4.4. Interpretation of soil analysis data for citrus using the Mehlich 1 (double-acid) extractant.

Element	Soil test interpretation				
	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 = lbs/acre.
[2]A Ca-to-Mg ratio greater than 10 may induce Mg deficiency.
[3]The Univ. of Florida 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 4.5. 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	
	Mg mg/kg (ppm)		Low	Medium	High	
Mehlich 1			< 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	
	Ca mg/kg (ppm)	Less than sufficient			Sufficient	
Mehlich 1		≤ 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 = lbs/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).

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 (Fig. 4.6).
- 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 non-metal bucket to form a composite sample. Take a subsample from this mixture and place it into a labeled paper bag.

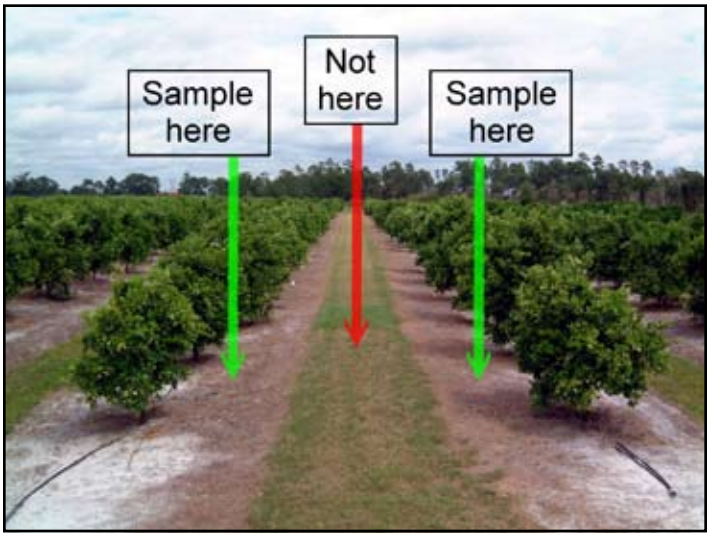


Fig. 4.6. Sample soil near the dripline of the trees, not in the row middle. (Thomas Obreza)

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.
- Since **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 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 4.4 and 4.5).
- The interpretations should be used to make management decisions regarding soil pH adjustment or fertilizer application (Table 4.6).

4.6. 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 over-fertilized and others may be under-fertilized. 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 (Fig. 4.7). 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).

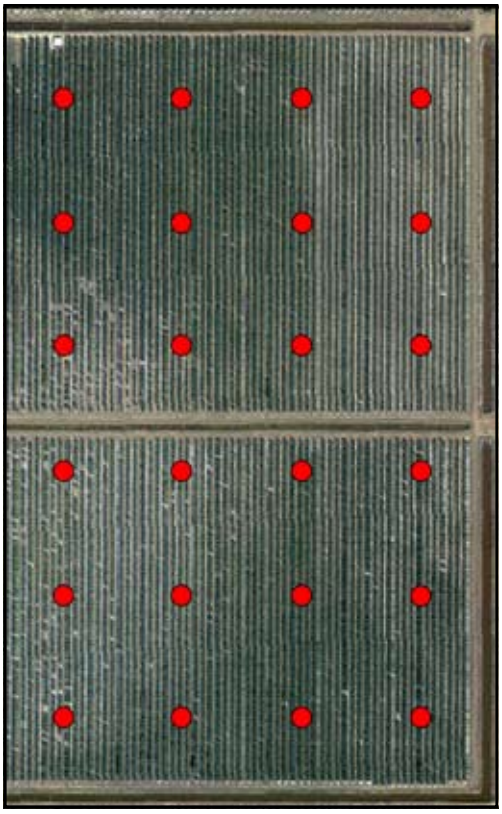


Fig. 4.7. Example of the grid sampling strategy for selecting soil and leaf sampling locations. The red dots show pre-determined sampling locations that will be recorded with GPS equipment and used to construct variability maps.

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 (Fig. 4.8). 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.

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.

Table 4.6. 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]	1. Lime to pH 6.0.	1. Do nothing. 2. Use acid-forming N fertilizer. 3. Apply elemental sulfur. 4. Change rootstocks.
Organic matter[2]	1. Do nothing (live with it). 2. Apply organic material.	1. Do nothing.
P	1. Check leaf P status. 2. Apply P fertilizer if leaf P is below optimum (see Chapter 8).	1. Do nothing.
K	1. Apply K fertilizer (see Chapter 8).	1. Lower K fertilizer rate.
Ca	1. Check soil pH and adjust if needed. 2. Check leaf Ca status.	1. Do nothing. 2. Check leaf K and Mg status.
Mg	1. Check soil pH and adjust with dolomitic lime if needed. 2. Check leaf Mg status.	1. Do nothing.
Cu	1. Do nothing.	1. 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.**

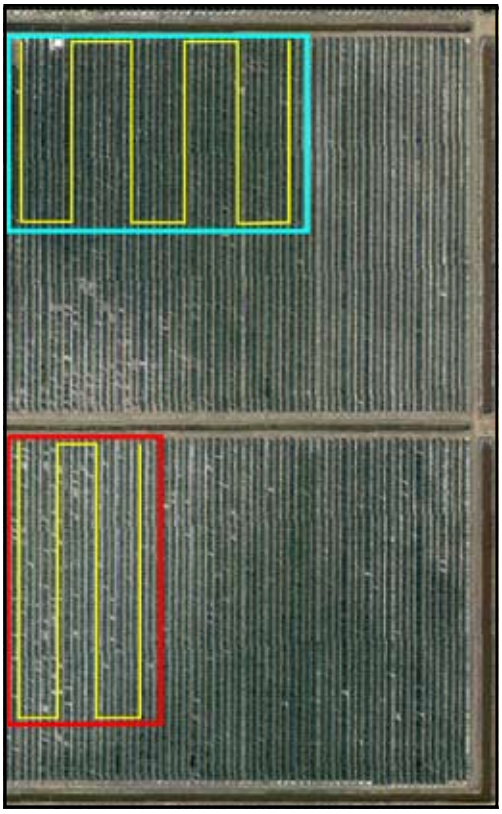


Fig. 4.8. Example of soil and leaf tissue sampling locations using the management zone method. The grove zone area delineated by the blue rectangle is a productive area, while that delineated by the red rectangle is a weak area. The yellow zigzag line denotes the sampling pattern within each management zone.

4.7. 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.

4.8. 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.

5. Precision Agriculture for Citrus Nutrient Management

Arnold W. Schumann and Edward A. Hanlon

5.1. 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 non-destructive 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 electro-magnetic 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, 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 (geo-referencing of data, observations, objects, maps and images with GPS) is an essential prerequisite 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, 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.

5.2. Objectives of precision agriculture for nutrient management

Many possible objectives exist for different precision agriculture programs. Four important objectives related to citrus nutrient 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.
- Automate and digitally record grove operations to speed data analysis and increase efficiency and convenience.

5.3. Remote sensing

5.3.1. 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. Since fertil-

izers are salts, changes in dissolved and adsorbed fertilizer can be sensed as changes in electrical conductivity. Since the measurement involves all salts in the soil, the portion attributed to fertilizer can only be estimated, but 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 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 are infertile and droughty.
- In citrus flatwoods production areas, root damage may result from shallow (perched) water tables and associated capillary rise.
- Flatwoods production areas 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.
- Citrus grove soils are often prone to soil compaction due to vehicular traffic.

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

5.3.2. Ultrasonic canopy measurements

Citrus tree canopy height and volume can be measured remotely using a vertical sensor array that sends out ultrasonic pulses and detects the distance to the tree canopy (Fig. 5.1). 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 (Fig. 5.2).

Calculated canopy volumes (light green) are superimposed on an aerial photograph of the grove (Fig 5.2), which has a

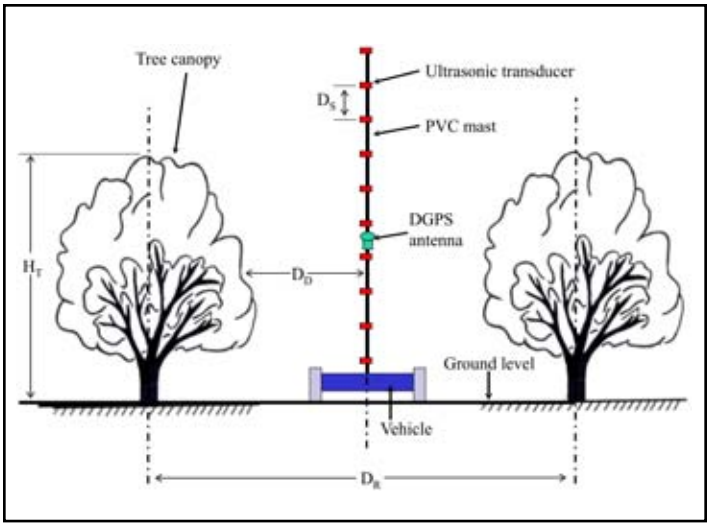


Fig. 5.1. Sensing the height and volume of the tree canopy.



Fig. 5.2. Map of citrus tree canopy volume.

considerable number of resets. From this map, tree canopy sizes can be displayed on a frequency diagram (Fig 5.3). When shown in this manner, new resets, resets planted in 1989 after a freeze, and original grove trees can be identified.

Since 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.

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

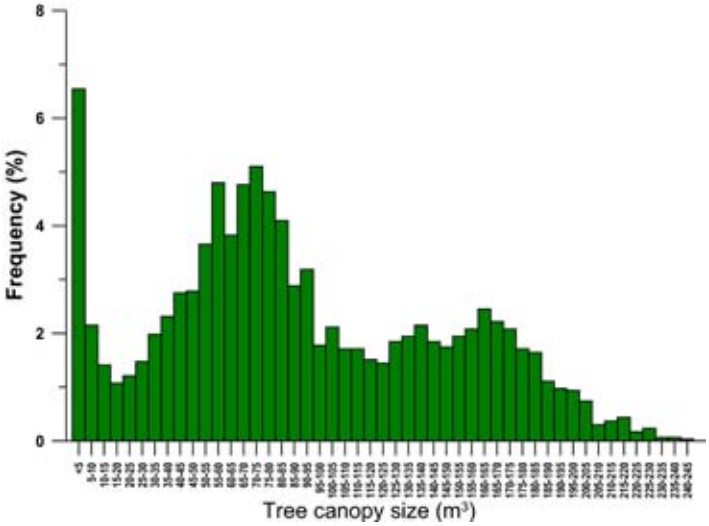


Fig. 5.3. Frequency histogram of tree size within a citrus grove.

5.3.3. Citrus yield mapping

An automatic tub position logger can record the grove position where fruit was harvested using GPS technology (Fig. 5.4). 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 Fig. 5.5, 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. Fertilizer savings can be realized by applying the rate of fertilizer needed by the trees based on their yield (Section 8.2, Fig. 8.3) using yield maps like the one in Fig. 5.5 with a variable rate fertilizer applicator (Section 5.4).

5.4. 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

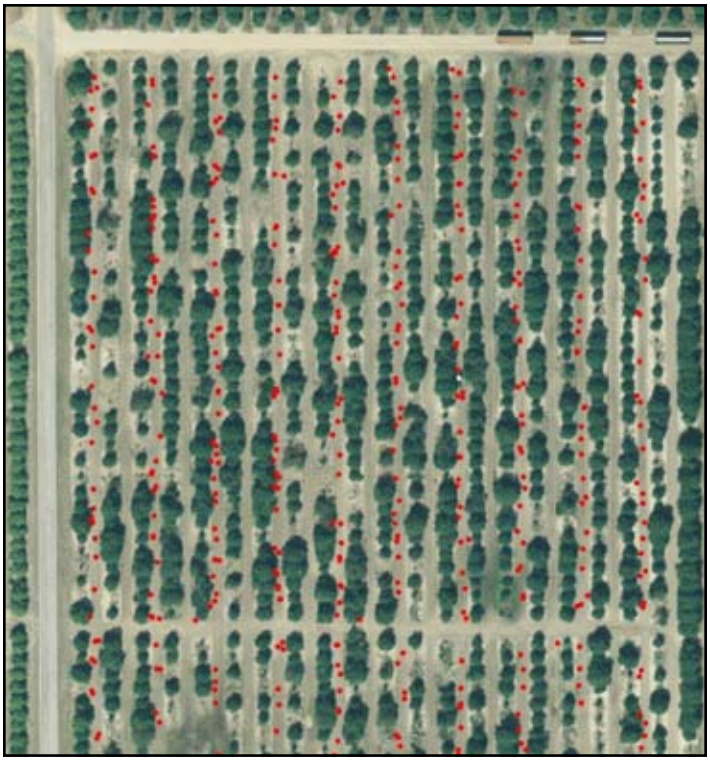


Fig. 5.4. Locations of harvested tubs of fruit are marked by the red dots.



Fig. 5.5. Citrus yield map identifying areas of high (dark green) and low (yellow) production.

where roots are not present. Tree spacing and bedding also affects 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 (Fig. 5.6). 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.

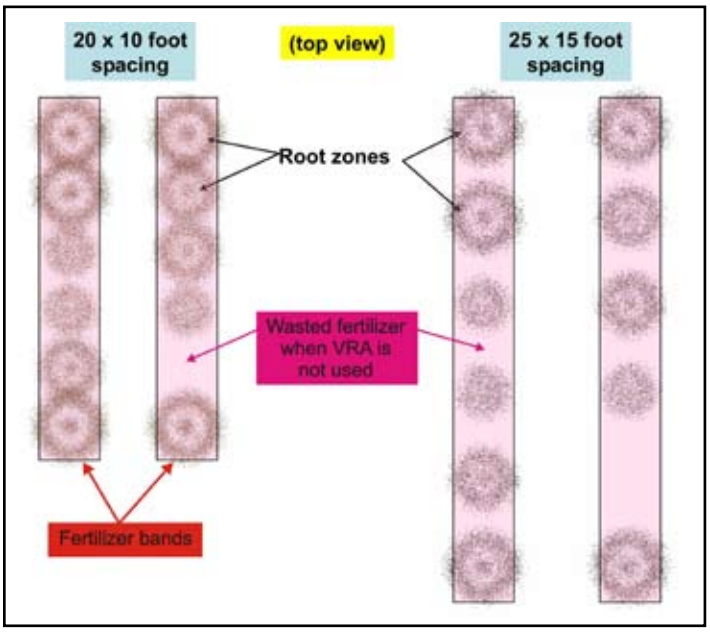


Fig. 5.6. Areas in the tree row where fertilizer can be wasted when using simple band placement. The fertilizer bands cover considerably more area than the area in which citrus roots are located. Fertilizer applied in areas without roots is wasted.

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 Fig 5.3) 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.

Fig. 5.7 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 Fig. 5.1, and note the reduced height of the sensor array in Fig. 5.7.

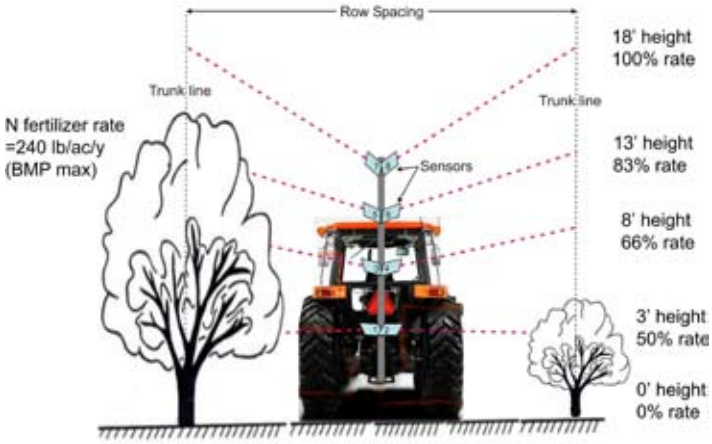


Fig. 5.7. Variable rate fertilization is linked to measurements of tree height.

Since 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 Fig. 5.7. 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 (Fig. 5.8). 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 Fig. 5.7 for applicable tree heights in this particular example. A rule of thumb is not to reduce

variable fertilizer rates based on tree height to less than 50% of the maximum rate used. The smallest trees have a less efficient root system and a smaller horizontal canopy profile that further reduces the applied rates.

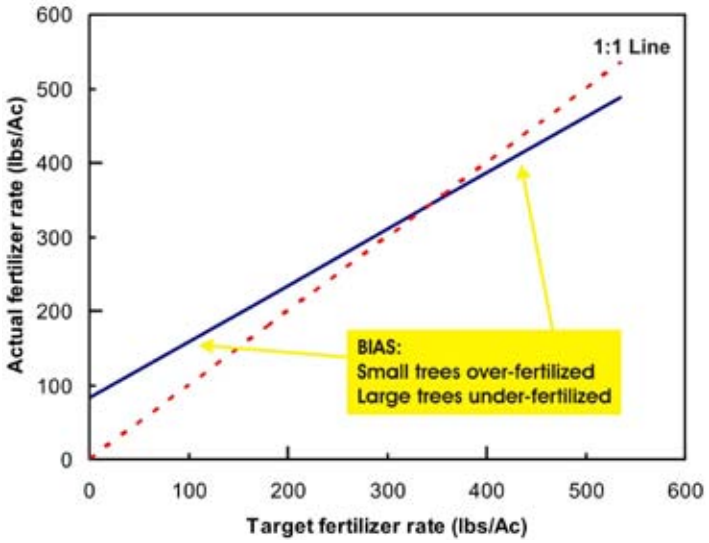


Fig. 5.8. Bias in actual applied fertilizer rate compared with the required rate when using a variable rate spreader with slow response times.

5.5. 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.
- Grove managers should consider use of precision agriculture tools to keep production costs low and improve citrus yields while avoiding potential environmental concerns.

6. Fertilizer Sources and Formulations

Thomas A. Obreza and Brian J. Boman

6.1. 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 high-analysis N fertilizers 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 of these products 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.

The other macronutrients (P, K, Ca, Mg, and S) 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 applied to citrus are usually inorganic or synthetic organic fertilizers. Common micronutrient fertilizers and their analyses are listed in Appendix B. Salt index values (Section 11.5) for typical fertilizer sources and examples of how to calculate the salt index of a fertilizer blend are shown in Appendix C.

6.2. 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 (Fig. 6.1).

Most solid nutrient sources are readily water-soluble and rapidly available for tree uptake (Fig. 6.2; Appendix D, Table D.1). Solid fertilizers are applied with conventional spreading equipment and 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



Fig. 6.1. Unloading dry solid fertilizer from a delivery trailer to a grove spreader. (Stephen Futch)

- Potassium nitrate
- Diammonium phosphate

Phosphorus
- Ordinary superphosphate
- Concentrated superphosphate
- Monoammonium phosphate
- Diammonium phosphate

Potassium
- Potassium chloride (muriate of potash)
- 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 (sul-po-mag)
- Magnesium sulfate
- Magnesium oxide

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

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

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

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

Copper
- Copper sulfate

Boron
- Borax (Sodium tetraborate)

Molybdenum
- Ammonium molybdate
- Sodium molybdate

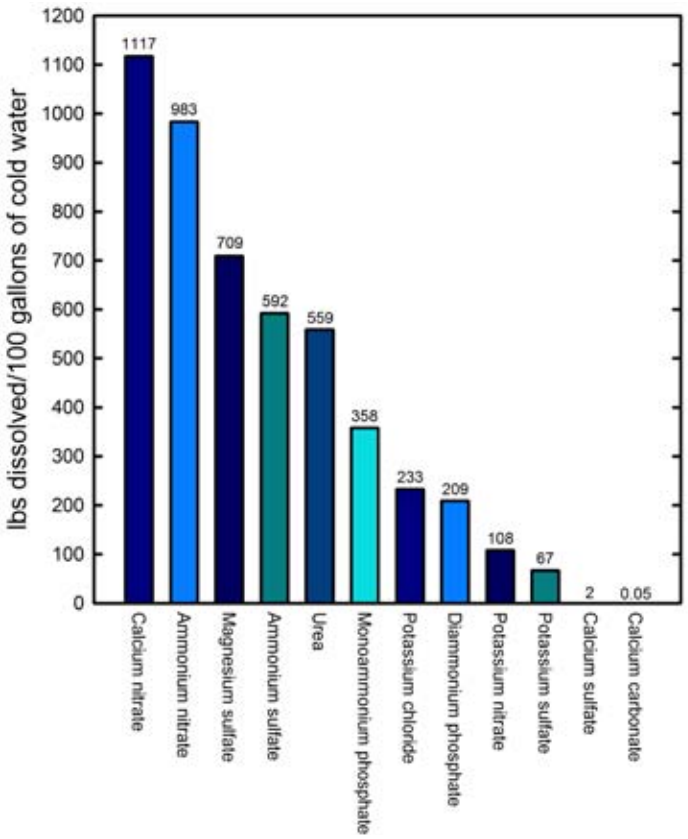


Fig. 6.2. Cold water solubility of macronutrient fertilizer sources.

6.3. 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 acidic 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 is 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. Note that N fertilizer in the nitrate form is not subject to volatilization.

6.4. Solution sources – Fertigation

Fertigation is the application of solution fertilizer with irrigation water, typically through a microsprinkler or drip system (Fig. 6.3; 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



Fig. 6.3. Nutrient solution sources for fertigation are stored in large plastic tanks at the irrigation pump station. (Thomas Obreza)

are made by dissolving readily-soluble sources of plant nutrients in water. 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

Micronutrients
- Borax
- Copper sulfate (acidified)
- Magnesium sulfate
- Manganese sulfate (acidified)
- Zinc sulfate
- 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. Similarly, when using a Ca-based source like calcium nitrate in solution, avoid any form of phosphate or sulfate, and use chelated, complexed or nitrate forms of micronutrients instead of the sulfate form.

Some commonly used liquid formulations, their analyses, and weights per gallon are listed in Appendix D.

6.5. Solution fertilizer salt-out

Solution fertilizer salt-out (crystallization) in storage tanks can be a problem during the winter. As a rule of thumb, the more complex the formulation, the greater the tendency for salt-out. The most important factor affecting salt-out temperature of a fertilizer solution is its concentration of N and K. 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 does not significantly change the 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_2O analyses 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.

6.6. 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. Use caution when tank mixing urea with pesticides, crop oil, and other products because it 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
- Potassium thiosulfate
- Monopotassium phosphate
- Dipotassium phosphate

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

6.7. 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 non-dissolved 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 Section 6.4).

6.8. 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

6.9. 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 era because they can reduce potential negative environmental effects of crop fertilization.

Controlling the release of nutrients is accomplished by surrounding conventional water-soluble fertilizer sources with a coating (Fig. 6.4). Substances used as coatings include polymers, plastics, waxes, and sulfur, either alone or in combination. 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 or water content.

CRFs 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



Fig. 6.4. Coated fertilizer sources control the release of water-soluble nutrients to citrus trees and can last up to 12 months. (Thomas Obreza)

combination with small concentrations of micronutrients. Growers are advised to consult the label of such products to determine release characteristics and recommended application strategy.

6.10. Formulating fertilizer products

More then 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 by blending the various base sources listed 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 described in Appendix E.

6.11. Nutrient sources for organic citrus production

Organic citrus production relies on animal manures (Table 6.1), plant materials, and some mined raw minerals as nutrient sources as opposed to inorganic chemicals and compounds. Essentially all manufactured or synthetic fertilizers are prohibited in certified organic groves. In particular, materials containing chloride, nitrate, and highly-soluble phosphate cannot be used. Although biosolids (processed domestic wastewater residuals) are organic materials, they are prohibited from organic farming.

Examples of nutrient sources that can potentially be used for organic citrus production are listed below. Some are allowed with no restrictions, and 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
  - Dairy
  - Poultry
  - Horse
- 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

Section 11.9 presents additional information about soil fertility and nutrient management guidelines for organic citrus production.

Table 6.1. Manure nutrients.

Manure	lbs of nutrient per ton of manure			C:N ratio
	N	P_2O_5	K_2O	
Beef				24:1
scraped from paved surface	11-14	7-9	10-13	
scraped from dirt feedlot	21-26	14-16	20-23	
Dairy				11-30:1
scraped from paved surface	10	3-6	6-9	
with bedding	9	3	6	
Poultry				
broiler house litter	72	78	46	10-14:1
stockpiled litter	36	80	34	
layer-deep pit	38	56	30	3-10:1
layer-undercage	26	31	20	
Horse (fresh)	12	6	12	22-50:1

Note: Nutrient contents listed are general averages. Samples of the manure to be applied should be analyzed before calculating application rates.

7. Methods of Fertilizer Application

Thomas A. Obreza, Brian J. Boman, Mongi Zekri, and Stephen H. Futch
(Includes contributions by David P. H. Tucker)

7.1. 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 Fig. 7.1:

- 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 distributed from 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 lbs/acre or lbs/tree, **assuming the spreader is fertilizing two rows at a time, i.e. running every other row middle**:

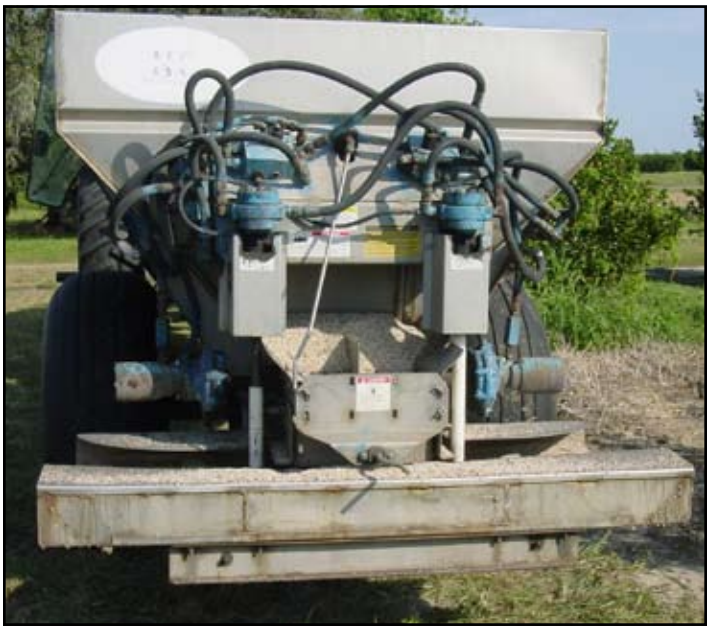


Fig. 7.1. Conventional fertilizer spreader equipped with a split chain and rear deflector plates to apply dry, solid fertilizer beneath the citrus tree canopy. (Mongi Zekri)

Fertilizer material application rate (lbs/acre) =

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

For example, if an average of 28 lbs of fertilizer were collected and the grove density was 145 trees/acre, the application rate would be:

28 lbs ÷ (10 ÷ 145) = **406 lbs/acre**.

7.2. 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 since 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 (Fig. 7.2).
- Soluble fertilizers are more expensive than granular fertilizers on an equal nutrient basis.
- Fertilizers injected into an irrigation system may contribute to emitter plugging.
- Fertigation does not allow for variable rate fertilization based on tree size.

To effectively fertigate citrus trees, growers must properly maintain their microirrigation systems to apply water and fertilizer uniformly (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;
- The timing and frequency of applications per season.



Fig. 7.2. Fertigation equipment, including fertilizer tank (left), filters (center), and injector (right). (Mongi Zekri)

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 pre-determined 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 varying 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 hand-made 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. Thus, they are less spill-prone than dry fertilizer. Although transportation cost makes liquids more expensive, they save time and labor and prevent problems associated with hand-made 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 since 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 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;
- 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 if they contact the skin. When fertigating, take these safety precautions:

- Wear appropriate protective clothing and eye wear 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 shut-down periods in particular.

- Calibrate and frequently re-check 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 (TDS). 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 (Fig. 7.3). Managers should consult state and local regulations that address their equipment needs based on the type of water supply and selected injection device.

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 non-dissolved 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 back-washing. If the system has a filter that uses part of the supply water to continuously back-wash, 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.

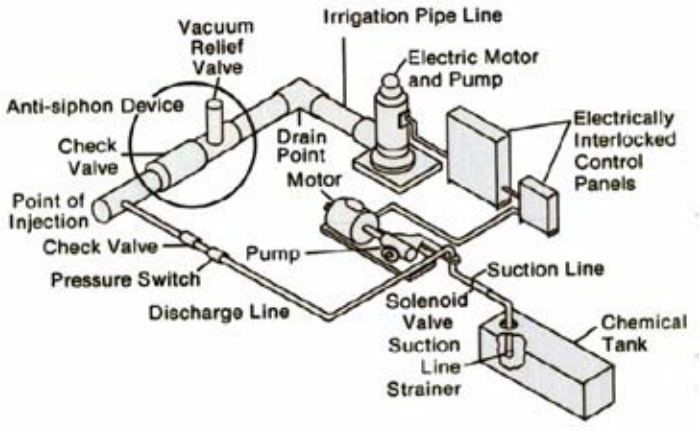


Fig. 7.3. Schematic diagram of fertigation equipment with backflow prevention devices circled.

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 furthest 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.

Maximum injection time depends on soil type and water requirement of the trees. Flush time should not be excessive to avoid leaching freshly-applied fertilizer below the root zone.

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 x N) ÷ (F x 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 (lbs 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 (lbs/gal)

The weight per gallon of the liquid fertilizer solution is usually shown on the fertilizer label. Alternately, a known volume of solution can be weighed and converted to a weight per gallon. Appendix D (Table D.2) lists the density of many common fertilizer solutions.

Example

- The desired N rate is 150 lbs/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 potassium chloride.
- The fertilizer solution density is 9.7 lbs/gal.
- The grove to be fertilized is 80 acres.

Calculations:

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

Volume = (80 acres x 7.5 lbs N/ac) ÷ (0.08 N x 9.7 lbs/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 micro-sprinklers 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 micro-sprinklers that confine the irrigation pattern to a 3 to 4-ft 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 to achieve successful fertigation. 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.

7.3. Applying suspension fertilizers

Suspension fertilizers are applied with a standard herbicide boom that places the fertilizer directly over the root zone (Fig. 7.4). 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 through air sparging or mechanical recirculation to assure application uniformity.

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 co-apply other agrichemicals like herbicides, insecticides, and fungicides. 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.



Fig. 7.4. Boom applicator used to apply suspension fertilizers. (Stephen Futch)

7.4. 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 to the tree on a timely basis during critical stages of 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 por-

tion 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 application in the short-term with the exception of Fe. Foliar sprays are taken up more rapidly by the tree but their effect typically lasts 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 ability of the tree 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 (Fig. 7.5), typically in 100 to 250 gal of water per acre. The goal of airblast spraying is to replace the air contained within 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.

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.



Fig. 7.5. Airblast sprayer used to apply soluble nutrients to citrus tree foliage. (P. Chris Wilson)

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 cause phytotoxicity and occasionally 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.

8. Recommended Fertilizer Rates and Timing

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(Includes contributions by James J. Ferguson, Frederick S. Davies, David P. H. Tucker, Ashok K. Alva, and T. Adair Wheaton)

8.1. Fertilizer rates, application frequency, and timing for non-bearing trees (first 3 years in the grove)

8.1.1. Solid plantings

Nitrogen

Young citrus tree care requires managing irrigation, nutrition, weeds, diseases, pests, and cold protection to stimulate rapid canopy growth. Water 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 non-productive, costly, and may result in loss of N by leaching or runoff.

Nitrogen fertilizer recommendations for non-bearing trees were derived from numerous young-tree fertilization studies conducted throughout Florida (Table 8.1 and Fig. 8.1). 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 (e.g. 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.

The annual N rate applied to solid-set 2 to 3 year old trees should not exceed 200 lbs/acre (Fig. 8.1).

Phosphorus

Before deciding to apply P fertilizer to young trees, test the soil for P and compare the results with the ranges in Tables 4.4 or 4.5.

- 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 Tables 4.4 or 4.5 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 Table 4.2.

Potassium

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

Calcium

Liming the soil to pH 6.0 to 6.5 and maintaining it in that range will supply needed Ca. If soil pH is favorable, there is no need to apply Ca unless soil test Ca is less than sufficient. In this case, an application of gypsum or soluble Ca fertilizer may be considered. If soil pH is above 6.5, the soil will likely contain sufficient Ca for tree growth.

Magnesium

If soil test Mg is medium or lower (Tables 4.4 and 4.5), 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 non-cultivated 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.

Table 8.1. Recommended N rates and minimum number of annual applications for non-bearing citrus trees.

Year in grove	lbs 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

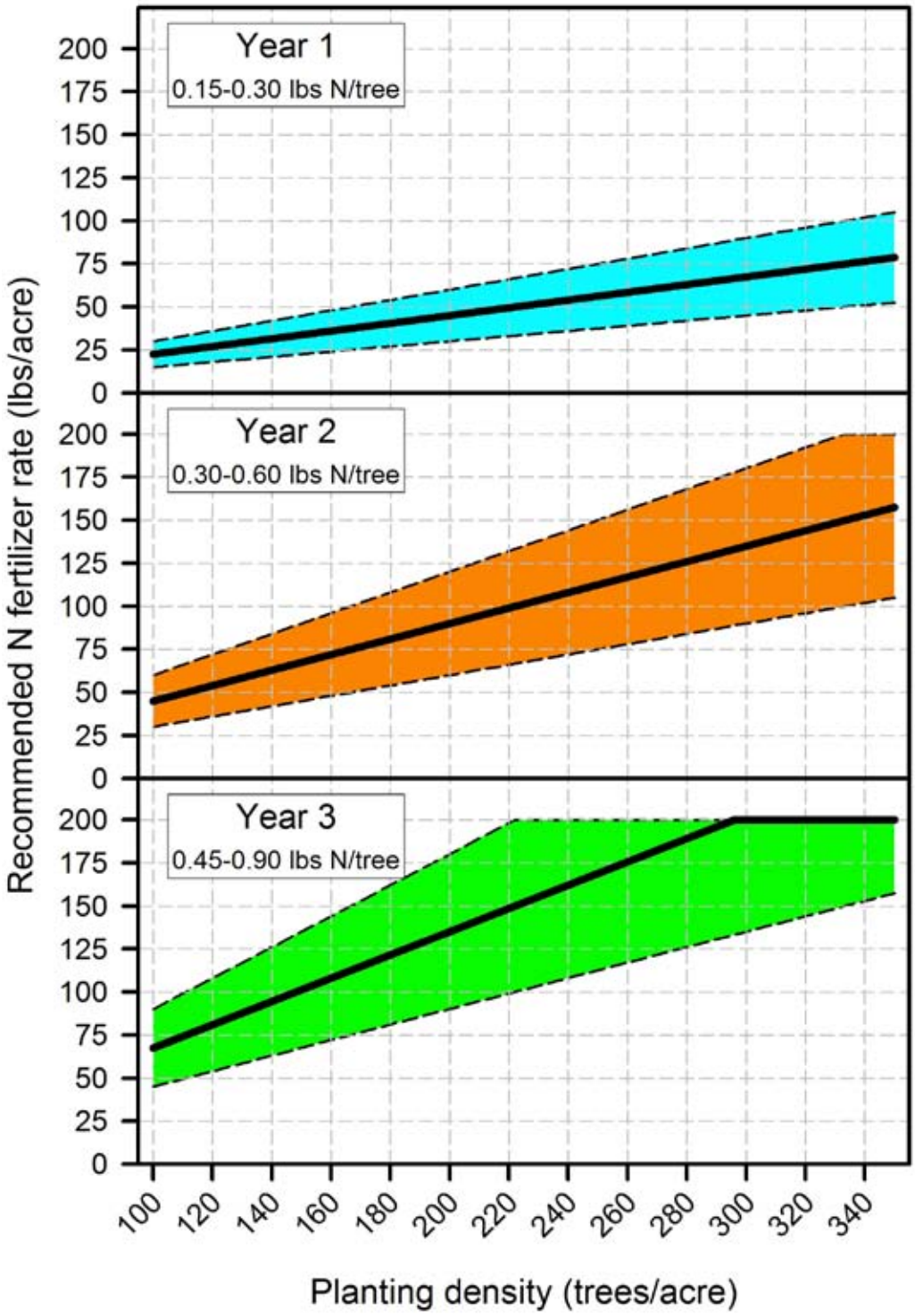


Fig. 8.1. Recommended N rates for non-bearing citrus trees on a per-acre basis as a function of planting density. To determine the per-acre rate, find the planting density on the x-axis, move up into the colored band, and find the recommended N rate range on the y-axis.

Nutrient management

Applying fertilizer in several small doses increases fertilizer efficiency because it maintains more constant N availability and reduces leaching potential. A minimum of 4 to 6 annual applications of dry fertilizer is recommended for young trees. Splitting fertigation into 10 or more yearly applications 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 is satisfactory because nutrients are protected from leaching. Controlled-release formulations may be applied pre-plant, incorporated after planting, or broadcast to insure uniform distribution of nutrients throughout the enlarging root zone of young trees.

Non-bearing trees fertilized after September 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. Nutrient uptake is reduced at lower soil temperatures, particularly for trees on Swingle citrumelo rootstock. Trees on Swingle can become quite chlorotic 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. 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 young 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.

8.1.2. Resets in established groves

Resets in established groves should be fertilized like solid-set non-bearing 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.

8.1.3. Example fertilizer program for non-bearing 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 lbs N per tree per year in four equal applications, then 0.1 lbs N will be applied each time. Using a fertilizer containing 10% N, the tree will receive 1.0 lb of fertilizer per application.

8.2. Fertilizer rates for bearing trees (4+ years in grove)

Nutrient management for bearing trees requires many of the same considerations important for non-bearing 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 (Table 3.3), 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, since returns are based on lbs 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 8.2) provide enough N for canopy expansion towards 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 (Table 4.2).

- For grapefruit, the recommended annual N rate is **120 to 160 lbs/acre**.
- For oranges and other varieties, the recommended annual N rate is **120 to 200 lbs/acre**.
- If justified by an exceptionally high-producing young grove (>650 boxes/acre), the yield-based N recommendation for trees 8+ years of age (Table 8.2) may be used.

Mature bearing trees (years 8+ in the grove). Once trees reach containment size, further canopy growth is not

Table 8.2. Recommended N rates and minimum number of annual applications for bearing citrus trees.

Year in grove	Oranges	Grapefruit	Other varieties	Lower limit of annual application frequency		
	lbs N/acre/year (range)			Controlled-release fertilizer	Dry soluble fertilizer	Fertigation
4 through 7	120 – 200	120 – 160	120 – 200	1	3	10
8 and up	140 – 250 Yield-based[1]	120 – 160[2]	120 – 300[3]	1	3	10

[1]See Fig. 8.3 for specific production-based N fertilizer rate recommendations.
[2]For grapefruit groves producing more than 800 boxes/acre, the maximum recommended N rate is 180 lbs/acre.
[3]For Orlando tangelos, the maximum recommended N rate is 250 lbs/acre. For Honey tangerines (Murcotts), the maximum recommended N rate is 300 lbs/acre.

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 lbs/acre**. For groves producing more than 800 boxes/acre, up to 180 lbs/acre may be considered. The N rate applied 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% (Fig. 8.2), 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%.

Oranges:

- The annual N rate should fall within the range of **140 to 250 lbs/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 12+ year-old-trees) expressed as either fruit yield or soluble solids production (Fig. 8.3).
- 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 (Fig. 8.4), and may reduce some aspects of fruit quality.

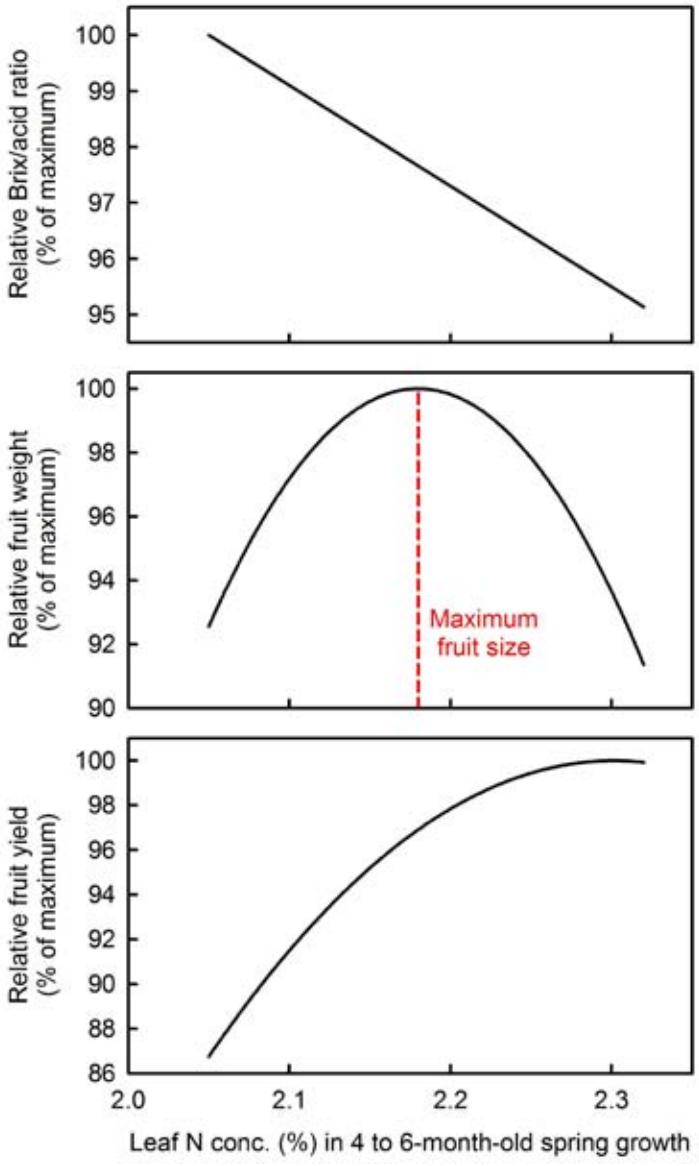


Fig. 8.2. As grapefruit leaf N increases from 2.0 to 2.3%, yield increases and Brix/acid ratio decreases slightly. Fruit size increases as leaf N approaches 2.2%, then decreases substantially (He et al., 2003).

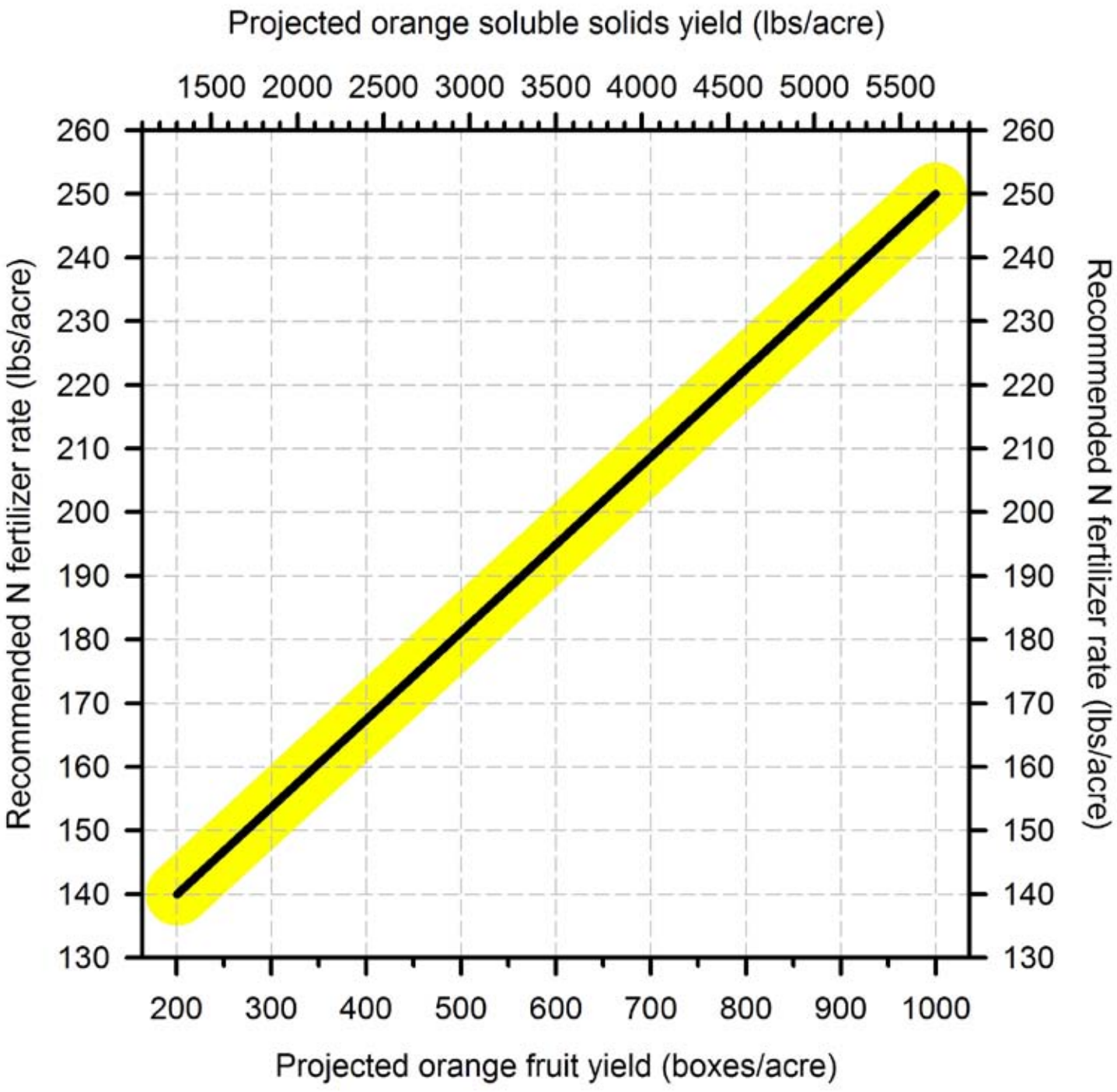


Fig. 8.3. Production-based N fertilizer rate recommendations for Florida oranges. Find the projected yield potential (8 to 11 year-old-trees) or 4-year running average production (12+ year-old trees) on the x-axis, move up or down to the straight line, and find the recommended N rate range on the y-axis.

- The base N rate recommendation (140 lbs/acre) is for groves producing 200 boxes/acre or 1300 lbs solids/acre.
- The high end of the N rate range (250 lbs/acre) is for groves producing 1000 boxes/acre or 5800 lbs solids/acre.
- Beginning at the base N rate, the recommended N rate increases:
  - 14 lbs N/acre for every 100 box/acre increase in expected yield potential or 4-year running average yield; or
  - 2.5 lbs N/acre for every 100 lbs solids/acre increase in expected yield potential or 4-year running average yield.

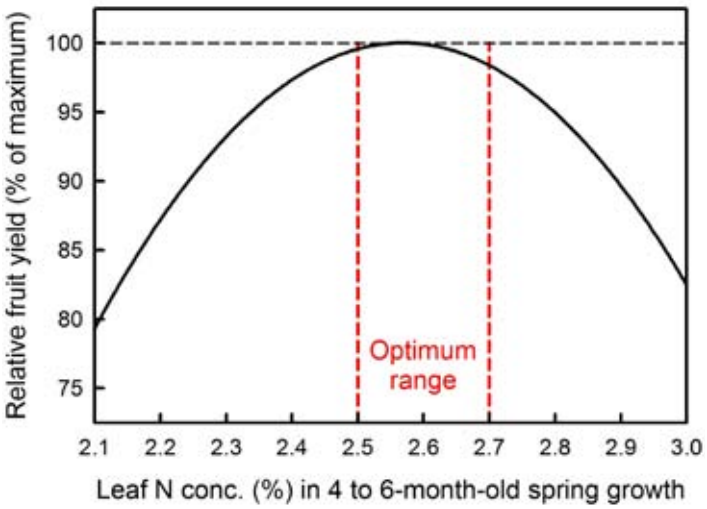


Fig. 8.4. As orange leaf N increases from 2.1% to 3.0%, yield increases to a maximum around 2.6%, then decreases (Alva et al., 2006).

Applying nutrients, particularly N, using **variable rate application** should be considered (see Section 5.4). Yield maps (Section 5.3.3) indicate how yield varies across a block or grove. The use of variable rate technology is encouraged if the necessary equipment or custom applicator is available.

Other varieties:

- For other varieties, the recommended annual N rate is **140 to 250 lbs/acre** using the method above to calculate a production-based rate for specific groves.
- For the special case of Orlando tangelos, the maximum recommended annual N rate is 250 lbs N/acre.
- For the special case of Honey tangerines (Murcotts), the maximum recommended annual N rate is 300 lbs 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] x 14 lbs/acre}

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

Recommended N rate = 140 lbs N/acre + {[(500 – 200)/100] x 14 lbs N/acre}
= 140 + 42 = 182 lbs N/acre

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

Recommended N rate = Base N rate + {[(Avg. yield – 1300 lbs sol./acre)/100] x 2.5 lbs/acre}

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

Recommended N rate = 140 lbs N/acre + {[(3500 – 1300)/100] x 2.5 lbs N/acre}
= 140 + 55 = 195 lbs N/acre

Leaching rain rule: If 3 or more 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 lbs/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 Tables 4.2, 4.4, and 4.5.
- Follow the P fertilization guidelines in Table 8.3.

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.

Table 8.3. 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 or 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 re-evaluate.
Optimum	Sufficient	
Optimum	Less than sufficient	Apply 8 lbs 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 re-evaluate.
Low	Less than sufficient	Apply 12 lbs 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 re-evaluate.
Deficient	Less than sufficient	Apply 16 lbs 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 re-evaluate.

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

Calcium

Liming the soil to pH 6.0 to 6.5 and maintaining it in that range will supply needed Ca. If soil pH is favorable, there is no need to apply Ca unless soil test Ca is less than sufficient or leaf tissue Ca is below optimum. In these cases, application of gypsum or soluble calcium fertilizer should be considered. If soil pH is above 6.5, the soil will likely contain sufficient Ca for tree growth and fruit production.

Magnesium

If soil test Mg is medium or lower (Tables 4.4 and 4.5) or if leaf Mg is below optimum (Table 4.2), 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 (Table 3.3). Removal of micronutrients by the harvested fruit from even 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 8.4.

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 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 post-bloom or summer sprays, preferably timed when leaves of new growth flushes are two-thirds to fully expanded.

Copper. Some central ridge and east coast grove soils contain 300 to 400 lbs Cu/acre in the top 6 inches of soil. A moderate routine disease control spray program contributes an additional 3 to 4 lbs Cu/acre/year so no soil application of Cu fertilizer is needed in this situation. Soil pH below 5.5 can solubilize soil Cu that is toxic to plants. As little as 1 ppm Cu in the soil solution can kill roots.

Table 8.4. 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				
Rates		**lbs metallic equivalent/acre**				
	Foliar	3 to 5	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.

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 non-cultivated 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 8.1.1).

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, resulting in an inactivation or immobilization of Fe in plant tissue. Citrus rootstocks vary widely in their ability to overcome low Fe stress (Table 8.5). The easiest way to avoid alkaline-induced Fe chlorosis in citrus trees that are 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 8.6). 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. Choose Fe-DTPA for mildly-alkaline soils (pH 7.5 or less), and choose Fe-EDDHA 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 in a complexed form that does not readily precipitate. Research with Fe-humate applied to citrus trees showed that moderate Fe deficiency could be corrected for relatively low cost.

Table 8.5. 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* x *P. trifoliata*)	↓
Trifoliate orange (*P. trifoliata*)	Highest susceptibility
Swingle citrumelo (*C. paradise* x *P. trifoliata*)	↓

Table 8.6. 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

Zinc. Soil pH is the most important factor regulating plant-available Zn. Zinc precipitates at alkaline pH markedly decreasing availability 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.

If Zn deficiency symptoms are transient and not widespread in a citrus grove, applying Zn fertilizer is not recommended. However, special consideration should be given to groves being visually monitored for citrus greening disease 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 lbs 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 rarely economically practical due to the massive rates required to correct a deficiency. Zinc should not be soil-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 lbs of Mn as $MnSO_4$ per acre is recommended. On calcareous or heavily limed acid soils, foliar application of 3 to 5 lbs 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 miniscule amounts and there is only a small range between deficient and toxic fertilizer rates. It should be applied annually as a foliar spray or in a dry fertilizer mixture at approximately 1/300 of the N fertilizer rate. If trees are irrigated with reclaimed water, B fertilization may not be necessary.

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

8.3. 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, after which nutritional requirements for fruit development decrease. 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 initiation of flowering.
- The second increment should be made available between flowering and late May.
- Third increment should be made available between September and mid-October, **avoiding the summer rainy season as much as possible**.

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, fertilizer applied in January may not be readily taken up if soils are cold. If a freeze occurs shortly after a winter fertilizer application, much of the fertilizer will be lost by leaching if micro-sprinklers are used for freeze protection.

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.

8.4. 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 in half 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 mineraliza-

tion 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 lbs/acre of total N to a grove, about 66 lbs 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 8.7). 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 suggested 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.

Table 8.7. 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

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 per year 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. Since they are considerably more expensive than water-soluble materials, applying coated fertilizers at lower rates may be necessary to maintain an economically-competitive fertilization program. Since the marketing of coated fertilizers for mature citrus groves is relatively new, growers are encouraged to consult the fertilizer manufacturer or blender for release rates and efficiencies of specific products.

8.5. 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 (Table 3.1) but leaves are not usually thought of as a major uptake site for macronutrients. However, there are special cases where foliar application of N, P, and/or K is justified. Citrus growers should realize that a positive response to foliar sprays of N or P 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 to 60 lbs 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 24 to 48 hours after spray application. Optimum conditions for foliar uptake include:

- Air temperature between 77 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 lbs urea/acre applies 23 lbs N/acre. If the fertilization plan calls for a total of 180 lbs N/acre/year, only 157 lbs N/acre (180 – 23) 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 leaching potential is the 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 pre-bloom 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 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 such as 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 fruit size (Table 3.4).

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 (Section 11.5) 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 to 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 lbs 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.

If foliar spraying with 100 or more gal of water/acre, the potential for burn is relatively low, so the least expensive K source may 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; Appendix C, Table 1) makes it 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 post-bloom 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 non-treated plots. In addition, there was a corresponding increase in soluble solids yield in the Valencia experiments. Combining pre-bloom, post bloom, and summer K sprays may 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 recommend program for most citrus varieties is 8 lbs K_2O/acre per application, applied pre-bloom (typically February), post-bloom (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 during 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:
  - 25 lbs KNO3/acre applied in 125 gal of water/acre.
  - 15 lbs MKP/acre applied in 32.5 gal of water/acre.
  - 15 lbs MKP/acre applied in 10 gal of water/acre by airplane.

9. Irrigation Management to Improve Nutrient Uptake

Kelly T. Morgan and Thomas A. Obreza

9.1. 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, but 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.

9.2. Production region characteristics important to irrigation management

The central Florida ridge (Fig. 2.7) 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 (Fig. 2.7) 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.

9.3. 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.

9.4. Allowable soil water depletion

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 to 66% 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.

9.5. Irrigation scheduling

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 4th day during the dry season)
- Monitoring soil water status
- Calculating a water budget

9.5.1. Soil moisture 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 hand-held. They measure soil moisture at one depth or at multiple depths. General categories include:

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

Considerations when using soil moisture sensors to schedule irrigation include:

- Knowing the soil water-holding capacity and tree root zone depth (Appendix A, Table A.1).
- 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).

Fig. 9.1 shows an example of how a multi-level 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.

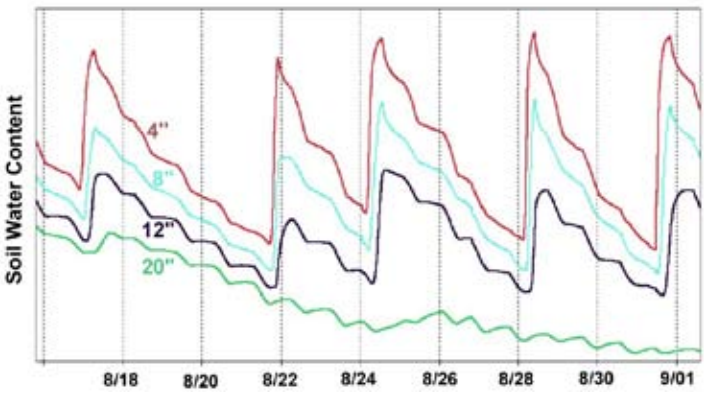


Fig. 9.1. Continuous monitoring of soil moisture at 4, 8, 12, and 20-inch depths in the soil by a multi-level capacitance probe installed in the root zone of a mature citrus tree.

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. Since the goal here 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 the 20-inch depth during the following 2-week period showed that the grower had attained optimum irrigation water management.

9.5.2. Water budgeting

An alternative method to schedule irrigation uses a computer program that estimates grove 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 (FAWN) 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 in the next section.

9.6. 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 micro-sprinkler per tree with a 16-ft 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 (Fig. 9.2).

Nutrient leaching risk in this grove is higher within the wetted pattern due to potential over-irrigation plus the fact that most fertilizers are applied to that zone (Fig. 9.3). A good irrigation manager will control this risk with careful water management.

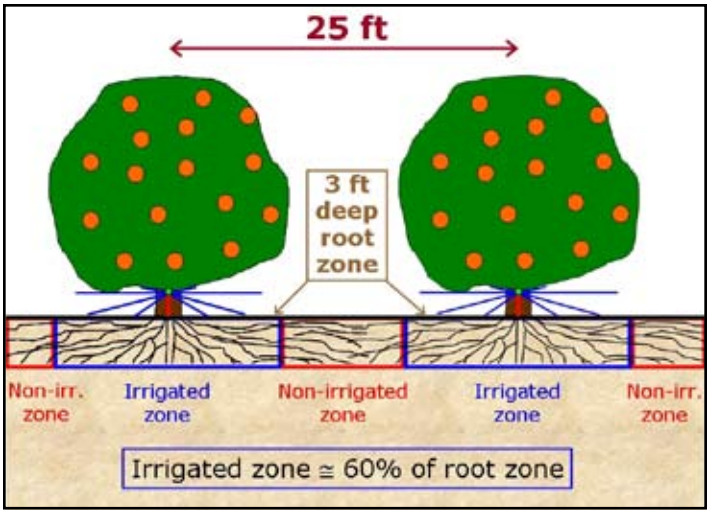


Fig. 9.2. Scaled diagram of example citrus grove described above.

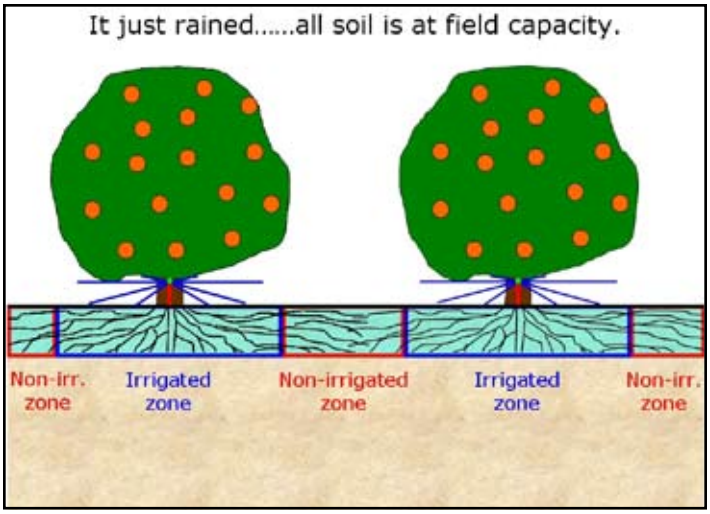


Fig. 9.4. The citrus grove at field capacity soil water content (time = 0).

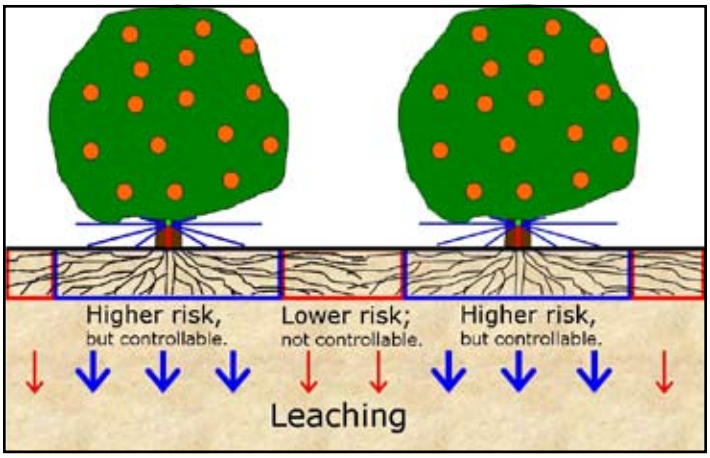


Fig. 9.3. Irrigated and non-irrigated zones in a citrus grove have different leaching potentials that depend on irrigation scheduling and fertilizer placement.

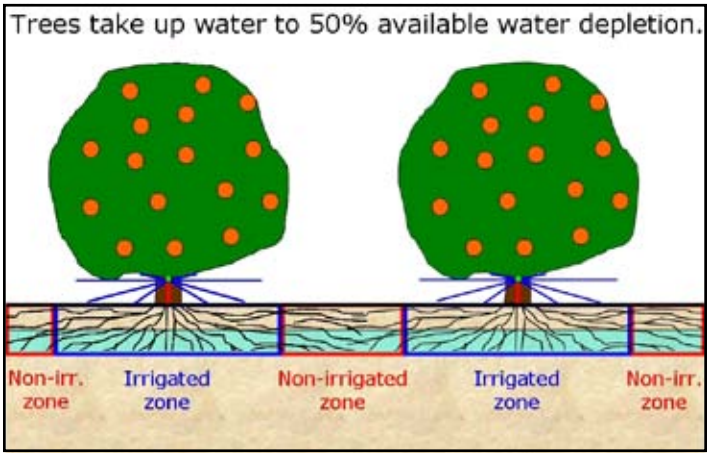


Fig. 9.5. The citrus grove several days later, after half of the available water has been removed from the root zone. Note that water extraction has occurred from both the irrigated and non-irrigated zones.

Note: The following depictions of water content changes in the citrus tree root zone (Figs. 9.4 to 9.7) 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 (Fig. 9.4). 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 (Fig. 9.5).

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 (Fig. 9.6). 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.

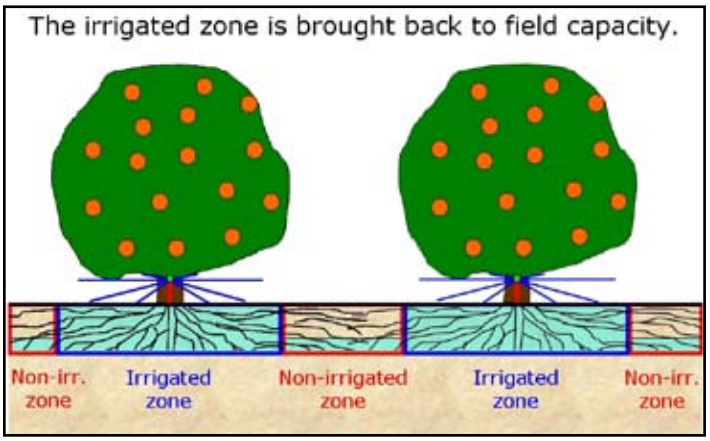


Fig. 9.6. The citrus grove after irrigation returns the wetted zone to field capacity. Note that the non-irrigated zone contains very little available water.

If the grove manager operates the irrigation system too long and applies more water than the soil can hold, water will move beneath the 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 (Fig. 9.7).

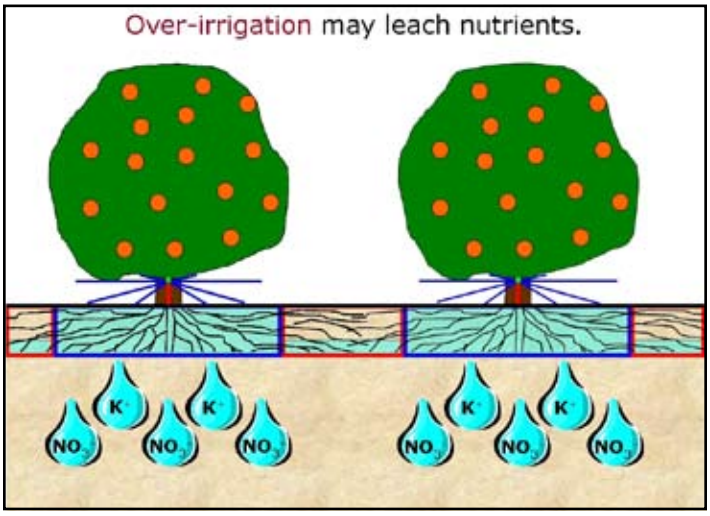


Fig. 9.7. Excessive irrigation leaches mobile nutrients like nitrate and potassium.

How much water can the root zone hold?
From Appendix A, Table A.1:

- 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 micro-sprinklers	60%
Micro-sprinkler flow rate	16 gal/hr
Tree spacing	12½ ft x 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.

10. Environmental Issues and Best Management Practices (BMPs)

Brian J. Boman, Thomas A. Obreza, and Kelly T. Morgan
(Includes contributions by Larry K. Jackson, Ashok K. Alva, David P. H. Tucker, and D. V. Calvert)

10.1. Environmental nutrient issues related to Florida citrus production

Although N fertilizer is required for tree growth and fruit production, there is little net increase in tree size in a mature grove. 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 10.1 illustrates the citrus tree as a component in the environmental N cycle.

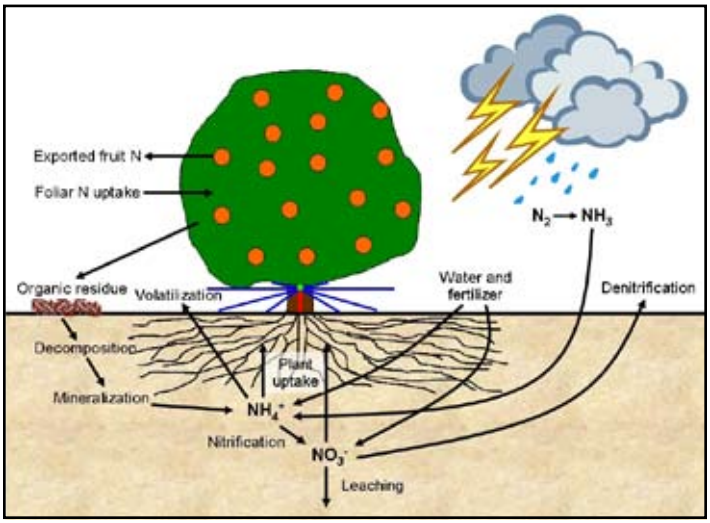


Fig. 10.1. The citrus tree as a component of the environmental N cycle.

A 600 box/acre crop of oranges removes about 72 lbs of N/acre from the grove. If this mature grove receives 200 lbs N/acre annually, approximately 128 lbs 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 was not recovered even when water was 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 (denitrified) to gaseous N that disperses in the atmosphere.

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 plant growth in water furrows may be an indication of lateral nitrate movement.

10.2. The 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 (Fig. 2.7).

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 qual-*

ity 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 nitrate leaching from fertilizers to groundwater.

Citrus production BMP development 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 about BMPs (http://www.floridaagwaterpolicy.com/).

The following are the steps growers should 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.

10.3. 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 ground water.
- 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 over-irrigate.
- 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.

11. Special Situations

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11.1. 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 higher 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 lbs/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 the fruit 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.

11.2. Rootstock/nutrition interaction

Citrus rootstocks influence nutrient uptake and can make the difference between a productive and non-productive 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 > 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 by reducing 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.

11.3. 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 in citrus production, the Mehlich 1 soil test Cu interpretations in Table 4.4 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, take the following steps:

- 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 1M 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.

11.4. 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 non-calcareous 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 N 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 an alkaline condition (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 K concentrations are common in groves planted on calcareous soils. If low yield, small fruit, fruit splitting, and/or creasing are observed, application of additional K fertilizer is justified. One approach is to increase the N:K_2O fertilizer rate ratio to 1:1¼, i.e. apply 25% more K_2O than normal.

If 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). Precautions should be taken to avoid foliar burn 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.

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

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 over-liming) 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 that neutralizes $CaCO_3$ (Table 11.1) and decreases soil pH. Ammonium sulfate [$(NH_4)_2SO_4$] acidifies the soil through nitrification that releases H^+ as NH_4^+ converts to NO_3^-.

Elemental S is the most effective soil acidifier. The powder form can be difficult to handle due to dustiness and fire hazard, and 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 non-corrosive and non-hazardous to handle, and 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 micro-irrigation 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.

Table 11.1. Materials that can be used to lower soil pH, and their acidifying power relative to $CaCO_3$.

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

11.5. 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 x 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 lbs of salt. Since 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 lbs salt in 100 gallons) can create salt stress.

Since 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. Since 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. 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 index 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, since 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.

11.6. 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 11.2) can be expected to occur among varieties and rootstocks.

Table 11.2. Chemical composition of reclaimed municipal effluent from the city of Orlando and 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.

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/yr of reclaimed water containing 10 ppm N would supply 113 lbs N/acre. However, even in low rainfall years, trees in Florida do not need 50 inches of irrigation, so considerable leaching would occur if this volume was applied. Hence, N fertilization is still needed when irrigating with reclaimed water.

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.

Table 11.3. Average chemical composition of citrus processing wastewater (Koo, 1973).

	Source A	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

11.7. Fertilization strategies for damaged trees

11.7.1. 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 lbs 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 re-build 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.

11.7.2. Freeze damage

Trees should not be fertilized or irrigated following a severe freeze until the extent of damage is determined and re-growth 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 post-freeze 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.

11.8. 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, 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 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 vein yellowing typical of N deficiency. The deficiency pattern may be associated with individual limbs in the case or 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.

11.9. Organic citrus production

11.9.1. 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. Limitations include an insufficient supply of non-synthetic 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 non-certified 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 U.S. Dept. of Agriculture (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.

11.9.2. 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.
    - 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.
  - Non-composted 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 non-synthetic 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 non-synthetic 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.
    - Burning as a means of disposal for crop residues produced on the operation. (Exception: burning may be used to suppress the spread of disease.)

12. References and Further Reading

(Note: References in Sections 12.1 through 12.3 are the information sources from which new material in this second edition of "Nutrition of Florida Citrus Trees" was obtained.)

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13. Glossary

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

Adsorption - the adhesion in an extremely thin layer of molecules (as of gases, solutes, or liquids) to the surfaces of solid bodies or liquids with which they are in contact.

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 non-packaged form, usually in semi-trailers.

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 non-manipulated 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 (P2O5), and potash (K2O); 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 lbs.

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.

Marl – A friable earthy deposit consisting of clay and calcium carbonate.

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 byproduct 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.

Sorb – To take up and hold by either adsorption or absorption.

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 lbs.

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.

14. Appendices

Appendix A. Physical and chemical properties of typical Florida citrus soils.

Table A.1. 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 A.2. 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 fertilizer materials.

Table B.1. Conventional and slow-release sources.

Material	Percentage composition							Availability
	N	P_2O_5	K_2O	Ca	Mg	S	Other	
Conventional sources								
Ammonium molybdate							54 Mo	Rapid
Ammonium nitrate	34							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				0 – 2		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
Manganese sulfate						13	24 Mn	Moderate
Monoammonium phosphate	11	48				0 – 2		Rapid
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
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

(continued on p. 83)

Table B.1. *(continued)*

Material	Percentage composition							Availability
	N	P_2O_5	K_2O	Ca	Mg	S	Other	
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 B.2. 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					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	1		1					Rapid (if fresh)

Appendix C. Salt index of fertilizer materials.

Table C.1. Salt index of water-soluble fertilizers.

Material and analysis	Salt index	
	Per equal weights of materials (Basis: sodium nitrate = 100)	Per unit (20 lbs) 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 C.2. Example salt index calculation for a dry fertilizer.

15-4-15 dry granular			Nutrient units			Salt index	
Material	Nutrient conc.	lbs/ton	N	P_2O_5	K_2O	per unit (20 lbs) (from table C.1)	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 C.3. Example salt index calculation for a solution fertilizer.

8-0-8 solution			Nutrient units			Salt index	
Material	% Nutrient	lbs/ton	N	P_2O_5	K_2O	per unit (20 lbs) (from table C.1)	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 D.1. Water solubility of fertilizer sources.

Material	Amount (lbs) 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, $Na_2B_4O_7 \bullet 10H_2O$	0.17	14.2
Calcium carbonate (limestone), $CaCO_3$	0.00013 (77° F)	0.00016 (167° F)
Calcium nitrate, $Ca(NO_3)_2 \bullet 4H_2O$	10.1 (64° F)	31.4
Calcium sulfate (gypsum), $CaSO_4 \bullet 2H_2O$	0.020	0.019
Copper sulfate, $CuSO_4 \bullet 5H_2O$	2.6	17.0
Diammonium phosphate, $(NH_4)_2HPO_4$	4.8 (50° F)	8.8 (158° F)
Ferric sulfate, $Fe_2(SO_4)_3 \bullet 9H_2O$	36.7	Decomposes
Ferrous sulfate, $FeSO_4 \bullet 7H_2O$	1.3	4.1 (122° F)
Magnesium sulfate, $MgSO_4 \bullet 7H_2O$	5.9 (68° F)	7.6 (104° F)
Manganese sulfate, $MnSO_4 \bullet 4H_2O$	8.8	9.3 (129° F)
Monocalcium phosphate, $Ca(H_2PO_4)_2 \bullet 2H_2O$	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, $ZnSO_4 \bullet 7H_2O$	8.1 (68° F)	55.4

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

Table D.2. Common fertilizer solutions.

Analysis			Density	Materials and formulation	Additional nutrients
N	P	K			
%			lbs/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	11.3	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 lbs of N, 40 lbs of P_2O_5, 160 lbs of K_2O, and 36 lbs of Mg per acre, and that the yearly rate will be split into four applications.
2. The nutrients required per application are 40 lbs of N, 10 lbs of P_2O_5, 40 lbs of K_2O, and 9 lbs 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 lbs N per acre) ÷ (0.16) = 250 lbs per acre. If the grove is 80 acres, then the amount of fertilizer to order is: (250 lbs per acre) × (80 acres) = 20,000 lbs = 10 tons.
4. One ton of this fertilizer contains 320 lbs of N, 80 lbs of P_2O_5, 320 lbs of K_2O, and 72 lbs 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 lbs P_2O_5) ÷ (0.46) = 174 lbs DAP.
6. The Mg fertilizer is also supplied by only one source, SPM. The amount needed is: (72 lbs Mg) ÷ (0.11) = 655 lbs SPM.
7. In addition to supplying P, DAP also supplies some N: (174 lbs DAP) × (0.18) = 31 lbs N.
8. The balance of the N, to be obtained from ammonium nitrate, is: (320 lbs N) – (31 lbs N) = 289 lbs N. Thus, the amount needed is: (289 lbs N) ÷ (0.34) = 850 lbs ammonium nitrate.
9. In addition to supplying Mg, SPM also supplies some K_2O: (655 lbs SPM) × (0.22) = 144 lbs K_2O.
10. The balance of the K_2O, to be obtained from potassium chloride, is: (320 lbs K_2O) – (144 lbs K_2O) = 176 lbs K_2O. Thus, the amount needed is: (176 lbs K_2O) ÷ (0.60) = 293 lbs potassium chloride.

The following table summarizes the above calculations.

Table E.1. 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
	lbs 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 lbs/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 lbs 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 lbs 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 lbs/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 lbs/acre, divided as follows:

   February application (1/3) = 60 lbs/acre.
   May application (1/3) = 60 lbs/acre.
   October application (1/3) = 60 lbs/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 lbs by 10%: (60 ÷ 0.10) = 600. Thus, we will apply 600 lbs of 10-4-10 to each acre in February, May, and October.
11. Multiply the lbs/acre of fertilizer needed by the number of acres in the grove to get amount needed per application.

    600 lbs/acre of 10-4-10 × 40 acres = 24,000 lbs
    = 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 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**

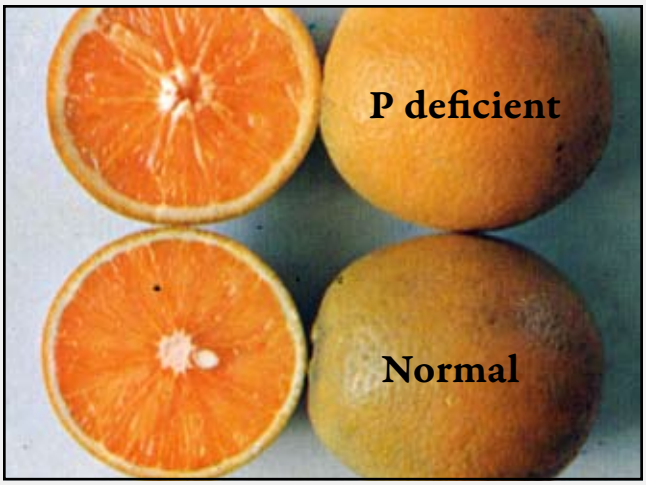
Appendix H. Color plates.

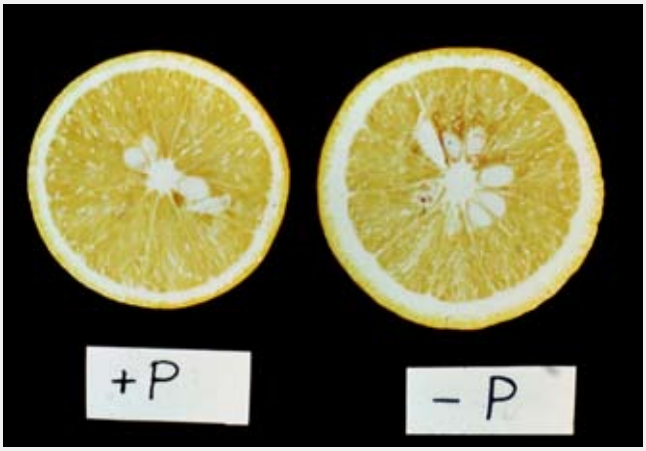






Fig. H1. **Nitrogen deficiency**. Top: Moderate leaf N deficiency. Center: Severe leaf N-deficiency. Bottom: Severely N-deficient leaf at left compared with increasing N status to the right.





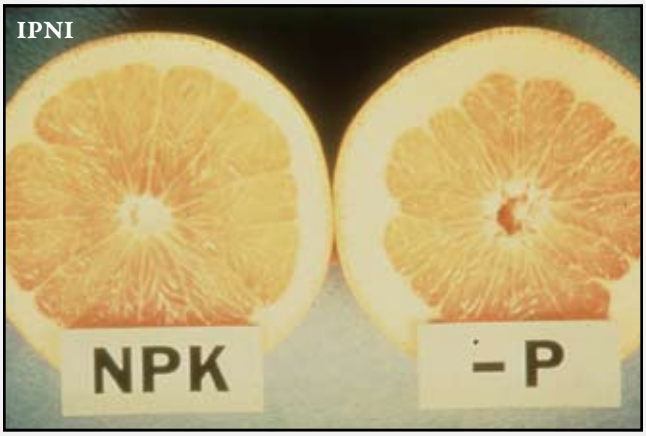
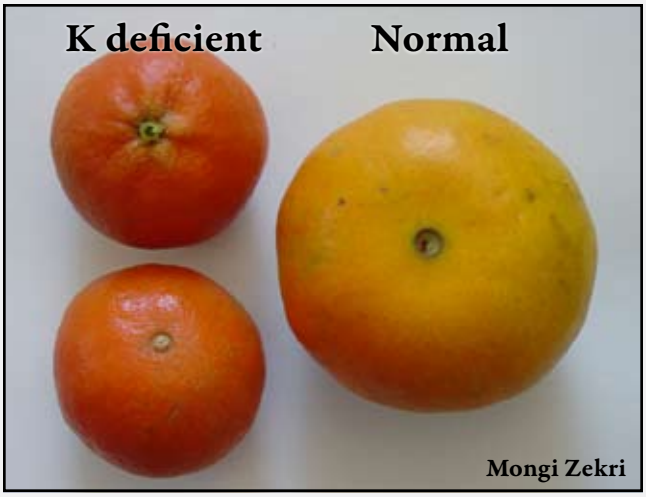


Fig. H2. **Phosphorus deficiency**. Note the thicker peel and hollow core of P-deficient fruit compared with normal fruit.





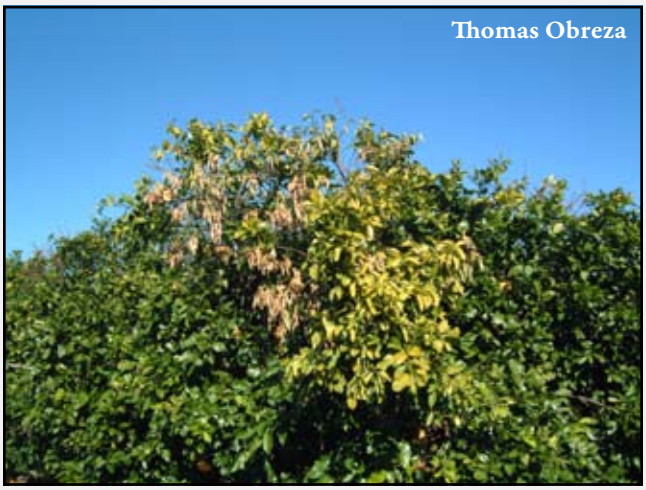


Fig. H3. **Potassium deficiency**. Top: K deficiency produces smaller fruit with smoother peel and higher color compared with normal fruit. Center: Leaf chlorosis caused by K deficiency. Bottom: Severe K deficiency can cause leaf and twig death.



Fig. H4. **Sulfur deficiency**. General leaf chlorosis that looks similar to N deficiency.





Fig. H5. **Magnesium deficiency**. Chlorosis begins at the leaf margins and moves inward as the severity increases, producing a "Christmas tree" effect.







Fig. H6. **Iron deficiency**. Mild to severe from top to bottom. The major symptom is inter-veinal chlorosis. In severe cases, leaves are small and almost white, with twig die-back.







Fig. H7. **Zinc deficiency**. The major symptoms are inter-veinal chlorosis and smaller than normal leaves.

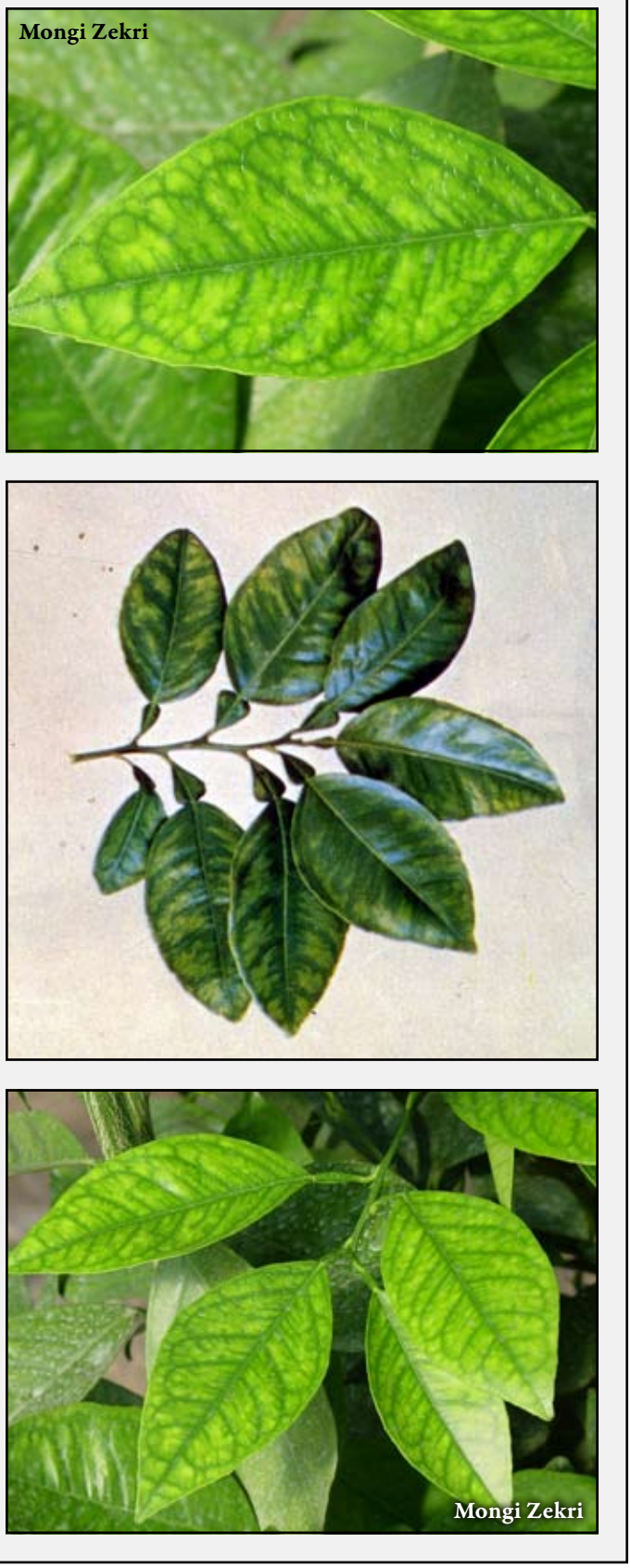


Fig. H8. **Manganese deficiency**. The main symptom is inter-veinal chlorosis of normal-size leaves.



Fig. H9. **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.

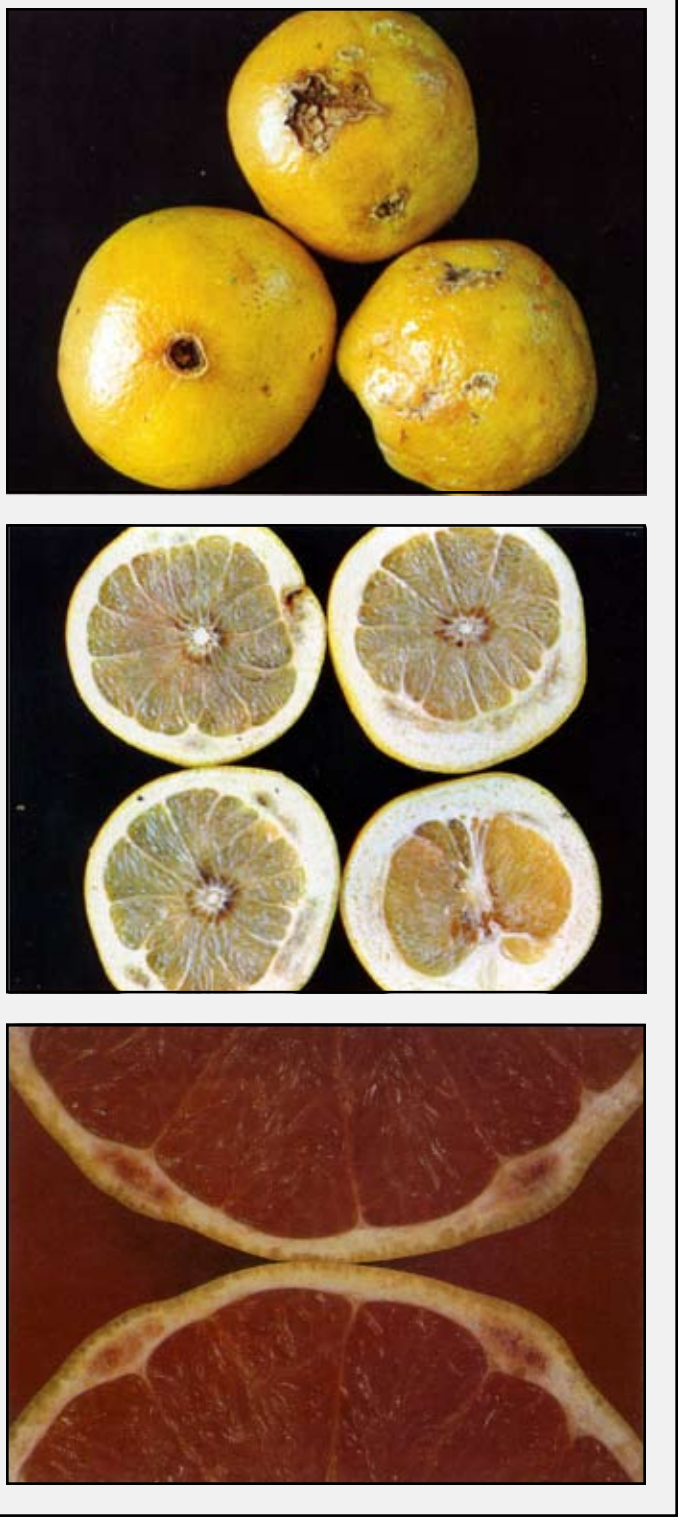


Fig. H10. **Boron deficiency**. Top: External symptoms on grapefruit. Center: Internal symptoms on grapefruit (thick peel, gum pockets in peel, gumming around core). Bottom: Close-up of gum pockets in peel.

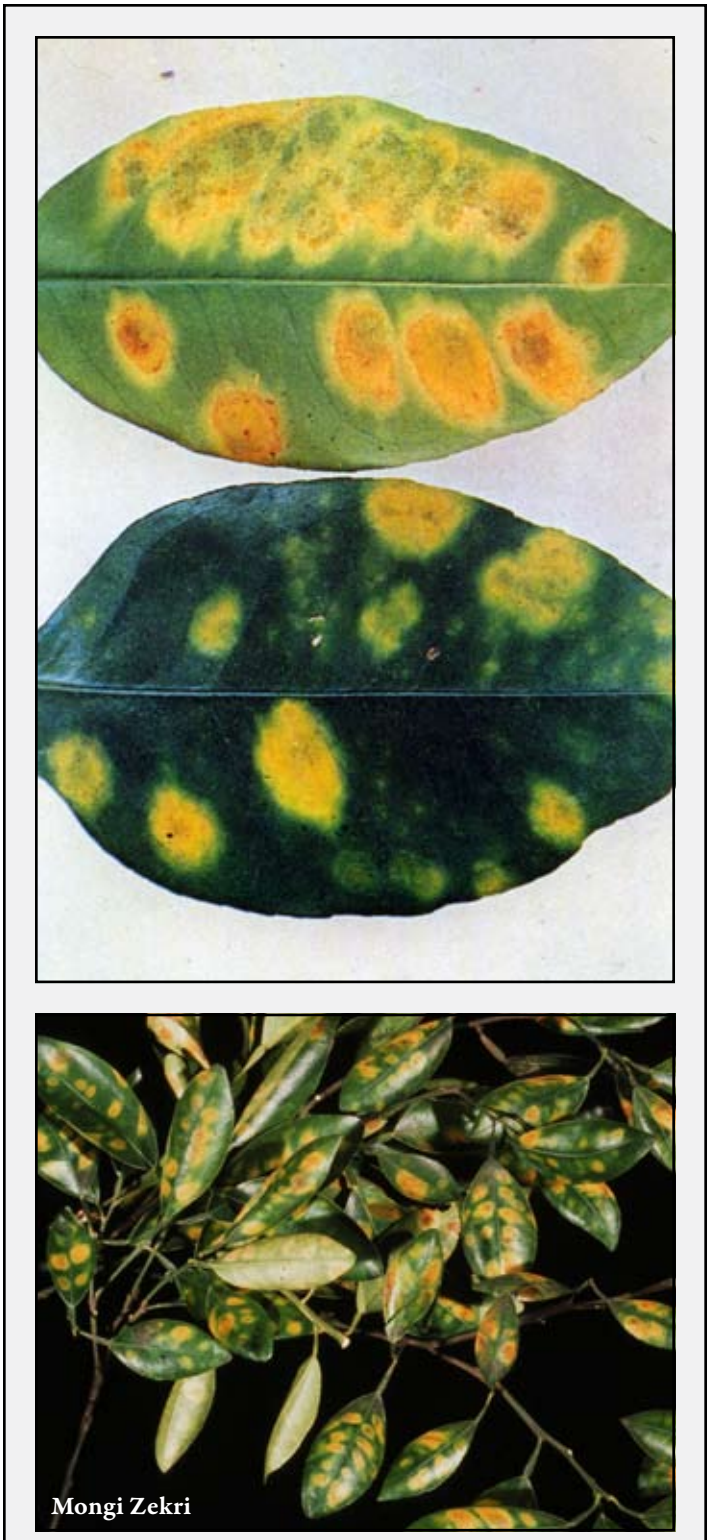


Fig. H11. **Molybdenum deficiency**. The main symptom is large yellow spots.







Fig. H12. **Salt damage**. Top: Burn on leaf edges compared with normal leaf at right. Center: Salinity-induced chlorosis. Bottom: Severe leaf burn in the field.







Fig. H13. **Biuret toxicity** (top and center). **Urea spray burn** (bottom).



Fig. H14. 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 mid-vein. (Contrast with nutritional deficiencies that usually exhibit a symmetrical pattern in relation to the midrib.)

SL 253

Nutrition of Florida Citrus Trees



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