# Citrus Nutrition Day

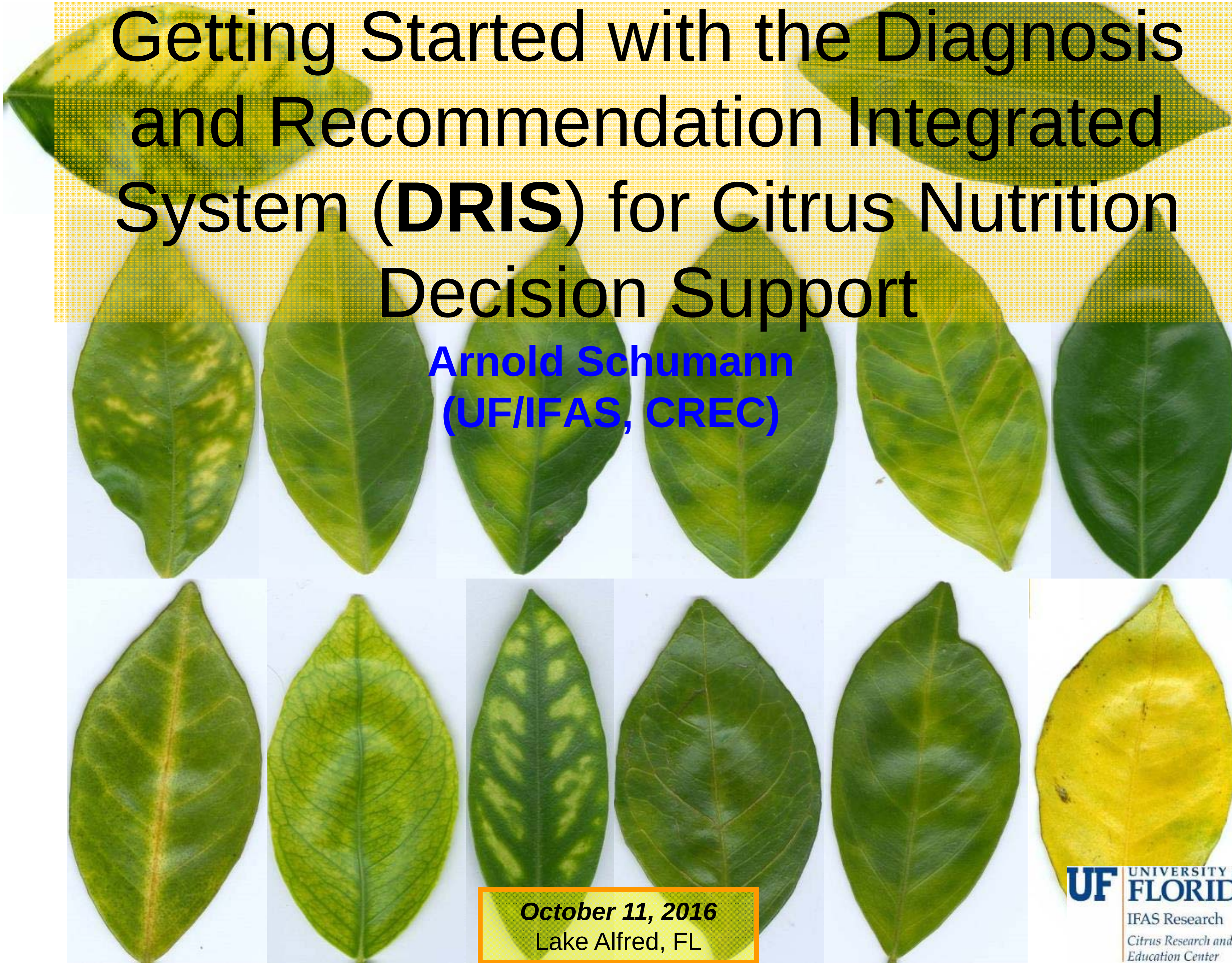
## Tuesday, October 11, 2016

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

| | |
|---|---|
| 9:00 am | Check-in begins |
| 9:45 am | Welcome and Introductions, Michael Rogers, UF/IFAS CREC |
| 10:00 am | Getting Started with the Diagnosis and Recommendation Integrated System (DRIS) for Citrus Nutrition Decision Support, Arnold Schumann, UF/IFAS CREC |
| 10:20 am | Managing Nutrient Accumulation and Uptake Using Advanced Citrus Production Systems, Davie Kadyampakeni, UF/IFAS CREC |
| 11:00 am | Refreshment Break and visit with exhibitors |
| 11:20 am | Clues Emerging Regarding the Relationship of Nutrition and Root Health in HLB-infected trees, Jude Grosser, UF/IFAS CREC |
| 11:40 am | Foliar Fertilization for Grapefruit Production in the Indian River Region, Alan Wright, UF/IFAS IRREC |
| 12:00 pm | Lunch and visit with exhibitors |
| 1:00 pm | A Grower's Perspective on UF/IFAS Grower Nutrition Trials, Vic Story, Story Citrus |
| 1:15 pm | A Grower's Perspective of Nutrition for Fresh Grapefruit, Tom Stopyra, The Packers of Indian River, Ltd. |
| 1:45 pm | Refreshment Break and visit with exhibitors |
| 2:00 pm | UF/IFAS Grower Nutrition Trials-Update and New Trials, Tripti Vashisth, UF/IFAS CREC |
| 2:25 pm | Question and Answer; Conclude |

# Getting Started with the Diagnosis and Recommendation Integrated System (**DRIS**) for Citrus Nutrition Decision Support

**Arnold Schumann**
**(UF/IFAS, CREC)**



***October 11, 2016***
Lake Alfred, FL

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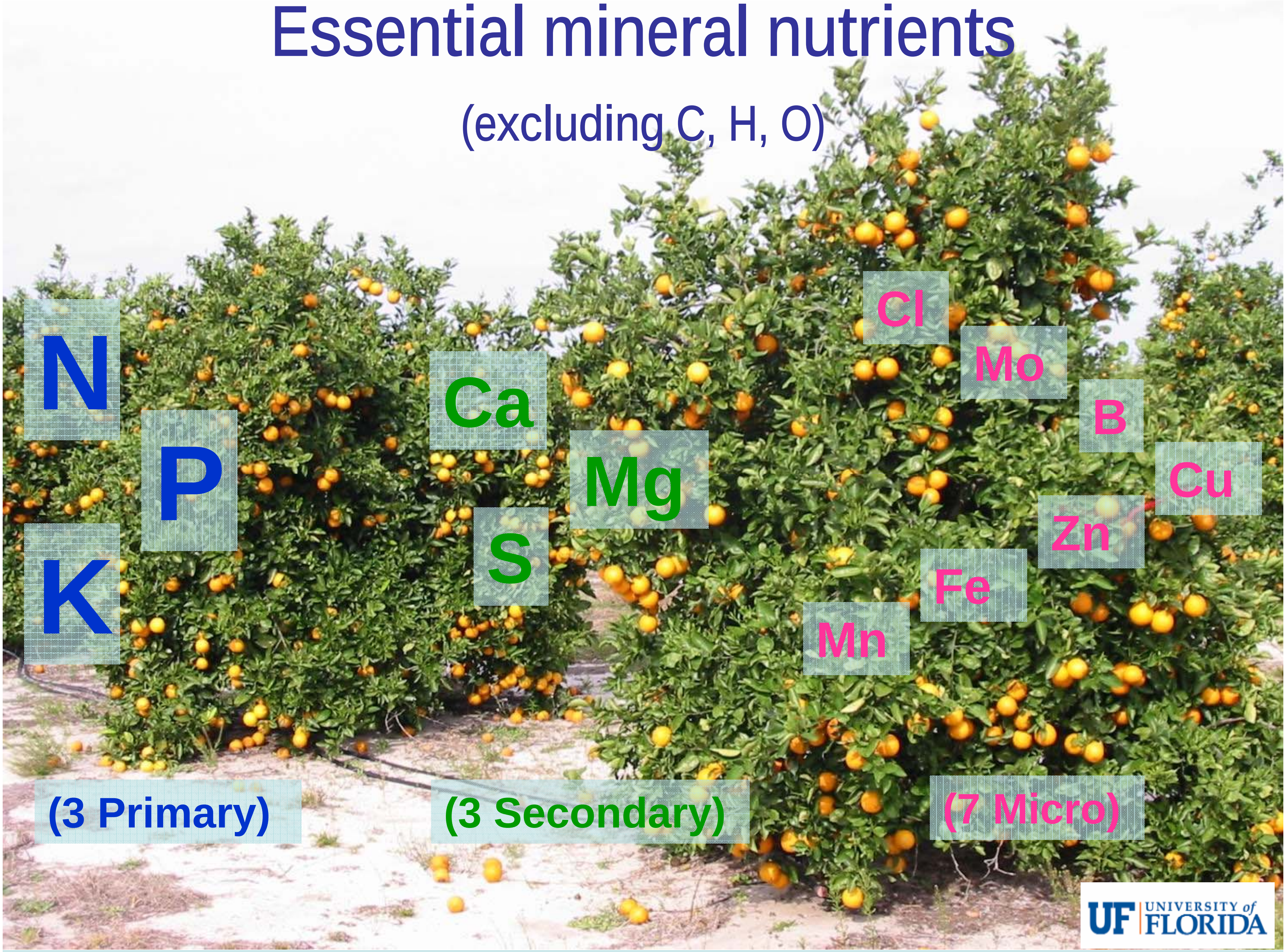
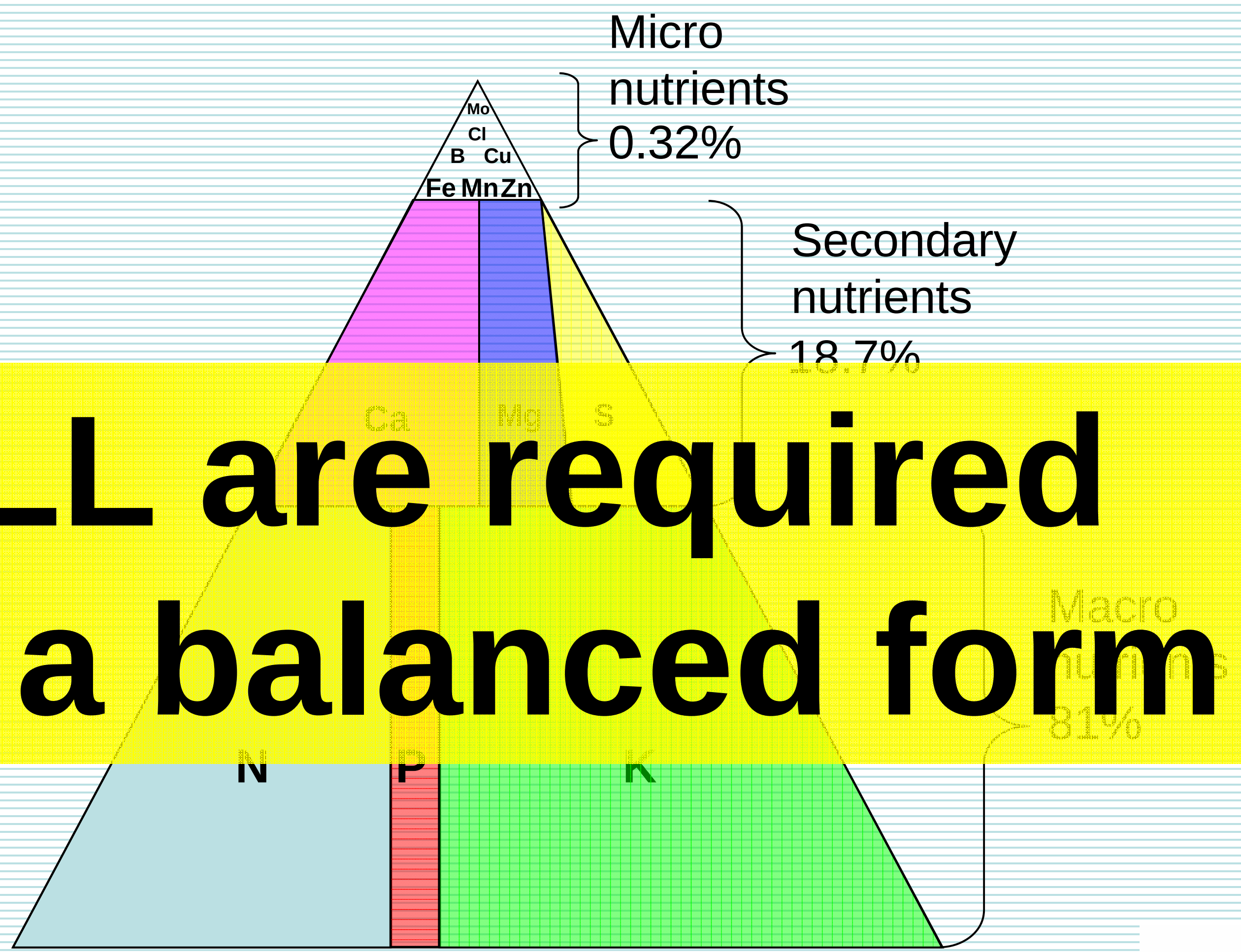
# Essential mineral nutrients

## (excluding C, H, O)



# Relative abundance of the different nutrients

**The essential nutrient pyramid for citrus**




# ALL are required - in a balanced form

*AWS, 2009*

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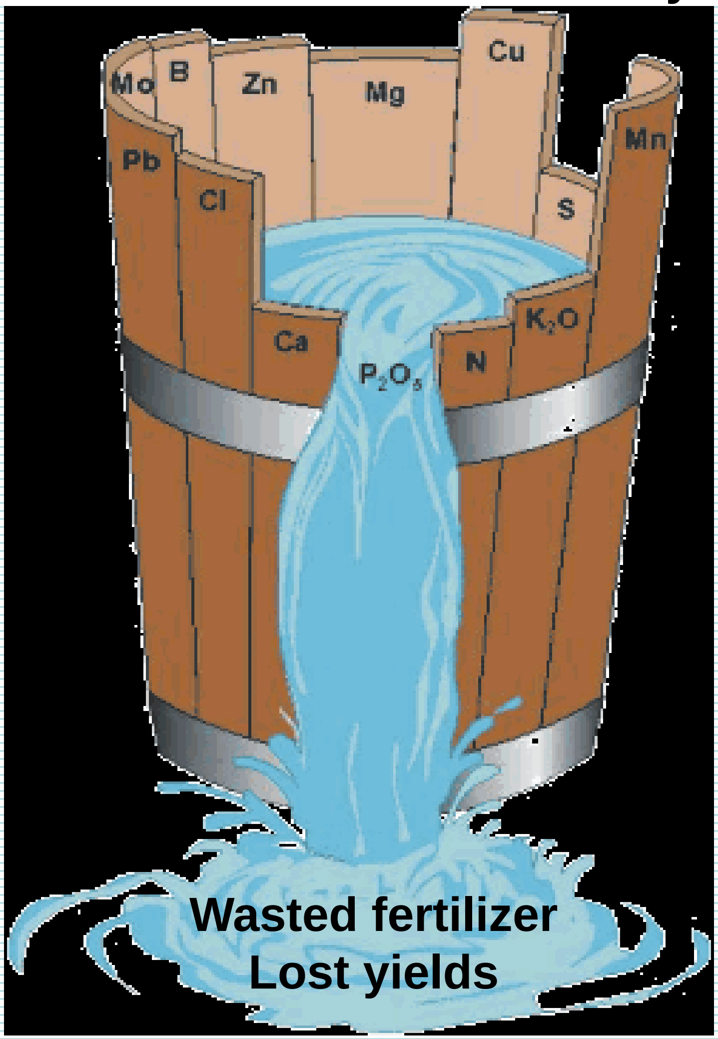
# BALANCED mineral nutrition is important: Liebig's Law of Minimum

**"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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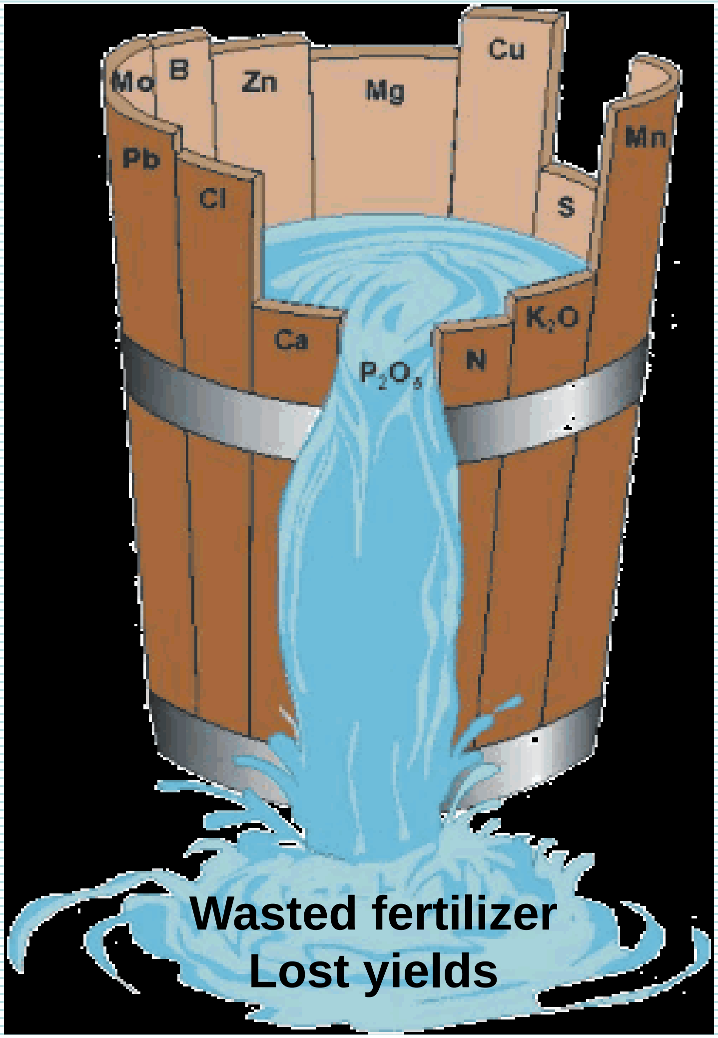
# Challenges of achieving nutrient balance




- Identifying and correcting ALL the limiting nutrient deficiencies is often like chasing a moving target
- Sometimes nutrient deficiencies cause growth disruptions which can trigger other nutrient excesses; e.g. Cu deficiency → excess N
- Nutrient imbalances are also linked to other growth disruptions caused by disease or accumulations of e.g. starch; dilution & concentration
- A leaf nutrient diagnosis method that identifies deficiencies based on a holistic analysis of all likely imbalances would be useful

Source: The Fertilizer Institute
WP graphic by Michelle Houlden

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# How can DRIS help?
## Diagnosis and Recommendation Integrated System

- **Leaf nutrient diagnoses are calculated with ratios of ALL the nutrients, using a high-yielding grove as a reference; e.g. 770 boxes/acre/yr, average of 4 yrs**

Citus.NCV - Notepad

File Edit Format View Help

DRIS norms for round oranges (Hamlin) from Fort Meade, Gapway; Mean yield over 4 years=770 boxes/ac.

RRRRRRRRRRRR

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.103 | 0.039 | 0.597 | 1.073 | 0.140 | 0.106 | 9.443 | 19.463 | 7.550 | 0.193 | 3.713 | 27.752 |
| 0.000 | 0.120 | 15.444 | 27.750 | 3.611 | 2.750 | 244.194 | 503.333 | 195.250 | 5.000 | 96.028 | 717.694 |
| 0.000 | 0.000 | 1.853 | 1.797 | 0.234 | 0.178 | 15.811 | 32.590 | 12.642 | 0.324 | 6.218 | 46.469 |
| 0.000 | 0.000 | 0.000 | 3.330 | 0.130 | 0.099 | 8.800 | 18.138 | 7.036 | 0.180 | 3.460 | 25.863 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.433 | 0.762 | 67.623 | 139.385 | 54.069 | 1.385 | 26.592 | 198.746 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.330 | 88.798 | 183.030 | 71.000 | 1.818 | 34.919 | 260.980 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 29.303 | 2.061 | 0.800 | 0.020 | 0.393 | 2.939 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 60.400 | 0.388 | 0.010 | 0.191 | 1.426 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 23.430 | 0.026 | 0.492 | 3.676 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.600 | 19.206 | 143.539 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 11.523 | 7.474 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 86.123 |
| 1.132 | 7.712 | 3.334 | 11.556 | 0.574 | 12.079 | 8.573 | 5.508 | 9.184 | 17.787 | 11.552 | 10.925 |
| 0.000 | 8.333 | 9.002 | 5.663 | 7.333 | 8.012 | 1.512 | 2.547 | 2.661 | 21.102 | 11.642 | 9.252 |
| 0.000 | 0.000 | 2.246 | 14.171 | 3.303 | 15.083 | 9.645 | 6.632 | 11.396 | 14.493 | 14.791 | 14.121 |
| 0.000 | 0.000 | 0.000 | 12.573 | 10.661 | 3.295 | 6.680 | 7.686 | 3.010 | 26.263 | 8.949 | 6.038 |
| 0.000 | 0.000 | 0.000 | 0.000 | 1.332 | 11.800 | 8.036 | 4.956 | 8.734 | 17.759 | 11.533 | 10.774 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 13.209 | 9.670 | 9.824 | 5.787 | 28.203 | 5.918 | 3.110 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 9.038 | 3.209 | 3.682 | 20.773 | 13.073 | 10.619 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 5.930 | 4.904 | 19.034 | 11.947 | 10.046 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 10.056 | 23.477 | 10.066 | 7.379 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 16.667 | 30.248 | 30.009 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 12.675 | 2.839 |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 12.081 |

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# How can DRIS help?

## Diagnosis and Recommendation Integrated System

- **By including all the nutrients in the calculation, an approximate ranking of nutrient deficiency severity is possible (same for nutrient excesses)**
- **e.g. Mg<Zn<N**
- **This approximates simultaneously repairing the dysfunctional staves of the leaking barrel yield analogy**

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# How can DRIS help diagnose HLB+ tree nutrition?

## Diagnosis and Recommendation Integrated System

Consider a dry leaf tissue sample, where DW="dry weight":

Ca% = Ca*100/DW, where DW = Ca+Mg+…+starch+cellulose…

Therefore if DW increases (starch ↑), Ca% "decreases"

- Even though total Ca content remains the same.

- If instead we use DRIS, which analyzes ratios of all nutrients,
- Then the DW factor cancels out:
- The ratio:

$$\frac{Ca\%}{Mg\%} \quad \text{becomes:} \quad \frac{Ca*100/DW}{Mg*100/DW}$$

and thus the confounding influence of DW (starch) is eliminated.

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# How can DRIS be implemented?

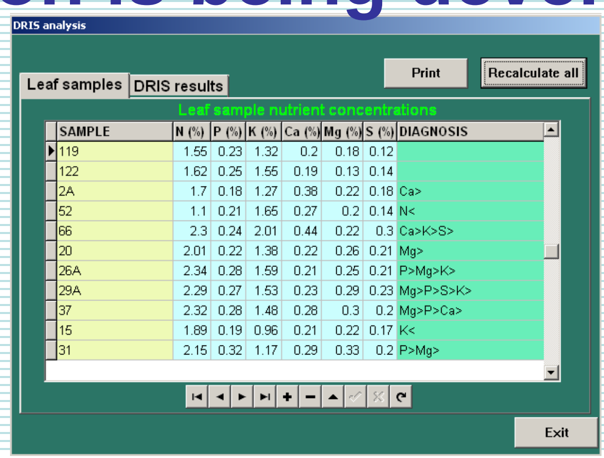
## Diagnosis and Recommendation Integrated System

- **Due to the intensive nature of the DRIS calculation, it is best implemented in a software code, with nested loops and IF statements:**

```
{============ Calculate nutrient ratios ==============}
for i:=1 to 12 do ratio[i,i]:=nutr[i]; {load nutrient concs as DM ratios}
for i:=1 to 11 do begin {11 rows in matrix}
for j:=i+1 to 12 do begin  {columns}
if nutr[i]>1e-11 then ratio[i,j]:=nutr[j]/nutr[i];
end; {j}
end; {i}
{====================================================}
```

- **A Windows DRIS application is being developed**

- **How to best implement nutrient diagnoses?**




| SAMPLE | N (%) | P (%) | K (%) | Ca (%) | Mg (%) | S (%) | DIAGNOSIS |
|---|---|---|---|---|---|---|---|
| 119 | 1.55 | 0.23 | 1.32 | 0.2 | 0.18 | 0.12 | |
| 122 | 1.62 | 0.25 | 1.55 | 0.19 | 0.13 | 0.14 | |
| 2A | 1.7 | 0.18 | 1.27 | 0.38 | 0.22 | 0.18 | Ca> |
| 52 | 1.1 | 0.21 | 1.65 | 0.27 | 0.2 | 0.14 | N< |
| 66 | 2.3 | 0.24 | 2.01 | 0.44 | 0.22 | 0.3 | Ca>K>S> |
| 20 | 2.01 | 0.22 | 1.38 | 0.22 | 0.26 | 0.21 | Mg> |
| 26A | 2.34 | 0.28 | 1.59 | 0.21 | 0.25 | 0.21 | P>Mg>K> |
| 29A | 2.29 | 0.27 | 1.53 | 0.23 | 0.29 | 0.23 | Mg>P>S>K> |
| 37 | 2.32 | 0.28 | 1.48 | 0.28 | 0.3 | 0.2 | Mg>P>Ca> |
| 15 | 1.89 | 0.19 | 0.96 | 0.21 | 0.22 | 0.17 | K< |
| 31 | 2.15 | 0.32 | 1.17 | 0.29 | 0.33 | 0.2 | P>Mg> |

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# Optimizing balanced nutrition

- A well-tuned, balanced crop nutrition program should deliver the highest, earliest fruit yields
- Hydroponically grown crops with frequent liquid fertigation receive near optimal nutrition 24/7, and the results show:

**Up to 30x field tomato yield**

Image credits: www.commercial-hydroponic-farming.com

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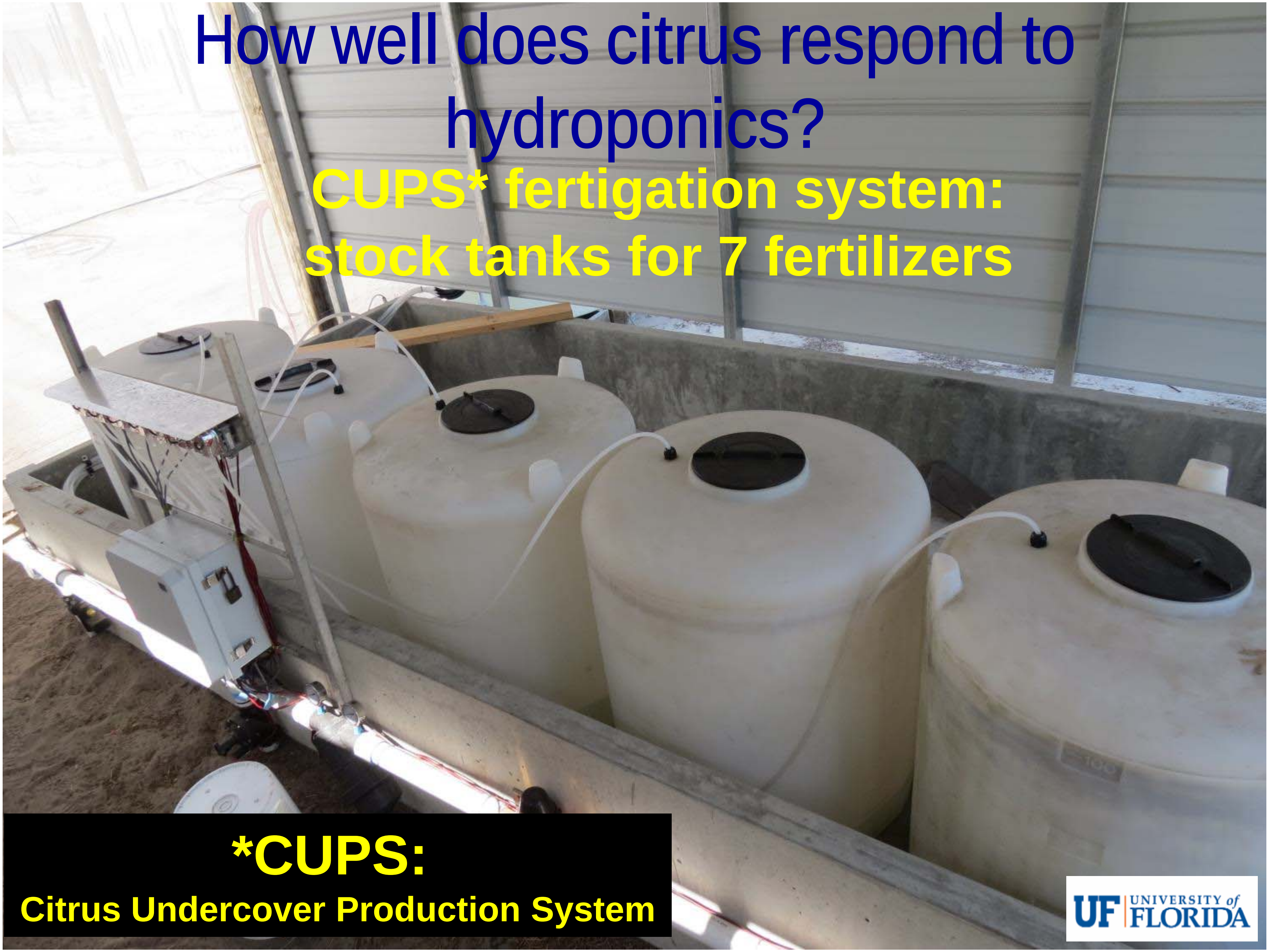
# How well does citrus respond to hydroponics?

**CUPS* fertigation system: stock tanks for 7 fertilizers**



***CUPS:**

**Citrus Undercover Production System**

# CUPS fertigation system: mixing tank

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CUPS
'Ray Ruby' grapefruit /Sour Orange
@15 months: 192 boxes/acre (0.22 box/tree)
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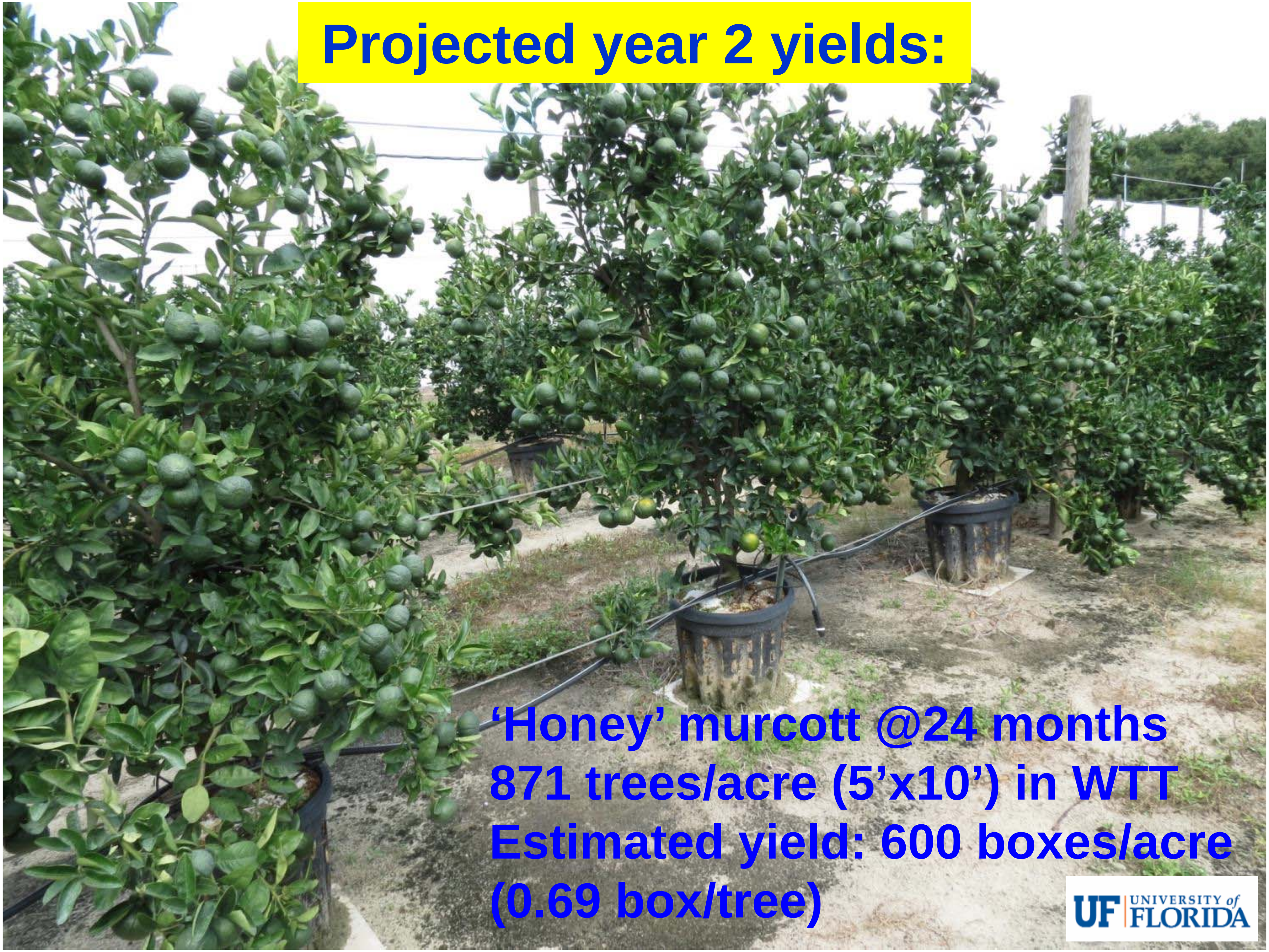
# Projected year 2 yields:



**'Honey' murcott @24 months**
**871 trees/acre (5'x10') in WTT**
**Estimated yield: 600 boxes/acre**
**(0.69 box/tree)**

# CUPS year 2 Murcott: 600 boxes/acre (0.69 box/tree)

# CUPS year 2 Murcott: 600 boxes/acre (0.69 box/tree)

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# CUPS year 2 Murcott: 600 boxes/acre (0.69 box/tree)

# Key points:

- Keeping stock fertilizer solutions in separate tanks allows custom blending of nutrients by computerized injection
- A complete (13 essential 'mineral' nutrients) hydroponic fertigation method is recommended
- Monthly leaf analysis permits frequent 'course corrections' to the nutrient program
- Foliar nutrient sprays are nearly obsolete in a properly managed hydroponic system
- Nutrient use efficiency is high, and less fertilizer is needed for hydroponic crops per unit of yield

# Summary

- Maintaining balanced nutrition is one of the more difficult challenges facing crop production
- Disease and pest pressures can exacerbate nutrient imbalances
- DRIS may assist to unravel multiple deficiencies
- Some nutrient deficiencies in HLB trees are real; others are induced by changes in dry weight (starch).
- Hydroponic crop production may be the pinnacle of balanced crop nutrition possible with current technologies

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# Acknowledgements

USDA-SCRI

Florida Department of Agriculture and Consumer Services

CREF
Citrus Research and Education Foundation, Inc.

CRDF
Citrus Research and Development Foundation, Inc.

Email schumaw@ufl.edu for more information

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# MANAGING NUTRIENT ACCUMULATION AND UPTAKE USING ADVANCED CITRUS PRODUCTION SYSTEMS

Davie Kadyampakeni
CREC, UF/IFAS, Lake Alfred

# Outline

- Overview
- Biomass accumulation studies
- Nutrient accumulation studies
- BMP considerations for water and nutrient management
- Take home message

# Overview

- Florida citrus production ranked #1 in the US
- FL citrus valued at $1.29 billion per year
- Citrus production ~ 480,121acres (USDA, 2016)
- Nutrient management critical for successful & profitable production due to sandy soils
- Good irrigation management is crucial for retaining the nutrients in the soil

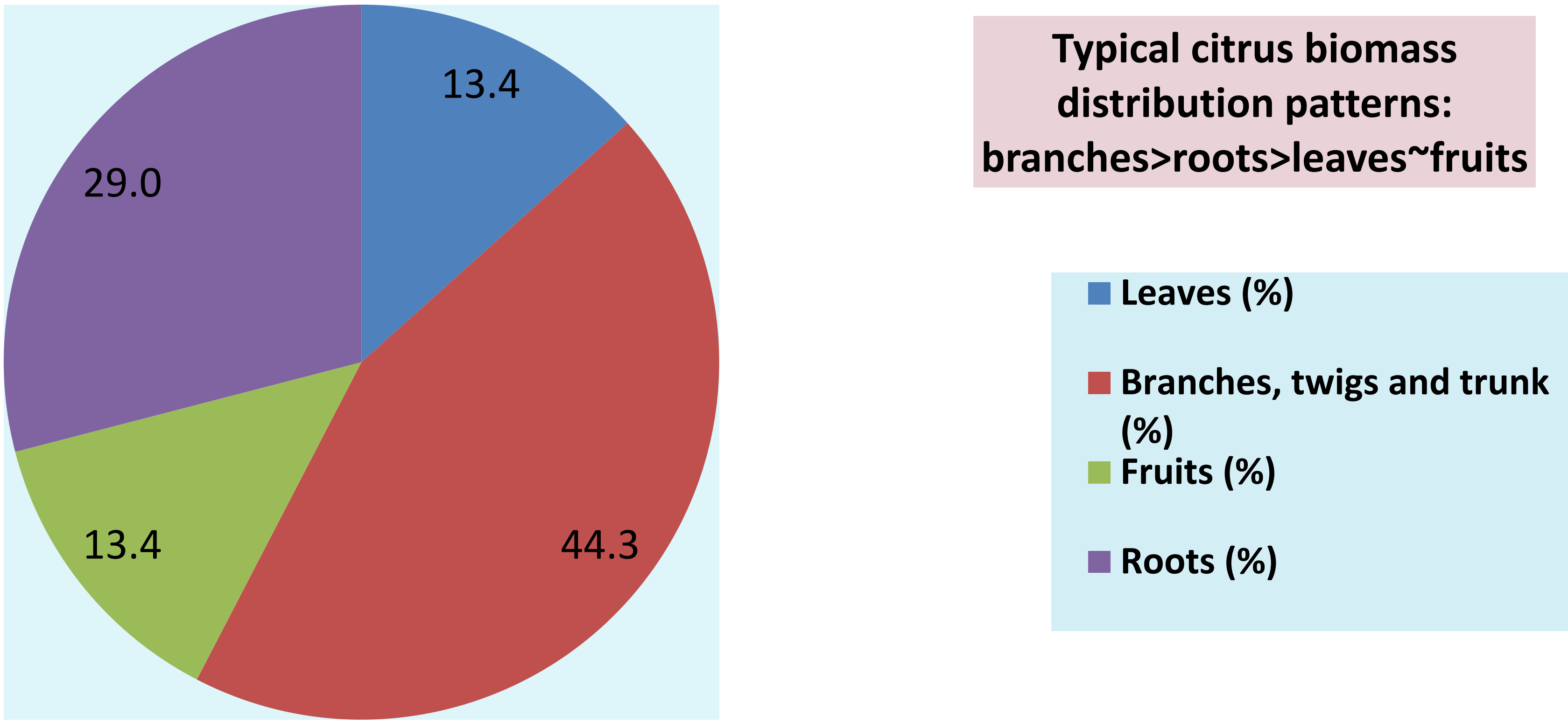
# Overview (2)

- Advanced citrus production system (ACPS) uses high density plantings coupled with intensive fertigation practices for improved tree nutrition and yield.
- Merits of ACPS include rapid tree growth & high yield within the first 5 yrs of establishment.
- ACPS tested using the open hydroponic system (OHS) with drip and microsprinklers

# Biomass accumulation

Destructive tree sampling for nutrient accumulation and biomass analyses

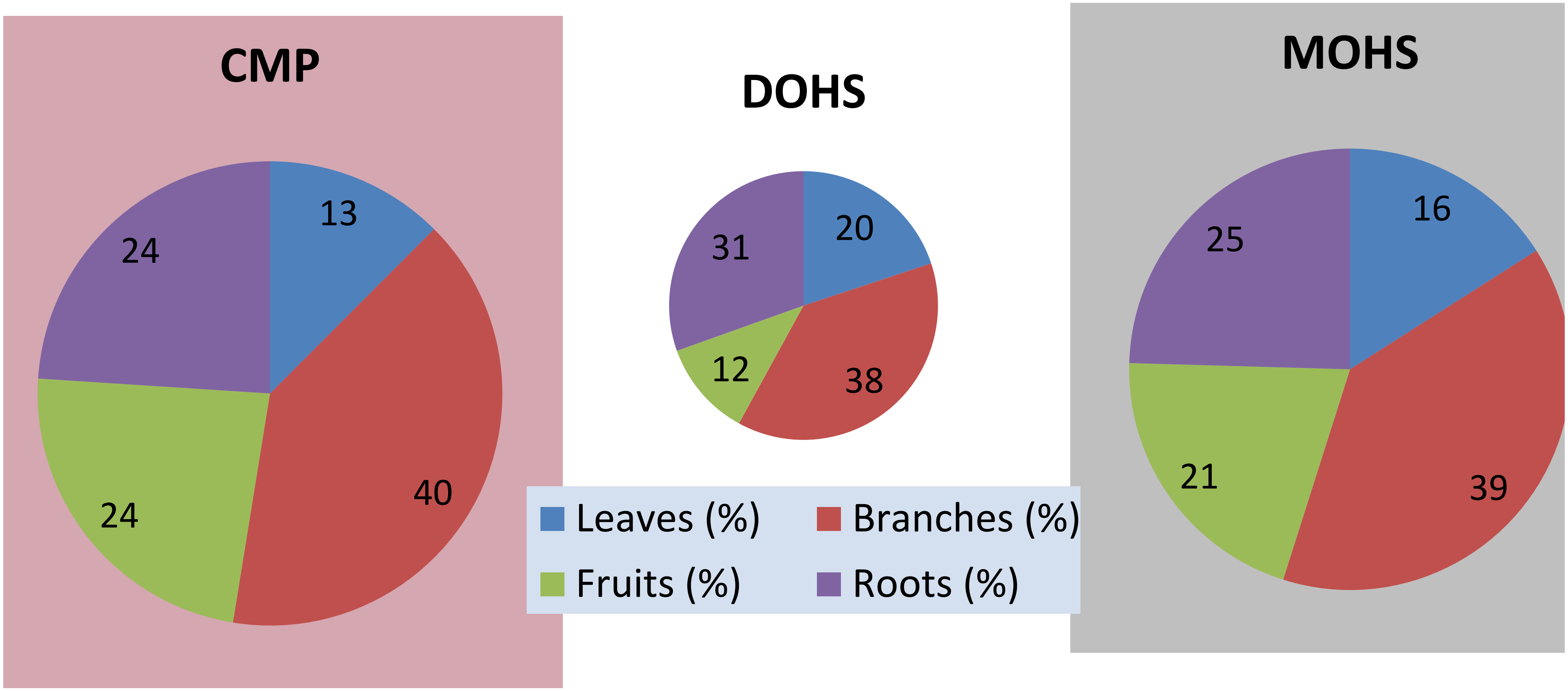
# Biomass accumulation (2)




**Typical citrus biomass distribution patterns: branches>roots>leaves~fruits**

Barnette et al., 1931; Mattos et al. 2003a,b; Morgan et al., 2006; Quinones et al. 2003a,b, 2005; Feigenbaum et al., 1987; Cameron and Appleman, 1935; 1945

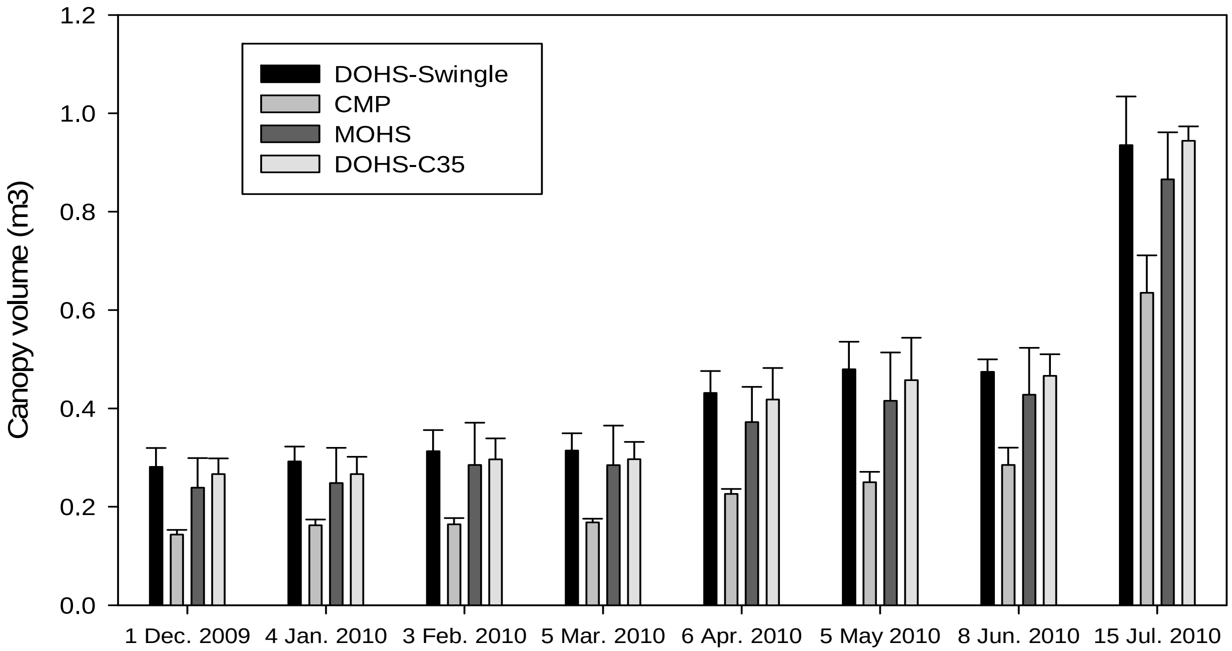
# Biomass accumulation with ACPS (3)




DOHS-Drip open hydroponic system; MOHS-Microsprinkler open hydroponic system; CMP-conventional microsprinkler practice

Kadyampakeni et al. 2016. Journal of Plant Nutrition, 39:589-599

# Biomass accumulation: Canopy development

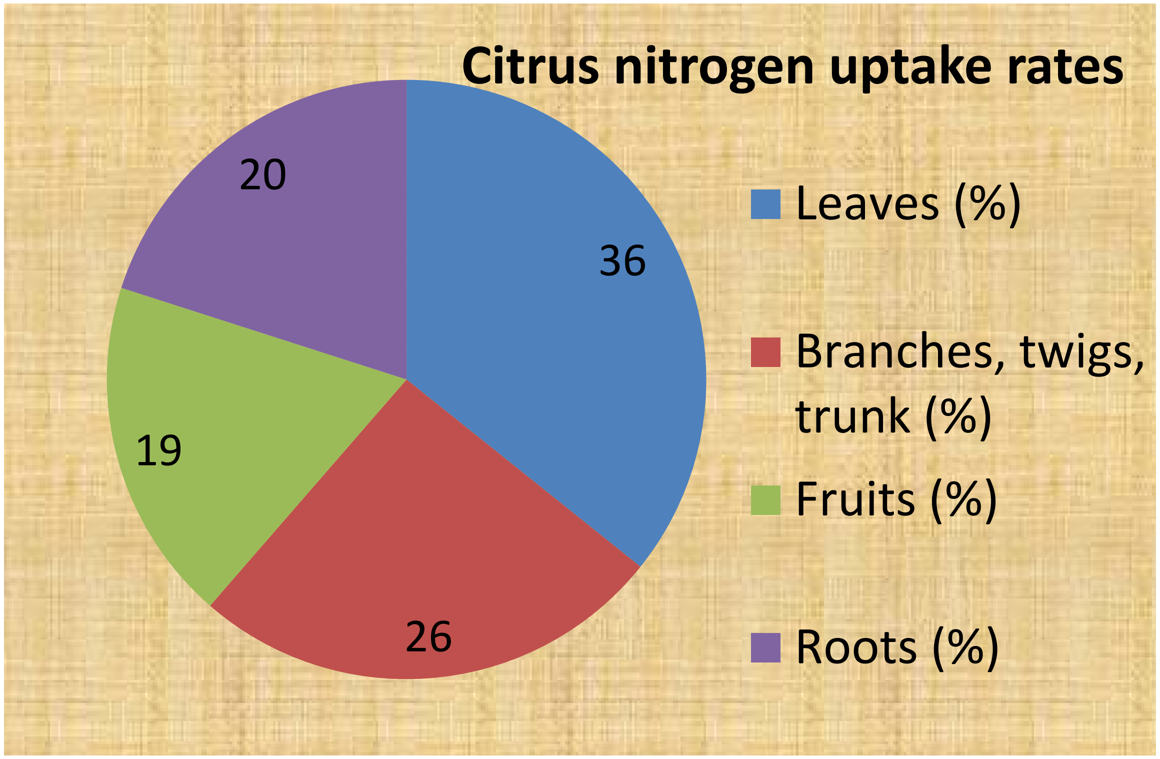



Canopy volumes: DOHS-Swingle>DOHS-C35>MOHS>CMP

DOHS-Drip open hydroponic system
MOHS-Microsprinkler open hydroponic system
CMP-conventional microsprinkler practice

Kadyampakeni et al. 2016. Journal of Plant Nutrition, 39:589-599

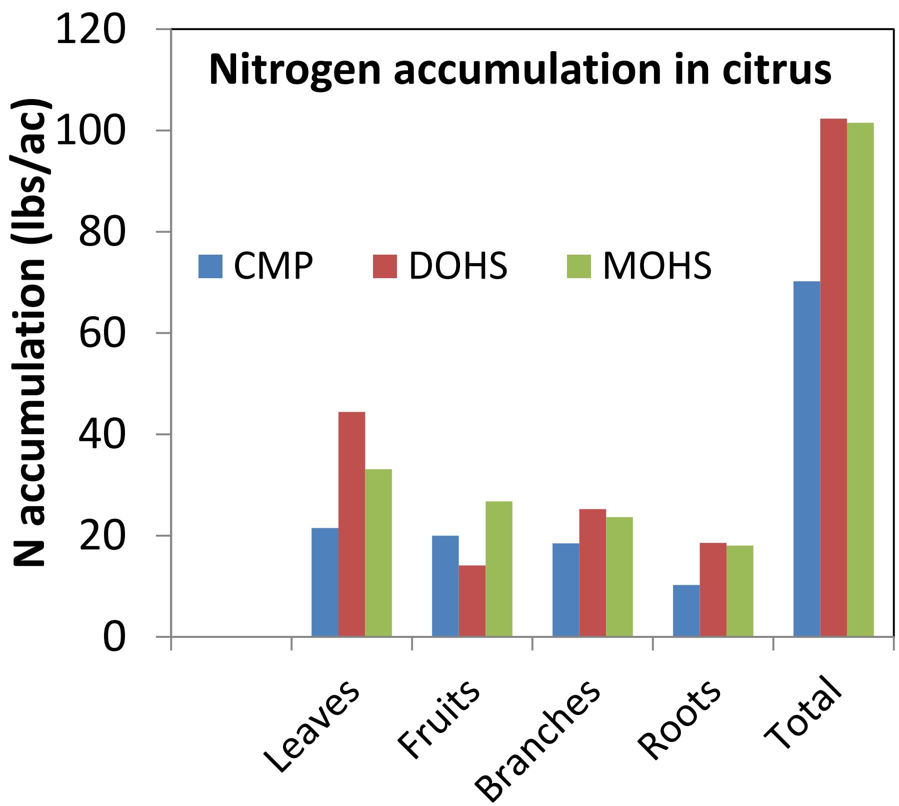
# Nitrogen accumulation in citrus




N concentration follows the pattern: leaves>branches>roots> fruits

Cameron and Appleman (1935); Cameron and Compton (1945); Feigenbaum et al. (1987); Quiñones et al. (2005); Legaz et al. (1982); Legaz et al. (1995) Quiñones et al. (2003)

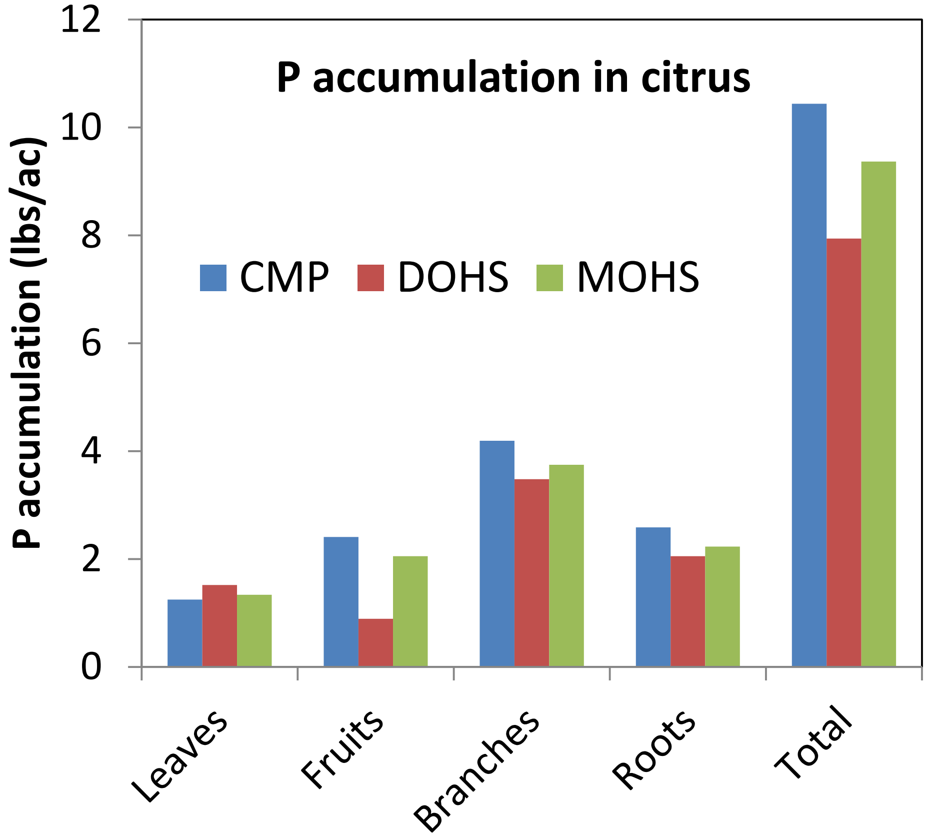
# Nutrient accumulation (N)




- Greater N accumulation with DOHS and MOHS
- More N in leaves than other plant parts
- Comparable N distribution in fruits, branches and roots

DOHS-Drip open hydroponic system; MOHS-Microsprinkler open hydroponic system; CMP-Conventional microsprinkler practice

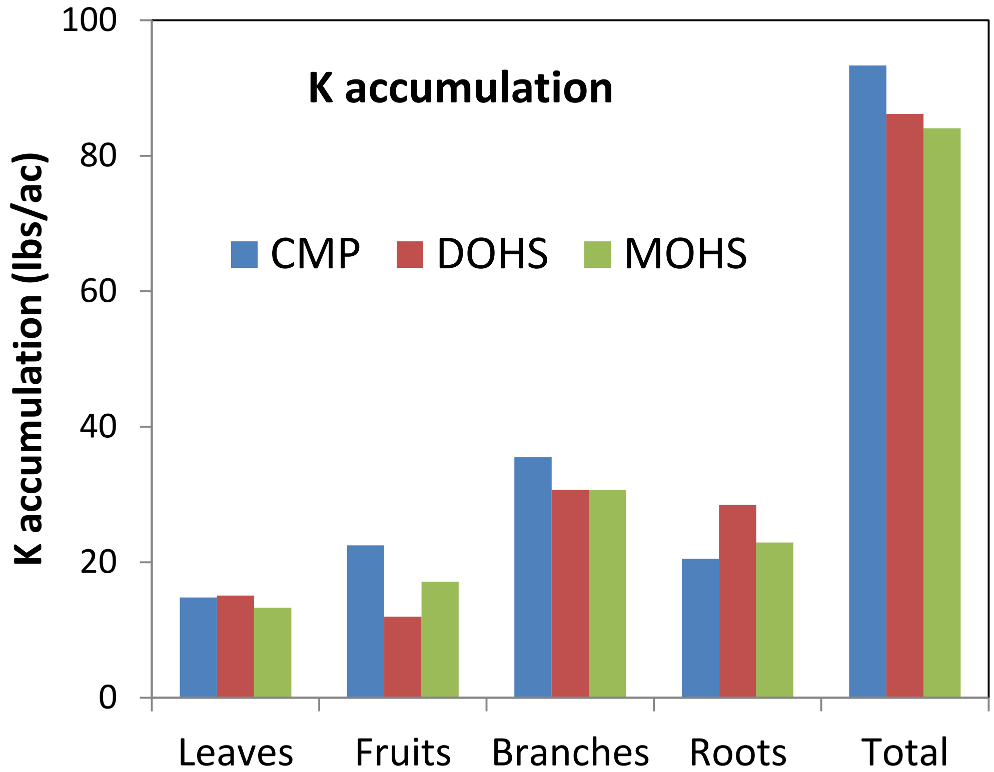
# Nutrient accumulation (P)




- Higher P accumulation in CMP and MOHS than DOHS
- Greatest P accumulation in branches, twigs and trunk across all methods

DOHS-Drip open hydroponic system; MOHS-Microsprinkler open hydroponic system; CMP-conventional microsprinkler practice

# Nutrient accumulation (K)




- Greatest K accumulation in branches, twigs and trunk than other parts
- K accumulation in CMP>DOHS>MOHS

DOHS-Drip open hydroponic system; MOHS-Microsprinkler open hydroponic system; CMP-conventional microsprinkler practice

# BMP considerations for nutrient and water management

- **Use of UF/IFAS recommendations:**

Nitrogen rate & timing for the growth of young non-bearing trees depending on soil type, fertilizer source and placement, crop load, citrus variety, tree age and irrigation method

- **Use of soil analyses information for fertilizer application:**

Growers can make informed decisions about the fertilization requirements of citrus trees.

# BMP considerations for water and nutrient management (2)

- **Use of tissue analyses for fertilizer application decisions:**

This helps in assessing nutrition status of trees for macronutrients (e.g. N and K) and micronutrients (e.g. Cu, Mn, Zn, Fe, B)

- **Training of fertilizer applicators:**

Adequate training of the field operators in the handling, loading and operating of fertilizer spreaders and accurate calibration of equipment.

# BMP considerations for water and nutrient management (3)

- **Fertilizer placement near or over the root zone:**

Accurate placement of fertilizer facilitates uptake and reduces nutrient losses through runoff and leaching.

- **Avoiding fertilization during high water table or flooded conditions:**

Applying nutrients during wet conditions leads to leaching and lateral flow of nutrients, thus increasing costs of production and posing environmental concerns to surface and groundwater.

# BMP considerations for water and nutrient management (4)

- **Use of CRF for mature trees:**

CRF, @ 90lbs/ac found to be effective with one time application

- **Use of organic amendments**:

Adding organic amendments to the soil facilitates slow release of nutrients and improves water and nutrient retention.

- **Avoiding fertilizer application between mid-June and mid-September**:

Applying fertilizer before or during intense rainfall is not advisable on highly erodible soils.

# BMP considerations for water and nutrient management (5)

- **Split fertilizer applications:**

Split fertilizer applications >4 times per year can reduce leaching losses particularly for N and K during excessive rainfall events.

- **Use of fertigation practices:**

Helps in precise control of nutrient placement in concert with irrigation for optimal water and nutrient uptake.

# BMP considerations for water and nutrient management (6)

- **Soil moisture based irrigation scheduling:**

Use of TDR, tensiometers and other soil moisture measurement devices. This can reduce nutrient leaching beyond the root zone.

- **ET-based irrigation scheduling:**

Use of weather data to decide when and how much to irrigate. FAWN and other weather data help in using the soil water budget for irrigation.

# Take home message

- Good nutrient and water management through ACPS improve biomass accumulation and canopy development

- N accumulation greater with ACPS than grower practice

- BMPs critical for reducing nutrient loads, irrigation water volumes and production costs.


THANK YOU FOR THE ATTENTION!

# Clues Emerging Regarding the Relationship of Nutrition and Root Health in HLB-infected trees

**Jude Grosser**

UF UNIVERSITY of FLORIDA
IFAS
Citrus Research and Education Center

Gary Barthe, Jim Baldwin, Ahmad Omar, Tripti Vashisth,
Orie Lee, Frank Rogers, Ed English, Alton Green,
Jobie Sherrod, Jim Graham, Bryan Belcher, Matt Shook, Brian Patterson, Jim Chason, Ward Gunter, Jack Zorn, & Gary Anderson

Citrus Nutrition Day – CREC 2016

I tried ‘nutrition’ and it didn’t work!  WHY???

Foliar nutritional treatments only temporarily address nutrient deficiencies in the leaves; micro-nutrient deficiencies are much greater in the roots.

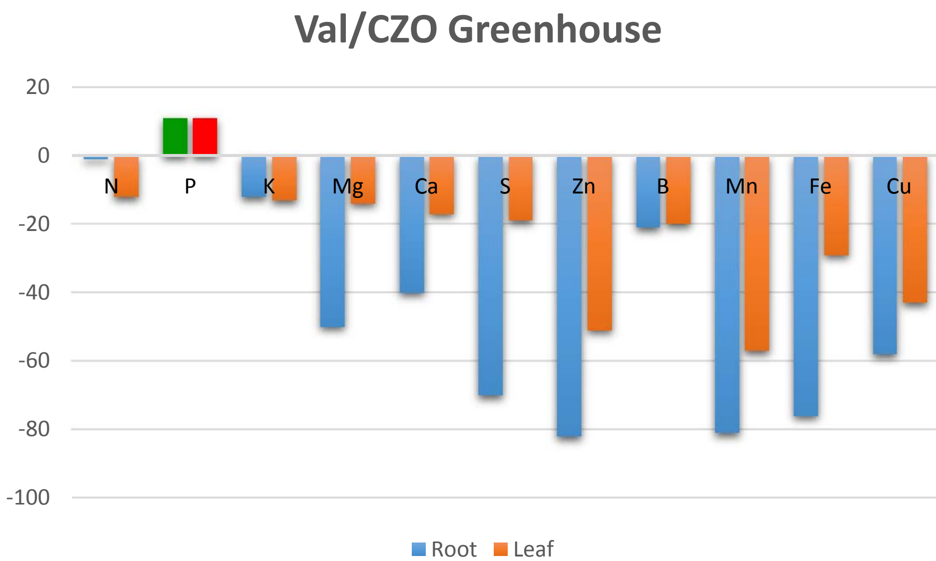
The complete ‘Maury Boyd’ program is more than foliar nutrition; Maury uses a modified ground program that includes compost and calcium nitrate.

The HLB problem with roots is much more than severe feeder root loss; remaining roots have altered micro-nutrient metabolism.

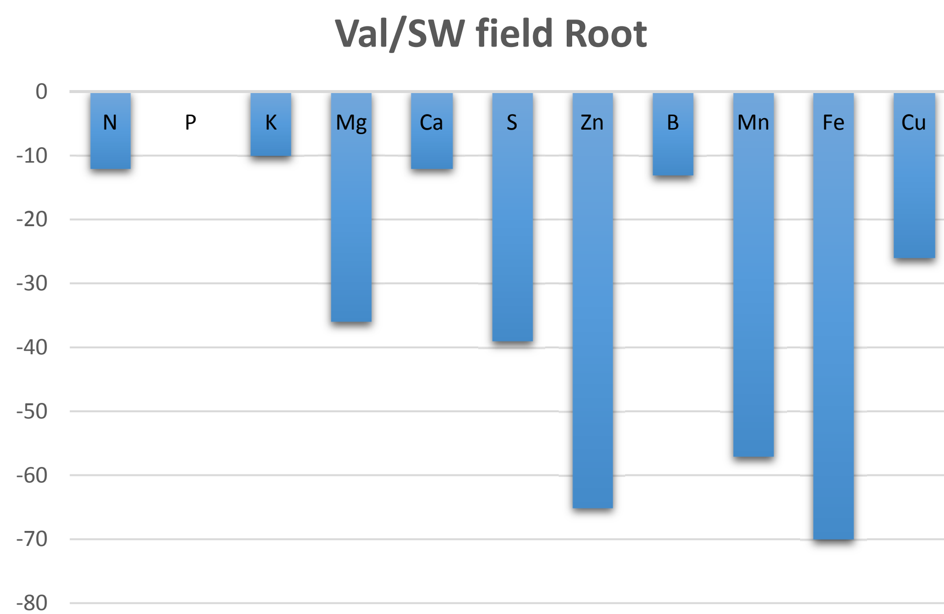
You can’t go from yellow-to-green overnight;
God made roots to mine and translocate nutrients to the scion.  Productivity requires a significant volume of functional feeder roots. Tree recovery requires the regrowth and stabilization of the entire feeder root
system – THIS TAKES TIME – AND PATIENCE FROM THE GROWER!

With improved ‘hybrid’ nutrition programs, don’t expect to see a significant difference in tree productivity for 12-18 months. Reversing tree ‘momentum’ is a slow process, but it can be done!

# HLB Impacts Root Micro-nutrient Metabolism




- Comparison of Healthy/Symptomatic trees (average of 10 trees) - % change compared to healthy GH trees
- Root deficiencies are much higher than leaf deficiencies



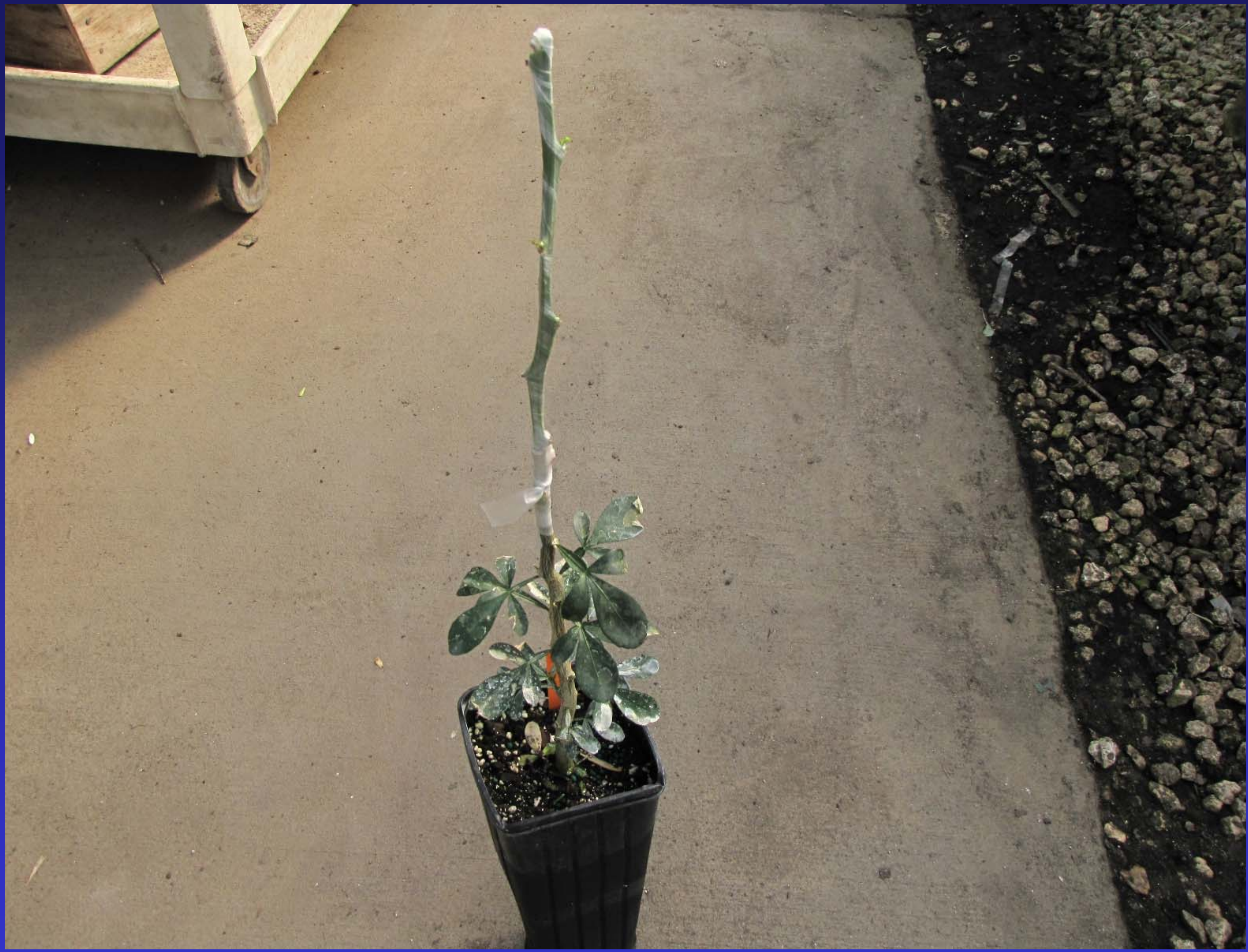

- Comparison of Healthy/Symptomatic trees - % change compared to healthy field trees
- Same patterns as greenhouse trees
- Soil pH and micro-nutrient content not responsible!
- Foliar sprays do not address this!

# 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

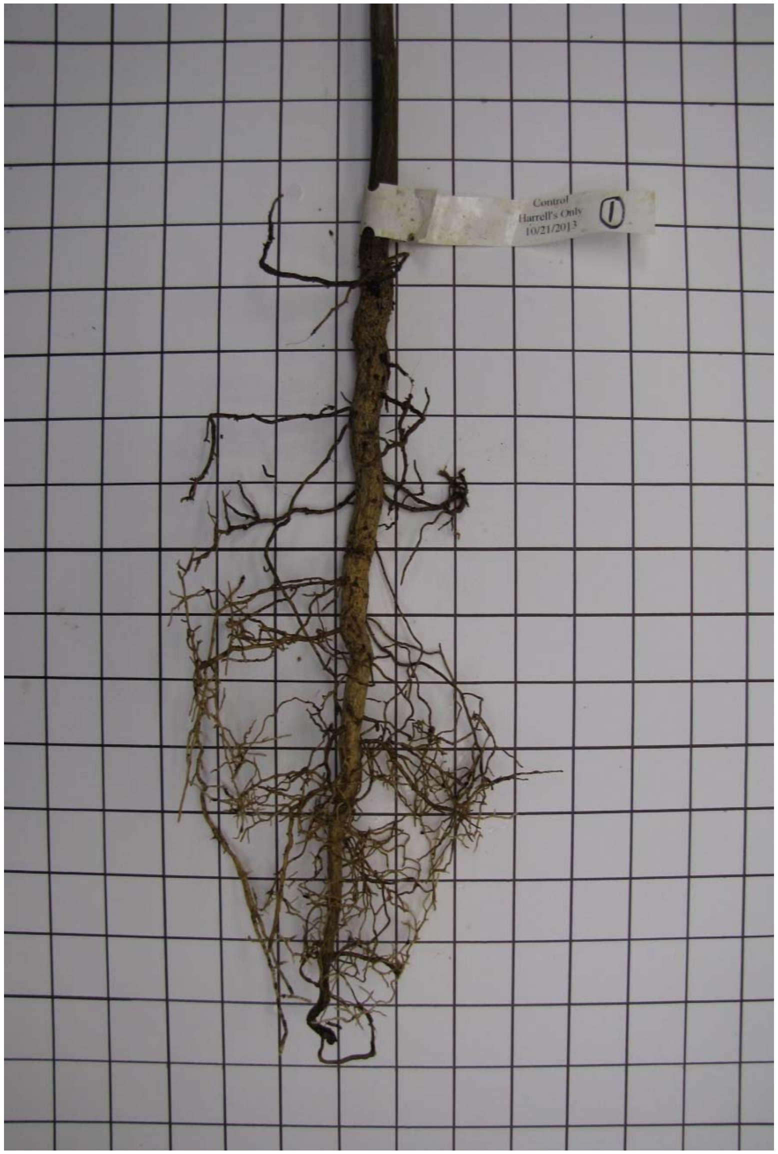
# Harrell's UF Mix + Tiger-Sul Manganese (3X)
# HLB-infected Valencia/Orange #15 rootstock

**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    Harrell's CRF+TigerSul Mn
HLB-infected greenhouse trees after one year; Valencia/UFR-3.




Harrell's CRF Control #1


Harrell's+TigerSul Mn #10

Regarding micronutrient nutrition – there may be more to it than just figuring out what an infected tree needs; consider possible interactions with the pathogen!

Liberibacter has not been successfully cultured – WHY?
Maybe there is something it doesn't like!

Is it possible that trees could be fed one or more micronutrients at levels that are toxic to the Liberibacter that are below the toxicity thresholds for the trees?  MAYBE!

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


Sweet orange OLL #7 topworked onto severely symptomatic HLB-infected Valencia on Swingle. Tree treated with Harrell's UF mix CRF + Mn and boron overdoses. Fruit set 2nd year.

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What are ‘HYBRID’ Nutrition Programs?

Any program that combines multiple sources of nutrient delivery with a goal of providing a <u>constant</u> supply of all required nutrients year round (including winter!) at an affordable cost. Can be tailored to address micronutrient deficiencies in HLB-impacted roots. Continued fine-tuning will improve results and lower costs!

Examples:

1. Fertigation supplemented with CRF (Controlled Release Fertilizer) during the rainy season (Tropicana program).

2. Traditional dry soluble N & K, monthly liquid micronutrient nitrates; separate liquid phosphoric acid (E. English program).

3. Traditional NPK supplemented with CRF: (Duda program) – 30/70% CRF/WS January; 50/50% CRF/WS April; 30/70% CRF/WS September.

## NO SILVER BULLET, BUT THESE PROGRAMS WORK!!!

**Hughes Post Office Block Yields – New 'Hybrid' nutrition program with micro-nutrient overdose treatments per row – results after one year**

12 year old Valencia trees on Swingle and C-35, 100% HLB

Overall yield for 2015 harvest: 1.25 boxes per tree – severe drop; 2016 harvest: 1.72 boxes per tree (increase of half-box/tree – 45 lbs. per tree) – normal drop

Change from traditional soluble dry program to 50-50 traditional/Basacote CRF (200 lbs. N per acre), 2 applications plus the per row treatments below.

Data per 2 rows:

| Rows | Treatment | # of trees | total boxes | Boxes/ tree |
|---|---|---|---|---|
| 1 & 5 | Arnolds TigerS mix# | 173 | 260 | 1.50 |
| 2 & 7 | 3x polycoated boron* | 172 | 296 | 1.72 |
| 3 & 6 | 3x TigerS manganese | 169 | 285 | 1.69 |
| 4 & 8 | 3x Tiger mn + 3x pc boron | 169 | 302 | 1.79 |
| 9 & 10 | Arnolds + 3x mn + 3x boron | 175 | 331 | 1.89 |

#Arnolds Mix: TigerSul Fe + TigerSul Mn + TigerSul Zn

*Florikan product

13-year old Valencia/Swingle, 100% HLB-infected; after 2 years on 50/50 CRF/dry soluble fertilizer program (2 applications/year);Trees have good crop, fruit sizing well – 2nd consecutive yield increase expected.

# Ed English (Alton Green) Program:

Citra-Guard Nitrate Soil Ammendment 7-0-0; monthly treatment. Material is being applied through airblast sprayer, bottom two nozzle ports open on each side. It is applied at 50 GPA.

7% Nitrate nitrogen
0.75% copper
4.60% iron
3.80% manganese
3.80% zinc
all nitrate derived

Phosmax (Phosphorous Acid ) @ 1 quart per acre. The goal is to get 60 lb of phosphorus per acre per year.

Dry and Foliar: 11-37-0

Revived 100% HLB-infected Valencia/Swingle trees in Alva, Ed English (Alton Green) monthly liquid nitrate program. Concept of ‘tree momentum’

Inside fruit on Ed English Valencia/Swingle trees; 7.4 lbs. solids!

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.

Low seeded cybrid Dancy on UFR-5. 2 trees on left treated with CRF + extra Mn and boron – good fruit. Two trees on right just standard CREC program – no edible fruit. NUTRITION!

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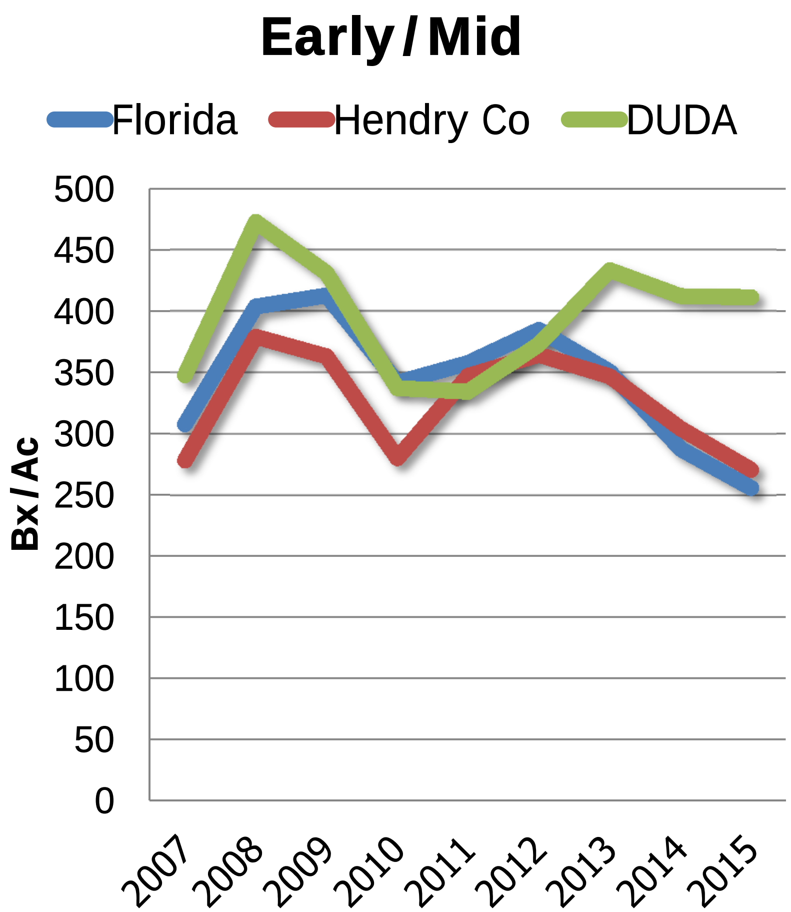
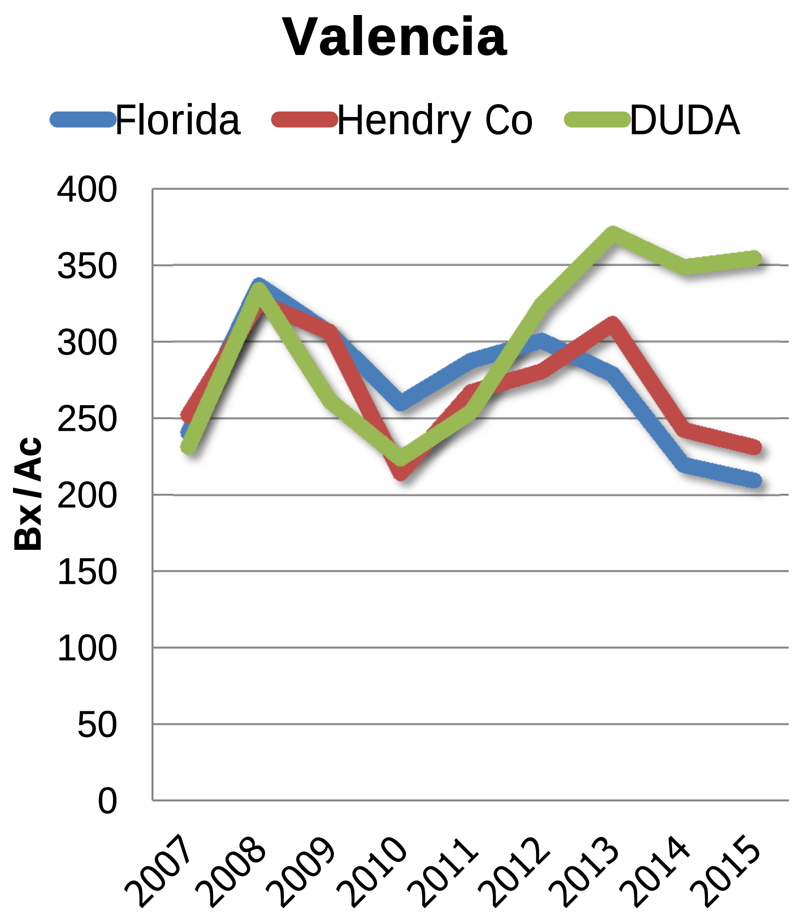
Valquarius/UFR-2: two years ago >70% fruit drop; after supplemental CRF + Mn and boron – last year <20% fruit drop; this year heavy crop!

# Duda 'Hybrid' Fertilization Program

| Month | Lbs N/Ac | Lbs K/Ac |
|---|---|---|
| Jan | 60 | 90 |
| | 30/70-CRF/WS (1-2 mo) | 30/70-CRF/WS |
| April | 60 | 80 |
| | 50/50-CRF/WS (1-2 mo, 2-3 mo, 3-4 mo, 4-5 mo) | 44/56-CRF/WS |
| Oct | 55 | 55 |
| | 30/70-CRF/WS (1-2 mo) | 30/70-CRF/WS |
| **Total** | **175** | **225** |

# Yield History



Bryan Belcher (Joe L. Davis Inc.), working with Jim Graham, has had good success reviving flatwoods groves by correcting the water pH/bicarbonate problem with acidification – However; until recently, less success with this on ridge groves – WHY?

# Addition of $MgSO_4$ (Epsom salts) to the fertigation program in ridge soil to emulate Mg supply in flatwoods

(Bryan Belcher, Davis Management; slide provided by Jim Graham)

- Acidification of high bicarbonate water releases Ca & Mg
- Inadequate supply in ridge soils due to low cation exchange of Ca and Mg
- Addition of 11% $MgSO_4$ at 5 gal/acre/month in 6 apps to supply ~40 lb Mg/acre (since March 2016)
- Tree response is increase in canopy density, darkening of leaves and absence of yellow shoots

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# CONCLUSIONS

- Micro-nutrient deficiencies in HLB-infected trees are greater in roots than in leaves; foliar treatments temporarily help leaves, but do not address this.
- Micro-nutrient metabolism in remaining roots is also compromised; a constant supply of nutrients year-round helps address this.
- Calcium, magnesium, manganese, zinc, iron, copper and boron are all impacted. We need to ‘re-write’ the book on recommended nutrient levels in the HLB world.

# CONCLUSIONS

- Enhanced ground nutrition featuring ‘hybrid’ programs that include CRF or monthly liquid applications can help restore and sustain production from HLB-infected trees – but it takes time!

- Supplemental CRF with micro-nutrient overdoses can reduce fruit drop, improve fruit quality and increase fresh pack-outs.

- Even with thermotherapy and anti-biotic applications, you still need to regrow the trees feeder root systems – get started now – what you learn will also help you with resets and new plantings!

# QUESTIONS???

- Can micro-nutrient overdoses (manganese and boron) reduce Liberibacter populations and restore vascular function? Research underway.

- Is there any benefit from having minor nutrients coated in CRF mixes? For trees without HLB, the answer is no; jury still out for HLB-infected trees. Research underway – promising results with young infected trees.

- Can optimized nutrition reduce the need for psyllid control and allow us to return to more affordable IPM programs that include psyllid control agents such as Tamarixia? MAYBE! – more research needed!

- Do different scion varieties, and different scion/rootstock combinations require different nutrient regimes? i.e. grapefruit is slower to respond – more research needed.

# NUTRITION CHALLENGE!

- Citrus nutrition programs for HLB-infected trees still require fine-tuning for optimal results at the most affordable cost.
- Our industry is blessed with a multitude of good fertilizer companies with outstanding reps – I challenge each company to design their best products and work with industry collaborators to have them thoroughly tested in commercial groves.
- CREC, IRREC and SWFREC all have new plant physiology/soils/horticulture faculty – I encourage you to engage these talented young researchers to determine optimal nutrient levels and the most economically viable delivery methods.

To HALL OF FAME CITRUS GROWER-RESEARCHER
And Outstanding Industry Collaborator Mr. Orie Lee

Funding: Mr. Orie Lee, Grants from the Citrus Research and Development Foundation (CRDF); the late Mr. Jim Hughes; and the Citrus Research and Education Foundation (CREF) for grove support.

Thanks to Florikan (Brian Patterson), Harrell's (Matt Shook, Dave Edison), Everris (Ward Gunter), Basacote/COMPO (Jim Chason), TigerSul (Jack Zorn), Growers Fertilizer (Gary Anderson) for assistance with CRF products.

Thanks also to: Gary Barthe, Ahmad Omar, Jim Baldwin, Joby Sherrod (Duda), Ed English, Alton Green, Jim Graham, Bryan Belcher (Joe L Davis), Allison Drown (Tropicana), Mauricio Rubio, JoLisa Thompson, Eric Ramjit, Kaidong Xie, Gary Test, Troy Gainey, Tripti Vashisth, Evan Johnson and Arnold Schumann.

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# Thanks!

UF-CREC Citrus Genetic Improvement Team
2016

# Foliar Fertilization for Grapefruit Production in the Indian River Region

Diego Ramirez, Jose Chaparro
Brian Boman, Barrett Gruber
Alan Wright, Silvia Marino

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- HLB-induced nutrient transport limitations
- Nutrient deficiencies in tree components
- Proper fertilization important
  - Rates
  - Timing
  - Sources
- Foliar application potentially shows promise

- Minimize stoppage of phloem by direct application of nutrients to leaves
  - Adjuvant selection important
  - Increase nutrient uptake efficiency
- Many questions about efficacy of foliar applications
  - Increase in leaf tissue nutrient concentrations observed
  - But yield effects?
- Wide variety of suggested foliar fertilization programs

# Objective

Evaluate different combinations of macro and micronutrients applied as a foliar fertilizers on citrus accompanied by ACP control to determine the response of the trees in terms of productivity

# Methods

- 2 commercial groves evaluated
- Varieties
  - Flame red grapefruit on Swingle
  - Ruby Red grapefruit on sour orange
- HLB infection rate 80-100%
- Dry fertilizer 4 times/year
- Foliar fertilizers applied 3-4 times/year

Treatments and fertilizers evaluated.

| Treatments | (DKP) Urea + DKP | (KN) Urea + KNO3 | (KP) Potassium Phosphite | (M) Micros | (Ca) CaNO3 |
|---|---|---|---|---|---|
| Control | | | | | |
| Ca | | | | | ✓ |
| KN + K | | ✓ | ✓ | | |
| DKP + K | ✓ | | ✓ | | |
| KN + M | | ✓ | | ✓ | |
| DKP + M | ✓ | | | ✓ | |
| KN+K+M | | ✓ | ✓ | ✓ | |
| DKP+K+M | ✓ | | ✓ | ✓ | |
| KN+K+M+Ca | | ✓ | ✓ | ✓ | ✓ |
| K + M | | | ✓ | ✓ | |

# Results

* No significant differences in canopy growth or density

* When micros are applied, the concentration of Mn and Zn increase significantly.

Fruit production, fruit drop, and fruit size for Ruby Red grapefruit.

| Treatment | Fruit per tree | Fruit drop (%) | % of fruit by fruit Size | | |
|---|---|---|---|---|---|
| | | | Large | Medium | Small |
| **Control** | **282** | **20.6** | **17 b** | **29** | **13** |
| KP+M | 339 | 14.8 | 24 ab | 32 | 12 |
| Ca | 326 | 18.2 | 17 b | 29 | 14 |
| KN+KP+M | 335 | 16.7 | 20 ab | 31 | 13 |
| KN+KP+M+Ca | 352 | 19.6 | 20 ab | 31 | 13 |
| DKP+KP+M | 384 | 13.2 | 25 a | 31 | 12 |
| KN+KP | 371 | 15.1 | 24 ab | 30 | 11 |
| DKP+KP | 367 | 11.8 | 20 ab | 33 | 14 |
| KN+M | 381 | 15.1 | 17 b | 34 | 15 |
| DKP+M | 350 | 12.7 | 17 b | 32 | 15 |

## Productivity and fruit quality variables for Ruby Red grapefruit

| Treatment | Boxes / tree | %+ | GPV | %+ | Juice % | Sugar / Acid ratio |
|---|---|---|---|---|---|---|
| Control | 3.2 | | $83 | | 54.6 | 8.5 |
| K + M | 4.3 | 36 | $120 | 44 | 54.4 | 8.6 |
| Ca | 3.6 | 13 | $92 | 10 | 56.5 | 8.3 |
| KN + K + M | 3.8 | 21 | $102 | 22 | 55.3 | 8.2 |
| KN + K + M + Ca | 3.9 | 23 | $104 | 25 | 55.2 | 8.4 |
| DKP + K + M | 4.8 | 51 | $134 | 60 | 56.1 | 8.5 |
| KN + K | 4.7 | 46 | $130 | 56 | 55.5 | 8.7 |
| DKP + K | 4.6 | 45 | $123 | 47 | 54.7 | 8.1 |
| KN + M | 4.8 | 39 | $122 | 47 | 54.8 | 8 |
| DKP + M | 4 | 25 | $100 | 21 | 54.5 | 8.4 |

# CONCLUSIONS

- Foliar fertilization increased leaf tissue nutrient concentrations
  - Most remarkably for Zn and Mn
- Yields increased for some treatments
- Fruit size increased for some foliar fertilizer treatments
- Positive economic benefits for foliar fertilization programs
  - Further evaluation necessary

# ACKNOWLEDGMENT

CRDF Citrus Research and Development Foundation, Inc.

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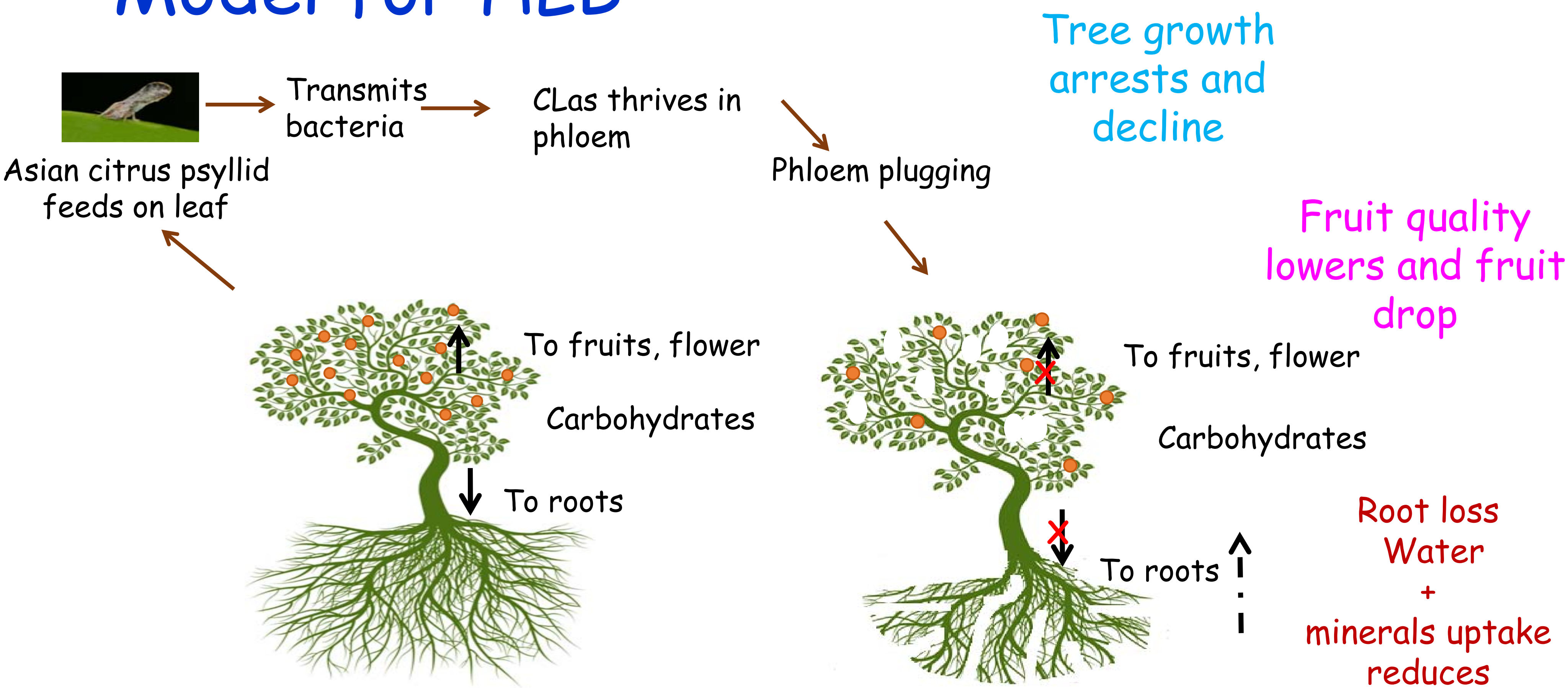
Jerry Britt
Judy Gersony
Randy Burton
et al.

# THANK YOU

# Nutrient uptake in HLB-affected and Healthy citrus plants-preliminary study

Tripti Vashisth, Changpin Chun, Arnold Schumann

# Model for HLB

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# Mineral Nutrition and HLB

- HLB-affected sweet orange leaves showed lower concentrations of K, Ca, Mg, Cu, Fe, Zn, Mn, and B as compared to healthy leaves
- HLB-affected trees require higher rates of some essential mineral nutrients in order to circumvent any development of nutrient deficiencies
- Up to 3X the recommended rate of foliar application of Zn and Mn can be beneficial

  Number of research trials are underway to evaluate required rate of mineral nutrients for HLB-affected trees

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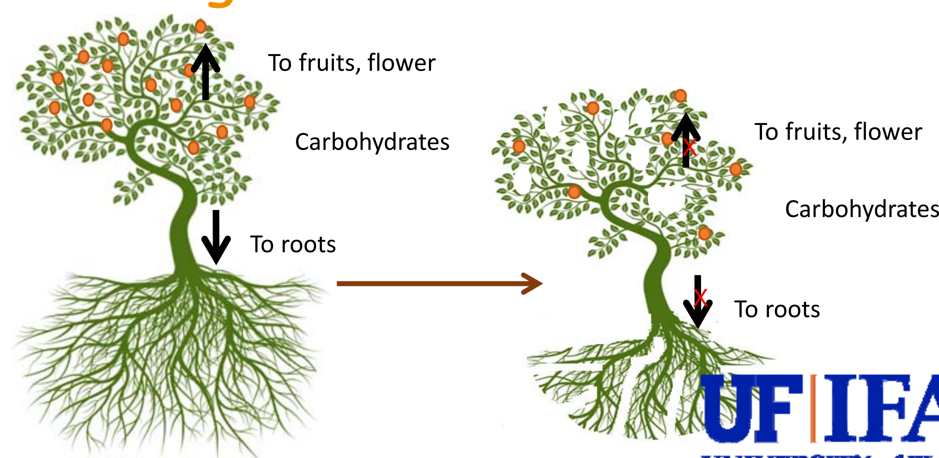
# Mineral Nutrition and HLB

- HLB-affected trees have smaller and weaker root systems, therefore, it is suggested to apply fertilizer in frequent small doses as this maintains a constant supply of nutrients and reduces potential nutrient leaching

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# Objective

1. To investigate the <u>quantitative</u> difference in nutrient uptake in HLB-affected plants versus healthy
2. To investigate the <u>qualitative</u> difference in nutrient uptake in HLB-affected plants versus healthy

Preliminary Study

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# Materials and Methods

- Scion-Midsweet (Healthy or HLB) on rootstock- Kuharske
- 9 month old greenhouse plants in citrus potting mix
- Both type of plants are not fertilized for last 4 months
- Hydroponic Study- 3 week
    - Plants were grown in water
    - Hoagland solution was added to at the beginning of experiment
    - Containers were sampled at every three days

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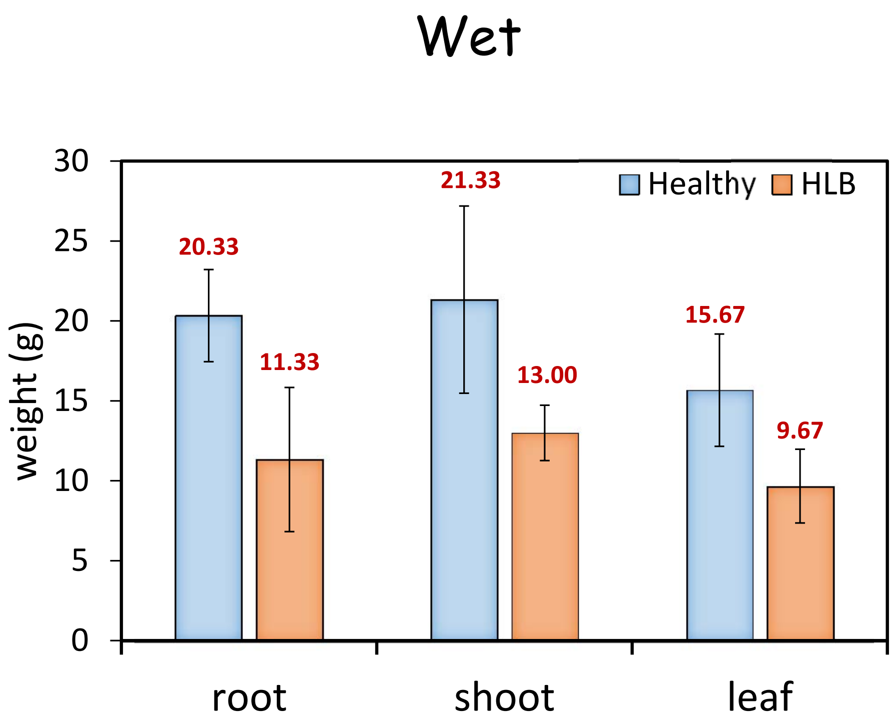
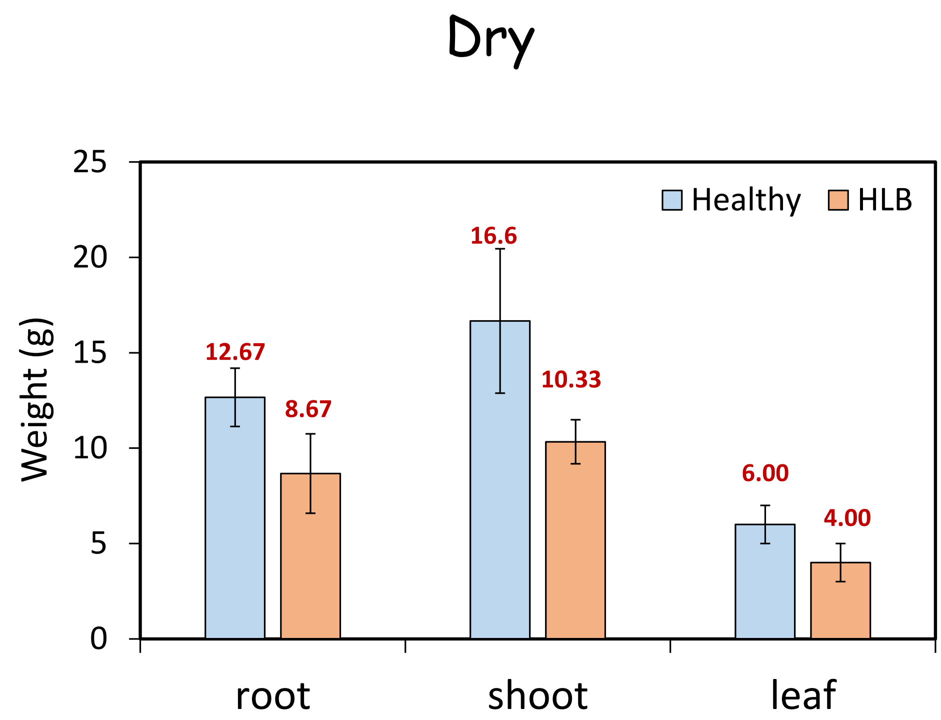
HLY 3
70
60
50
40
30
20
10
CM


HLB3


HLB3
HLB2
HLB 1
HLY 3
HLY 2
HLY 1

# Root, Shoot and Leaf Biomass

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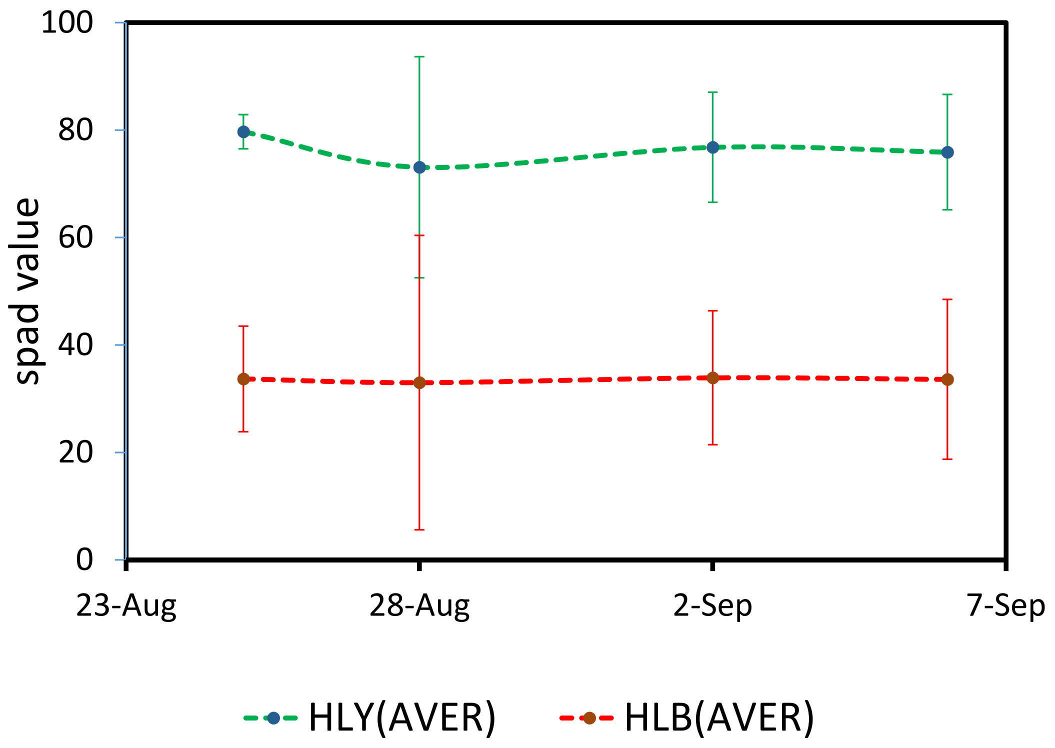
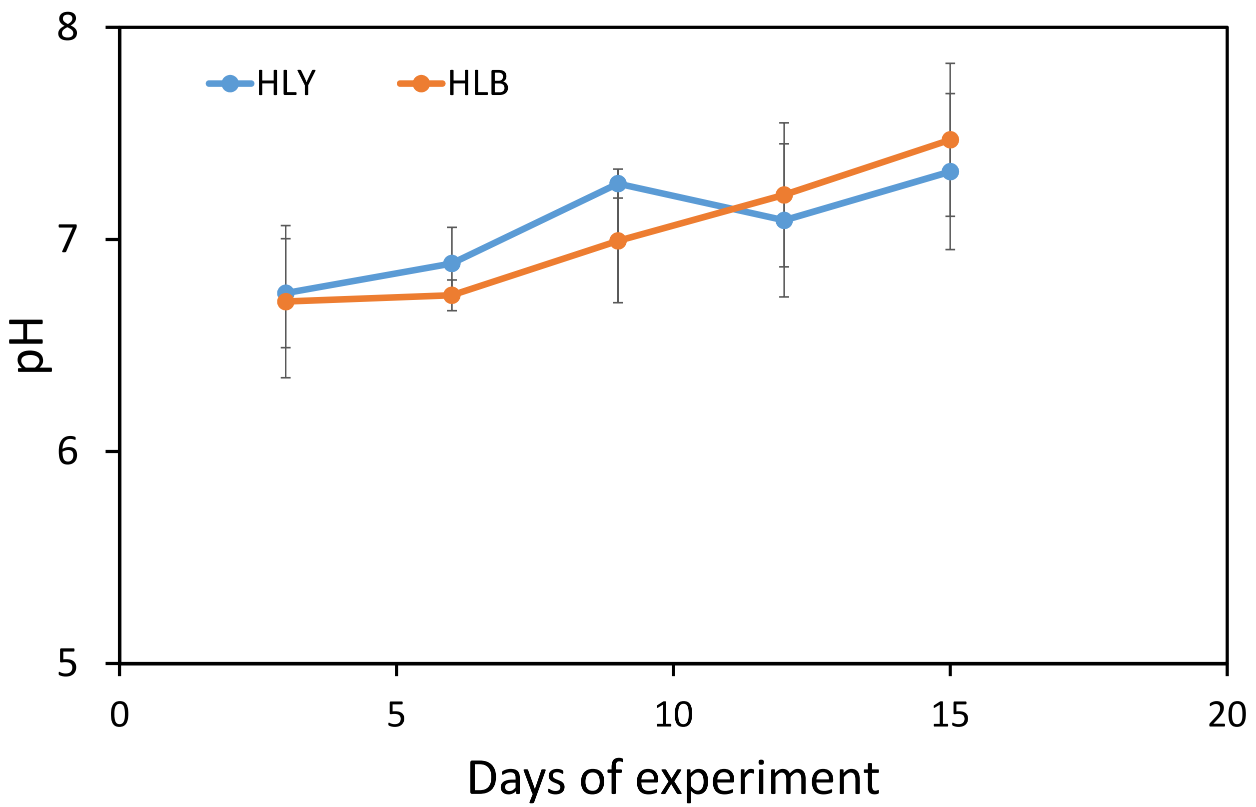
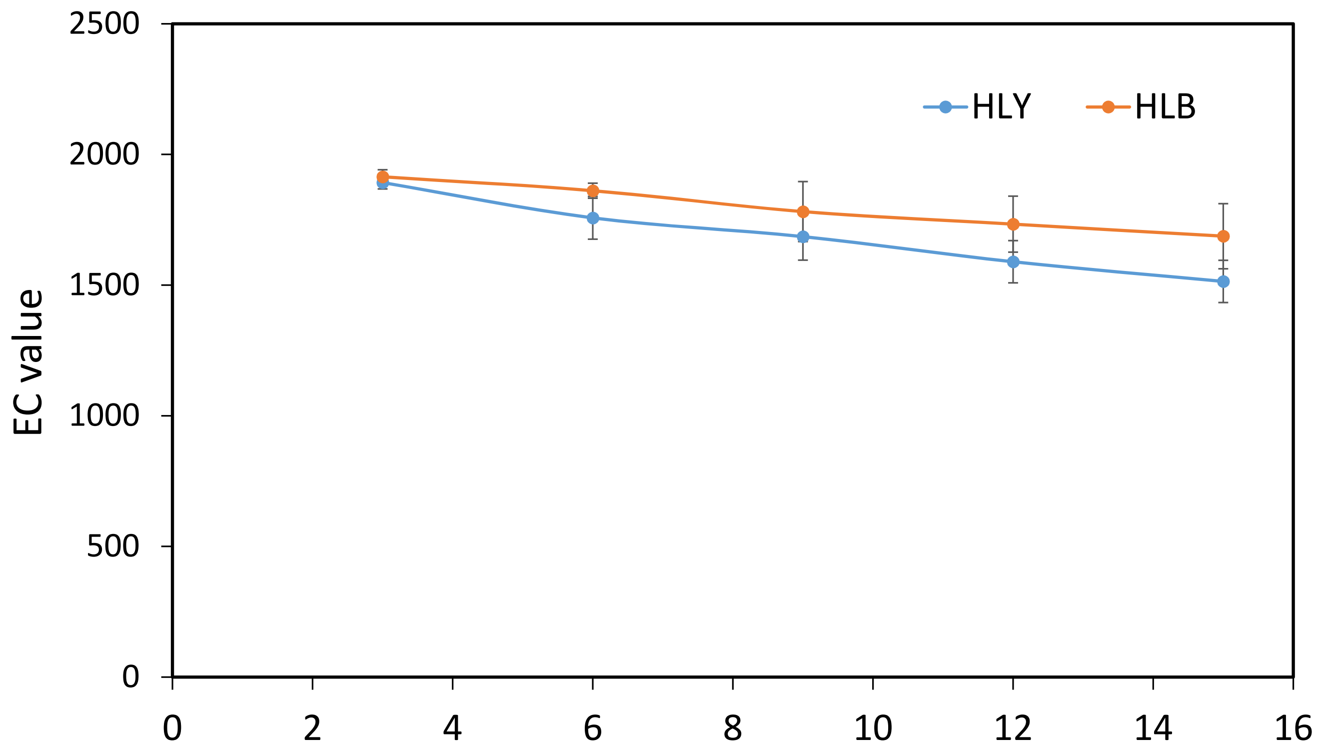
# Chlorophyll measurement of leaves



# pH of hydroponic solution

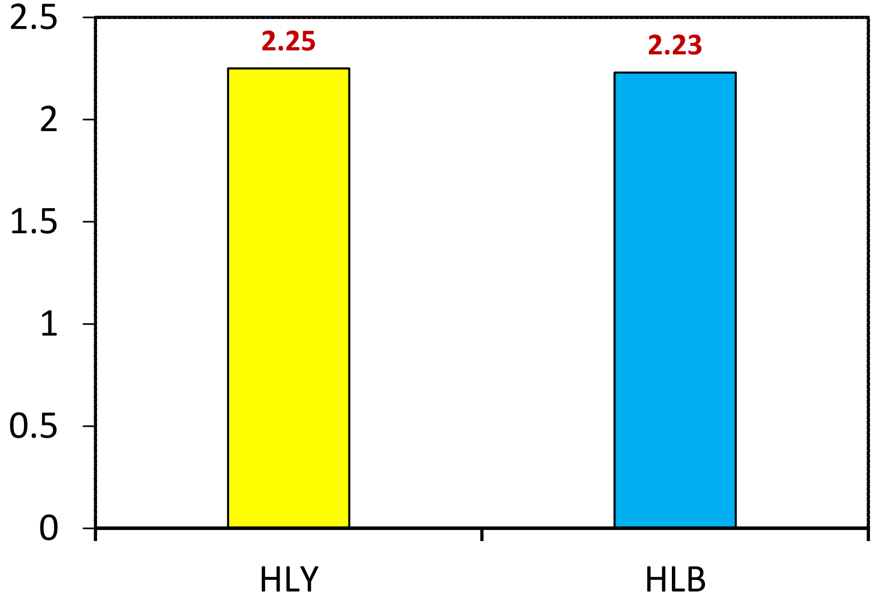


# Electrical Conductivity of hydroponic solution

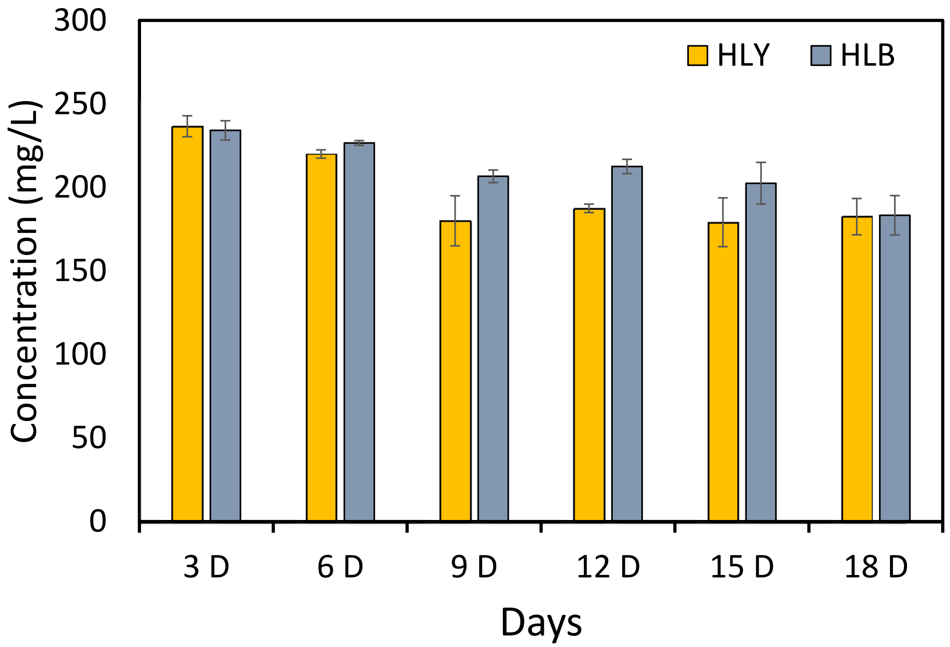


# Nitrogen

## Leaf




## Hydroponic Solution

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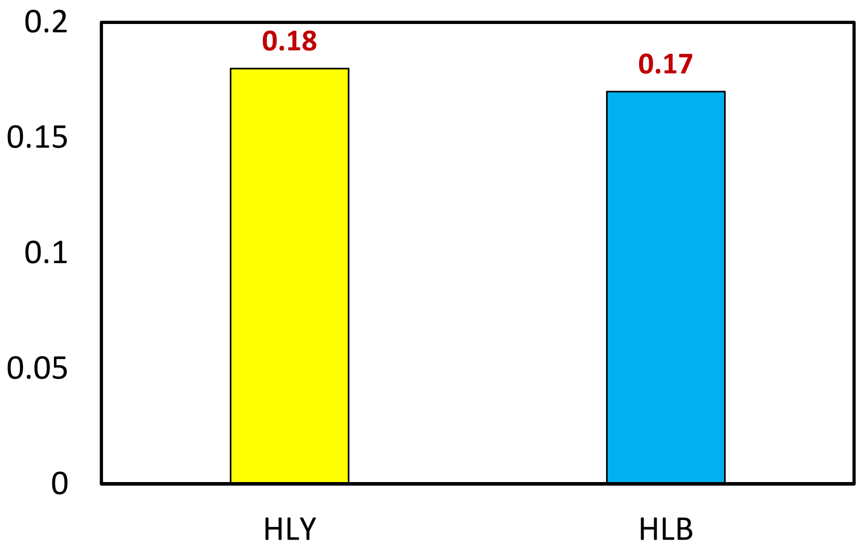
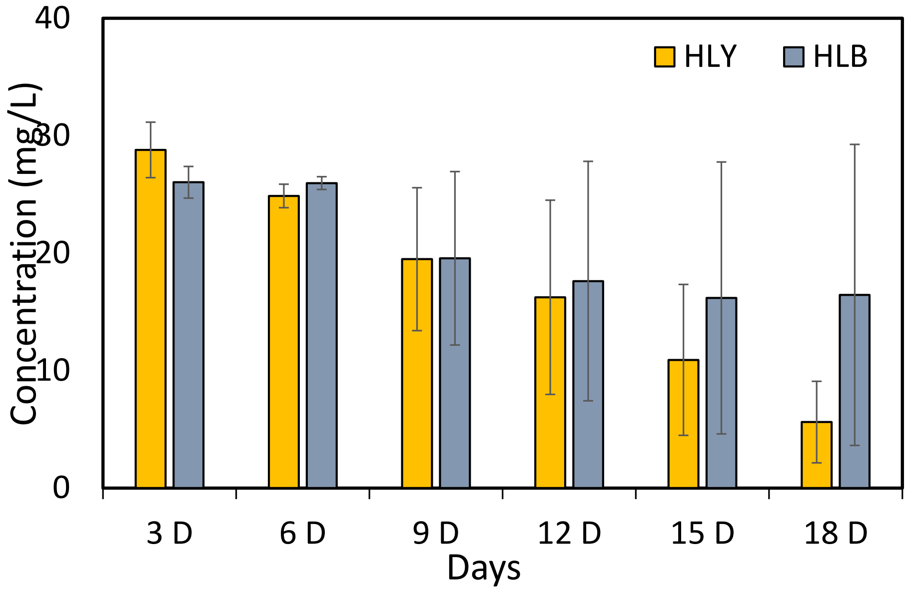
# Phosphorus

## Leaf

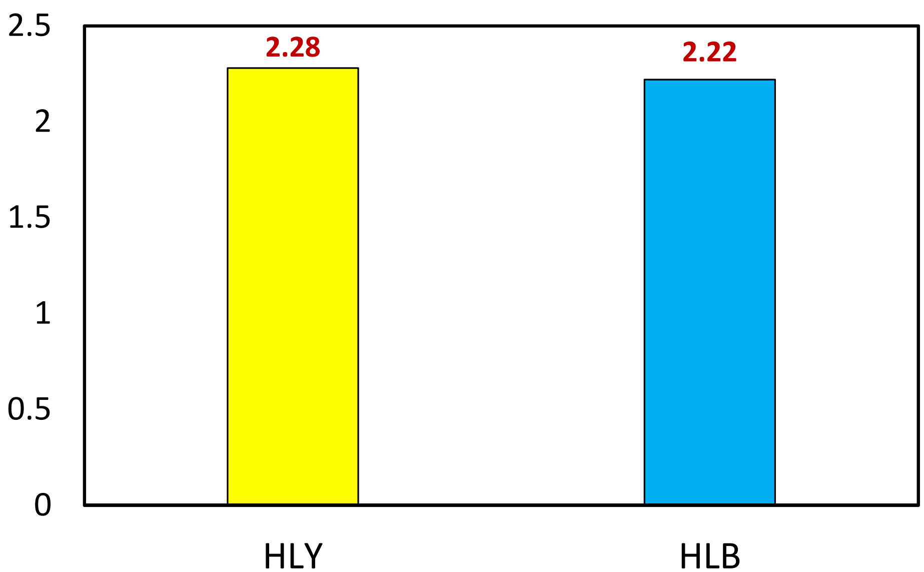



## Hydroponic Solution

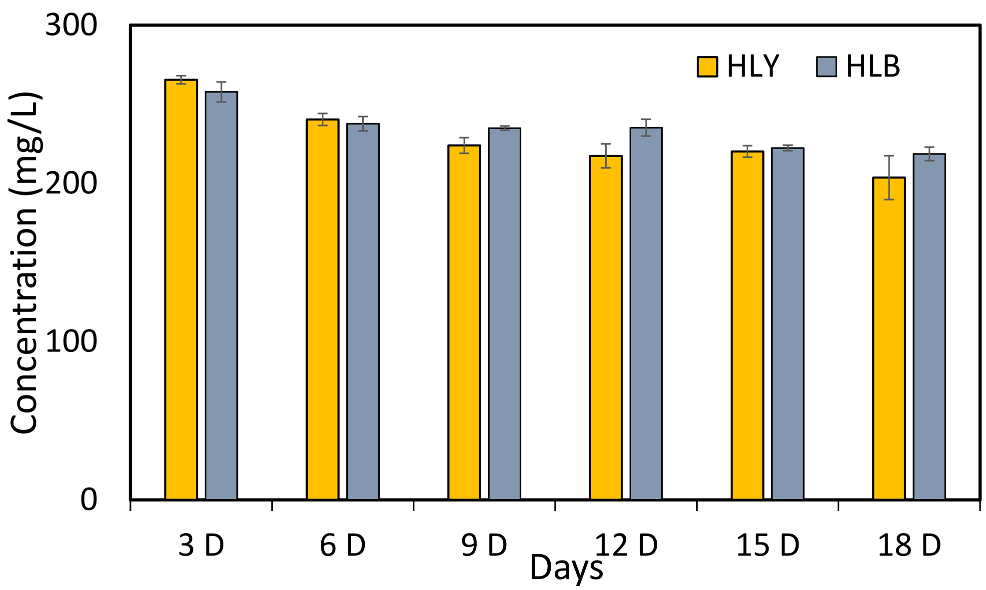


# Potassium

## Leaf




## Hydroponic Solution

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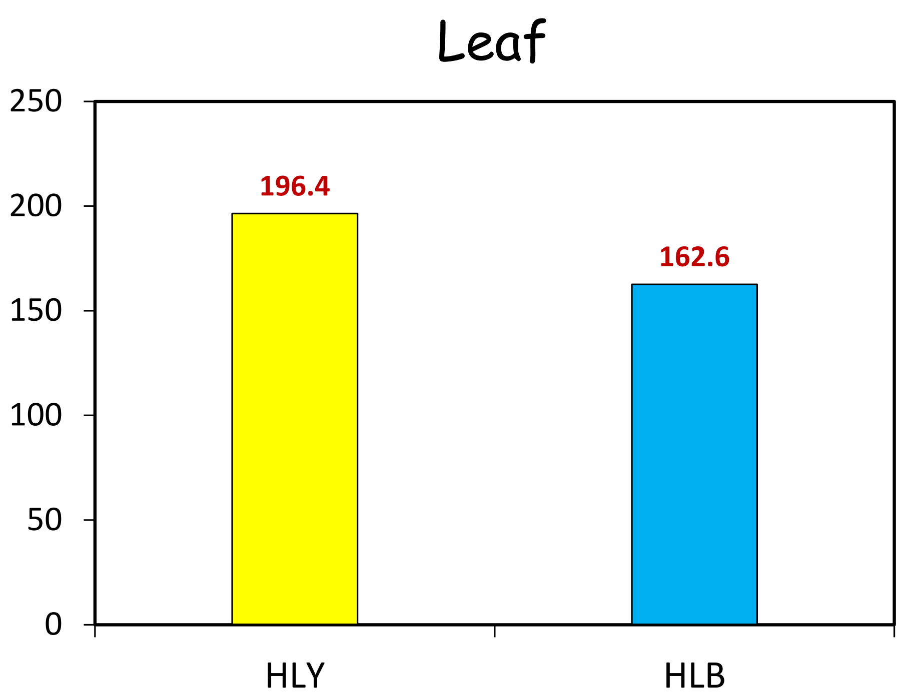
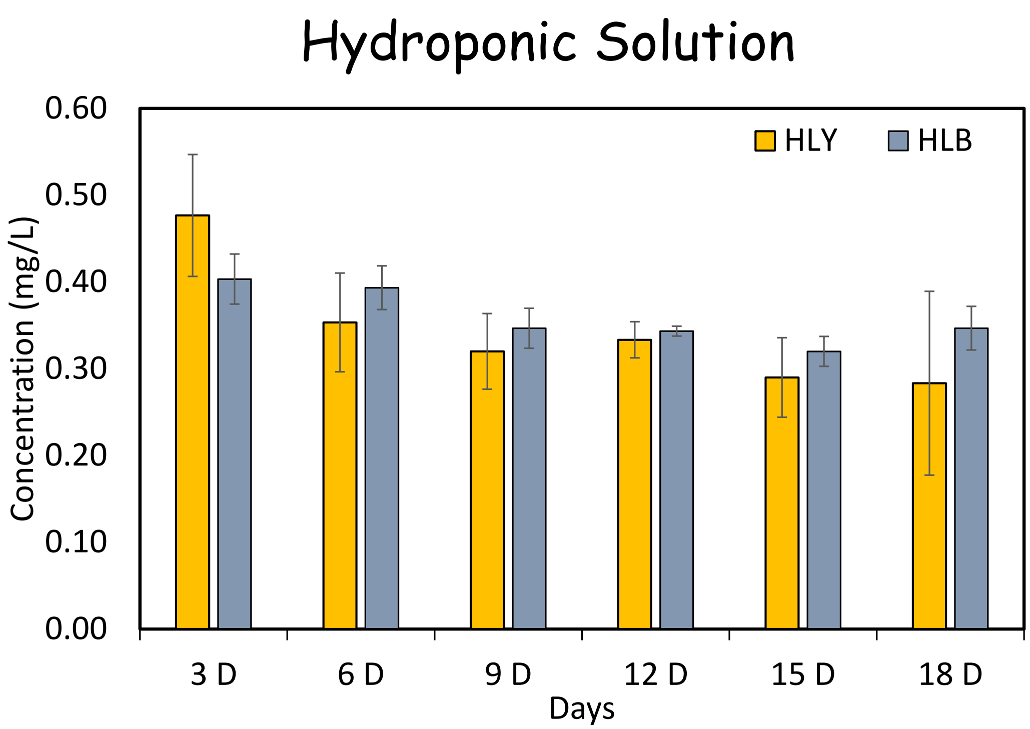
# Iron

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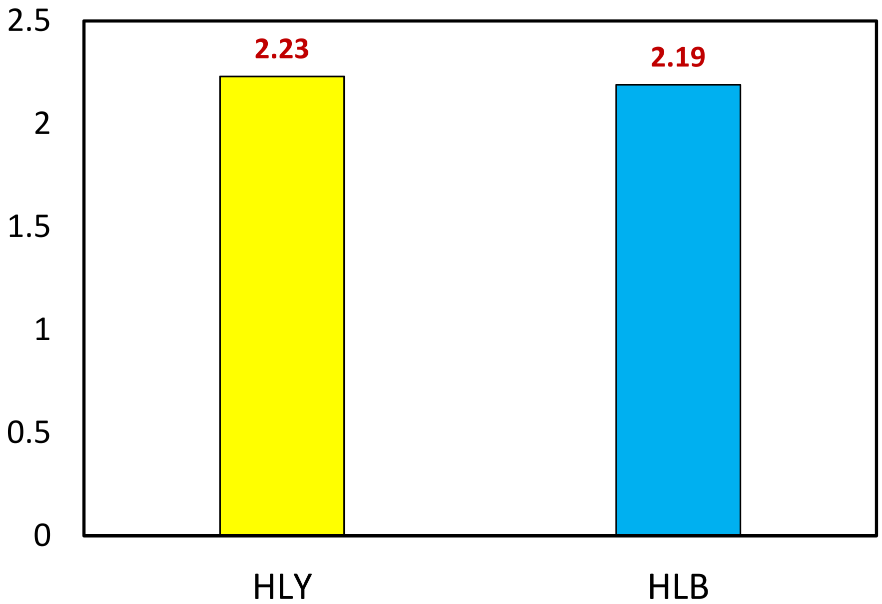
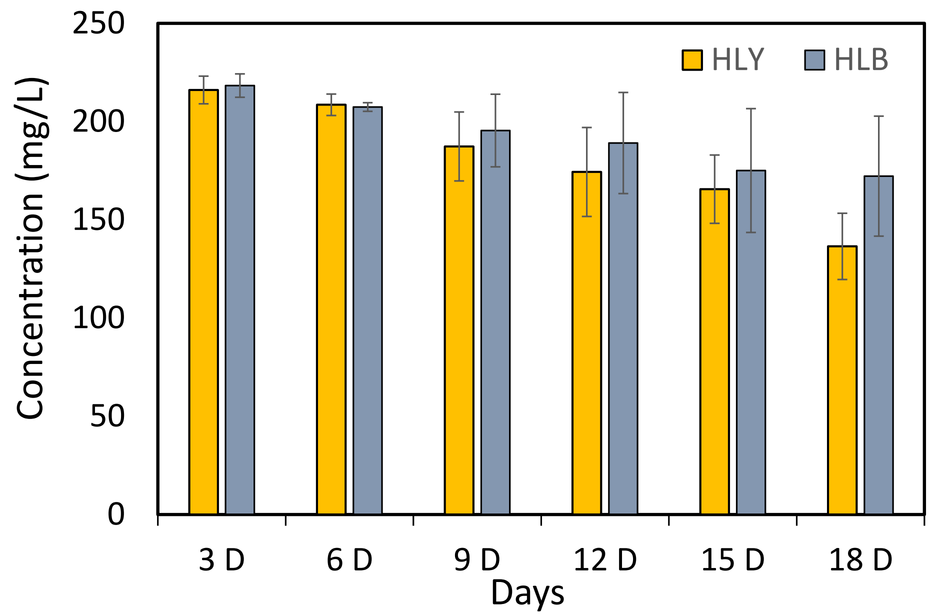
# Calcium

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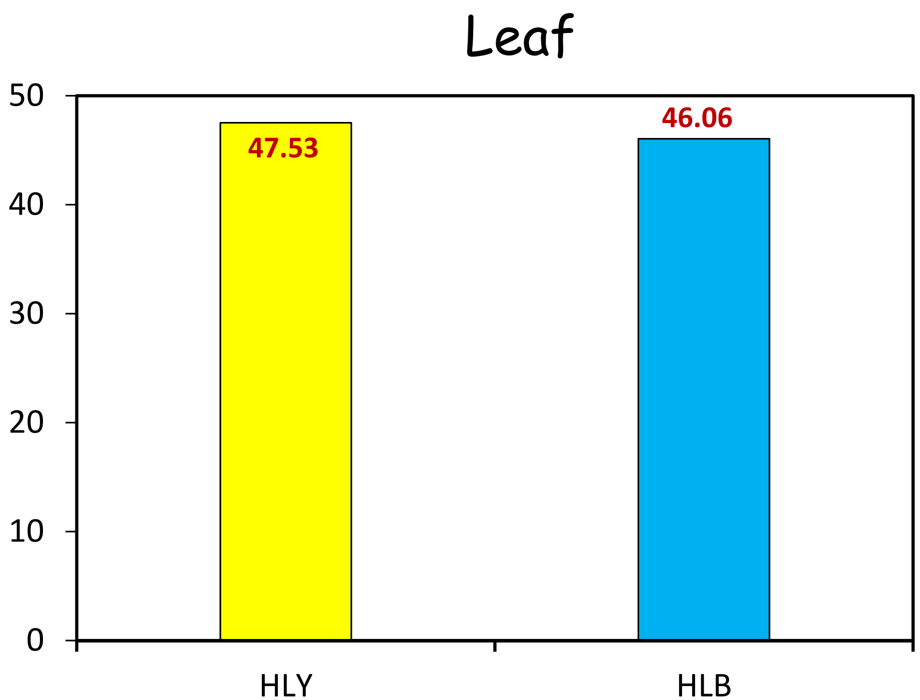
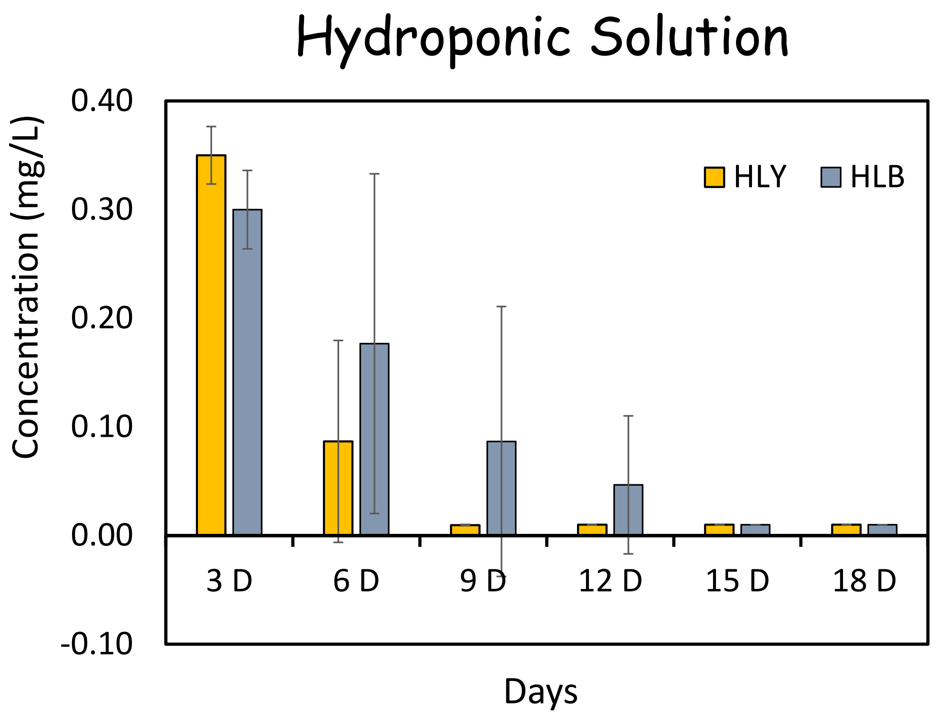
# Manganese

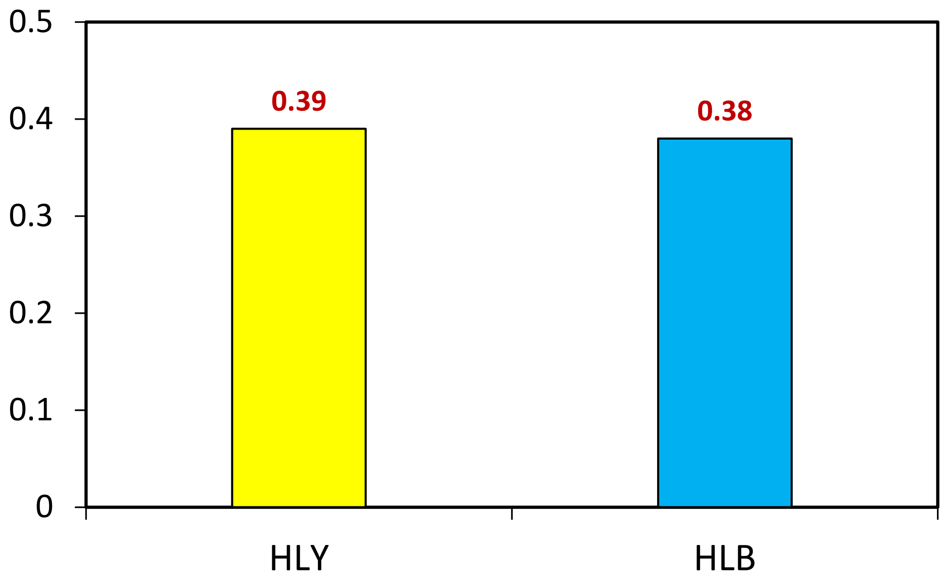


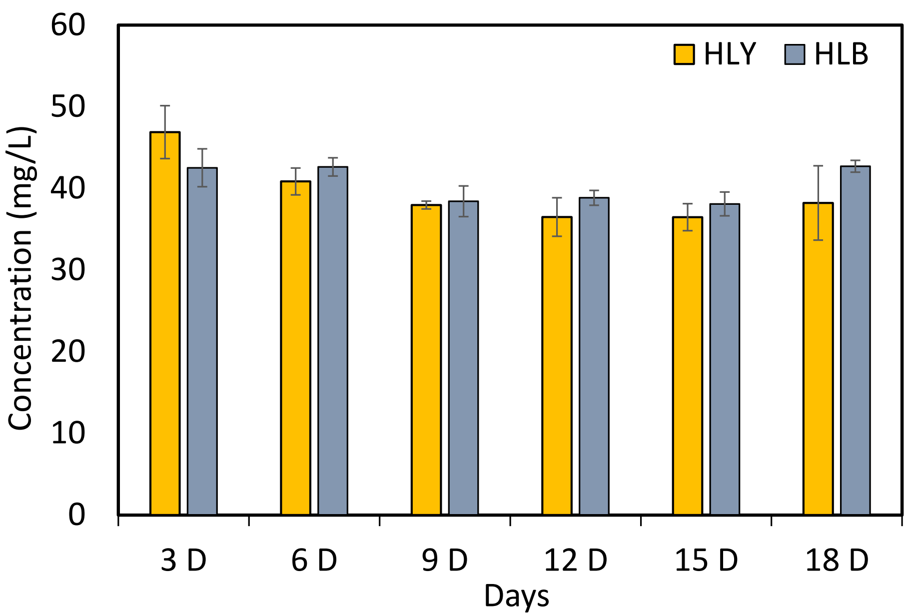
Leaf
50
40
30
20
10
0
47.53
46.06
HLY
HLB

Hydroponic Solution
0.40
0.30
0.20
0.10
0.00
-0.10
Concentration (mg/L)
HLY
HLB
3 D
6 D
9 D
12 D
15 D
18 D
Days

# Magnesium

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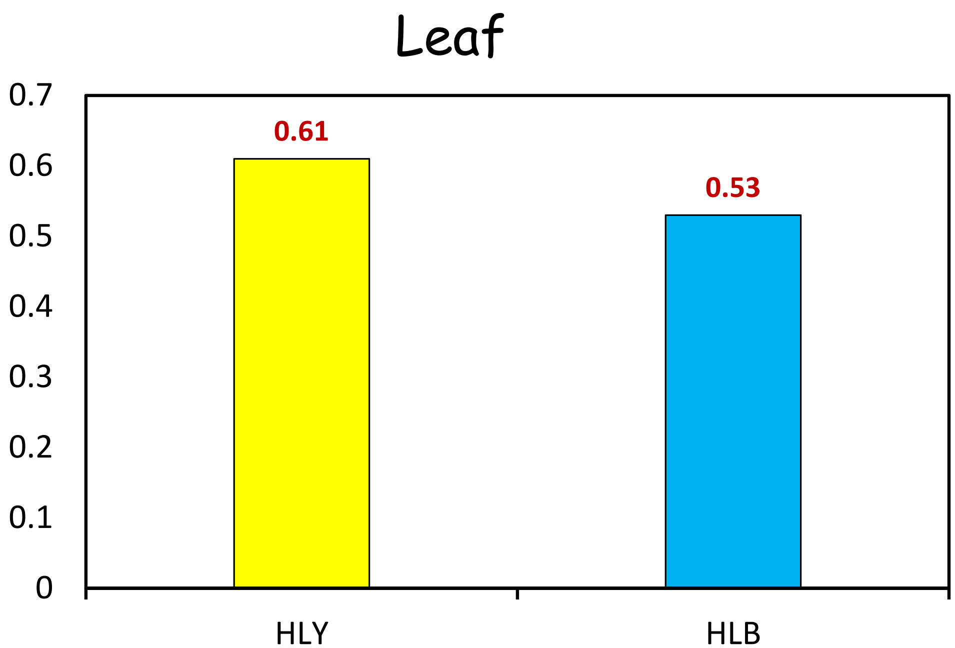
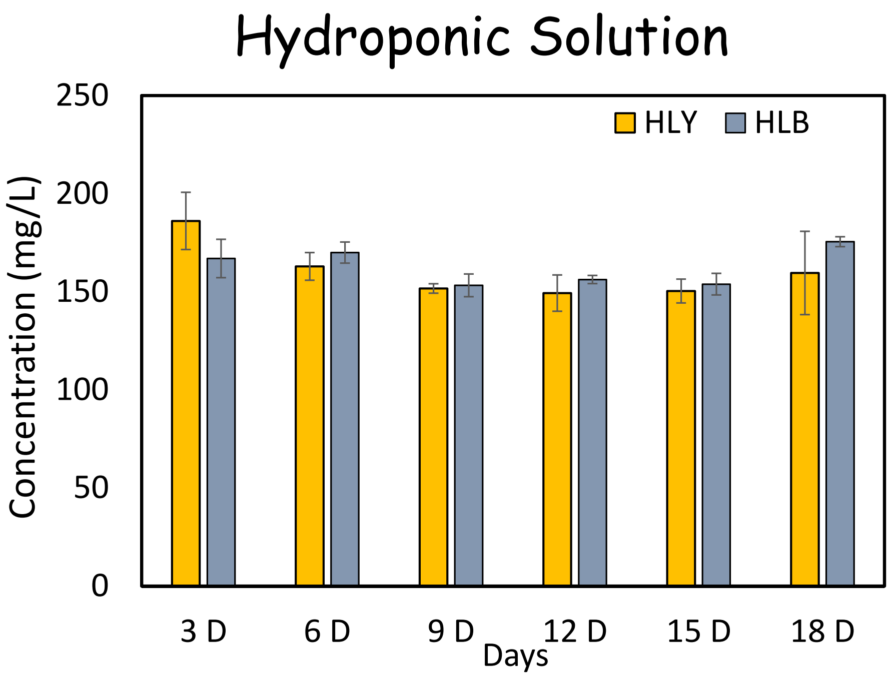
# Sulfur

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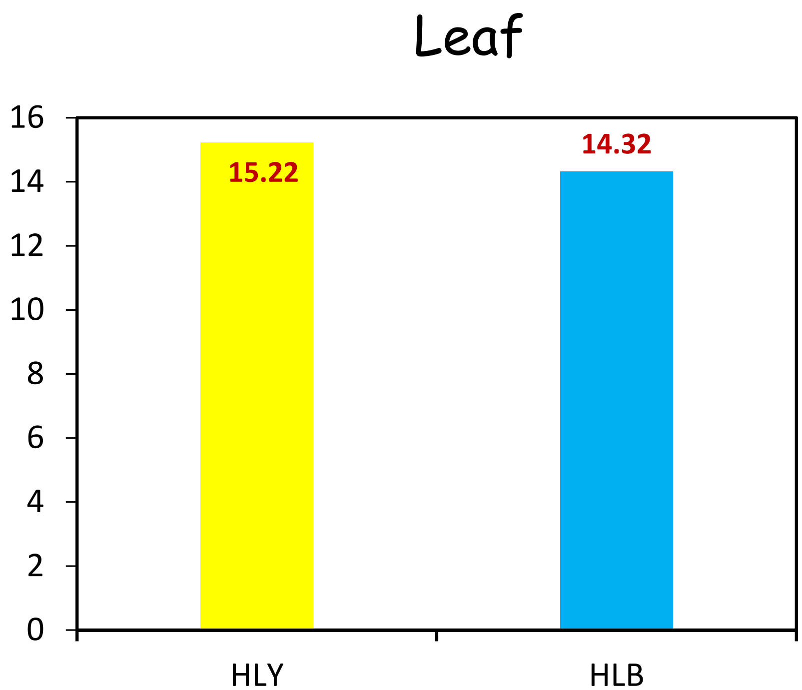
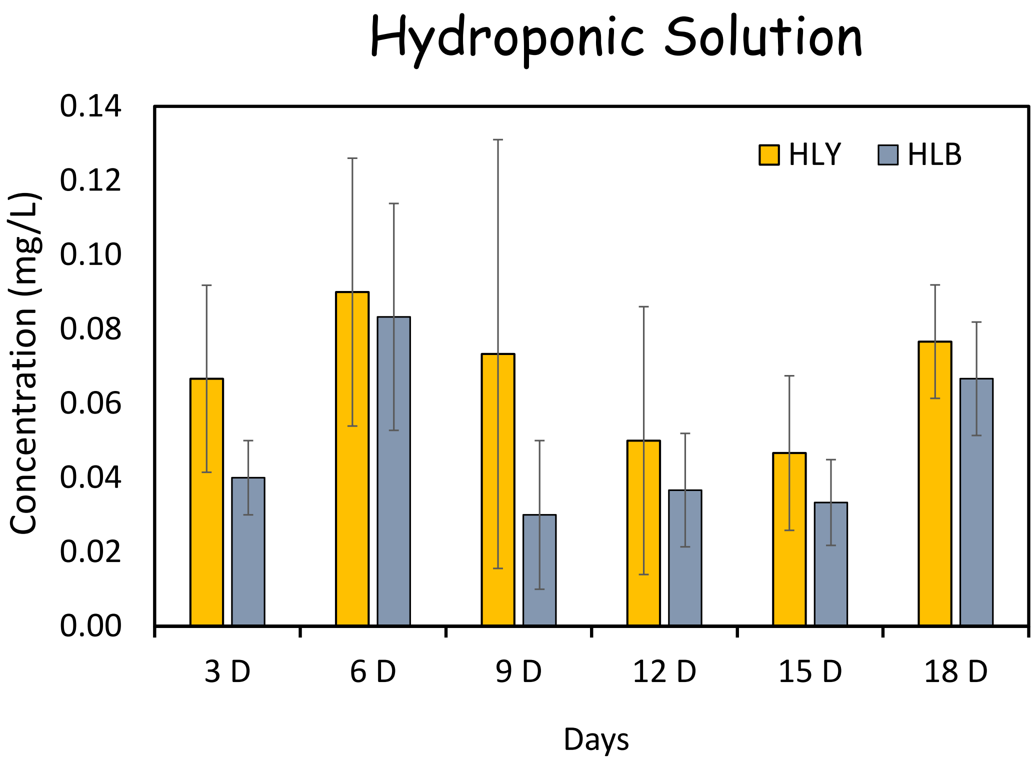
# Zinc

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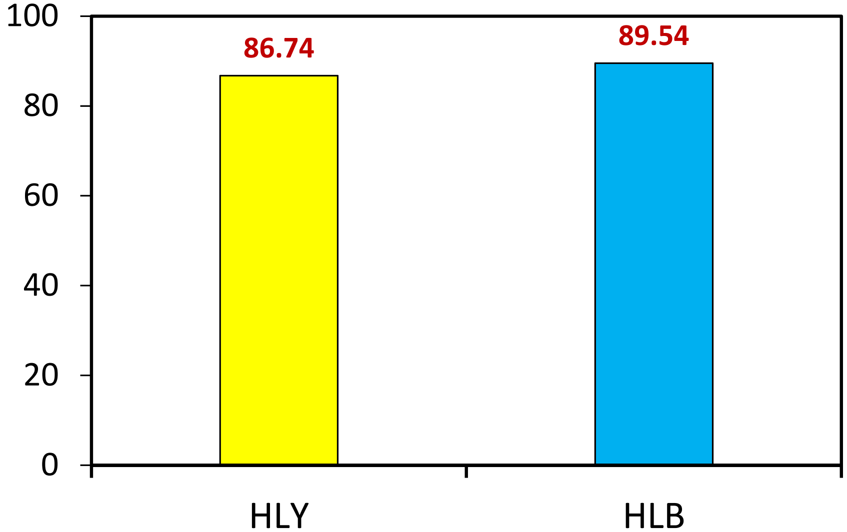
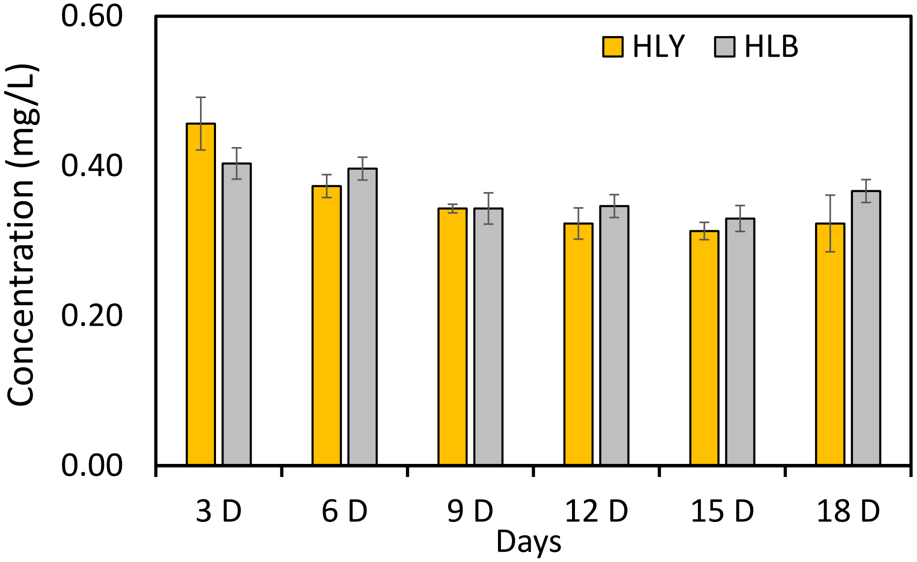
# Boron

## Leaf




## Hydroponic Solution

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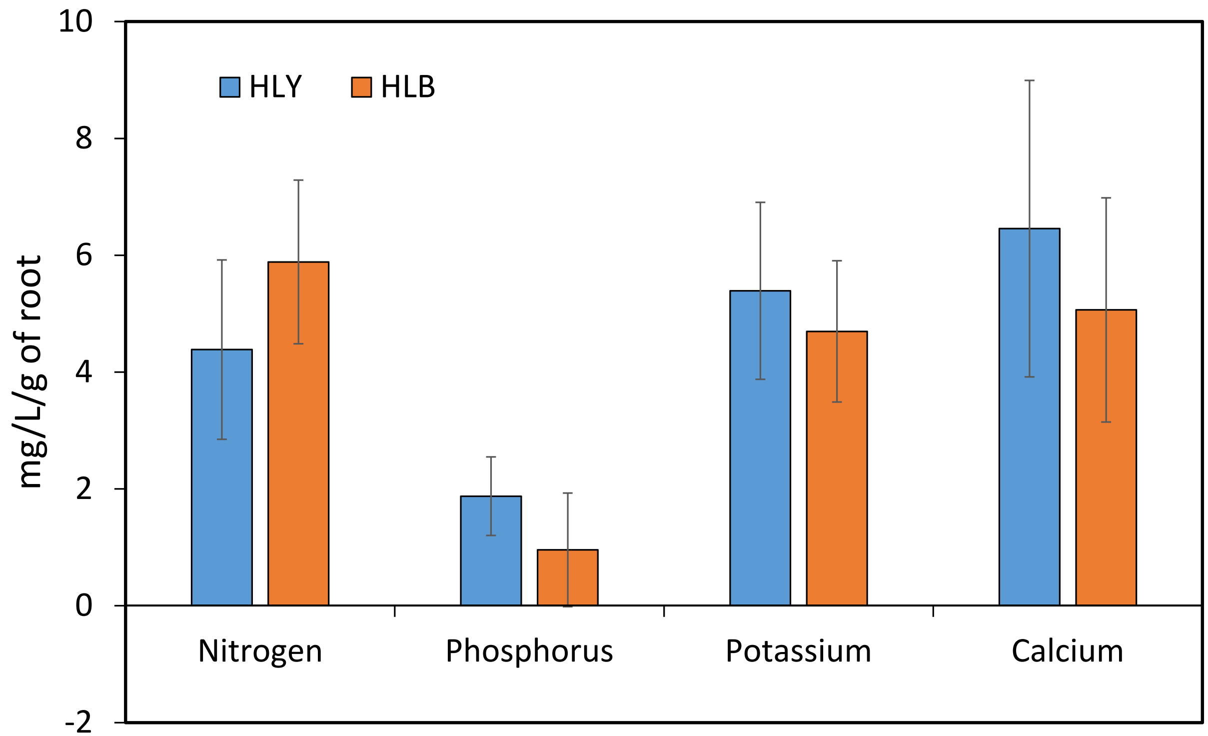
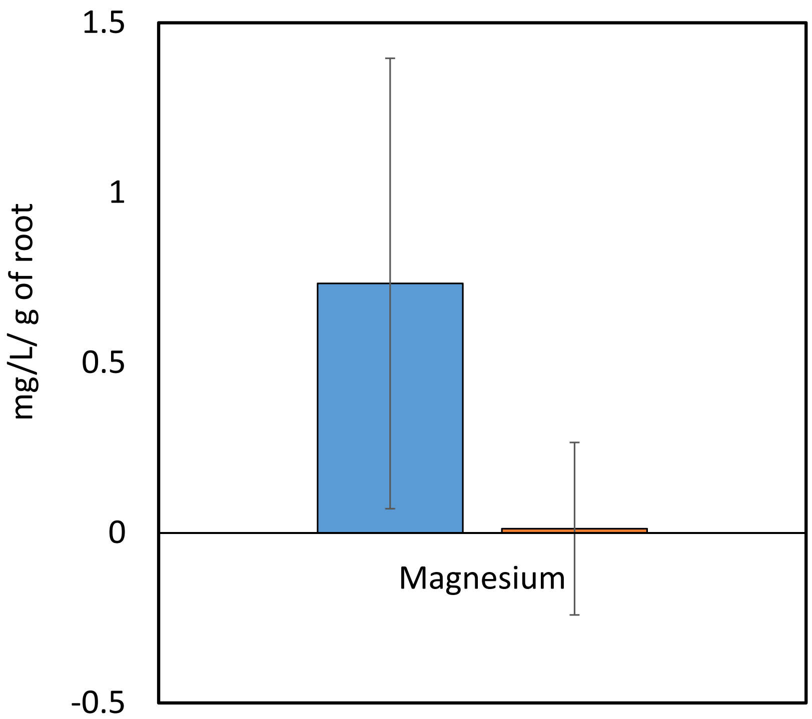
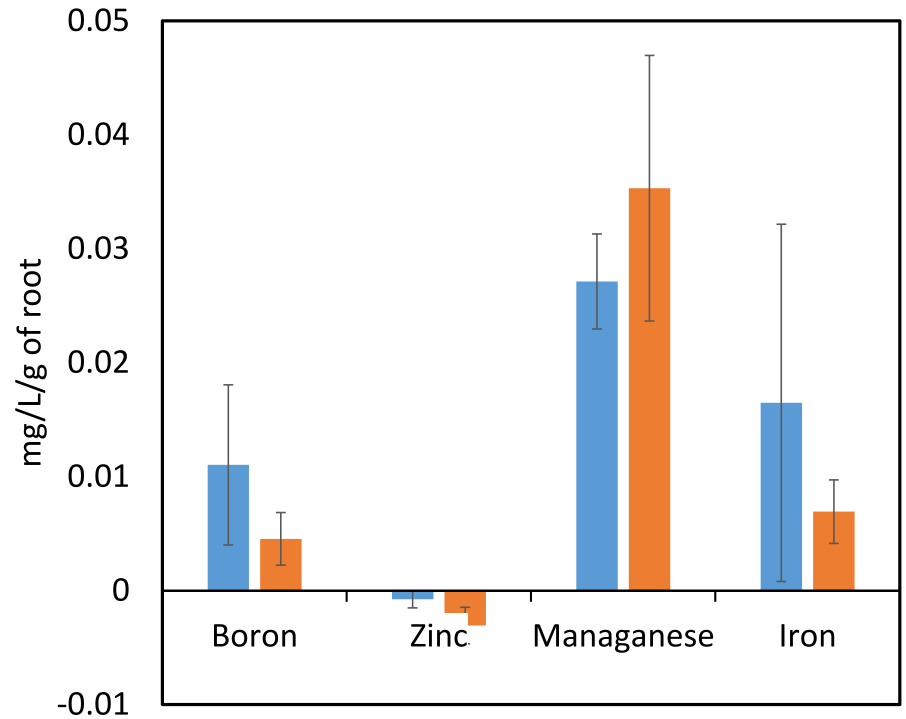
# Nutrient uptake per gram of root biomass



# Nutrient uptake per gram of root biomass

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# Conclusion

This study should conducted again for longer duration (approx. 3 months) with more replicates

- This is a preliminary study, conducted for a duration of 3 weeks
- The results are not statistically significant; although interesting patterns were observed
- pH of nutrient solution of HLB plants increased more than healthy trees
- Leaf nutrient analysis showed reduced nutrients in HLB affected plants
- The nutrient uptake in HLB plants was slower, even though same amount of nutrients were available
- When corrected for reduced root biomass, nutrient uptake pattern for each nutrient was low in HLB plants, except nitrogen and manganese

# IFAS Grower Nutrition Trial Update

Tripti Vashisth

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## IFAS-Growers Field Trials: **Goal**

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

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# 2015-2017 Nutrition Trials-3Trials

- Compared with growers control

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)

3. Foliar Nutritional Sprays

    Sulfates vs Glucoheptonates (Chelated) vs Nitrates

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# 2015-2016 Nutrition Trials

- Trials are ongoing at 4 sites, "sweet orange varieties" on "Swingle"
  - 3 sites have all the three trials
  - 1 site-Tiger Micronutrient
- Trials are initiated in February, 2016
- All the pre-treatment data has been collected
- Leaf and soil nutrient analysis data collected twice a year
- All the tree health, nutrient analysis, and yield data will be updated on http://www.crec.ifas.ufl.edu/extension/horticulture/citrus_nutrition/

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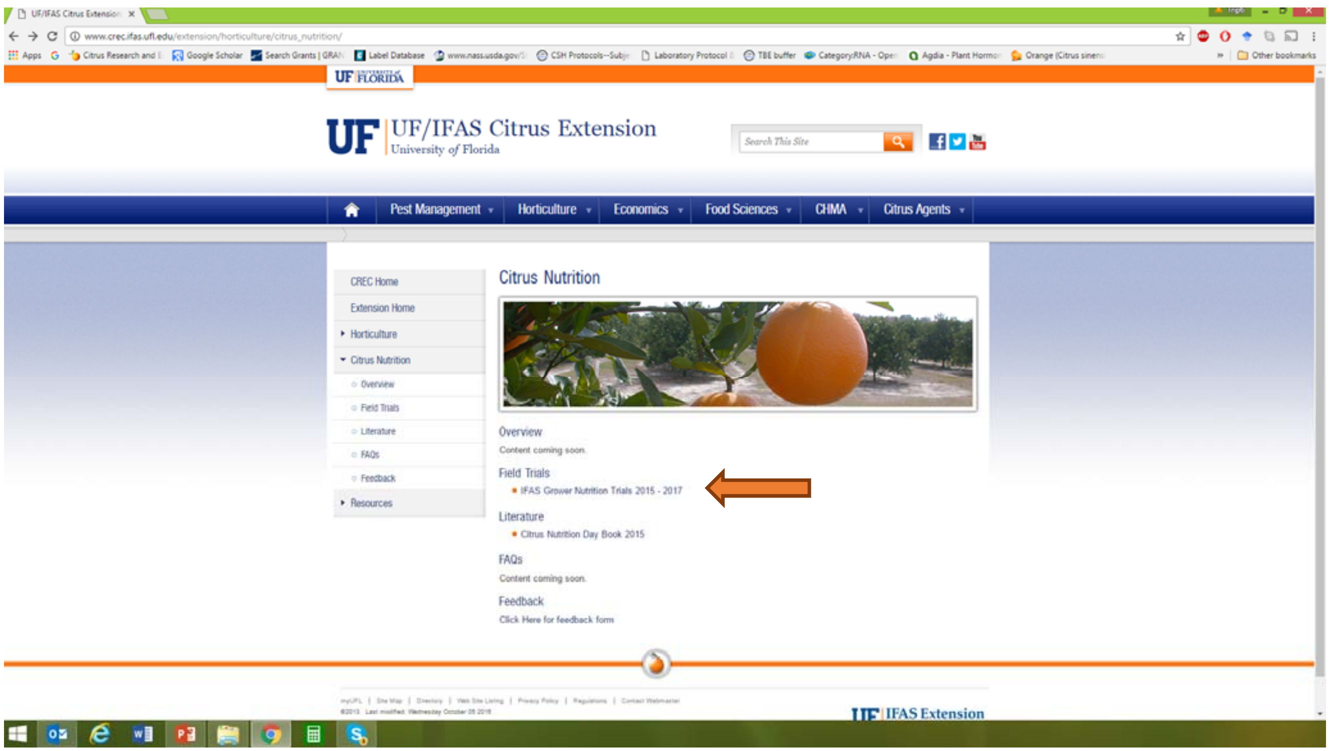

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Content coming soon.
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IFAS Grower Nutrition Trials 2015 - 2017
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Citrus Nutrition Day Book 2015
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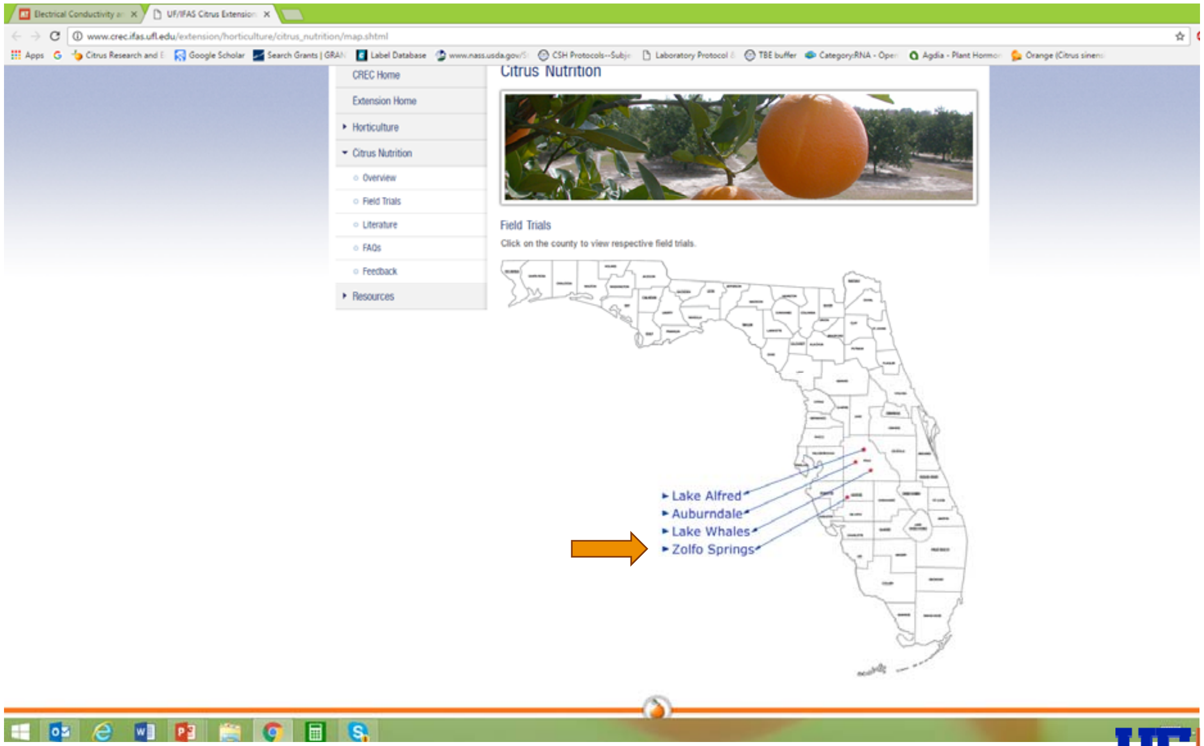

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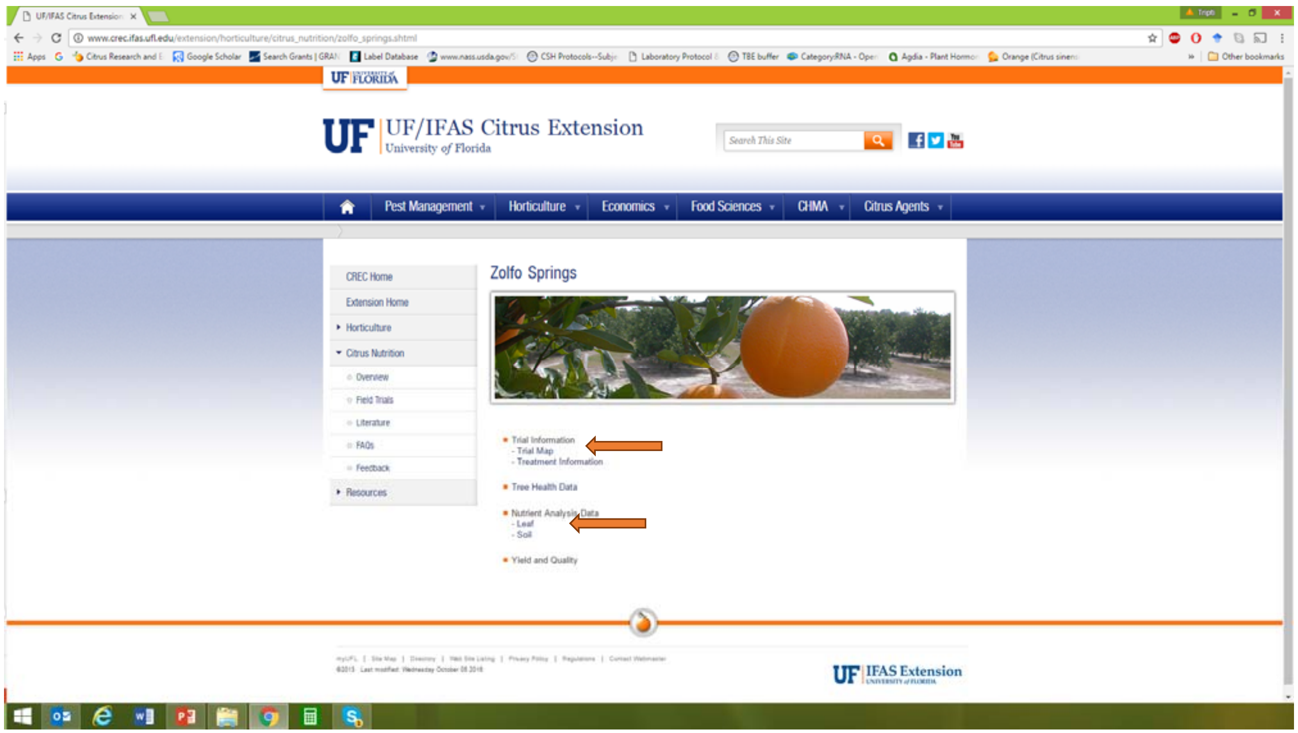
Lake Whales
Zolfo Springs



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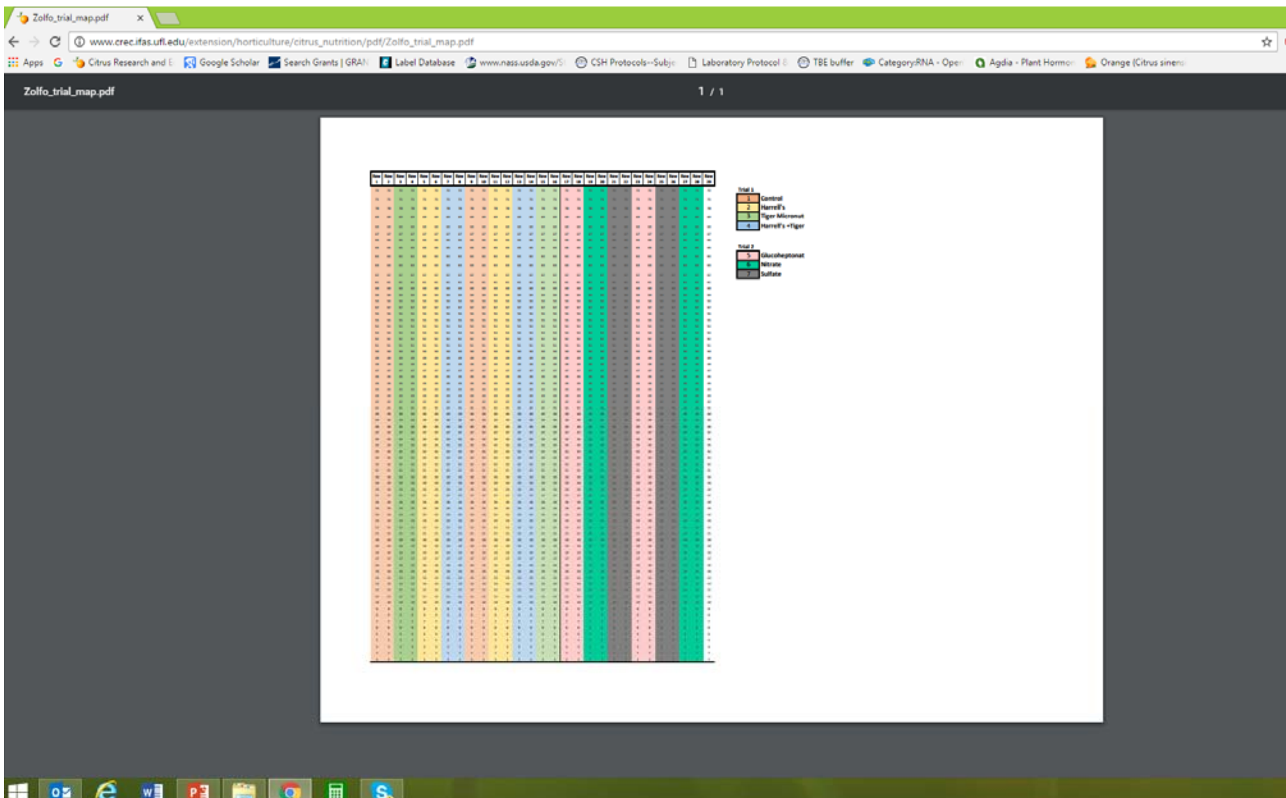


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# Leaf Nutrient Analysis

Growers Trials: Zolfo Springs

| | N | | P | | K | | Mg | | Ca | | S | | B | | Zn | | Mn | | Fe | | Cu | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | *Feb* | *July* | *Feb* | *July* | *Feb* | *July* | *Feb* | *July* | *Feb* | *July* | *Feb* | *July* | *Feb* | *July* | *Feb* | *July* | *Feb* | *July* | *Feb* | *July* | *Feb* | *July* |
| Control | 2.6425 | 2.6175 | 0.16 | 0.1275 | 1.3475 | 1.155 | 0.31 | 0.3575 | 3.545 | 3.455 | 0.335 | 0.295 | 106.43 | 102.27 | 52.75 | 107.91 | 58.888 | 85.255 | 79.863 | 56.878 | 5.7725 | 7.1625 |
| Harrell's | 2.6575 | 2.725 | 0.1525 | 0.125 | 1.1925 | 1.09 | 0.3725 | 0.3725 | 4.055 | 3.6875 | 0.4075 | 0.3375 | 119.93 | 127.08 | 65.195 | 125.4 | 72.273 | 104.94 | 91.93 | 59.503 | 5.7475 | 7.1125 |
| Tiger | 2.7125 | 2.8025 | 0.1575 | 0.12 | 1.2125 | 0.97 | 0.355 | 0.355 | 3.71 | 3.72 | 0.3775 | 0.3125 | 110.03 | 150 | 56.548 | 131.7 | 64.193 | 111.3 | 88.188 | 62.918 | 5.5825 | 7.505 |
| Harrell's + Tiger | 2.6325 | 2.78 | 0.145 | 0.13 | 1.2125 | 1.1675 | 0.3325 | 0.3475 | 3.4225 | 3.345 | 0.3275 | 0.295 | 102.73 | 168.4 | 53.988 | 119.31 | 54.4 | 98.34 | 83.055 | 54.68 | 5.6025 | 7.2475 |
| Sulfate | 2.7525 | 3.275 | 0.15 | 0.12 | 1.1275 | 1.105 | 0.3625 | 0.3675 | 3.9325 | 3.6875 | 0.315 | 0.26 | 128.28 | 118.9 | 78.75 | 46.783 | 89.698 | 67.133 | 107.04 | 74.57 | 6.53 | 5.7925 |
| Nitrate | 2.6225 | 2.9775 | 0.1425 | 0.1275 | 1.1 | 1.1575 | 0.3675 | 0.405 | 3.72 | 3.5675 | 0.3525 | 0.28 | 128.2 | 117.1 | 75.13 | 50.323 | 88.525 | 72.233 | 86.063 | 68.82 | 6.5375 | 6.1275 |
| Glucoheptonate | 2.6375 | 3.045 | 0.145 | 0.1175 | 1.1825 | 0.955 | 0.375 | 0.4 | 3.59 | 4.0775 | 0.345 | 0.2825 | 119.88 | 136.23 | 68.155 | 64.698 | 82.438 | 102.61 | 95.123 | 83.135 | 5.8025 | 7.585 |

| | |
|---|---|
| (red) | Deficient |
| (orange) | Low |
| (green) | Optimum |
| (yellow) | High |
| (purple) | Excess |

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# IFAS Grower Nutrition Trial
# 2016-2018

# 2015-2016 Nutrition Trial: Objective

- To evaluate fertilizers for 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 Nutrition 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

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# IFAS-Growers Field Trials: **Benefits**

- Currently, number of fertilizer/nutrition program are being advertised and used in the Florida citrus industry with little or anecdotal evidences of effectiveness.
- Products evaluated at multiple sites by same protocol
- TIME IS OF THE ESSENCE –Trials will help in collecting data fast
- Data collected will be accessible 24*7 and can be used for decision making

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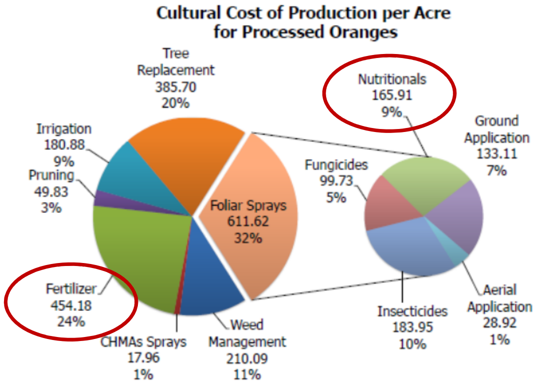
# Products to be evaluated

- Due to logistics of experimental design - only controlled release fertilizer
- Controlled release fertilizer can provide constant nutrition to diminished root system
- CRFs are often expensive as compared to conventional granular fertilizer!
- Advantages of CRF:
    - Fewer application
    - Minimum maintenance
    - Constant supply of nutrition
    - Soil application of nutrients




Reference -Dr. Ariel Singerman

## Product Evaluation

- Participating companies have provided complete nutrient programs and will be donating the product for trials
- Each product has unique features and benefits
- Comparison will be made against growers control
- Product will be evaluated for % change in tree health and yield
- Evaluation will be conducted for at least 2 years

florikan CRF

WITH nutricote GAL-Xe ONE

# 12-3-9 Citrus Total

WITH NUTRICOTE® $CaNo_3$

**GUARANTEED ANALYSIS:**

| | |
|---|---|
| **Total Nitrogen (N)*** | 12% |
| 6.40% Nitrate Nitrogen | |
| 5.60% Ammoniacal Nitrogen | |
| **Available Phosphate (P2O5)** | 3% |
| **Soluble Potash (K2O)** | 9% |
| Calcium (Ca) | 2.00% |
| Magnesium (Mg) | 2.90% |
| 1.95% Water Soluble Magnesium (Mg) | |
| Sulfur (S) | 6.90% |
| 6.90% Combined Sulfur (S) | |
| Boron (B) | 0.11% |
| Chlorine (Cl) Not More Than | 0.92% |
| Copper (Cu) | 0.08% |
| 0.02% Water Soluble Copper (Cu) | |
| Iron (Fe) | 2.08% |
| 0.59% Chelated Iron (Fe) | |
| 0.49% Water Soluble Iron (Fe) | |
| Manganese (Mn) | 0.57% |
| 0.48% Water Soluble Manganese (Mn) | |
| Molybdenum (Mo) | 0.001% |
| Zinc (Zn) | 0.30% |
| 0.24% Water Soluble Zinc (Zn) | |

**DERIVED FROM:** Polymer Coated Ammonium Nitrate, Polymer Coated Calcium Nitrate, Polymer Coated Ammonium Phosphate, Polymer Coated Calcium Phosphate, Polymer Coated Ammonium Polyphosphate, Polymer Coated Potassium Sulfate, Polymer Coated Iron EDTA, Polymer Coated Sulfate of Potash Magnesia, Polymer Coated Magnesium Sulfate, Polymer Coated Iron Citrate, Polymer Coated Manganese Sulfate, Polymer Coated Copper Sulfate, Polymer Coated Zinc Sulfate, Polymer Coated Sodium Borate, Ferrous Sulfate, Iron Sucrate, Iron EDTA, Iron Citrate, Magnesium Sulfate, Magnesium Sucrate, Manganese Sucrate, Zinc Sucrate, Copper Sucrate, Sodium Borate, Sodium Molybdate, Manganese Sulfate, Zinc Sulfate, *The (LIST NUTRIENTS) have been polymer coated to provide 13% Slow Release Nitrogen (N), 3% Slow Release Available Phosphate (P2O5), 9% Slow Release Soluble Potash (K2O)

The below rates are provided as a guide only. Specific rates will vary by region, soil type, and performance requirements. Before deciding which formulation, release type, and rate to use, contact your Florikan Technical Representative. They will advise you in choosing the right product for your crop and conditions.

UP TO: **360 DAYS**

AVG MEDIAN TEMPS

| 60° | | 70° | | 80° | |
|---|---|---|---|---|---|
| 420 | 14 | 390 | 13 | 360 | 12 |
| Days/Mnths | | Days/Mnths | | Days/Mnths | |

GUARANTEED BY: F1062

QUALITY CONTROL BATCH NUMBER:

PER TREE APPLICATION RATES

| Type | UP TO 360 DAYS |
|---|---|
| Item # | 12-3-9-360 |
| YEARS IN GROVE | Lbs. |
| 1 YEAR | .75-1 |
| 2 YEARS | .75-1.5 |
| 3 YEARS | 1.0-2.0 |
| 4 YEARS | 1.5-2.5 |
| 5 YEARS | 2.0-3.0 |

Conversion: 5 Grams = 1 Teaspoon | 15 Grams = 1 Tablespoon

WEDGWORTH'S

FLA. License No. F1622

BIG W BRAND 13-1-13

13- 1- 13

| | | | |
|---|---|---|---|
| Mg | 1.50 | Mn | 0.01 |
| B | 0.03 | Zn | 0.04 |
| Fe | 0.07 | S | 5.49 |

| | |
|---|---|
| Total Nitrogen * | 13.00 |
| 0.83 Ammoniacal Nitrogen | |
| 5.68 Nitrate Nitrogen | |
| 6.49 Water Soluble Organic Nitrogen | |
| 0.00 Water Insoluble Nitrogen | |
| Available Phosphorous (P2O5) | 1.00 |
| Soluble Potash (K2O) * | 13.00 |
| Chlorine | 2.04 |

* 5.91 slowly released nitrogen, 2.60 slowly released potassium

| | |
|---|---|
| Total Magnesium as Mg | 1.50 |
| Water Soluble Magnesium as Mg | 1.50 |
| Total Manganese as Mn | 0.01 |
| Water Soluble Manganese as Mn | 0.01 |
| Boron as B | 0.03 |
| Total Zinc as Zn | 0.04 |
| Total Iron as Fe | 0.07 |
| Water Soluble Iron as Fe | 0.01 |
| Free Sulfur as S | 5.49 |
| Combined Sulfur as S | 5.64 |
| Calcium as Ca | 7.60 |

Derived From: Polymer Coated Sulfur Coated Urea, Ammoniated Phosphate, Sulfate of Potash Magnesium, Polymer Coated Muriate of Potash, Sulfate of Potash, Boric Acid, Sodium Borate, Potassium Tetraborate Tetrahydrate, Ferrous Sulfate, Iron Oxide, 62% Humic Acid+10%HAP, Ammoniated Phosphate, Manganese Sulfate, Zinc Sulfate, Zinc Oxide, Magnesium Sulfate, Magnesium Oxide, Magnesium Carbonate, Polymer Coated Urea, Calcium Nitrate, Sulfur

YARA

Knowledge grows

## 9-1-14 2 Mg 7.7S + 11% Calcium

## Analysis

| | |
|---|---|
| Total Nitrogen | 9.00 |
| Ammoniacal Nitrogen | 0.75 |
| Nitrate Nitrogen | 8.25 |
| Available Phosphorous | 1.00 |
| Soluble Potash (P2O5) | 14.00 |
| Chlorine | 0.19 |
| All Micros | To spec per recommended rate |

## Sample Label

Blending powered by YaraLiva Calcium Nitrate and YaraVita micronutirents

| Product/Material | Pounds per a ton |
|---|---|
| YaraLiva Calcium Nitrate | 1161 |
| Triple Super Phosphate | 44 |
| Sulphate of Potash Magnesium | 200 |
| Granular SOP | 472 |
| YaraVita Advanced Chelated Iron | Rate per Soil Test |
| YaraVita PROCOTE BMZ | Rate per Soil Test |
| Filler or other | Material / Rate per Soil Test |

florikan CRF

WITH nutricote GAL-Xe ONE

# 13-3-9 Citrus Total

WITH NUTRICOTE® $CaNo_3$

**GUARANTEED ANALYSIS:**

| | |
|---|---|
| **Total Nitrogen (N)*** | 13% |
| 6.80% Nitrate Nitrogen | |
| 6.20% Ammoniacal Nitrogen | |
| **Available Phosphate (P2O5)** | 3% |
| **Soluble Potash (K2O)** | 9% |
| Calcium (Ca) | 2.10% |
| Magnesium (Mg) | 2.50% |
| 1.58% Water Soluble Magnesium (Mg) | |
| Sulfur (S) | 5.80% |
| 6.00% Combined Sulfur (S) | |
| Boron (B) | 0.11% |
| Chlorine (Cl) Not More Than | 0.98% |
| Copper (Cu) | 0.08% |
| 0.01% Water Soluble Copper (Cu) | |
| Iron (Fe) | 1.43% |
| 0.53% Chelated Iron (Fe) | |
| 0.52% Water Soluble Iron (Fe) | |
| Manganese (Mn) | 0.59% |
| 0.46% Water Soluble Manganese (Mn) | |
| Molybdenum (Mo) | 0.001% |
| Zinc (Zn) | 0.29% |
| 0.23% Water Soluble Zinc (Zn) | |

**DERIVED FROM:** Polymer Coated Ammonium Nitrate, Polymer Coated Calcium Nitrate, Polymer Coated Ammonium Phosphate, Polymer Coated Calcium Phosphate, Polymer Coated Ammonium Polyphosphate, Polymer Coated Potassium Sulfate, Polymer Coated Iron EDTA, Polymer Coated Sulfate of Potash Magnesia, Polymer Coated Magnesium Sulfate, Polymer Coated Iron Citrate, Polymer Coated Manganese Sulfate, Polymer Coated Copper Sulfate, Polymer Coated Zinc Sulfate, Polymer Coated Sodium Borate, Ferrous Sulfate, Iron Sucrate, Iron EDTA, Iron Citrate, Magnesium Sulfate, Magnesium Sucrate, Manganese Sucrate, Zinc Sucrate, Copper Sucrate, Sodium Borate, Sodium Molybdate, Manganese Sulfate, Zinc Sulfate, *The (LIST NUTRIENTS) have been polymer coated to provide 13% Slow Release Nitrogen (N), 3% Slow Release Available Phosphate (P2O5), 9% Slow Release Soluble Potash (K2O)

UP TO: **180 DAYS**

AVG MEDIAN TEMPS

| 60° | | 70° | | 80° | |
|---|---|---|---|---|---|
| 240 | 8 | 210 | 7 | 180 | 6 |
| Days/Mnths | | Days/Mnths | | Days/Mnths | |

GUARANTEED BY: F1062

QUALITY CONTROL BATCH NUMBER:

WARNING TO PURCHASER. THIS IS A DISCLAIMER. The performance warranty and/or release of this product, whether stated or implied, is null and void if improperly stored.

Heavy Metal Statement: Information regarding the contents and levels of metals in this product is available on the internet at http://www.aapfco.org/metals.htm

CAUTION: KEEP OUT OF THE REACH OF CHILDREN HARMFUL IF SWALLOWED. This product must be stored under cool and dry conditions.

Environmental Caution: As a precaution, fertilizer products should not be applied within 10 feet of any water body.

Caution: The application of fertilizer containing Molybdenum (Mo) may result in forage crops containing levels of Molybdenum which may be toxic to ruminant animals.

PER TREE APPLICATION RATES

| Type | UP TO 180 DAYS |
|---|---|
| Item # | 13-3-9-180 |
| YEARS IN GROVE | Lbs. |
| 1 YEAR | .05-.75 |
| 2 YEARS | .75-1.5 |
| 3 YEARS | 1.0-2.0 |
| 4 YEARS | 1.5-2.5 |
| 5 YEARS | 2.0-3.0 |

Conversion: 5 Grams = 1 Teaspoon | 15 Grams = 1 Tablespoon

# 20-0-20

Harrell's Growing a Better World®

6 month

**FERTILIZER**

**Batch #: 1609-5022**

**GUARANTEED ANALYSIS**

| | |
|---|---|
| **Total Nitrogen (N)** | **20.0000%** |
| 0.9360% Nitrate Nitrogen | |
| 0.0640% Ammoniacal Nitrogen | |
| 19.0000% Urea Nitrogen | |
| **Soluble Potash ($K_2O$)*** | **20.0000%** |
| **Calcium (Ca)** | **1.2270%** |
| **Magnesium (Mg)** | **1.3280%** |
| 1.3280% Water Soluble Magnesium (Mg) | |
| **Iron (Fe)** | **1.0000%** |
| 0.2000% Water Soluble Iron (Fe) | |
| 0.2500% Chelated Iron (Fe) | |

Derived From: Polymer Coated Calcium Nitrate, Polymer Coated Muriate of Potash, Polymer Coated Urea, Ferric Oxide, Ferrous Sulfate, Iron EDTA, Iron Humate, Iron Sucrate, Kieserite

# 20-0-20

Harrell's Growing a Better World®

12 month

**FERTILIZER**

**Batch #: 1609-5022**

**GUARANTEED ANALYSIS**

| | |
|---|---|
| **Total Nitrogen (N)** | **20.0000%** |
| 0.9360% Nitrate Nitrogen | |
| 0.0640% Ammoniacal Nitrogen | |
| 19.0000% Urea Nitrogen | |
| **Soluble Potash ($K_2O$)*** | **20.0000%** |
| **Calcium (Ca)** | **1.2270%** |
| **Magnesium (Mg)** | **1.3280%** |
| 1.3280% Water Soluble Magnesium (Mg) | |
| **Iron (Fe)** | **1.0000%** |
| 0.2000% Water Soluble Iron (Fe) | |
| 0.2500% Chelated Iron (Fe) | |

Derived From: Polymer Coated Calcium Nitrate, Polymer Coated Muriate of Potash, Polymer Coated Urea, Ferric Oxide, Ferrous Sulfate, Iron EDTA, Iron Humate, Iron Sucrate, Kieserite

# IFAS-Growers Field Trials

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

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## FIELD TRIAL SIGN UP

**CONTACT INFORMATION**

Name: ______________________________________________

Address: ______________________________________________

City: ______________________ State: __________ Zip Code: ______________

Phone Number: ______________________________________________

**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): ______________ Trial Property Size (acres): ______________

Circle the types of fertilizer programs you currently use.

Ground Controlled Release Ground Soluble/Conventional Fertigation

**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**

If interested, please fill up the sign up sheet and return to registration desk

# 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

1. This document is SL253.04, one of a series of the Soil and Water Science Department, UF/IFAS Extension. Original publication date January 2008. Revised April 2010. Reviewed March 2015. Visit the EDIS website at http://edis.ifas.ufl.edu.

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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.

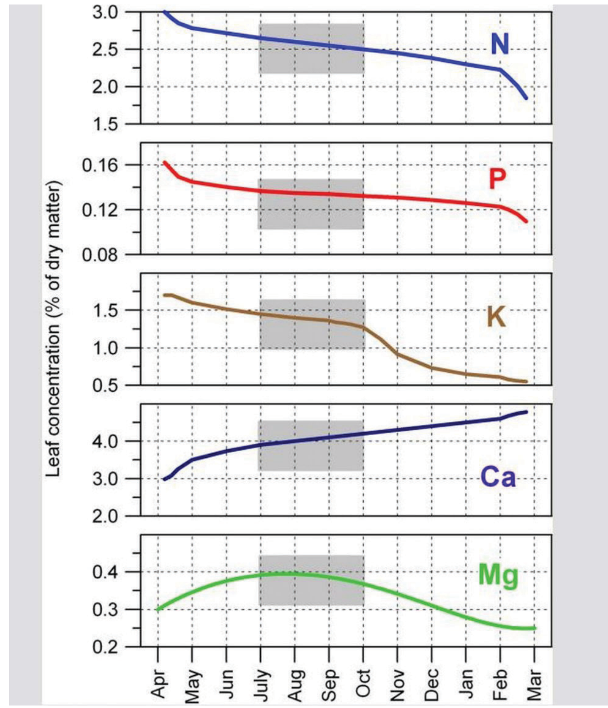


Figure 2. Changes in concentration of N, P, K, Ca, and Mg in citrus leaves with age. The shaded areas denote the recommended sampling period and the optimum concentration range for each element.

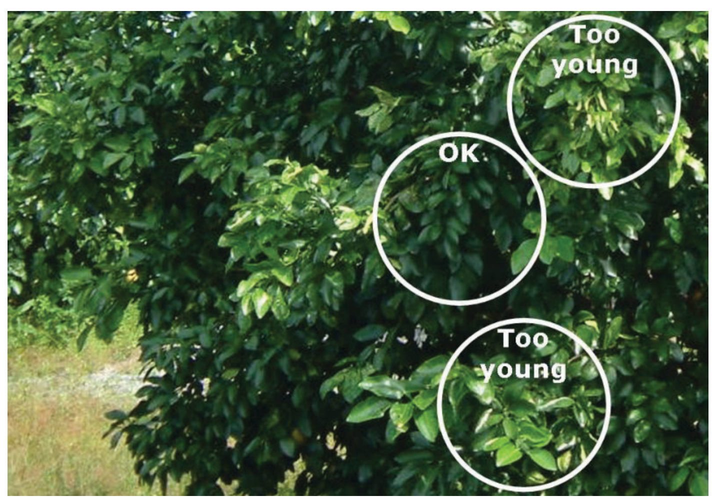


Figure 3. Sample four- to six-month-old spring flush leaves from nonfruiting twigs. (Photograph by Thomas Obreza.)

### 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).

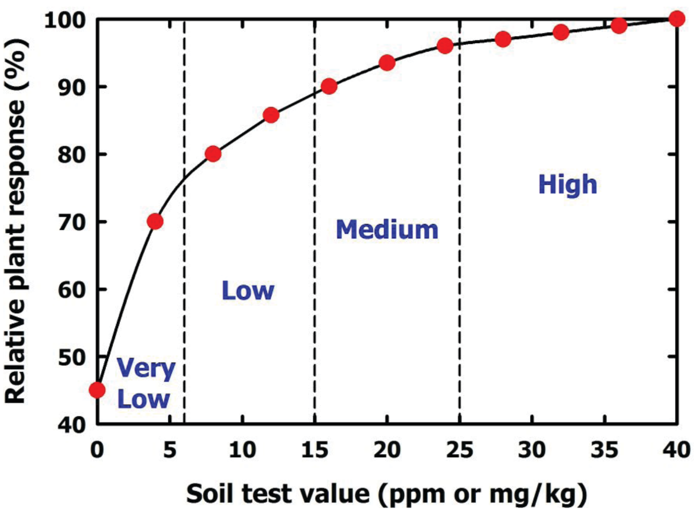

Figure 4. Ideal soil test calibration curve.

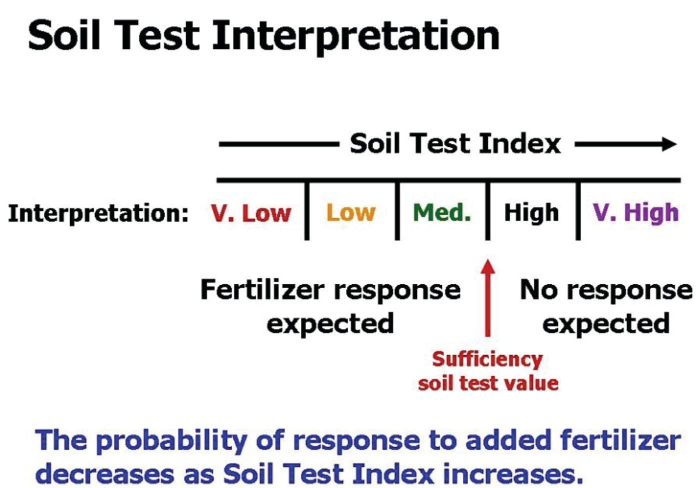

Figure 5. Soil test interpretation categories and their relationship to expected fertilizer response.

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).

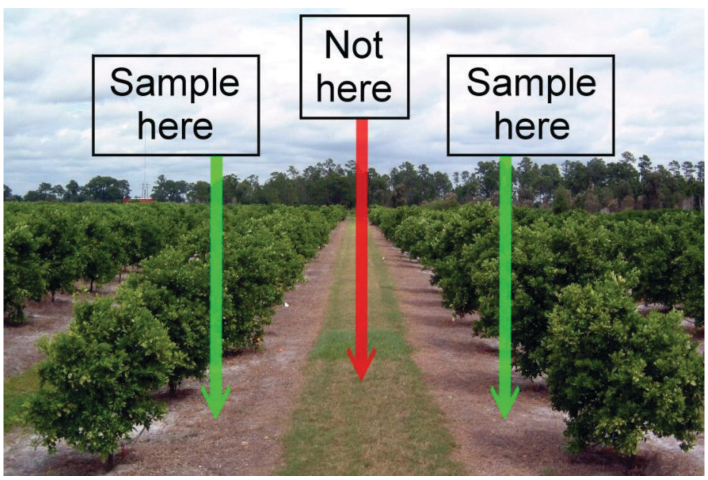


Figure 6. Sample soil near the dripline of the trees, not in the middle of the row. (Photograph by Thomas Obreza.)

- 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).

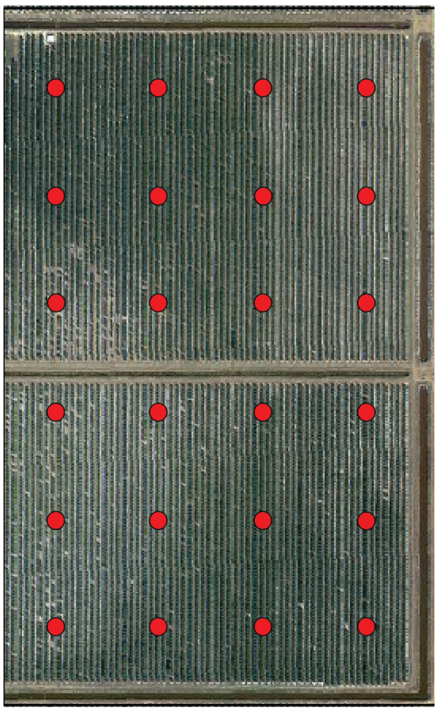

Figure 7. Example of the grid sampling strategy for selecting soil and leaf sampling locations. The red dots show predetermined sampling locations that will be recorded with GPS equipment and used to construct variability maps.

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.

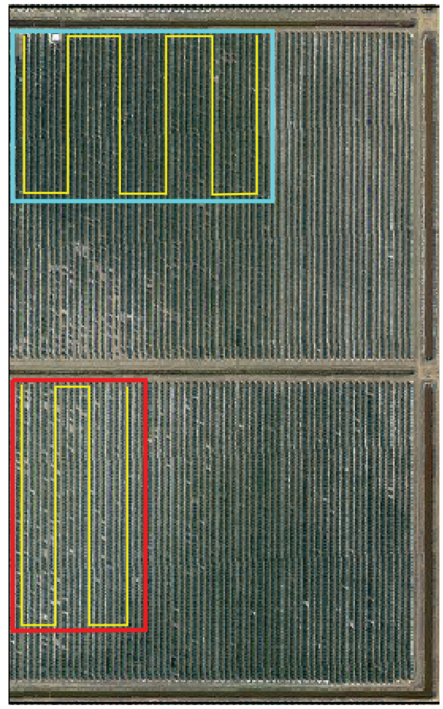

Figure 8. Example of soil and leaf tissue sampling locations using the management zone method. The grove zone area delineated by the blue rectangle is a productive area, while the one delineated by the red rectangle is a weak area. The yellow zigzag line denotes the sampling pattern within each management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

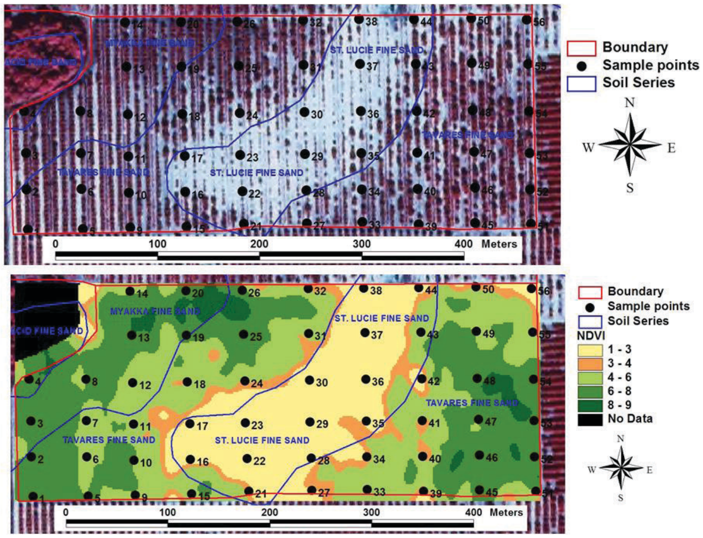


Figure 9. Example of grid sampling coupled with a soil map and resulting citrus yield map. Integration of these components can lead to effective sampling and better management decisions to optimize yield and quality. These strategies also qualify as Best Management Practices. (Image by Arnold Schumann.)

## 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

Alva, A. K. 1993. Comparison of Mehlich 3, Mehlich 1, ammonium bicarbonate-DTPA, 1.0M ammonium acetate, and 0.2M ammonium chloride for extraction of calcium, magnesium, phosphorus, and potassium for a wide range of soils. *Commun. Soil Sci. Plant Anal.* 24(7&8):603-612.

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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.<br>2.Review N fertilizer rate. |
| P | 1.Apply P fertilizer.<br>(see Chapter 8, SL 253). | 1.Do nothing. |
| K | 1.Increase K fertilizer rate.<br>(see Chapter 8, SL 253).<br>2.Apply foliar K fertilizer. | 1.Decrease K fertilizer rate. |
| Ca | 1.Check soil pH.<br>2.Check soil test Ca status.<br>3.Consider applying lime or soluble Ca fertilizer depending on soil pH. | 1.Do nothing. |
| Mg | 1.Check soil test Mg status.<br>2.Check soil pH.<br>3.Consider applying dolomitic lime or soluble Mg fertilizer depending on pH. | 1.Do nothing. |
| Micronutrients | 1.Check soil pH and adjust if needed.<br>2.Apply foliar micronutrients.<br>3.Include micronutrients in soil-applied fertilizer. | 1.Check for spray residue on tested leaves.<br>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.<br>2.Use acid-forming N fertilizer.<br>3.Apply elemental sulfur.<br>4.Change rootstocks. |
| Organic matter[2] | 1.Do nothing (live with it).<br>2.Apply organic material. | 1.Do nothing. |
| P | 1.Check leaf P status.<br>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.<br>2.Check leaf Ca status. | 1.Do nothing.<br>2.Check leaf K and Mg status. |
| Mg | 1.Check soil pH and adjust with dolomitic lime if needed.<br>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.

SL222

# Increasing Efficiency and Reducing Costs of Citrus Nutritional Programs[1]

Mongi Zekri, Thomas Obreza, and Arnold Schumann[2]

To maintain a viable citrus industry, Florida growers must consistently produce large, high quality, economic fruit crops from year to year. Efficiently producing maximum yields of high quality fruit is difficult without an understanding of soils 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 they are unable to retain sufficient quantities of available plant nutrients against leaching by rainfall or excessive irrigation.

## Nitrogen and Potassium

Nitrogen (N) and potassium (K) are the two most important nutrients applied as fertilizer in Florida citrus groves. Nitrogen influences vegetative growth, flowering, and fruit yield more than any other nutrient. Potassium plays a key nutritional role in determining yield, fruit size, and quality. Fertilizer application ratios of N to K are usually 1:1, but a ratio of 1:1.25 may be useful on high pH or calcareous soils if K is low in the tree.

Management practices that improve fertilizer efficiency include:

- checking leaf analysis results for nutritional deficiencies or excesses,
- basing N fertilizer rates on IFAS recommendations and expected production (Tables 1, 2, and 3),
- selecting fertilizer formulations appropriate for existing conditions,
- carefully placing fertilizer within the root zone,
- timing applications to avoid the rainy season,
- splitting applications, and
- irrigating to meet the needs of the tree while minimizing leaching.

### Leaf Analysis

Leaf sampling and analysis is a useful management tool for making fertilization decisions. One indicator of successful fertilizer management is a citrus tree with leaf nutritional standards within optimum ranges (Table 4). Trends of leaf N and K results over several years provide the best criteria for adjusting rates within the recommended ranges. Soil analysis is useful to determine soil pH and extractable phosphorus, calcium, and magnesium. Current Florida soil test interpretations for a variety of crops including citrus are presented in Table 5.

### Recommended Fertilizer Rates

Numerous N fertilizer rate and timing studies conducted by University of Florida and USDA-ARS scientists for many years on a wide range of soil types, tree ages, varieties, rootstocks, and cultural conditions have verified that N rates in excess of 200 to 240 lbs/acre are not justified except for unusually productive groves (e.g., > 700 boxes/acre for

1. This document is SL222, one of a series of the Soil and Water Science Department, UF/IFAS Extension. Original publication date January 2005. Revised April 2010. Reviewed August 2015. Visit the EDIS website at http://edis.ifas.ufl.edu.

2. Mongi Zekri, citrus Extension agent IV, UF/IFAS Extension Hendry County; Thomas Obreza, professor, Soil and Water Science Department; and Arnold Schumann, assistant professor, Citrus Research and Education Center; UF/IFAS Extension, Gainesville, FL 32611.

round oranges). Excessive rates of N can reduce yields and fruit size.

## Grove Conditions

In a mature grove where there is little net increase in tree size, N used for leaf growth is largely recycled as leaves fall, decompose, and mineralize. Replacing N removed by fruit harvest becomes the main focus of fertilization, and nutrient requirements should vary as the crop load changes. Nutritional programs should also be adjusted when leaf or tree canopy loss occurs due to severe pruning or freezes, or if extensive root damage occurs following flooding, tropical storms, or hurricanes. In the case where leaves and fruit have been lost but the root system remains intact, fertilizer rates may need to be elevated to support the growth of replacement leaves and fruit. If roots and canopy both suffer damage, fertilizer rates should be reduced proportionally to the amount of canopy loss. With the reduction in rates, application frequency should be increased.

Inorganic and synthetic organic N fertilizers are high-analysis materials and are generally most economical for use in citrus groves. They are rapidly available unless formulated as a controlled-release product. The use of high analysis fertilizers almost eliminates the need for filler, so a substantial portion of the mixing, transportation, and application cost is reduced. Loss of N through ammonia volatilization on calcareous soils is a concern when ammoniacal-N is applied to the soil surface without being incorporated by rainfall or irrigation. The use of controlled-release fertilizers for resets in established groves is a viable option.

## Applying Fertilizer

Two-thirds of the fertilizer applications to citrus each year should occur between January and early June, timed so that nutrients are available during the flowering and fruit-setting period. The remaining one-third can be applied in September or October. Split fertilizer applications or fertigation combined with sound irrigation management increase fertilizer efficiency by consistently supplying nutrients and by reducing leaching if unexpected rain occurs. With these circumstances, less fertilizer is required. Fertilizer reduction can also be realized by targeted placement within the root zone, timing applications to avoid rainy periods.

When fertigating, nutrients are placed in the wetted area where feeder roots are extensive. The fertilizer can be applied frequently in smaller amounts so it is available when the tree needs it. Thus, application costs are lowered when compared with dry or foliar fertilizers. Efficiency and cost savings of fertigation are greatest for young trees. Fertigation is not a recommended production practice if the irrigation system is non-uniform or poorly designed. Remember that fertilizer and water are wasted when a calendar-based fertigation schedule applies nutrients to very wet soil. Water and nutrient uptake are drastically reduced under saturated soil conditions.

Nutrient uptake is enhanced by foliar feeding when a soil is calcareous or possesses any other condition that decreases a tree's ability to take up nutrients. Foliar applications of low-biuret urea (25 to 28 lbs N/acre) or phosphorous acid (2.6 quarts/acre of 26 to 28% $P_2O_5$ material) in late December or early January are known to increase flowering, fruit set, and fruit yield. Post-bloom foliar applications of potassium nitrate or mono-potassium phosphate (8 lbs/acre $K_2O$) in late April have been found to increase fruit size and yield.

# Phosphorus

Phosphorus (P) applied to citrus groves during establishment and early growth stages does not leach significantly, but rather P accumulates in the soil where it becomes slowly available. Consequently, fertilizer applications containing P can be reduced or omitted in mature groves. Phosphorus does not leach readily when the soil pH is 6 or higher, and the fruit crop removes very little P. Therefore, regular P fertilizer applications are not necessary. Some soils used for new citrus plantings may be naturally low in P--for example the commonly known "sand-soaked" areas. In this situation, P fertilizer should be applied, but only until soil tests show it is no longer necessary.

# Micronutrients

The use of most micronutrients is recommended only when deficiency symptoms persist. Copper should not be included in the fertilizer if copper fungicides are used or if a soil test shows sufficient copper is present (5 to 10 lbs/acre). Molybdenum deficiency occurs on soils that have become very acidic, and can serve as an indicator of potential problems with aluminum toxicity. A lime application will raise soil pH and usually corrects this problem. Iron deficiency can be corrected by applying an Fe chelate, for example Fe-EDTA where soil pH < 7 and Fe-EDDHA where soil pH > 7. Foliar spray applications of micronutrients (manganese, zinc, copper, boron, and molybdenum) are much more effective and economically practical than soil applications. These micronutrients should be included with post-bloom or summer foliar sprays after full leaf expansion of the new growth flush.

## Soil pH

Targeted soil pH should be between 5.5 and 6.5. Soils high in copper should be maintained at the high end of the range. A distinct advantage of pH 6 compared with pH 5 has been demonstrated in several studies, and pH of 7 was no better than 6. Soil pH can be increased by application of either calcitic or dolomitic lime. Dolomite supplies both calcium and magnesium, so the choice of dolomite would be more advantageous if magnesium is also necessary. Liming a soil that has a pH of 6 or greater is costly and unnecessary. In groves where soils have a favorable pH, but a soil test or leaf analysis indicates low calcium, gypsum (calcium sulfate) can be applied as a source of calcium that will not affect soil pH. Applying dolomite as a source of magnesium is not a recommended practice if the soil pH is in the desired range. Under these conditions, soil application of magnesium sulfate or foliar application of magnesium nitrate are effective for correcting magnesium deficiency.

## Key Points Summarized

- Increasing the efficiency of applied nutrients is a key to economic citrus production.
- Nitrogen and potassium fertilizers affect fruit production and quality more than any other applied nutrients.
- Management practices that improve fertilizer efficiency include:

1. Using leaf and soil analysis to guide fertilization programs.
2. Choosing realistic fertilizer rates based on established guidelines and expected production.
3. Selecting fertilizer sources appropriate for grove conditions.
4. Careful placement and timing of fertilizer applications.
5. Managing irrigation to minimize leaching of soluble nutrients.

- Foliar feeding is appropriate when soil conditions prevent sufficient uptake of nutrients to meet tree demands.
- Phosphorus fertilizer should be applied judiciously because P can accumulate in the soil.
- Micronutrients should be applied only when deficiency symptoms persist.
- Keep soil pH in the range of 5.5 to 6.5. Do not overlime.

Table 1. Current UF/IFAS-recommended N fertilizer rates for citrus.

| Year in Grove | Oranges | Grapefruit | Tangerines | Murcotts | Other |
|---|---|---|---|---|---|
| | | ------------------------------ lbs N/tree/year --------------------------- | | | |
| 1 | 0.15–0.30 | same | same | same | same |
| 2 | 0.30–0.60 | same | same | same | same |
| 3 | 0.45–0.90 | same | same | same | same |
| | | -------------------------------- lbs N/acre/year ------------------------------ | | | |
| 4+ | 120–200 | 120–160 | 120–250 | 120–300 | 120–200 |
| | 120–200[A] | 120–210[A] | | | |

[A] Nitrogen Best Management Practices range as specified by the Florida Dept. of Agriculture and Consumer Services.

Table 2. Average amounts of various nutrients contained within 100 boxes of Hamlin oranges.[A]

| Nutrient | lbs of nutrient per 100 boxes (90 lbs/box) of fruit |
|---|---|
| N | 12.5 |
| P | 1.4 |
| K | 17.6 |
| Ca | 4.5 |
| Mg | 1.9 |
| S | 1.1 |
| Fe | 0.024 |
| B | 0.020 |
| Zn | 0.020 |
| Mn | 0.011 |
| Cu | 0.006 |

[A] A. K. Alva, unpublished data.

Table 3. Average amounts of various nutrients contained within 100 boxes of four citrus varieties.[A]

| Nutrient | Hamlin | Parson Brown | Valencia | Sunburst |
|---|---|---|---|---|
| | | --------- lbs of nutrient per 100 boxes[B] of fruit --------- | | |
| N | 10.6 | 11.2 | 13.3 | 13.5 |
| P | 1.5 | 1.5 | 2.0 | 1.8 |
| K | 13.5 | 13.2 | 14.3 | 13.9 |
| Ca | 4.0 | 4.9 | 4.3 | 3.3 |
| Mg | 1.1 | 1.2 | 1.2 | 1.0 |
| Fe | 0.02 | 0.03 | 0.07 | 0.04 |
| Mn | 0.02 | 0.02 | 0.02 | 0.02 |
| Zn | 0.03 | 0.03 | 0.03 | 0.04 |
| Cu | 0.005 | 0.006 | 0.007 | 0.007 |

[A] S. Paramasivam, A. K. Alva, K. H. Hostler, G. W. Easterwood, and J. S. Southwell. 2000. Fruit nutrient accumulation of four orange varieties during fruit development. J. Plant Nutrition 23:313-327.
[B] 1 box = 90 lbs of oranges.

Table 4. Standard table for assessing nutritional status and adjusting fertilizer programs for citrus: *Leaf analysis standard for assessing current nutrient status of citrus trees based on concentration of mineral elements in 4- to 6-month-old-spring-cycle leaves from non-fruiting terminals*.

| Element | Deficient less than | Low | Satisfactory | High | Excess more than |
|---|---|---|---|---|---|
| Nitrogen (N) (%) | 2.2 | 2.2–2.4 | 2.5–2.8 | 2.9–3.2 | 3.3 |
| Phosphorus (P) (%) | 0.09 | 0.09–0.11 | 0.12–0.17 | 0.18–0.29 | 0.30 |
| Potassium (K) (%) | 0.7 | 0.7–1.1 | 1.2–1.7 | 1.8–2.3 | 2.4 |
| Calcium (Ca) (%) | 1.5 | 1.5–2.9 | 3.0–5.0 | 5.1–6.9 | 7.0 |
| Magnesium (Mg) (%) | 0.20 | 0.20–0.29 | 0.30–0.50 | 0.51–0.70 | 0.80 |
| Sulfur (S) (%) | 0.14 | 0.14–0.19 | 0.20–0.40 | 0.41–0.60 | 0.60 |
| Chlorine (Cl) (%) | ------ | ------ | <0.5 | 0.5–0.7 | 0.7 |
| Sodium (Na) (%) | ------ | ------ | <0.2 | 0.2–0.5 | 0.5 |
| Iron (Fe) (ppm) | 35 | 35–59 | 60–120 | 121–200 | 250 |
| Boron (B)(ppm) | 20 | 20–35 | 36–100 | 101–200 | 250 |
| Manganese (Mn) (ppm) | 18 | 18–24 | 25–100 | 101–300 | 500 |
| Zinc (Zn) (ppm) | 18 | 18–24 | 25–100 | 101–300 | 300 |
| Copper (Cu) (ppm) | 4 | 4–5 | 6–16 | 17–20 | 20 |
| Molybdenum (Mo) (ppm) | 0.06 | 0.06–0.09 | 0.1–1.0 | 2–50 | 50 |

Table 5. Current Mehlich 1 (double-acid) soil test interpretation for Florida citrus on mineral soils.

| Element | Very Low | Low | Medium | High | Very High |
|---|---|---|---|---|---|
| | | ------------------------------------ mg/kg ---------------------------------- | | | |
| Phosphorus (P) | < 10 | 10–15 | 16–30 | 31–60 | > 60 |
| Potassium (K) | < 20 | 20–35 | 36–60 | 61–125 | > 125 |
| Magnesium (Mg) | | < 16 | 16–30 | > 30 | |
| Calcium (Ca) | | | 150–250 | | |
| mg/kg = parts per million (ppm) = (lbs/acre) ÷ 2. | | | | | |

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# Improving Citrus Nitrogen Uptake Efficiency: Understanding Citrus Nitrogen Requirements[1]

K.T. Morgan and E.A. Hanlon[2]

This publication is one in a series of three looking at improved citrus nutrition by increasing the efficiency of fertilizer use. In these three publications, we address citrus nitrogen (N) requirements, seasonal water use, and how irrigation scheduling and fertilizer management are linked. The objectives of this document are:

1. To better match citrus tree N requirements at selected life stages with fertilization practices based on tree growth;
2. To explain the demands for fertilization by citrus trees recovering from leaf loss caused by storms, insects, or disease;
3. To relate citrus nutrient uptake efficiency (NUE) as a means to improve or maintain productivity while minimizing ground and surface water pollution.

This series of publications, dealing with citrus nutrition and irrigation management would be of interest to citrus producers, fertilizer dealers, Certified Crop Advisers, and other parties interested in citrus fertilization practices.

## Citrus Fruit Crop Requirement for Nitrogen

The citrus fruit crop requirement for N is equal to the amount of N contained in the harvested fruit crop (Figure 1). Mature fruit contain approximately 0.1 pound of N per 90 pound box of fruit. This N amount is removed from the grove with the fruit, and so is unavailable for recycling within the grove. Thus, this N must be added back into the grove on an annual basis to become part of the next citrus harvest. This N is added back to the grove by the application of inorganic fertilizers, which are often quite soluble after wetting. However, other sources such as compost or controlled release fertilizers may also supply the appropriate amount of N.

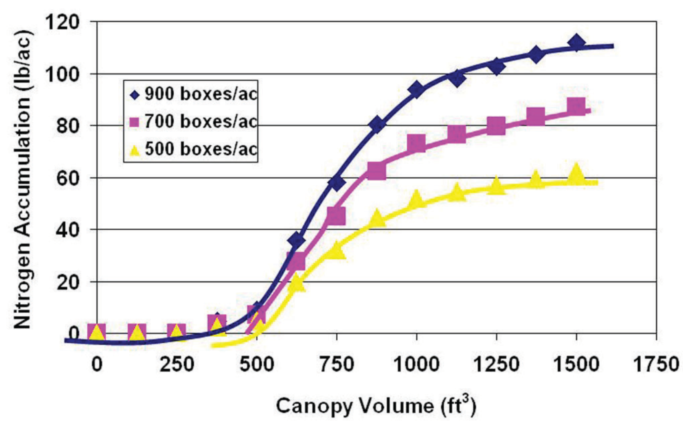


Figure 1. Relationship of tree size (canopy volume) to nitrogen accumulation and maximum harvestable citrus fruit yield.

The bulk of the N within the grove, however, is really not in the harvested fruit, but in the actively growing trees. Blooms, fruit, woody tissues (both above and below ground), and leaves all contain N and other nutrients. As

1. This document is SL-240, one of a series of the Soil and Water Science Department, UF/IFAS Extension. Original publication date March 2006. Reviewed May 2014. Visit the EDIS website at http://edis.ifas.ufl.edu.

2. K.T. Morgan, assistant professor, and E.A. Hanlon, professor, Soil and Water Science Department, Southwest Florida REC, Immokalee, Florida; UF/IFAS Extension, Gainesville, 32611.

these materials fall to the ground, some (approximately 50%) of the N they contain is recycled within the grove. Therefore, citrus trees must take up N in excess of the crop requirement for young trees to increase in size.

## Citrus Biomass Accumulation

The increase in amount of plant parts (leaves, branches, roots, etc.) as citrus trees grow larger is called biomass accumulation. Since the concentration of N in these plant parts is within a relatively narrow range, the amount of N in a tree (N accumulation) is directly related to biomass accumulation as trees increase in size. A review of previous research found no clear trends in biomass and nitrogen accumulation with increase in tree age. This finding appears due to inconsistent tree spacings, soil characteristics, and cultural practices among the studies resulting in variations in tree size with age.

To determine the relationships of biomass and N accumulation with tree size, a comprehensive study has documented the accumulation of N (and other nutrients) at selected growth stages. Sampled plant parts included roots, taproot, shoots, trunk, main scaffold branches, twigs, and leaves. In short, all of the plant parts were sampled except the citrus fruit. The findings indicated that N accumulation was directly related to biomass accumulation and thus tree size. This relationship was consistent regardless of rootstock or scion, and is useful for defining strategies to accurately manage N fertilization for citrus.

The above-ground portions of the tree accumulate more biomass than below-ground portions, indicating that scaffold limbs, twigs, and leaves must be present to support the increasing tree size and related increasing fruit production (Figure 2). Nitrogen accumulation in growing trees is proportioned between the above ground and below ground plant parts and is a sum of the two for the entire tree (Figure 3). The rate of N accumulation with increase in canopy volume decreases at trees get larger. Young trees (tree canopy 0-250 ft$^3$) have a higher proportion of leaves compared to stems. Leaves contain a greater N concentration than do stems, thus, accumulation of N for young trees is at the rate of 0.1 pound of N per 50 ft$^3$ increase in canopy volume. Larger trees (canopy volume 1000-1500 ft$^3$) have a greater increase in woody tissue than leaves and accumulate N at a lower rate of 0.05 pound of N for the same 50 ft$^3$ increase in canopy volume. Moderate sized trees (canopy volume 250-1000 ft$^3$) accumulate N at an intermediate rate.

Knowledge of tree biomass accumulation based on citrus tree size, allows one to estimate the total annual N requirement, because it is directly related to the sum of the amount of N removed in the harvested citrus fruit and the N accumulation with tree growth. This sum must then be multiplied by an efficiency factor, the so-called nutrient uptake efficiency (NUE), for the selected fertilization source in concert with irrigation management to derive an appropriate N fertilization rate (discussed below). Examples of these calculations are given at the end of this publication.

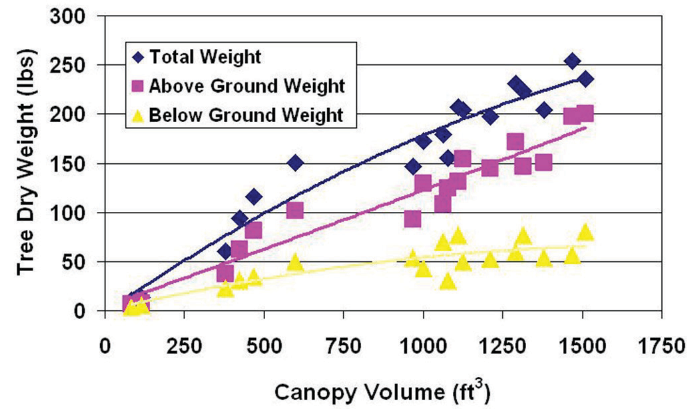


Figure 2. As tree size (canopy volume) increases, biomass (tree dry weight) is accumulated in both below ground and above ground plant parts similar to nitrogen accumulation. The above ground portions (trunk, scaffold branches, twigs, and leaves) accumulate more dry weight for a given tree size than below ground plant portions (taproot, lateral roots, and fibrous roots).

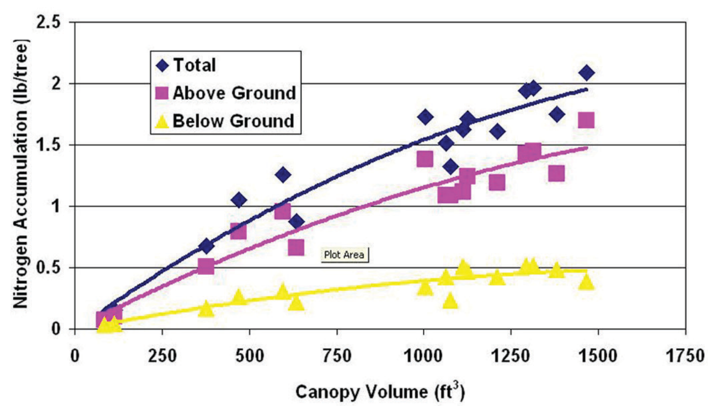


Figure 3. As tree size (canopy volume) increases, nitrogen is accumulated in both below ground and above ground plant parts. The above ground portions (trunk, scaffold branches, twigs, and leaves) accumulate more nitrogen for a given tree size than below ground plant portions (taproot, lateral roots, and fibrous roots).

## Fertilization for Rapid Tree Recovery from Storm, Pest, or Disease Damage

In addition to aiding fertilizer management decisions as tree size increases, knowledge of biomass and N accumulation can be useful to manage tree recovery after damage from storms or other defoliation causes. Leaves lost to storm, pest, or disease damage must be replaced rapidly to maintain fruit crop production. Nitrogen for new leaf growth is moved by the tree from woody tissue to the newly forming leaves. In turn, this N must be replaced from fertilizer or organic soil amendment sources to satisfy the crop nutrient requirements of the depleted woody tissue. To replace a 10% loss of leaves, a tree with a canopy size of 1,000 cubic feet requires approximately 15 pounds of N per acre (Figure 4). Similar sized trees that have lost 50 to 75% of their leaves, as happened to trees damaged by Hurricane Wilma, would require between 60 to 90 pounds of N per acre in the biomass to replace that N required to produce a full canopy of leaves. The amount of N application to replace these amounts of N will be discussed in the Improving Nutrient Uptake Efficiency section below.

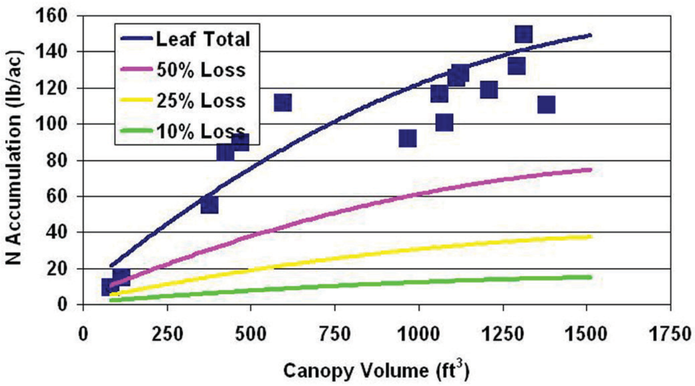


Figure 4. Relationship of tree size (canopy volume) to nitrogen accumulation and leaf loss due to storms or other damage.

If leaf loss is severe, leaves may not be replaced in one season, and may result in citrus yield reduction. A recent study determined that 25% leaf loss for two consecutive years had little effect on orange tree growth or yield. However, 50% leaf loss resulted in smaller leaves and fruit of both Hamlin and Valencia orange. Although yield of Hamlin oranges was not affected by 50% leaf loss, Valencia yield was significantly reduced in the second year. While yield loss is never a good thing, production managers can plan for this eventuality and implement additional fertilization practice changes. In cases where repeated defoliation has occurred, tree reserves will be lowered, decreasing the ability of the tree to recover. Again, grove managers can alter fertilization schedules to take advantage of this new information concerning N crop nutrient requirements based upon biomass measurements and the relationship to tree size.

# Improving Nutrient Uptake Efficiency

Although understanding that N accumulation is important when selecting fertilization rates, the efficiency with which N is taken up into the citrus plant must be incorporated into the fertilizer management plan. Nutrient uptake efficiency can be optimized by linking the nutrient application rate and timing to crop tissue concentration. This approach can work equally well for regular production or for improving growth of damaged trees (see Linking Citrus Irrigation Management to Citrus Fertilizer Practices, future EDIS publication for additional information on this subject).

In a well-managed grove where irrigation is correctly timed to avoid excessive leaching, and where fertilizer applications are timed appropriately to take advantage of citrus biomass needs, NUE should be within 40 to 60%. This percentage is the amount of applied N taken up by the citrus tree. The remainder of the fertilizer is either lost to conversions in the N cycle, taken up by microorganisms or other plants in the grove (ground cover, weeds, etc.), or lost due to leaching or runoff. Therefore, the example given above requiring 60 to 90 pounds of N to replace a 50 to 75% leaf loss, would require 120 to 180 pounds of N to replace these leaves. Movement of any nutrients, especially N, from the grove reduces NUE (to as low as 40%), is potentially a detriment to Florida's environment, and wastes fertilizer resources that are not used within the grove.

To calculate the amount of N needed, the total annual N requirement (from biomass accumulation and fruit crop) must be estimated and then divided by the NUE (Figure 5).

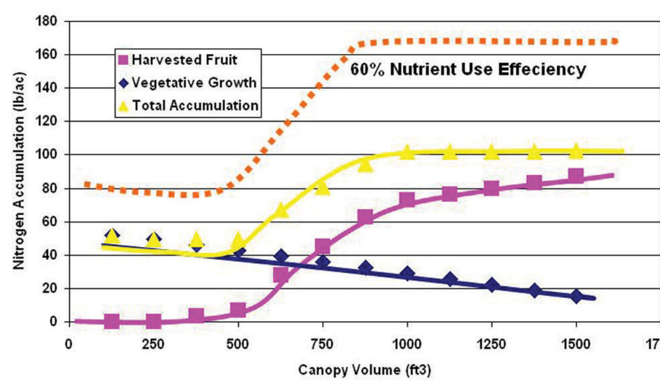


Figure 5. As tree size (canopy volume) increases, the total nitrogen accumulation reaches a plateau with much of the additional nitrogen accumulating in the harvested fruit. Total annual fertilizer requirement, assuming a 60% nutrient use efficiency for nitrogen, is shown as a function of tree size.

## Examples

**Example 1.** Assume trees average 750 $ft^3$ in canopy volume (12 ft tall and 9 ft in diameter), 200 trees per acre and produce 300 boxes of fruit per acre. Assume a canopy increase of 100 $ft^3$ and a 50% N uptake efficiency.

| | |
|---|---|
| Fruit N accumulation | 30 lbs of N per acre |
| Biomass N accumulation | 0.15 lb of N per tree |
| X 200 trees per acre | 30 lbs per acre |
| Total Fruit and Biomass N requirement | 60 lbs per acre |
| 50% maximum efficiency = 60 lbs/0.5 = 120 lbs per acre N requirement | |

**Example 2.** Assume trees average 1500 $ft^3$ in canopy volume (16 ft tall and 11 ft in diameter), 200 trees per acre and produce 700 boxes of fruit per acre. Assume a 50% N uptake efficiency.

| | |
|---|---|
| Fruit N accumulation | 70 lbs of N per acre |
| Biomass N accumulation (Figure 2) | 0.10 lb of N per tree |
| X 200 trees per acre | 20 lbs per acre |
| Total Fruit and Biomass N requirement | 90 lbs per acre |
| 50% maximum efficiency = 90 lbs/0.5 = 180 lbs per acre N requirement | |

## Conclusions

Recent research has documented the relationship between tree size and amount of leaves, branches, and roots of a citrus tree. Therefore, the need for N for both the tree growth and the harvested fruit can be estimated with increasing tree size. Using this new information about growth and tree development can be beneficial for N fertilization management. Also, this information must be considered when recovering from catastrophic leaf loss from storms, pests, and diseases. However, both fertilization rate and timing must be accompanied by efficient water management to avoid decreasing the nutrient use efficiency, which is at best between 50 and 60%. An integrated management approach must include knowledge of crop growth, fertilization efficiency, and matching irrigation management decisions. In addition to keeping fertilization and irrigation costs low, these actions ensure sustainable citrus production in Florida, and avoid environmental pollution associated with nutrient leaching from the grove.

## For More Information Regarding Citrus Biomass and N Accumulation


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# Improving Citrus Nitrogen Uptake Efficiency: Linking Citrus Irrigation Management To Citrus Fertilizer Practices [1]

K. T. Morgan and E. A. Hanlon[2]

This document is one in a series of three EDIS publications dealing with citrus nutrition and its relationship to both fertilizer management and irrigation scheduling. The objectives of this document are:

1. To match irrigation management with nitrogen fertilization practices;

2. To explain the components of an effective irrigation system for citrus that provides for high water uptake and fertilizer-uptake efficiency; and

3. To describe nutrient management planning and the possible role that precision agricultural techniques might play in both irrigation and fertilizer management for citrus production in Florida.

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

## Production Areas and Constraints

### Ridge

The Florida ridge lies in a generally north and south direction through the center of the peninsula, and is characterized by deep, well drained soils comprised mostly of sand (Figure 1). These soils permit rapid infiltration of rain and irrigation water, setting the scene for nutrient movement out of the citrus root zone (Figure 2). When nutrients are leached beyond the rootzone, the nutrients are no longer available to the plant, and may become an environmental pollution concern. Nitrate leaching is a major concern for citrus producers on ridge soils. In a survey of water wells in the Ridge citrus producing areas (McPherson et al., 2000), 63% of the wells had detectable levels of nitrate-nitrogen in the water, and 15% of the tested wells had concentrations greater than the regulatory maximum of 10 mg nitrate-nitrogen per liter (10 ppm).

### West Coast

The West Coast citrus production area (Figure 1) is described as a transitional area from the deep well drained soils found on the Ridge to the poorly drained soils found in the Flatwoods near the coasts. As with the Ridge, these soils have low water and nutrient holding capacities because they are composed mostly of sands (Figure 2).

### Flatwoods

The Gulf Coast and Indian River citrus production areas are dominated by so-called Flatwoods soils (Figure 1). Soils in the Flatwoods are characterized by poorly drained

1. This document is SL-246, one of a series of the Soil and Water Science Department, UF/IFAS Extension. Original publication date December 2006. Reviewed June 2014. Visit the EDIS website at http://edis.ifas.ufl.edu.

2. K.T. Morgan, assistant professor, and E.A. Hanlon, professor, Soil and Water Science Department, Southwest Florida REC, Immokalee, Florida; UF/IFAS Extension, Gainesville, FL 32611.

conditions requiring some form of drainage to develop a deep enough root zone to permit high quality citrus production (Figure 2). Many groves use beds to provide additional drainage, as well as drainage ditches and canals. Nitrate leaching in Flatwoods soils is greatly reduced compared to the well-drained soils found on the Ridge. Due to confining soil horizons and/or a perched water table, nitrates are reduced through a process called denitrification, the reduction of nitrate by microbial activity to N gases that disperse in the atmosphere. Nitrate concentrations are also reduced through lateral flow of water through the soil often entering surficial water bodies, rather than transporting the nitrates to the groundwater or surficial aquifers where the nitrates would be measured by well water testing. In Flatwoods soils, citrus growers must face the constraints of possible runoff and/or the accumulation of nutrients within drainage water or weeds in the grove.

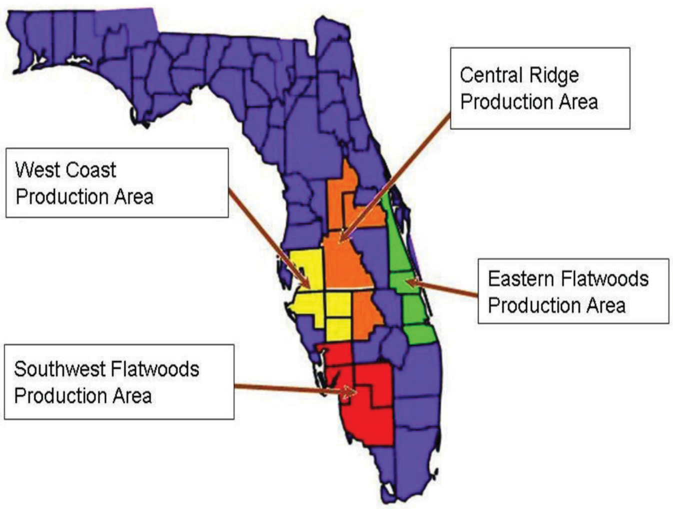


Figure 1. Florida citrus production areas by county.

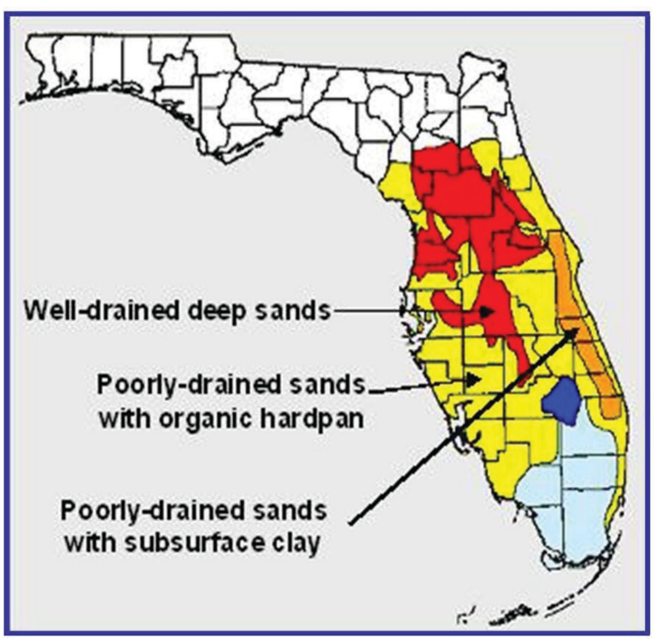


Figure 2. Soils in citrus production areas of Florida (Obreza et al., 2006).

## Water Supply

In all citrus production areas, the competition for water supply is increasing. Residential and commercial users demand more water from utilities, which, in turn, reduces the availability of water for agricultural and environmental uses. As Florida's population continues to grow, water available for agricultural purposes will continue to decrease or become more expensive. The growing of commercially acceptable crops, including citrus, is a water intensive activity; however, growers do have options. By increasing water uptake efficiency, a measure of the amount of water used by the plant compared to the amount of water added to the grove, growers can still produce high quality citrus while reducing their demand on the water supply. Reducing water consumption in commercial groves reduces the risk of insufficient water availability in the future.

## Water Uptake Efficiency

**Water Uptake Efficiency** is defined as:

$$\text{Water Uptake Efficiency (\%)} = \frac{\text{Tree Water Uptake}}{\text{Irrigation Amount}} \text{X } 100$$

While the calculation is simple, measurements needed to evaluate this equation are quite complex. Rather, growers should focus on the idea of improving water uptake efficiency through management techniques described in this document without actually trying to go to the time and expense of measuring efficiency of their water use.

# Irrigation Scheduling

As seen in the production constraints described above, most of Florida's citrus producing soils have low water and nutrient holding capacities. Therefore, appropriate irrigation scheduling is critical for proper citrus tree health as well as for minimizing water requirement. Healthy citrus trees are better able to withstand pest and disease pressures, as well as produce a high quality commercial product. Irrigation management should be geared toward maintaining optimal moisture and nutrient concentrations within the tree root zone. If that goal is achieved, trees will take up their maximum amounts of water and nutrients with minimum wastage. Equally important, as can be seen, excessive irrigation will reduce water uptake efficiency, as well as require more water and contribute to potentially negative environmental impacts.

## Nutrient Uptake Efficiency

Nutrients, especially nitrogen, move with water as the water passes through the soil (leaching) due to drainage, either downward to groundwater or laterally toward ditches and canals. Therefore, maximizing water uptake efficiency will also improve **nutrient uptake efficiency**. Nutrient uptake efficiency refers to the effectiveness of adding nutrients that are actually taken up by the plant, and not lost to leaching or other environmentally sensitive pathways.

**Nutrient Uptake Efficiency** is defined as:

$$\text{Nutrient Uptake Efficiency (\%)} = \frac{\text{Nutrient Taken Up by the Plant}}{\text{Nutrient Added in Fertilizer}} \times 100$$

The important point here is that Nutrient Uptake Efficiency and Water Uptake Efficiency are intrinsically linked. Management measures that improve one will likely improve the other.

Many different experiments have shown that citrus yield and quality do not increase meaningfully at nitrogen fertilization rates that are greater than **200 to 240 pounds nitrogen per acre** (for example, Alva and Paramasivam, 1998). Rates lower than 200 pounds N per acre can produce maximum yields if uptake efficiency is high. Other experiments with citrus fertilization have shown advantage in making **split fertilizer applications** throughout the season to reduce exposure of the soluble fertilizer to leaching from rainfall or excessive irrigation. Fertigation, (liquid fertilizer applied though the irrigation system) can effectively deliver split applications. Another common sense management technique is to avoid soluble fertilizer applications during Florida's rainy season, especially those sources containing nitrogen. Recent discussions concerning citrus fertilization best management practices may hold promise for cost sharing of controlled-release fertilizer applications (Obreza et al., 2006). Controlled-release fertilizers have been demonstrated to decrease the number of applications per year needed for appropriate citrus fertilization. In some instances, particularly for young trees, controlled-release fertilizers have higher nutrient uptake efficiencies compared with traditional soluble fertilizers. The UF/IFAS recommendations for soluble fertilizers include a maximum annual application rate, recommendations to use split fertilizer applications during the year, and avoiding applications during the wet season. Current UF/IFAS recommendations for the number of split applications of soluble fertilizers per year are 4 to 6 for young trees and at least 3 for mature trees. A minimum of 10 applications is recommended for fertigation. These recommendations are based upon the research findings described above.

## Management Goals and Tools

**Maintain adequate water and soil nutrient levels to maximize plant growth and health.**

There are a number of instruments available to help manage water within grove operations. Almost all of these instruments will do a better job of assisting with water management decisions than looking at the water level in field ditches or irrigating on the same day of the week. A number of extension documents are available through the UF/IFAS EDIS system (http://edis.ifas.ufl.edu/) describing a number of approaches to proper water management. As noted above, appropriate water management directly affects soil nutrient levels. By improving water management techniques and decision-making, growers are also improving their nutrient management.

**Decrease production cost and resource depletion**

By optimizing water and nutrient uses within the grove, growers will automatically decrease their production cost, as well as decrease their demand on limited water resources. Implementing measures to achieve this goal directly facilitates sustainable citrus production in Florida.

**Reduce nutrient losses and environmental impacts**

By focusing on improving both water and nutrient uptake efficiencies, growers will also be potentially reducing nutrient losses along with negative environmental impacts. Some nutrient loss due to seasonally frequent rains is unavoidable but loss due to poor management decisions can be minimized. Said another way, growers who focus on minimizing nutrient losses will also be facilitating maximum uptake by controlling fertilizer and water use, and improving water and nutrient uptake efficiencies within their grove operations.

## Management Method Options

### IRRIGATION SCHEDULING AND NUTRIENT MANAGEMENT PLANS

Addressing the **irrigation scheduling** issue through the use of instrumentation and/or a water budgeting approach ensures that water uptake efficiency is being addressed. Proper irrigation scheduling will have a positive effect on nutrient uptake efficiency. Irrigation scheduling through the use of soil water content sensors is the best method to accurately promote water use and provide the optimal amount of water to citrus trees. Many instruments are available for growers to use in irrigation scheduling. These instruments range from tensiometers to neutron probes and are described in Bulletin 343 (Munoz-Carpena, 2004)

The second method of irrigation scheduling is the use of estimates from computer programs. Some programs can be used to estimate both evaporation from the soil and transpiration through the tree. These predictions are based upon local weather data. This estimated water use is called evapotranspiration or ET and can be found for various locations across Florida by visiting the Florida Automated Weather Network site at http://fawn.ifas.ufl.edu. Use of water budgets for irrigation schedules is explained in SS459 (Morgan and Hanlon, 2006).

**Nutrient management plans** should be developed annually, and should include soil and plant-tissue test results. It is advisable to maintain these records to build a history of nutrient management within the grove. Realistic **production yield goals** should be based upon past production or potential production for younger trees. Coupling the soil and plant-tissue test results and related fertilizer recommendations with production yield goals and tree growth information (Morgan and Hanlon, 2006), grove managers can create nutrient budgets for nitrogen, phosphorus, and potassium fertilization. Information such as fertilization rate, application methods including the number of split applications, fertilizer sources, and dates of application should be recorded. This information coupled with subsequent yield information at the end of the season completes the annual plan. Using information collected from the previous years to refine the plan for the coming year means that managers are working systematically toward the goals expressed in this document.

The next steps for improving management decision-making processes and citrus production areas will likely be the adoption of **precision agricultural methods**. A part of the precision agricultural concept includes modifying existing irrigation systems, variable-rate fertilizer application, and an integrated **decision-support system.** Such methods can customize water and fertilizer applications for specific site variations in soils or tree size within a grove.

## Precision Agriculture

The components of a precision agricultural system must be by definition an information gathering and interpretation support system. Information collected from the grove should include soil and leaf nutrient concentrations, tree size (canopy volume), yields, and soil moisture availability. To be most effective, this information must be interpreted spatially. That is, information collected from the grove should be available to the decision maker through displays such as maps or computer graphics, showing where one or more of these measurements are placing constraints on realizing the goals established above. For example, soil moisture sensors may be indicating a dry region within the grove. Coupling this information with the soil survey map of the grove, this dry region may be a function of soil type.

In turn, this information can be used to design an effective irrigation management strategy; perhaps including this drier region in its own irrigation zone, if large enough to do so. If not, perhaps larger water emitters could be used in such a dry zone. This drier area could then be irrigated to appropriate soil moisture readings without over-irrigating the rest of the block or grove. In this example, the decision to create an irrigation zone addressing the dry area may save considerable irrigation pumping charges, and improve both the water and nutrient uptake efficiencies within the entire grove.

In another example, mapping of tree locations with related yields may identify considerable variation in production levels. In this case, another precision agricultural technique, variable-rate fertilizer applications, may prove beneficial. In research in citrus blocks that have different sized trees, variable-rate fertilizer applications can reduce fertilizer use by 20 to 40% relative to uniformly applied fertilizer (Schumann et al., 2006). Thus, such practices can pay for themselves very rapidly and reduce nutrient losses.

Decision-support systems are comprised of software programs that assist the manager with decisions concerning water and nutrient management as well as other grove operations. To use these systems, information on tree size and performance, are added to soil information to predict the need for irrigation and fertilizer applications in a site-specific manner. That is, schedules can be determined to improve both water and nutrient uptake efficiencies.

## Summary

Links between water uptake efficiency and nutrient uptake efficiency were discussed in light of selected management goals. By pursuing these goals, grove managers will promote healthy trees that produce commercially viable and high quality citrus products. At the same time, demands for scarce resources will be minimized and negative impacts on the environment will be reduced. Using both water and nutrients efficiently within grove operations can potentially decrease the costs of production. In turn, managers are contributing to the sustainability of the citrus industry within Florida.

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# 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.

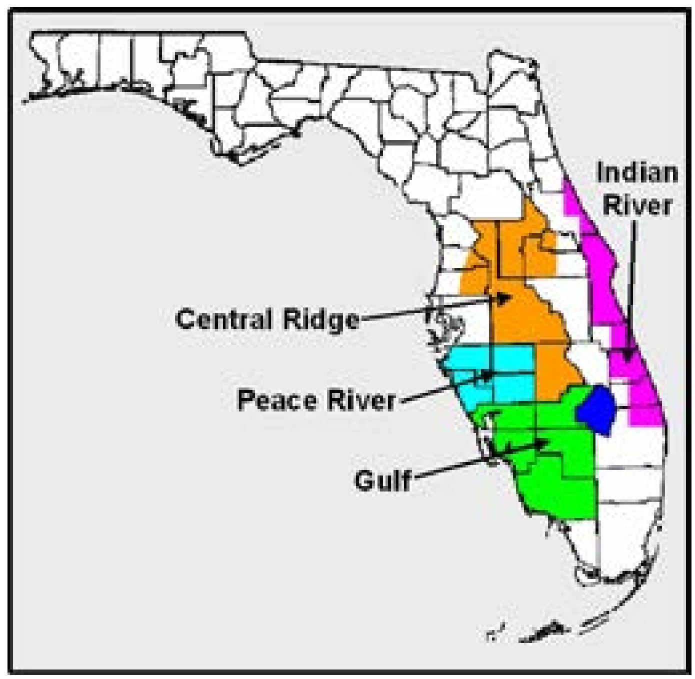


Figure 1. Citrus production areas of Florida.

1. This document is SL-243, one of a series of the Soil and Water Science Department,UF/IFAS Extension Original publication date July 2006. Reviewed June 2014. Visit the EDIS website at http://edis.ifas.ufl.edu.

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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.

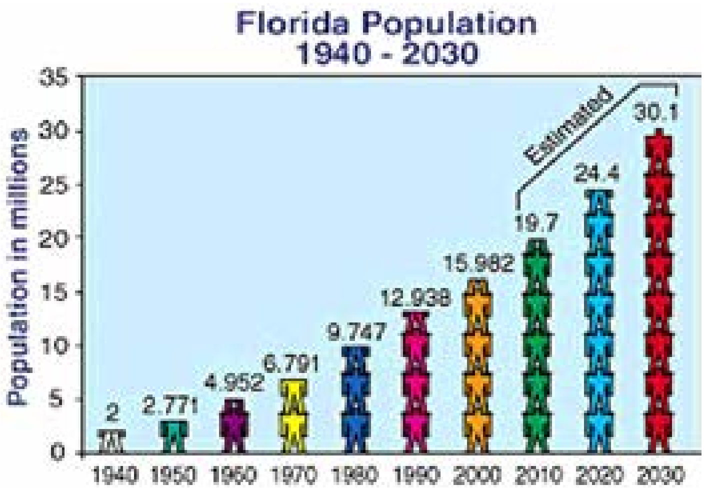


Figure 2. Florida human population growth from 1940 to 2000 and projected through 2030.

# 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.

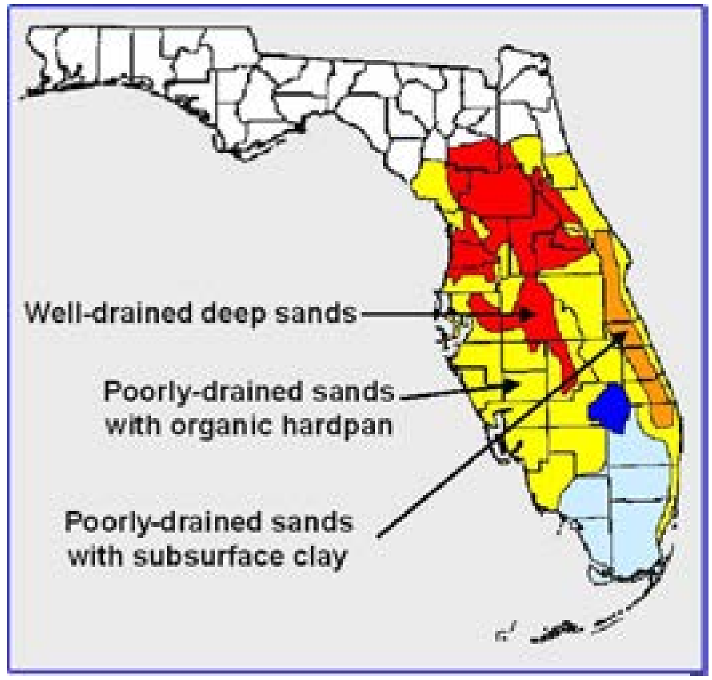


Figure 3. Soils in citrus production areas of Florida.

## 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 |

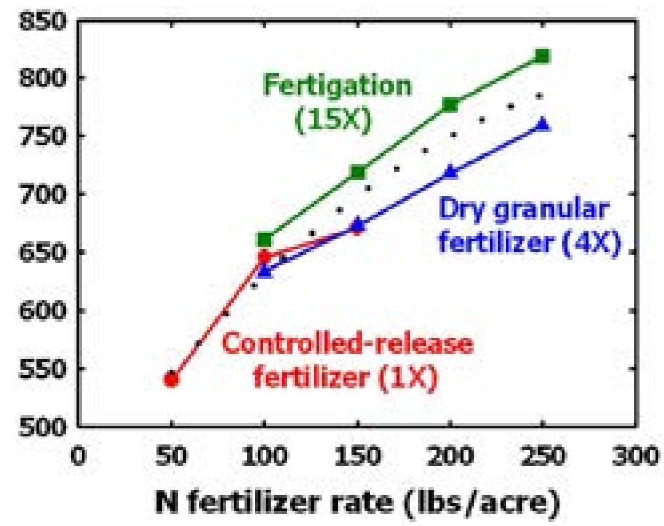


Figure 4. Orange yield (Hamlin) with nitrogen fertilizer rate from CRF applied once per year, dry granular applied in four equal amounts per year, and fertigation applied in 15 equal increments per year.

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<br><br>50% IBDU | 16 |
| 60% Ammonium nitrate<br><br>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.

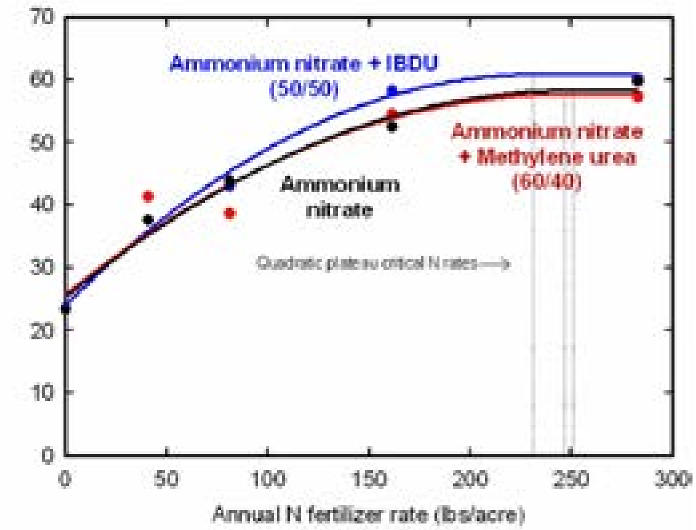


Figure 5. Mixtures of ammonium nitrate and either IBDU or Methylene urea rates used to produce 4-year cumulative pound-solids per tree.

### 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 |

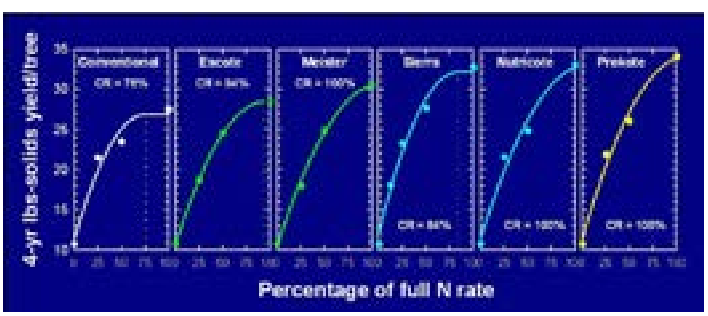


Figure 6. Comparison of five controlled-release fertilizer sources with conventional fertilization showing resulting 4-year pound-solids per tree responses.

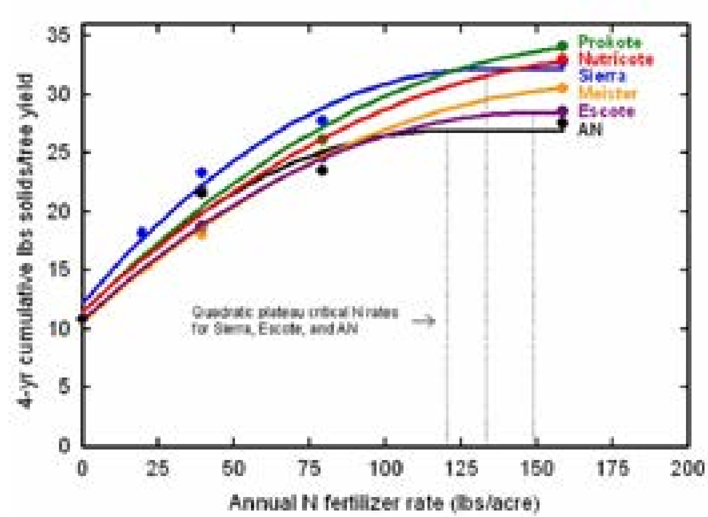


Figure 7. 4-year pound solids/tree as a function of annual nitrogen fertilizer rate. Regression analysis shows practical range of response to annual nitrogen fertilizer rate. Note that ammonium nitrate (AN) has the lowest critical nitrogen rate (120 pounds nitrogen per acre).

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 |

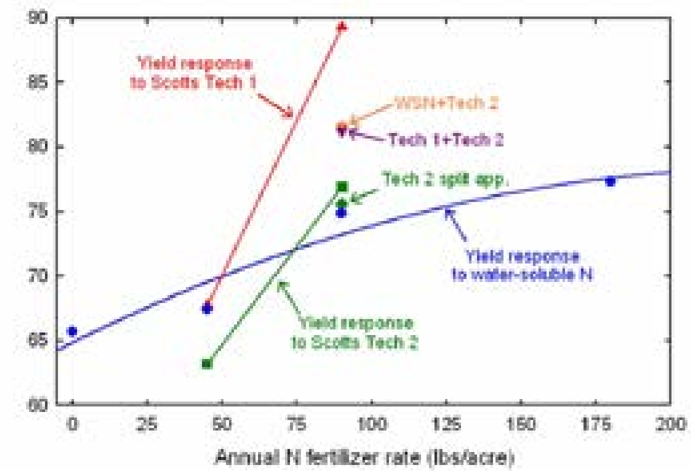


Figure 8. Experiment 3, showing a 5-year cumulative pounds solids per tree average as a function of the annual nitrogen fertilizer rate from water-soluble nitrogen, CRF sources, and the combination of these sources.

## 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.

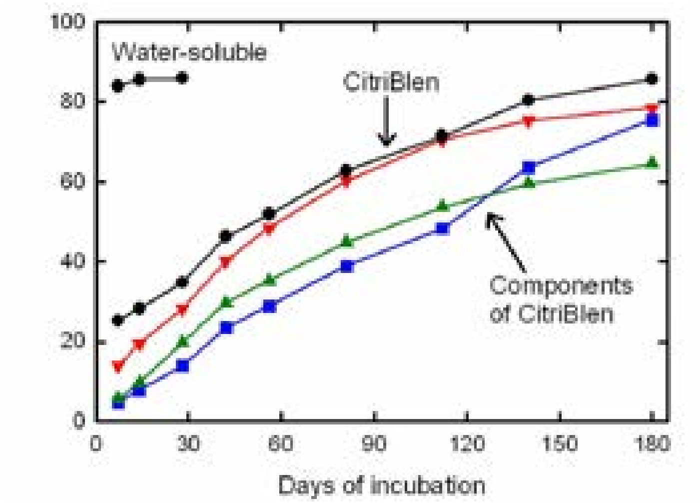

Figure 10. Current research showing results from a controlled laboratory experiment involving nutrient release from selected CRF sources with time.

## 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

The authors express their thanks to the Scott Company (Andree-Anne Couillard, Harvey Goertz, Ken Tornberg, and George McVey) and UF/IFAS support personnel (Bruce Saunders, Jaime Lopez, Joby Sherrod, and Sally Davenport) in funding and conducting these field experiments.

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# 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.

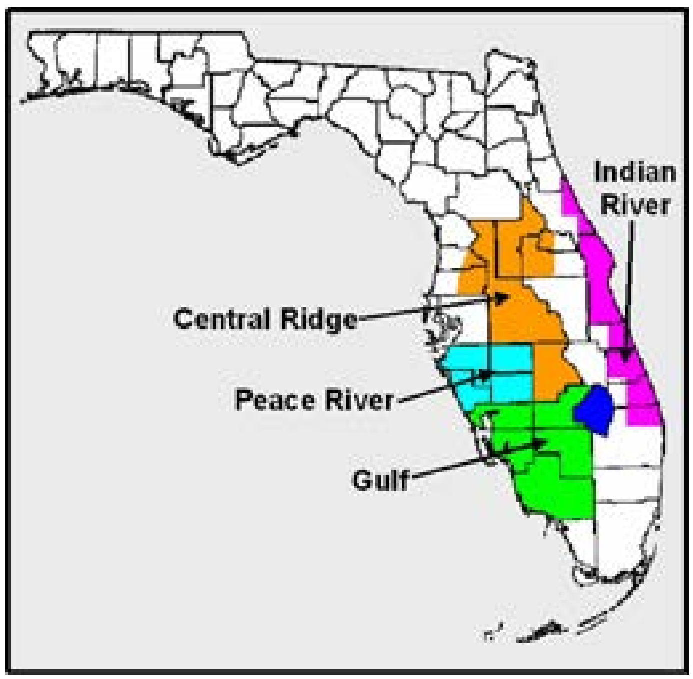


Figure 1. Citrus production areas of Florida.

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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.

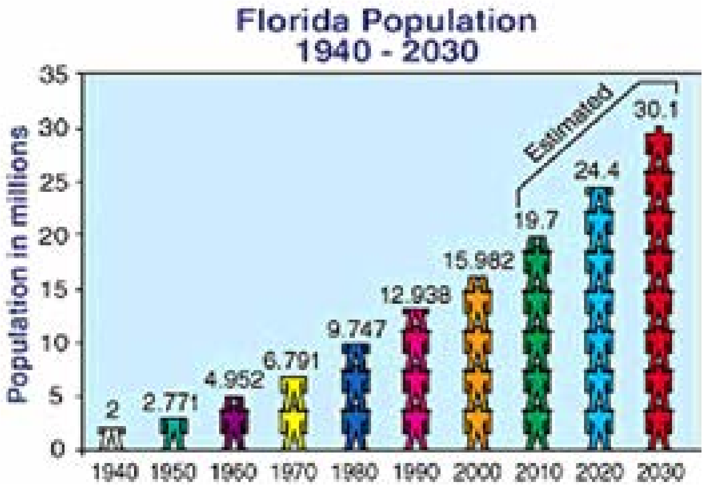



Figure 2. Florida human population growth from 1940 to 2000 and projected through 2030.

## 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.

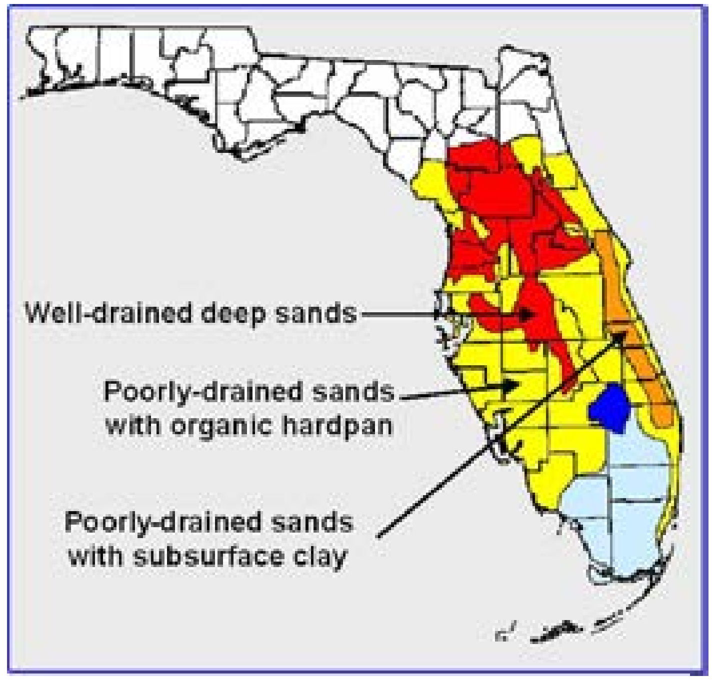



Figure 3. Soils in citrus production areas of Florida.

### 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 |

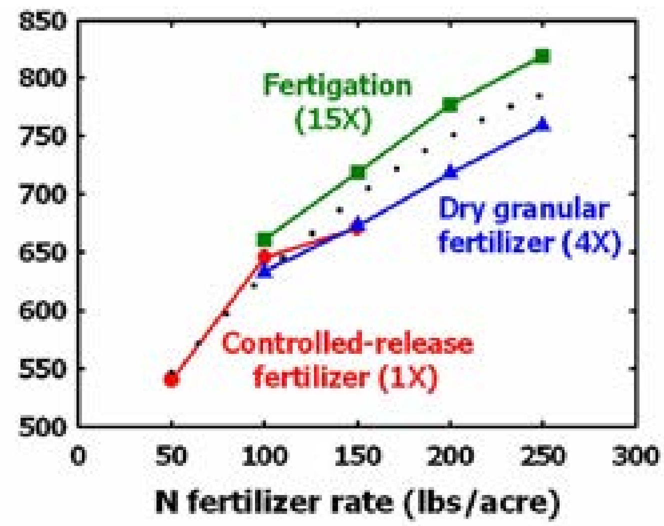



Figure 4. Orange yield (Hamlin) with nitrogen fertilizer rate from CRF applied once per year, dry granular applied in four equal amounts per year, and fertigation applied in 15 equal increments per year.

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<br><br>50% IBDU | 16 |
| 60% Ammonium nitrate<br><br>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.

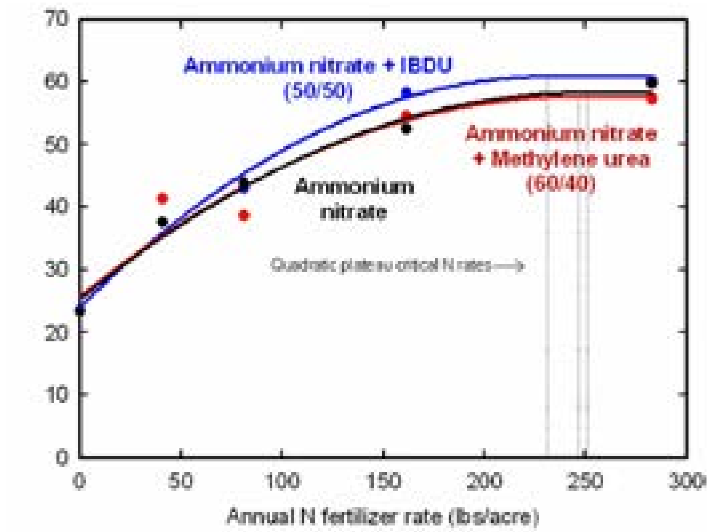



Figure 5. Mixtures of ammonium nitrate and either IBDU or Methylene urea rates used to produce 4-year cumulative pound-solids per tree.

### 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.

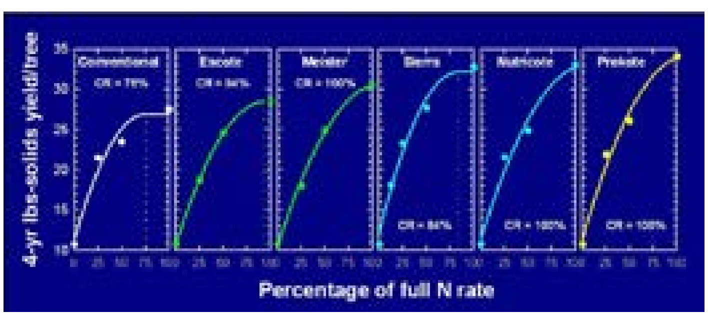
Prokote and Sierra produced higher pounds solids yield and subsequent dollar return compared with the traditional ammonium nitrate source (Table 8). Based upon the economics measured in this experiment, using coated CRF sources exclusively to fertilize citrus was not economically feasible.

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 |

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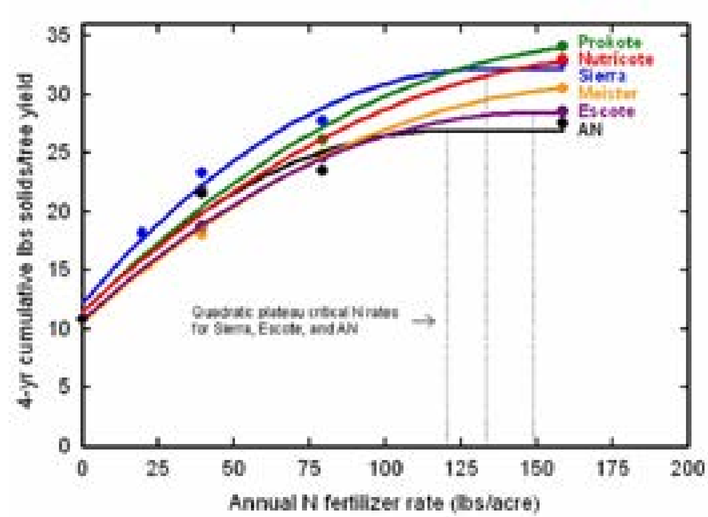


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| Nutricote | 19.85 | 26.5 | 27.47 |
| Meister | 15.81 | 25.8 | 26.41 |
| Escote | 14.90 | 24.9 | 25.98 |
| Conventional | 5.06 | 24.2 | 25.40 |
| None | 0.00 | 10.8 | 11.23 |

## 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 |

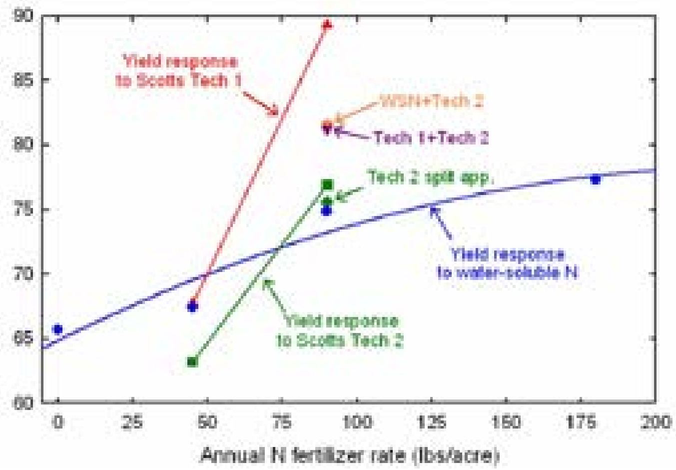


Figure 8. Experiment 3, showing a 5-year cumulative pounds solids per tree average as a function of the annual nitrogen fertilizer rate from water-soluble nitrogen, CRF sources, and the combination of these sources.

## 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.

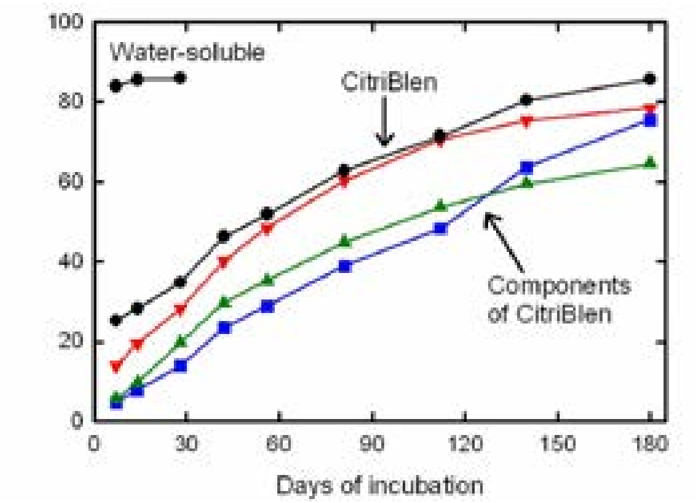

Figure 10. Current research showing results from a controlled laboratory experiment involving nutrient release from selected CRF sources with time.

## 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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SL556

# How to Characterize Soil Variability in Florida Citrus Groves as It Relates to Tree Growth and Yield[1]

Kirandeep K. Mann, Arnold W. Schumann, Thomas A. Obreza, Willie G. Harris, and Jerry B. Sartain[2]

Non-uniform tree growth and fruit yield are very common throughout many Florida citrus groves, particularly on sandy, flatwoods soils. In some cases, groves contain large, localized areas that do not support good growth and yield. Localized reduction in yield can affect as much as one-quarter of a given field. Nevertheless, variable groves are typically managed as if they were uniform. Uniform management of large citrus groves could result in under-fertilization of high-yielding areas (thus limiting yield) and over-fertilization of low-yielding areas, which may lead to nutrient leaching and environmental contamination. Uniform fertilization of a non-uniform grove decreases net economic returns because of the failure to attain yield potential and wasted fertilizer in variable groves. Therefore, optimal crop production efficiency and profitability cannot be achieved if a non-uniform grove is managed as a single, uniform unit.

The objectives of this publication are to 1) provide information about the relationship between soil variability and citrus production, 2) propose recommendations for soil sampling that account for spatial variability, and 3) suggest site-specific management practices for variable Florida citrus groves.

## Technology to Characterize and Manage Yield Variability

Citrus production managers are well aware of non-uniformity within their fields, but previously they did not have tools to manage variable soils. The introduction of "site-specific crop management" (SSCM), also known as precision farming, can be a valuable tool to increase the productivity of citrus groves that have spatially variable tree growth and yield. Using precision farming technologies, specific zones within a field are managed with different levels of input according to each zone's specific requirements. SSCM technology includes the global positioning system (GPS) and geographic information system (GIS) for producing maps, combined with yield monitoring, remote sensing, and variable rate application equipment. Each crop production unit (down to a single tree level if desired) can be managed with inputs on a site-specific basis to reduce waste, increase profits, and maintain environmental quality. There is high potential to adopt precision agriculture technologies in citrus production where site-specific tree growth and fruit yield can be mapped and related to site-specific soil characteristics. Using special spatially linked statistical tools (geostatistics), mapped survey data can be analyzed and interpolated from sampled points to unsampled locations. Therefore, precision soil sampling

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schemes coupled with geostatistics can improve the analysis of field soil properties by quantifying and mapping the spatial variation of the measured properties within the field. In addition, SSCM using variable-rate fertilizer application is more favorable economically compared with uniform application. SSCM of variable fields requires identifying the major soil properties that affect citrus production. To explore these relationships, we evaluated variation in tree growth, fruit yield, and soil properties within a variable citrus grove in Hardee County.

## Soil Properties Responsible for Tree Growth and Yield Variability

The primary factors responsible for yield variation are the occurrence of different soil series and/or the exposure of less fertile subsoil during grove leveling or bedding. Non-uniform citrus groves exhibit variable soil color that corresponds to tree variability, indicating that soil variability is responsible for localized yield reduction. Poor growth areas in a grove have a much "lighter" soil color (or high value, in Munsell soil color terminology) than surrounding productive areas (Figure 1). The presence of light-colored soils in poorly productive areas indicates that these soils are devoid of darker-colored coatings on sand particles. Iron and aluminum oxides and hydroxides are common cementing agents that coat sand grains in many Florida soils, and these coatings effectively bind fine particles to sand grains. These coatings increase the otherwise negligible surface area of sandy soils and are responsible for their increased nutrient-holding capacity. Sand grain coatings are the primary feature that differentiates the more highly productive grove areas (with coated sands) from the areas of lower productivity (with non-coated or "stripped" sands) (Figure 2).

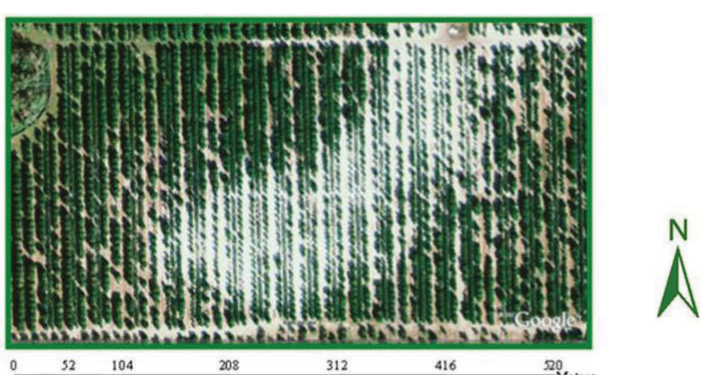


Figure 1. Aerial photograph of a Florida citrus grove showing the spatial variability of tree growth.
Credits: Google Earth

The map of soil color lightness in the Hardee County citrus grove (Figure 3a) exactly followed the patterns of tree growth and production (Figure 1). Soil color was significantly correlated with citrus grove productivity. The low-producing soil areas in the middle of the field were much lighter colored (higher values of lightness) compared with the soil in the surrounding productive areas. Soil color also relates to variations in organic matter content, with darker colors representing high organic matter content. The spatial distribution of organic matter in the top 24 inches of soil (Figure 3b) showed very low values (< 0.5%) along a north-south line across the center of the grove and higher values along the eastern and western edges. Organic matter is the single most important indicator of soil quality and productivity in most cases, and it is severely deficient in low-producing areas. Organic matter is of particular interest because of its role in improving nutrient- and water-holding capacity, soil structure, and as a precursor for biochemical transformations that occur in the soil. However, organic matter varies greatly within Florida citrus groves, and its variation is strongly and positively correlated with yield variability.

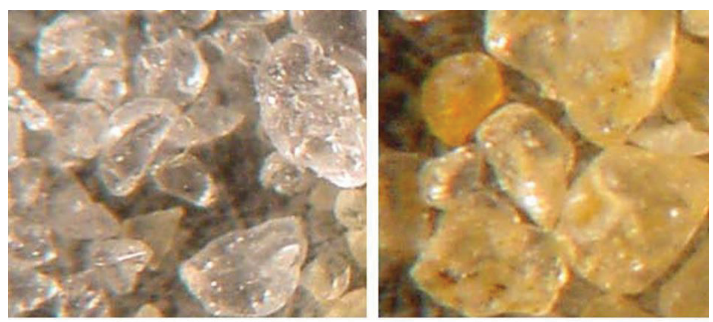


Figure 2. Microscopic morphology of sand grain coatings from the unproductive and productive areas of the grove.
Credits: UF/IFAS

In addition to organic matter, soil color also relates to moisture content. The spatial patterns of volumetric water content at permanent wilting point (15 bar soil moisture tension) (Figure 3c) were also similar to the patterns of organic matter and citrus tree growth. Florida citrus grove soils have sand content greater than 940 g $kg^{-1}$ (94%), and about half of the soils sampled had sand content greater than 970 g $kg^{-1}$ (97%). Hence, soil water retention is a major problem that limits Florida citrus production.

Comparing the variable patterns of soil properties with citrus tree growth (Figure 1) suggests that there are large variations in soil fertility along the productivity gradient. The spatial distribution of soil color, organic matter, sand grain coatings, and water retention identified the relative productivity of a non-uniform citrus grove. However, the present recommendation for soil analysis in Florida citrus groves does not include measurements of soil color or presence of sand grain coatings. Soil analysis in non-uniform groves should include these parameters to help quantify spatially variable productivity. The ability of easily measured soil properties to describe the productivity of various groves suggests that soil color or organic matter can be used to delineate management zones for SSCM.

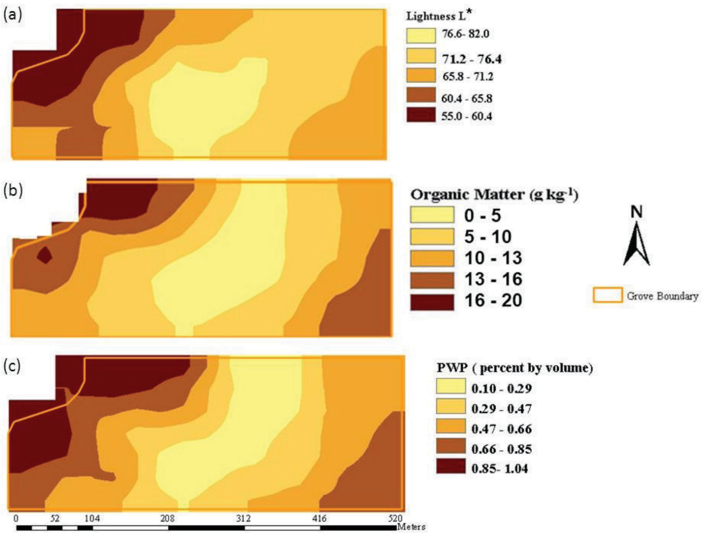


Figure 3. Spatial variation in (a) soil color lightness, (b) organic matter, and (c) water content at permanent wilting point in the variable citrus grove of Florida.

# Management of Soil and Yield Variability in Citrus Groves

## Dividing the Grove into Different Management Zones

A variable citrus grove should be divided into different management zones based on relative tree size or productivity. A management zone is defined as a subregion of a field with homogeneous yield-limiting factors. Management zones based on areas of similar productivity or yield potential are an effective way to plan soil sampling and characterize spatial variability of soil. Information about soil properties and yield from the different management zones within a field can be used for fertilizer and soil amendment recommendations, and then the variable fields can be managed on a site-specific basis. To match the fertilizer application requirement of individual trees, it is important to map the yield potential of each tree if possible. Fertilizer application practices for commercial Florida citrus production are based on tree age and projected yield (Obreza, Zekri, and Hanlon 2008), and these properties can be related directly to tree size. We used ultrasonically measured tree canopy volume to divide the Hardee County grove into different productivity/management zones and to collect soil samples (Figure 4). Ultrasound-based measurement of tree canopy volume is a rapid method to estimate tree size, which is positively correlated with citrus fruit yield, and, therefore, it can be used to divide the variable citrus groves into different management units for SSCM.

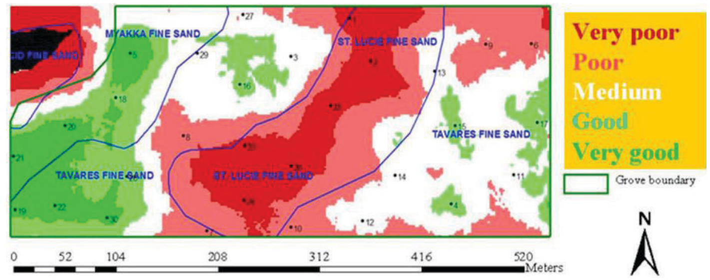


Figure 4. Citrus grove classified into five productivity zones based on tree canopy volume.
Credits: UF/IFAS

## Soil Sampling within the Management Zones

Management zones can be further used to develop future soil sampling plans. Further soil sampling can be conducted using a grid-based system, where grid size should be half of the distance beyond which the soil properties measured in the grove are no longer spatially dependent (also called range of spatial dependence). Most soil chemical and physical properties that we measured showed their maximum spatial dependence close to 500 ft. This information is useful because the sampling interval for new surveys typically should be less than half of the average range. Therefore, the range of soil properties in this study suggested a sampling interval of less than 250 ft within the grove, which corresponds to a grid size of less than 1.5 acres. Soil and leaf tissue testing procedures recommended for Florida citrus groves divide the grove into a management unit of 20 acres. This area is slightly less than the total area of the citrus grove in our study (25 acres; Figure 1), which represented a large variability in soil properties and citrus production. Therefore, soil sampling intervals in new fields should be based on the range of easily measured soil properties instead of using fixed sampling intervals.

## Variable Rate Fertilizer Application

Knowledge about how soil properties vary can help develop prescription maps and will allow the manager to match production practices with variations in crop growth, soil type, soil fertility, and moisture. The current fertilization strategy for Florida citrus groves involves determining an average fertilizer need for the whole grove and then applying a single rate to the entire field. However, with this strategy, some areas of the field receive more than the optimum amount of fertilizer needed while other areas may not receive enough. Grove managers should apply the fertilizer based on the soil fertility tests for specific areas of the field. They should apply fertilizer at the appropriate amount only where it is needed instead of applying a single rate throughout the field. This can be achieved by implementing SSCM using variable rate fertilization. This technology allows growers to apply different rates of fertilizer at different locations of a field. Variable rate fertilization equipment for citrus is commercially available and is used in modern citrus production. Variable rate fertilization will also reduce production costs and prevent environmental contamination by reducing excess fertilizer application to unproductive areas of fields where nutrient uptake is low and losses may occur.

### Improving the Unproductive Areas

Characterizing soil variability will help when making decisions about the land use in weak portions of fields. Based on the knowledge of key soil properties, these areas can be excluded or possibly improved by applying the appropriate amendments at the time of planting. Plans to make the unproductive areas in fields perform better should be based on soil analysis. Organic and inorganic soil amendments of waste by-products like phosphatic clay, municipal compost, and iron humate can be applied to poor areas of the grove at weight equivalent of 5%. These by-products are often provided at no cost other than transportation. Therefore, their application should be planned based on the proximity of a suitable supply and transportation, spreading, and incorporation costs. Soil amendments can be applied at the time of planting in new fields and to replanted trees in established groves. In new fields, the amendments can be applied down to the root zone (up to 18–24") depth of each tree in the weaker areas, which can be a cost-effective method to improve the weak portions of the field. Second, the amendments can also be surface-applied in established groves along tree rows in poor areas, allowing crop production and revenue to increase within a few years. For this practice, a grower should identify the weaker soils in the grove and apply soil amendments to those areas only.

## Summary

Variability of soil chemical and physical properties (e.g., soil color, organic matter, coatings on sand grains, and water retention) is a major factor responsible for non-uniformity of tree performance in Florida citrus groves. To manage non-uniform groves, soil samples should be collected from different areas, identified as "productivity zones" (i.e., areas of similar tree growth or yield). Variation in tree growth or soil properties can be used to map grove productivity to subdivide the grove into different management zones. These management zones can be used to target future soil sampling to characterize soil variability. Soil in new groves should be sampled based on half of the average range of easily measured soil properties such as organic matter and soil color. Information about soil properties and yield from different management zones within a field can be used for optimum placement of fertilizers and soil amendments on a site-specific basis. The SSCM of variable groves using variable rate equipment would help to avoid over- and under-applications of fertilizer, which can optimize yields and minimize the potential for nutrient losses. Organic and inorganic soil amendments should be applied to areas of poor growth to increase their productivity.

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