# Improved Water Management for Sustainable Citrus Production

**Davie Kadyampakeni**

Associate Professor

Soil, Water and Ecosystem Sciences

Citrus Research and Education Center

Email: dkadyampakeni@ufl.edu

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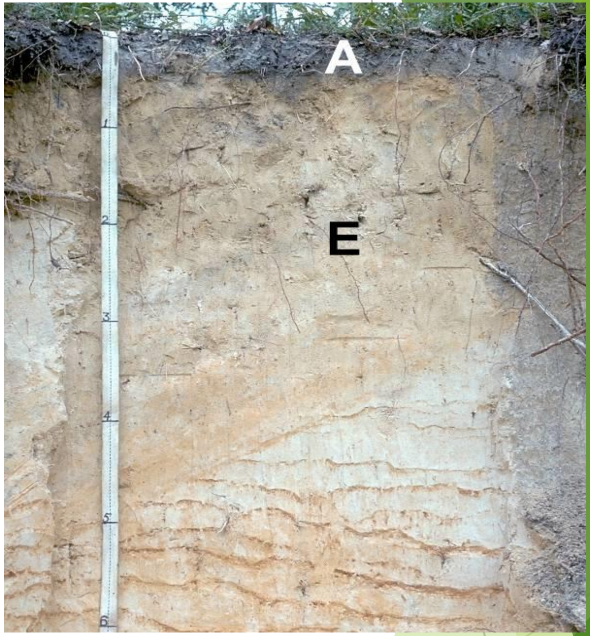
# Outline

- General Soils of Florida
- Evapotranspiration concept
- Weather-based tools and apps
- Examples of applications
- Sensors:
  - Soil-based sensors
  - Plant-based sensors
- Take home messages

# SOIL PHYSICAL & CHEMICAL CHARACTERISTICS

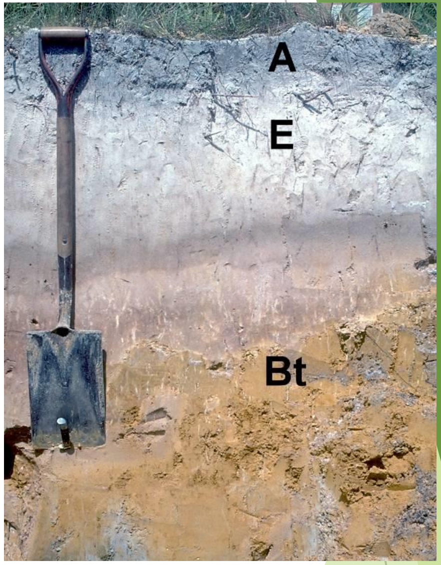
- Entisols:
  - Very common in central Florida ridge
  - Extremely well drained
  - Ideal for **pressurized irrigation systems with high precision**
  - Have low organic matter
  - Have low cation exchange capacity
  - Have low water holding capacity
  - Mostly acidic soils
  - Examples include Astatula, Basinger, Candler, Tavares soil series.



Profile of Astatula sand, an Entisol, showing surface (A) and subsurface (E) horizons. Sources: SL253

# SOIL PHYSICAL & CHEMICAL CHARACTERISTICS (2)

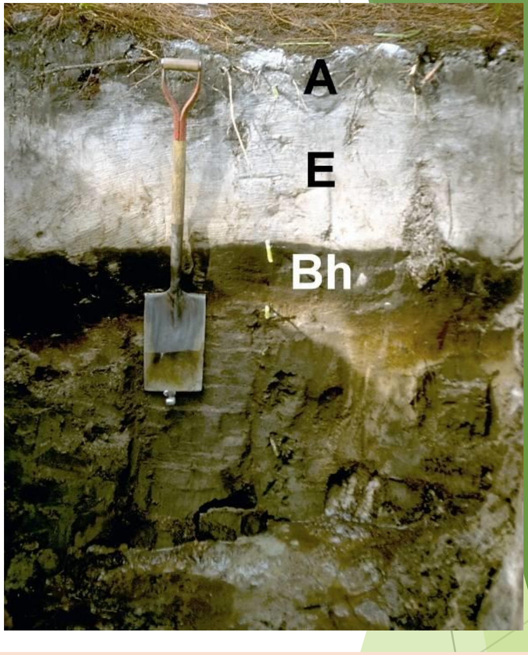
- Alfisols:
  - Very common on the southeast Florida Flatwoods
  - Poorly drained due to a restricting subsurface layer called the argillic horizon, always in need of good drainage
  - Ideal for **seepage irrigation and also pressurized irrigation systems**
  - Have low organic matter,
  - Have low cation exchange capacity
  - Have low water holding capacity
  - Mostly moderately acidic to alkaline pH due to high Ca or carbonate content
  - Examples include Boca, Holopaw, Pineda, Riviera, Winder soil series.



Profile of Rivera sand, an Alfisol, showing surface (A), leached (E), and restrictive ($B_t$) horizons. Source: SL253

# SOIL PHYSICAL & CHEMICAL CHARACTERISTICS (3)

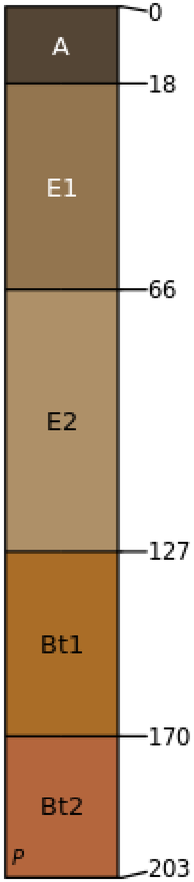
- Spodosols:
  - Very common on the southwest Florida Flatwoods
  - Poorly drained due to a restricting subsurface layer called the spodic horizon, always in need of good drainage
  - Ideal for **seepage irrigation and also pressurized irrigation systems**
  - Have low organic matter,
  - Have low cation exchange capacity
  - Have low water holding capacity
  - Mostly acidic to moderately acidic
  - Examples include Immokalee, Myakka, Oldsmar, Pomona, Smyrna, and Wabasso soil series.



Profile of Myakka sand, a Spodosol, showing surface (A), leached (E), and restrictive (Bh) horizons. Source: SL253

# SOIL PHYSICAL & CHEMICAL CHARACTERISTICS (4)

- Ultisols:
  - Very common on the Panhandle and north Florida and parts of central Florida
  - Ultisols are soils that have an argillic or kandic horizon (layer in the subsoil with higher clay content) and a low level of bases due to leaching.
  - Ultisols range from well-drained soils on upland ridges, rises and knolls to very-poorly-drained soils. Some of the more extensive Ultisols in Florida include the Apopka, Arredondo, Blanton, Millhopper, Orangeburg, and Troup soils. Ultisols cover approximately 6.9 million acres of the state
  - Ideal for seepage irrigation and also pressurized irrigation systems



# Soil Physical & chemical Characteristics (4)

***Typical root zone[1] soil physical and chemical properties for common soil series found in citrus groves in Florida. Adapted from Obreza and Collins (2008).***

| Soil orders(2) | Soil texture | | | Organic matter | Water-holding capacity | | pH | Cation exchange capacity |
|---|---|---|---|---|---|---|---|---|
| | sand | silt | clay | | | | | |
| | -------------- g $kg^{-1}$ ----------- | | | g $dm^{-3}$ | cm $m^{-1}$ | cm in the root zone | | $mmol_c$ $dm^{-3}$ |
| Entisols | 970-985 | 50-125 | 75-125 | 5-10 | 2.5-6.6 | 1.5-5.3 | 3.6-7.3 | 20-40 |
| Alfisols | 850-965 | 20-60 | 15-90 | 5-3 | 2.5-10.7 | 1.3-4.6 | 4.5-8.4 | 20-180 |
| Spodosols | 960-985 | 10-35 | 05-10 | 10-30 | 2.5-6.6 | 1.3-3.8 | 3.6-7.3 | 20-60 |

**(1) top 90 cm of soil for central Ridge Entisols and top 45 cm of soil for flatwoods Alfisols, Spodosols, and Entisols.**
**(2) according to the USDA Soil Taxonomy (Soil Survey Staff, 2014).**

# Soil Physical & chemical Characteristics (5)

***Physical and chemical properties of the subsurface diagnostic layers of typical Alfisols and Spodosols found in flatwoods citrus groves[1] in Florida. Adapted from Obreza and Collins (2008).***

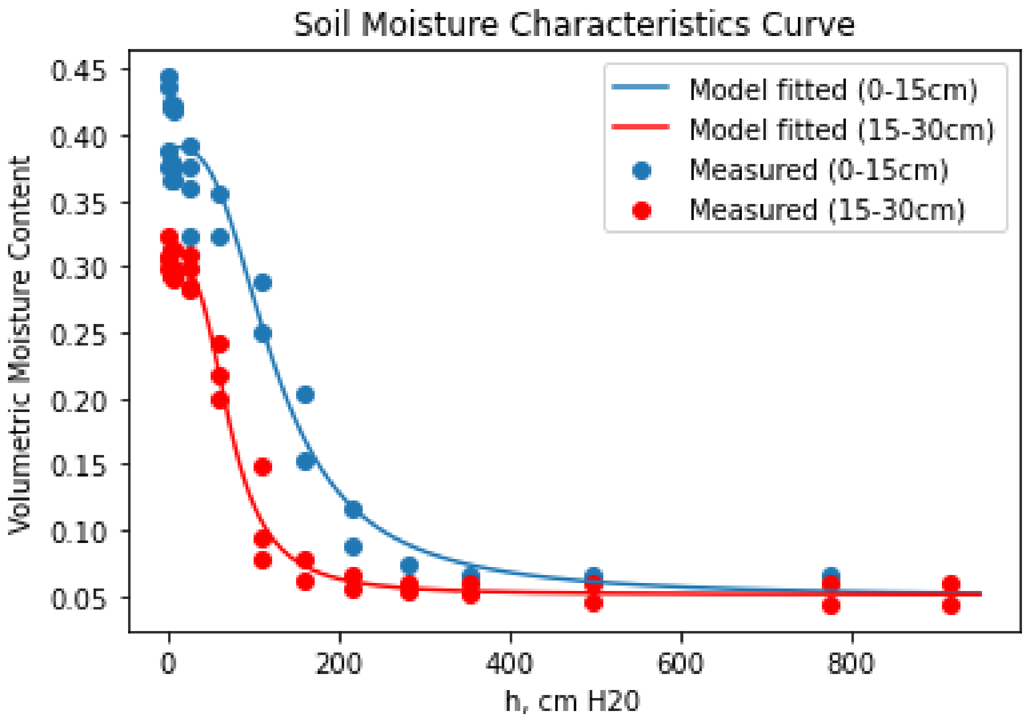
| **Soil orders** | **Layer[2]** | **Soil texture** | | | **Organic matter** | **Water-holding capacity** | **pH** | **Cation exchange capacity** |
|---|---|---|---|---|---|---|---|---|
| | | **sand** | **silt** | **clay** | | | | |
| | | ---------------- $g\ kg^{-1}$ | ---------------- | ---------------- | $g\ dm^{-3}$ | $cm\ m^{-1}$ | | $mmol_c\ dm^{-3}$ |
| Alfisols/Ultisols | Bt | 770-810 | 35-70 | 130-195 | 10-12 | 10.0-20.0 | 5.1-8.4 | 40-260 |
| Spodosols | Bh | 905-950 | 15-50 | 15-50 | 10-45 | 10.0-25.0 | 3.3-5.3 | 50-250 |

(1) these layers may reside in an undisturbed state beneath the root zone, or they may be partially excavated and mixed into the root zone soil during the bedding process.

(2) diagnostic subsurface horizons according to the USDA Soil Taxonomy (Soil Survey Staff, 2014).

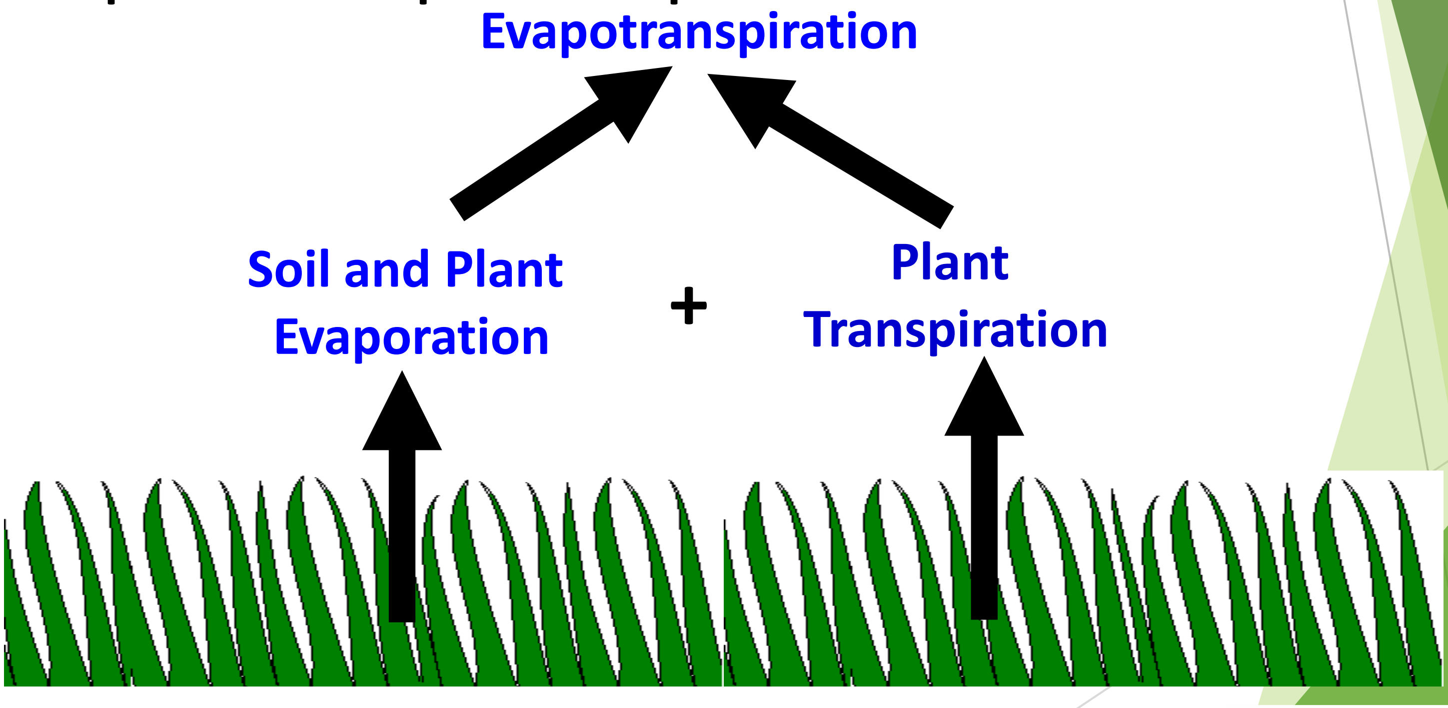
# Tensiometric moisture content

- Estimates water content on pressure basis



# Evapotranspiration (ET)

**Definition:  The loss of water from a vegetated surface through the combined processes of soil and plant evaporation and plant transpiration**



**Evapotranspiration**

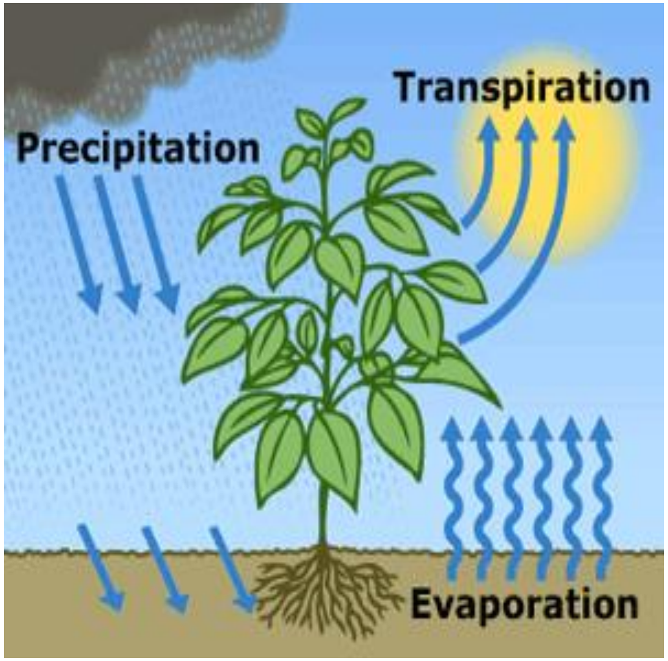
**Soil and Plant Evaporation**

**+**

**Plant Transpiration**

# Evapotranspiration (ET) Concept

**Definition: The loss of water from a vegetated surface through the combined processes of soil and plant evaporation and plant transpiration**

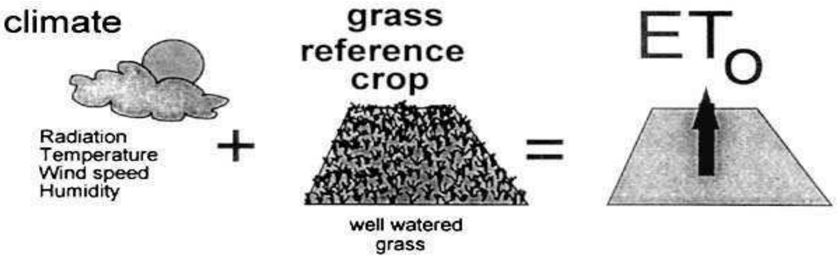


# $ET_o$ Calculation Methods

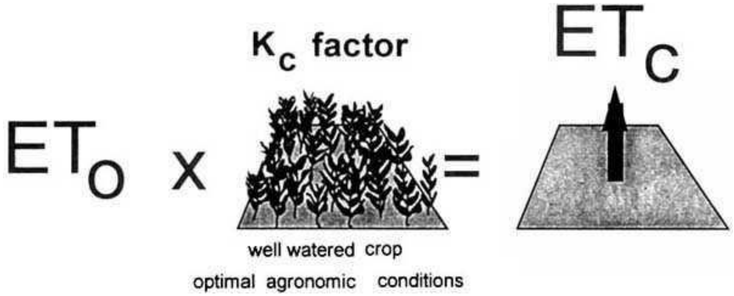
- Combination: Penman, Penman-Monteith
- Radiation: Jensen-Haise, Priestley-Taylor
- Temperature: FAO-Blaney-Criddle, Hargreaves
- Evaporation pan: FAO-Pan

# Reference ET vs. Crop ET

**Reference ET (ETo): The evapotranspiration from a hypothetical grass reference crop.**



**Actual ET (ETc): The crop evapotranspiration under standard conditions**



Adopted from: Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. *Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements*. FAO Irrig. and Drain. Paper No. 56, Rome, Italy.

# Crop Evapotranspiration ($ET_c$)

- $ET_c = ET_o * K_c * K_s$

- Where,
- $ET_o$ = Reference ET.
- $K_c$ = Crop Coefficient,
- $K_s$ = Soil water extraction factor.

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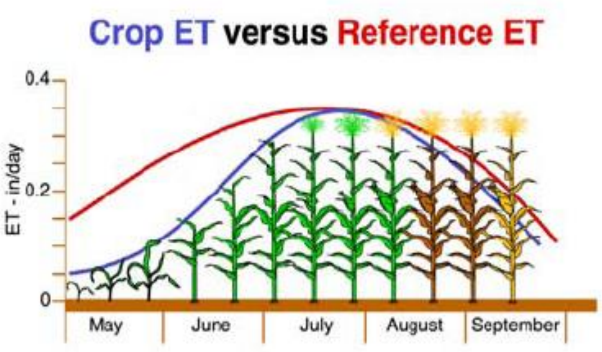
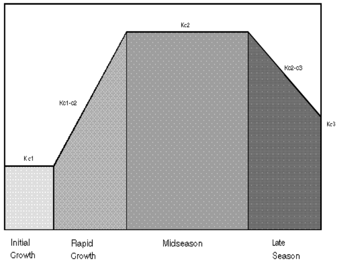
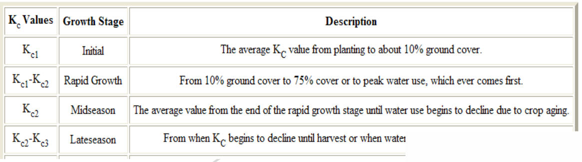
# Crop Evapotranspiration

- ET provides reference measure of water use based on plant water demand
- Scalable for specific crop, growth stage, climate, and season of year
- $ET_c = ET_o * K_c$



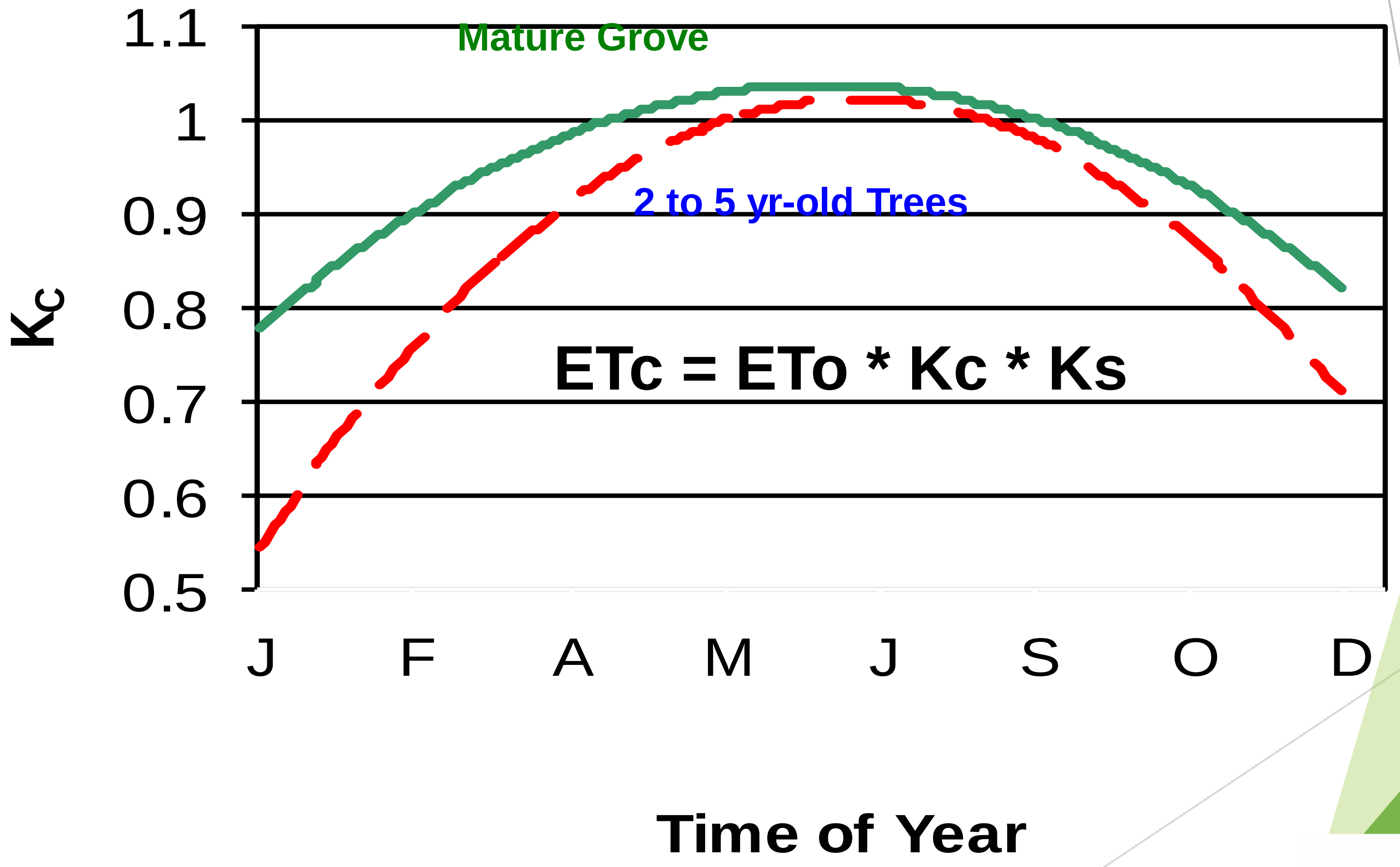
Generalized Crop Coeffecients and Crop Growth Stages





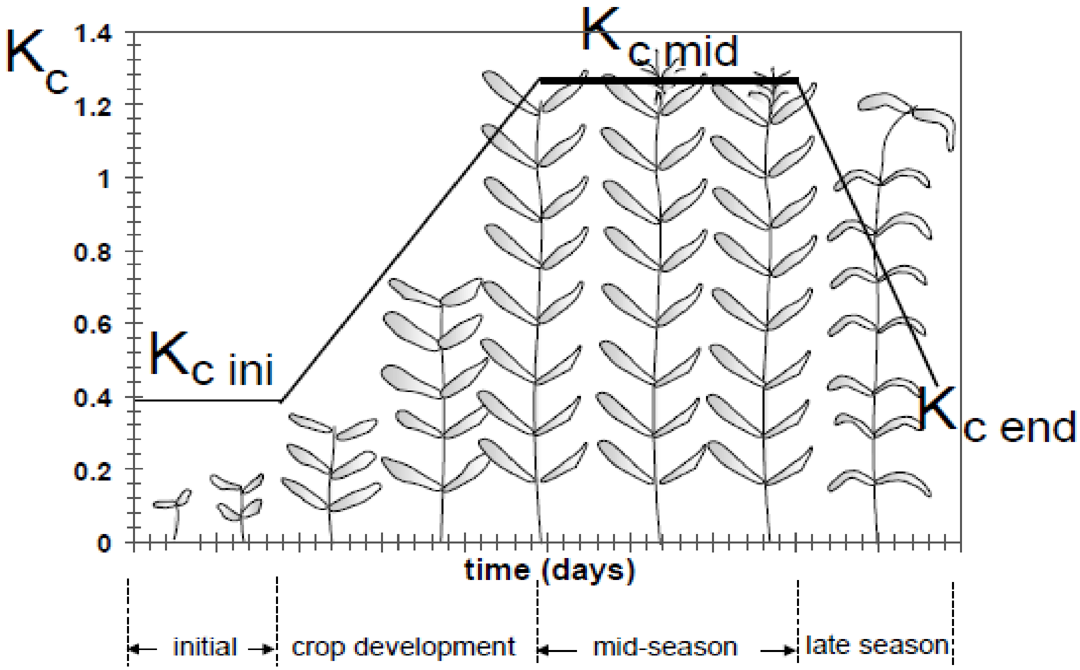
| $K_c$ Values | Growth Stage | Description |
|---|---|---|
| $K_{c1}$ | Initial | The average $K_C$ value from planting to about 10% ground cover. |
| $K_{c1}$-$K_{c2}$ | Rapid Growth | From 10% ground cover to 75% cover or to peak water use, which ever comes first. |
| $K_{c2}$ | Midseason | The average value from the end of the rapid growth stage until water use begins to decline due to crop aging. |
| $K_{c2}$-$K_{c3}$ | Lateseason | From when $K_C$ begins to decline until harvest or when water |

# Effect of Time of Year



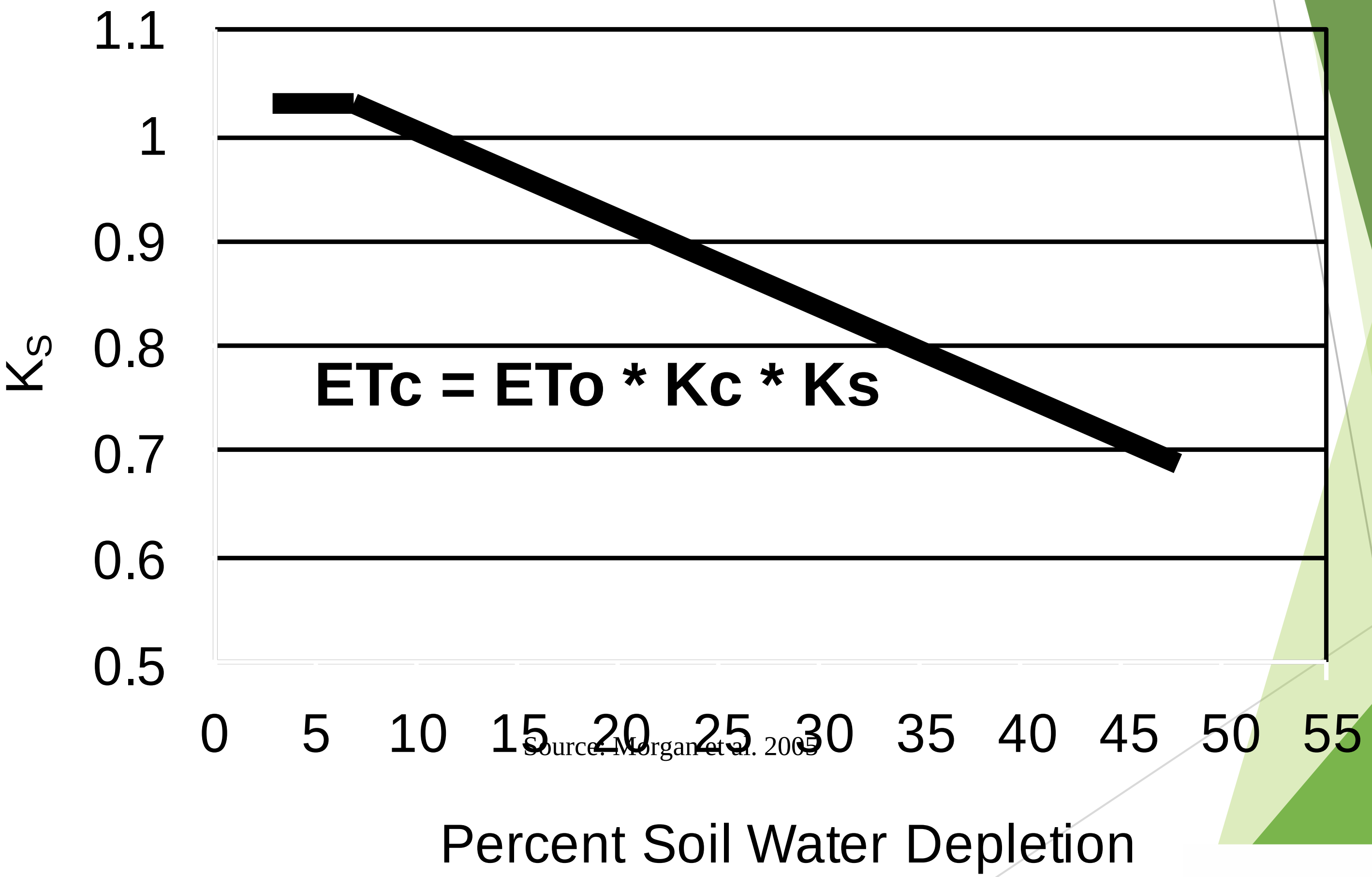
ETc = ETo * Kc * Ks

# Effect of Time of Stage of Crop Growth



**Schematic of the Crop Coefficient variation for seasonal crops e.g. maize (corn), tomato etc. Source: Allen et al. (1998).**

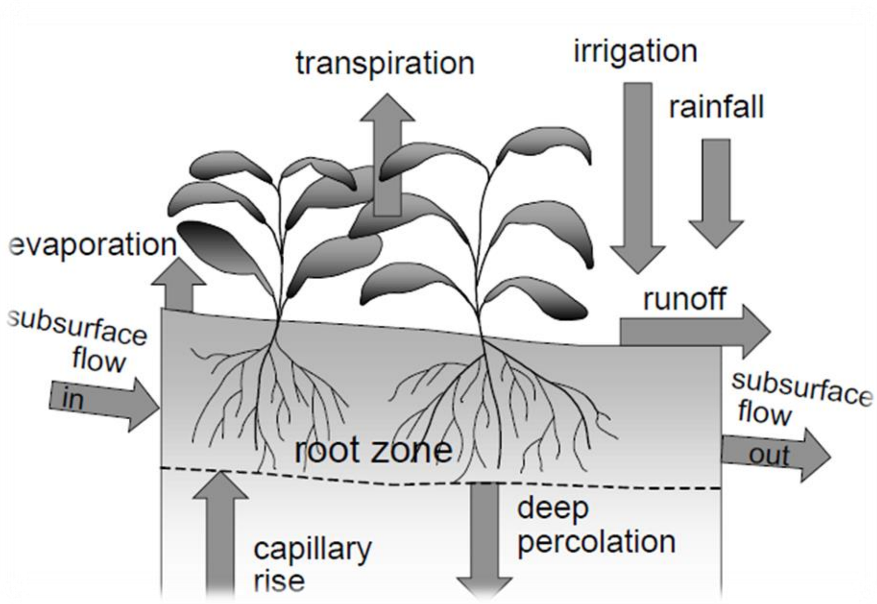
# Effect of Soil Drying



Source: Morgan et al. 2005

# Soil water balance

**Soil water balance of the root zone**



Irrigation (I) and rainfall (P) add water to the root zone.

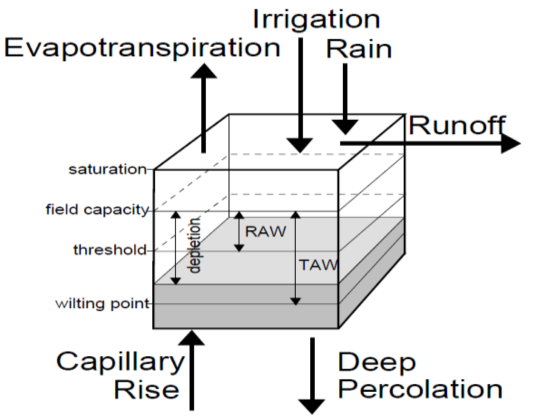
Part of I and P might be lost by surface runoff (RO) and by deep percolation (DP) that will eventually recharge the water table.

Water might also be transported upward by capillary rise (CR) from a shallow water table towards the root zone or even transferred horizontally by subsurface flow in (SFin) or out of (SFout) the root zone (**this is common on the Flatwoods soils**).

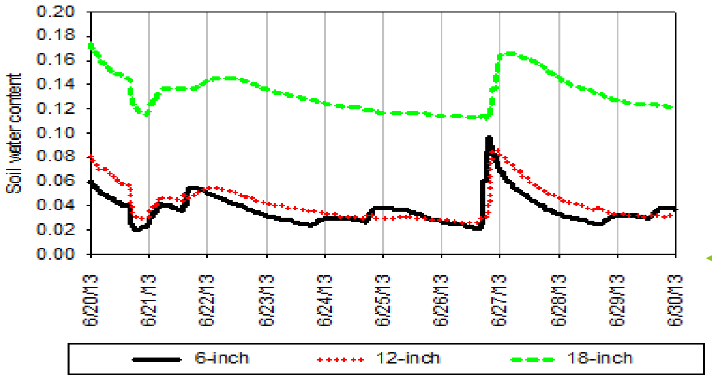
# Soil water balance (2)

If all fluxes other than evapotranspiration (ET) can be assessed, the evapotranspiration can be deduced from the change in soil water content (ΔSW) over the time period using the equation:

$$ET = I + P - RO - DP + CR \pm \Delta SF \pm \Delta SW$$



Soil water balance as seen in a big cube and including measurements of readily available water (RAW) and total available water (TAW). (Source, FAO, 1998)



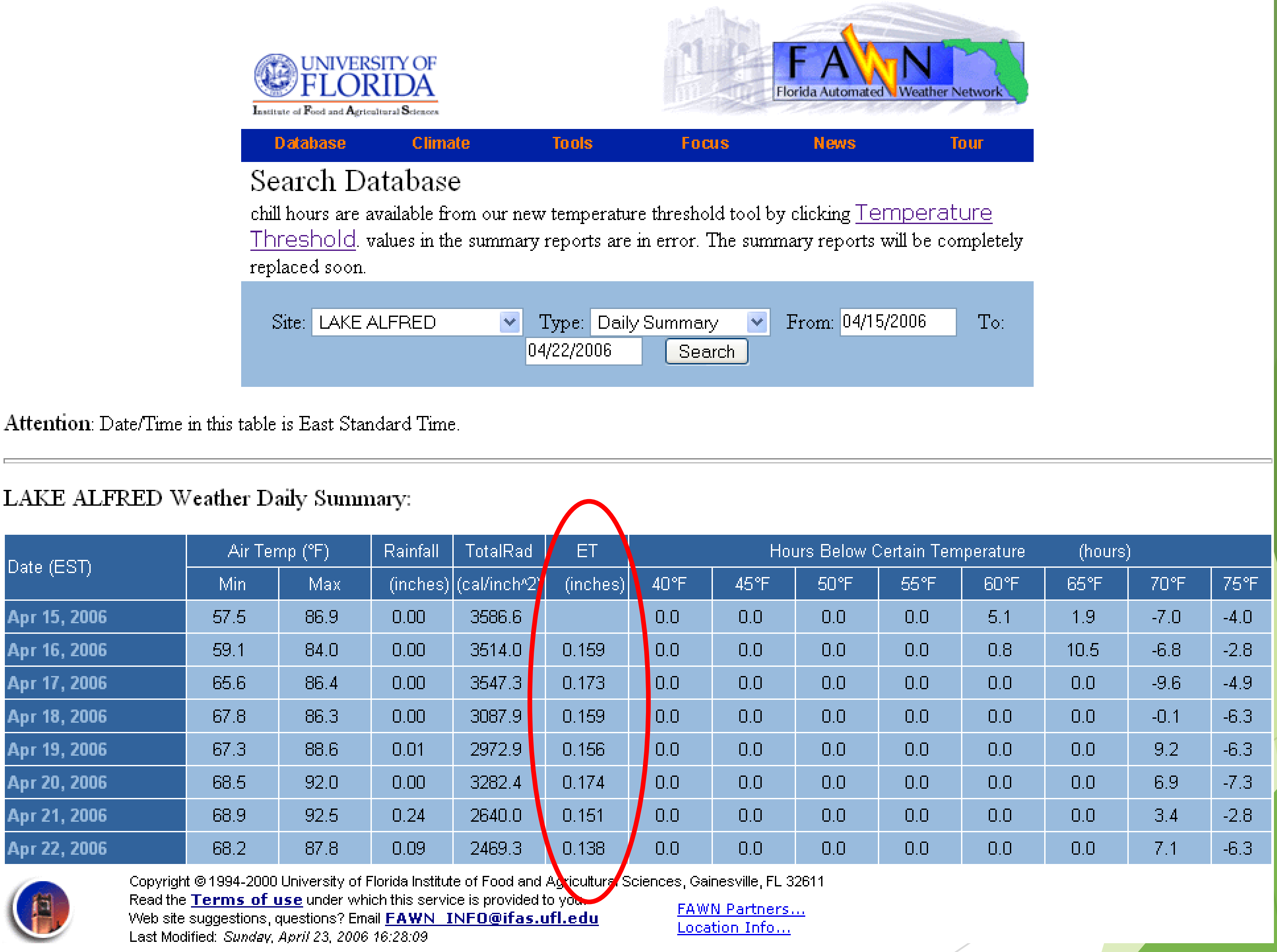
Continuous monitoring of soil moisture at 6, 12, and 18-inch depths in the soil by a multi-level capacitance probe installed in the root zone of a mature citrus tree.

# Water management strategies for citrus trees (2)

Water monitoring at grove scale and soil moisture measurement at 15, 30 and 60 cm soil depth

# Computer Programs

- Web based
  - Schedule based on nearest FAWN station (http://fawn.ifas.ufl.edu.)
  - Enter: Field capacity, spacing, irrigation specifications
- PC Irrigation program
  - Same information required
  - Stores irrigation data
  - Print reports
- Smart Phone Apps
  - Use real-time data
  - Irrigation schedule in units of time
  - Send notifications and forecasted probability of rainfall



## Search Database

chill hours are available from our new temperature threshold tool by clicking Temperature Threshold. values in the summary reports are in error. The summary reports will be completely replaced soon.

Site: LAKE ALFRED Type: Daily Summary From: 04/15/2006 To: 04/22/2006

**Attention**: Date/Time in this table is East Standard Time.

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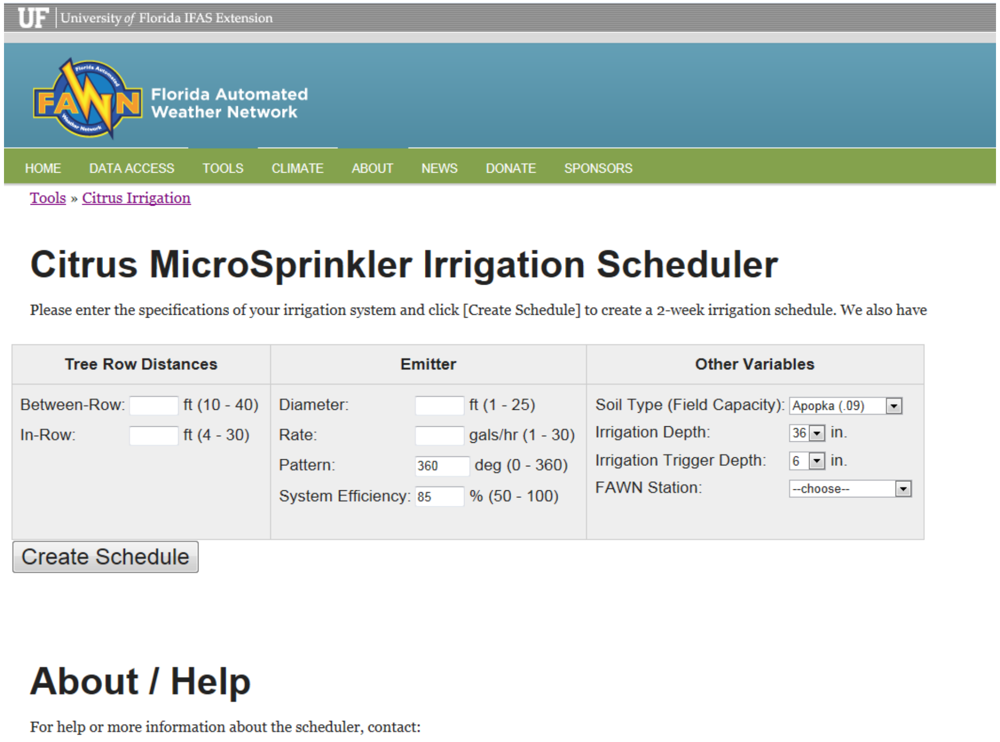
### LAKE ALFRED Weather Daily Summary:

| Date (EST) | Air Temp (°F) | | Rainfall | TotalRad | ET | Hours Below Certain Temperature | | | | | | (hours) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | (inches) | (cal/inch^2) | (inches) | 40°F | 45°F | 50°F | 55°F | 60°F | 65°F | 70°F | 75°F |
| **Apr 15, 2006** | 57.5 | 86.9 | 0.00 | 3586.6 | | 0.0 | 0.0 | 0.0 | 0.0 | 5.1 | 1.9 | -7.0 | -4.0 |
| **Apr 16, 2006** | 59.1 | 84.0 | 0.00 | 3514.0 | 0.159 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 10.5 | -6.8 | -2.8 |
| **Apr 17, 2006** | 65.6 | 86.4 | 0.00 | 3547.3 | 0.173 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -9.6 | -4.9 |
| **Apr 18, 2006** | 67.8 | 86.3 | 0.00 | 3087.9 | 0.159 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 | -6.3 |
| **Apr 19, 2006** | 67.3 | 88.6 | 0.01 | 2972.9 | 0.156 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.2 | -6.3 |
| **Apr 20, 2006** | 68.5 | 92.0 | 0.00 | 3282.4 | 0.174 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.9 | -7.3 |
| **Apr 21, 2006** | 68.9 | 92.5 | 0.24 | 2640.0 | 0.151 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.4 | -2.8 |
| **Apr 22, 2006** | 68.2 | 87.8 | 0.09 | 2469.3 | 0.138 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.1 | -6.3 |

Web site suggestions, questions? Email **FAWN_INFO@ifas.ufl.edu**
Last Modified: *Sunday, April 23, 2006 16:28:09*

FAWN Partners...
Location Info...

# Irrigation Scheduler - Input



Tools » Citrus Irrigation

## Citrus MicroSprinkler Irrigation Scheduler

Please enter the specifications of your irrigation system and click [Create Schedule] to create a 2-week irrigation schedule. We also have

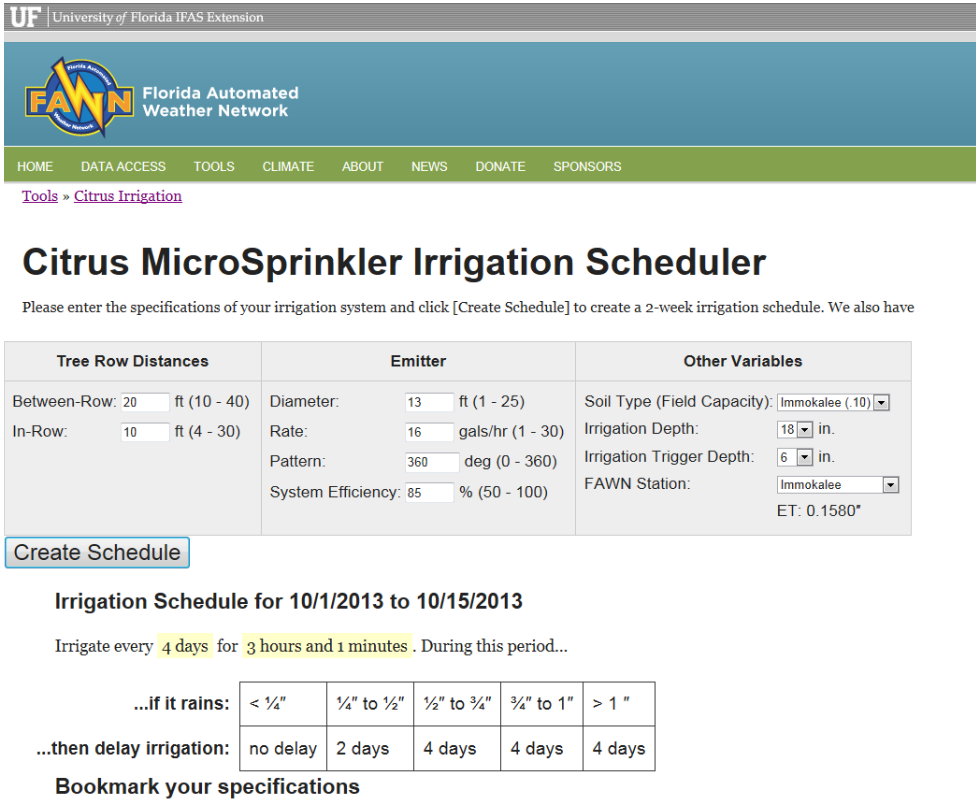
| Tree Row Distances | | | Emitter | | | Other Variables | |
|---|---|---|---|---|---|---|---|
| Between-Row: | | ft (10 - 40) | Diameter: | | ft (1 - 25) | Soil Type (Field Capacity): | Apopka (.09) ▾ |
| In-Row: | | ft (4 - 30) | Rate: | | gals/hr (1 - 30) | Irrigation Depth: | 36 ▾ in. |
| | | | Pattern: | 360 | deg (0 - 360) | Irrigation Trigger Depth: | 6 ▾ in. |
| | | | System Efficiency: | 85 | % (50 - 100) | FAWN Station: | --choose-- ▾ |

## About / Help

For help or more information about the scheduler, contact:

- Irrigation Schedulers
  - Citrus
  - Vegetable,
  - Strawberry
  - Row crops
  - Turf grass

# Irrigation Scheduler - Output



Tools » Citrus Irrigation

## Citrus MicroSprinkler Irrigation Scheduler

Please enter the specifications of your irrigation system and click [Create Schedule] to create a 2-week irrigation schedule. We also have

| Tree Row Distances | Emitter | Other Variables |
|---|---|---|
| Between-Row: 20 ft (10 - 40) | Diameter: 13 ft (1 - 25) | Soil Type (Field Capacity): Immokalee (.10) |
| In-Row: 10 ft (4 - 30) | Rate: 16 gals/hr (1 - 30) | Irrigation Depth: 18 in. |
| | Pattern: 360 deg (0 - 360) | Irrigation Trigger Depth: 6 in. |
| | System Efficiency: 85 % (50 - 100) | FAWN Station: Immokalee |
| | | ET: 0.1580" |

### Irrigation Schedule for 10/1/2013 to 10/15/2013

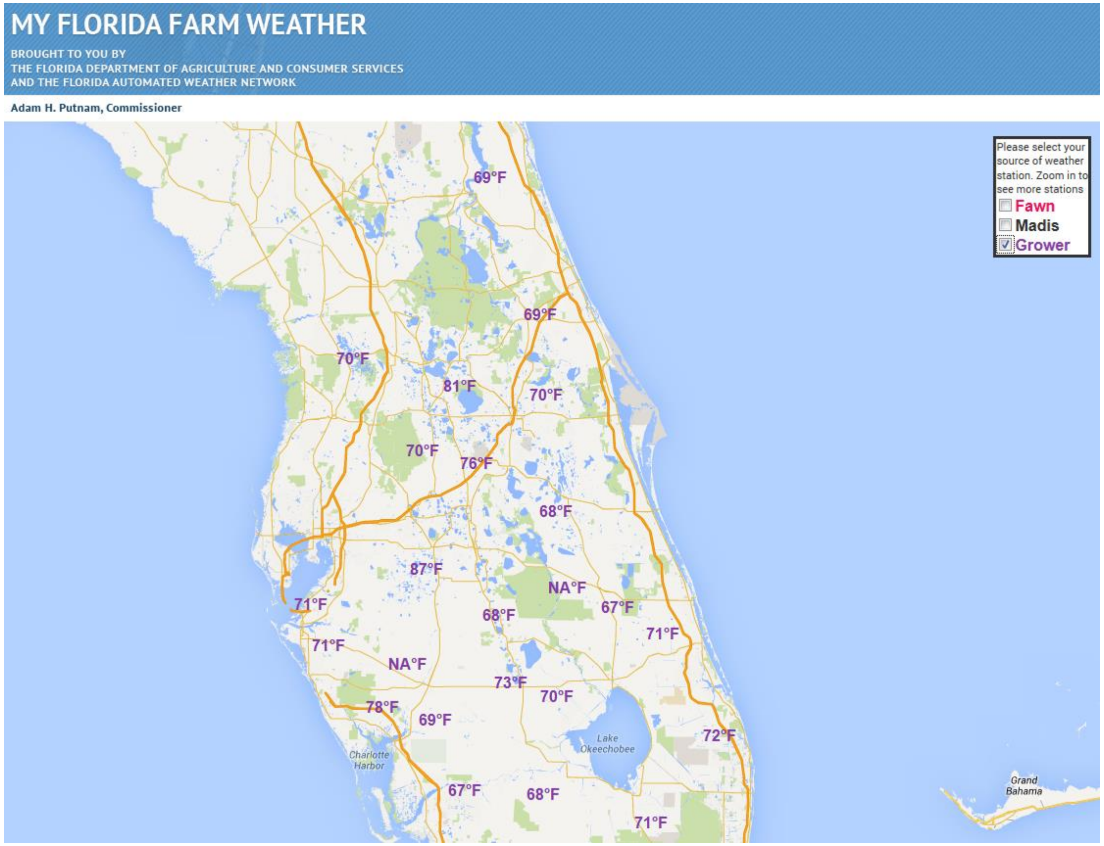
Irrigate every 4 days for 3 hours and 1 minutes. During this period...

| ...if it rains: | < ¼" | ¼" to ½" | ½" to ¾" | ¾" to 1" | > 1 " |
|---|---|---|---|---|---|
| ...then delay irrigation: | no delay | 2 days | 4 days | 4 days | 4 days |

**Bookmark your specifications**

- Provides record of inputs
- Two week schedule based on ET
- Delay for rainfall

# FDACS/IFAS – My Florida Farm Weather Program



MY FLORIDA FARM WEATHER

BROUGHT TO YOU BY
THE FLORIDA DEPARTMENT OF AGRICULTURE AND CONSUMER SERVICES
AND THE FLORIDA AUTOMATED WEATHER NETWORK

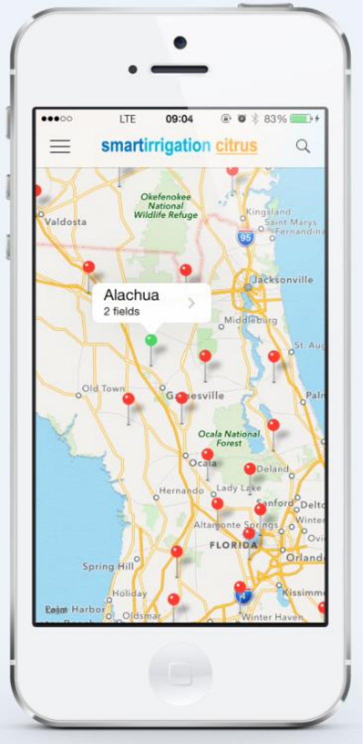
Adam H. Putnam, Commissioner

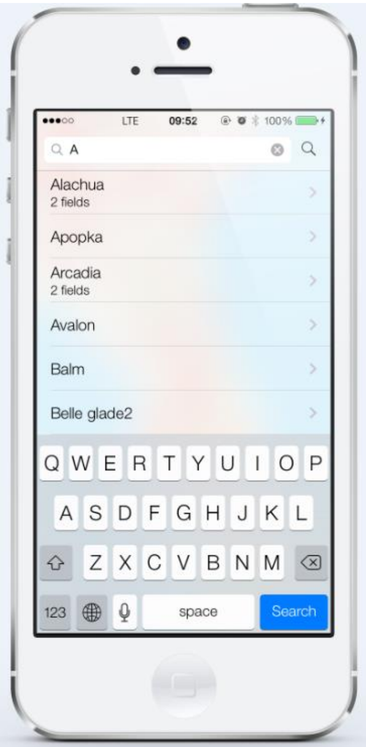
Please select your source of weather station. Zoom in to see more stations

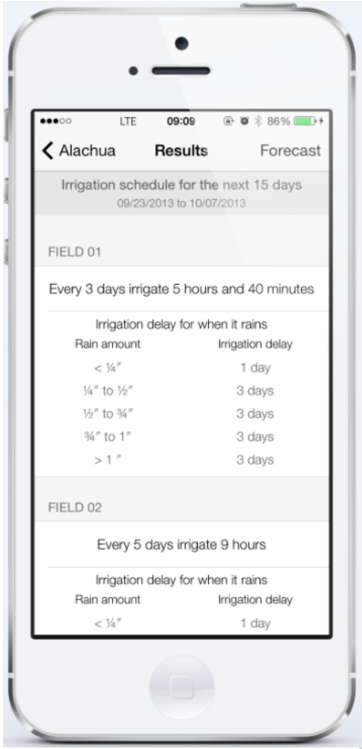
☐ Fawn
☐ Madis
☑ Grower

- Cost share for weather stations
- Real-time data
- Frost protection and irrigation scheduling

# Smartphone Apps







Irrigation schedule for the next 15 days
09/23/2013 to 10/07/2013

FIELD 01

Every 3 days irrigate 5 hours and 40 minutes

Irrigation delay for when it rains

| Rain amount | Irrigation delay |
|---|---|
| < ¼″ | 1 day |
| ¼″ to ½″ | 3 days |
| ½″ to ¾″ | 3 days |
| ¾″ to 1″ | 3 days |
| > 1 ″ | 3 days |

FIELD 02

Every 5 days irrigate 9 hours

Irrigation delay for when it rains

| Rain amount | Irrigation delay |
|---|---|
| < ¼″ | 1 day |

- I phone or Android
- FAWN ET, expand to grower weather stations
- Real-time data
- Citrus, Strawberry, Turf, expand to row crops, vegetable

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# Soil moisture sensor types

- Soil moisture measurement

Current electronic sensors may be fixed in one location, portable, or hand-held, and these sensors can be connected wirelessly to computer systems.

These advanced sensors may also measure soil moisture at one depth or at multiple depths.

General categories include time domain reflectometry (TDR), time domain transmission (TDT) and capacitance probes.

**Capacitance probes**

**TDT Acclima sensor**

# Soil moisture sensor types

- Soil moisture measurement

Soil moisture probes that measure three-way moisture, temperature and salinity are also suitable for Florida sandy soils. Supported by telemetry and data logging from provider.

Examples include Aquaspy and Sentek probes.

# Merits and demerits of some soil moisture sensors

**Main features, advantages and disadvantages of selected soil water sensors for use in Florida citrus groves. Desirable features are shown in green, with orange and red colors ranked less satisfactory. Source: Schumann et al. 2018. Using soil moisture sensors for citrus irrigation. https://crec.ifas.ufl.edu/extension/trade_journals/2018/2018_july_using_soil.pdf**

| Soil water sensor type | Measured soil volume | Sensitivity to air gaps / loose soil | Sensitivity to salinity | Suitability for sandy soils | Accuracy | Calibration for different soils | Maintenance |
|---|---|---|---|---|---|---|---|
| Tensiometer | large | high | low | low | high | no | high |
| Granular matrix | large | high | medium-high | low | low | no | high |
| Capacitance | medium | high | medium-high | medium | medium | yes | low |
| Time domain transmission (TDT) | large | medium-low | low | high | high | no | low |
| Time domain reflectometry (TDR) | large | medium-low | low | high | high | no | low |

# Plant-based irrigation scheduling

Water use by plants is via transpiration. This can be measured in different ways such as sapflow sensors and lysimeters.

Use of sapflow sensors supported by a datalogger, solar panel, and 12-V battery (right and top)

Weighing lysimetery for measuring water use (left)

# Plant-based irrigation scheduling

Dendrometers used for tracking changes in stem water potential in real time

Pressure bomb method for tracking water stress

# Examples of applications

- Initiated in November 2017 with eight-month-old sweet orange ‘Valencia’ (Citrus sinensis) trees grafted on the ‘US-897’
- Two and three rows of five-540-foot-long beds with drainage swales on each side.
- Two irrigation treatments (62% and 100%) of daily crop evapotranspiration (ETc) were adjusted during 2019 to (81%, 53%, 40.5%, and 26.5% of ETc).

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The aim of the study was to determine the amount of water required to grow young trees at higher tree densities.

# Citrus planting densities

**The grove comprised 60 sub-plots divided into six trees densities as following:**

**1) 181 trees per acre (10 feet * 24 feet),**

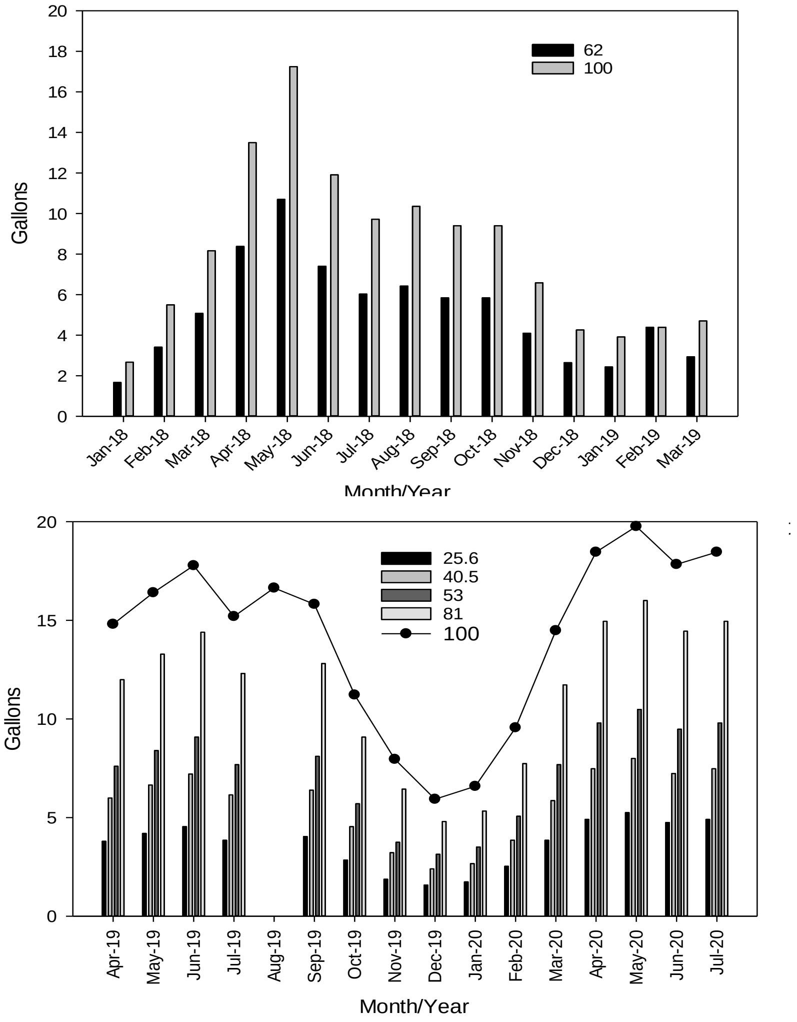
**2) 207 trees per acre (14 feet * 15 feet),**

**3) 242 trees per acre (7.5 feet * 24 feet),**

**4) 290 trees per acre (10 feet * 15 feet),**

**5) 303 trees per acre (6 feet * 24 feet ), and**

**6) 363 trees per acre (8 feet *15 feet).**

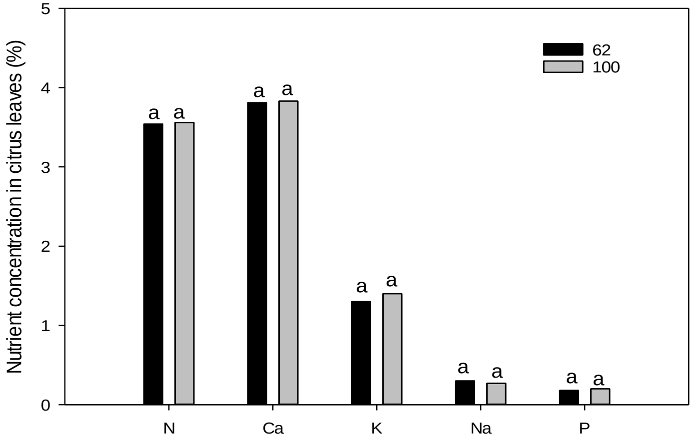


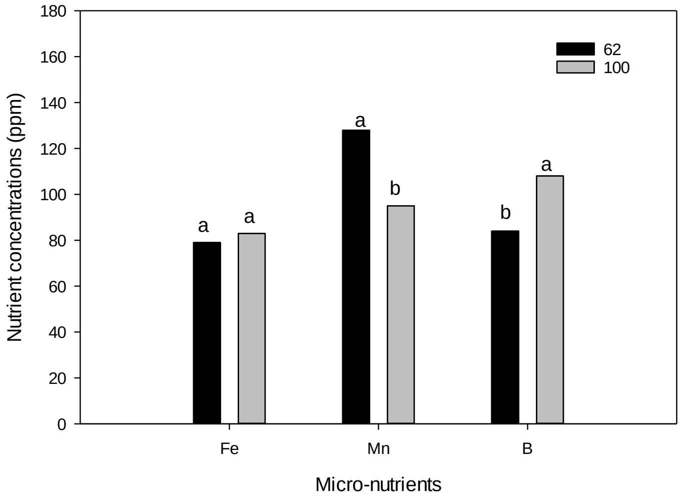
The volume of water applied per young citrus trees under different irrigation rates on daily bases

- **Water applications were proportional to percentage ETo during the experiment at both two rates and four rates**
- **100% line is the amount of water that would have been applied if ETo was applied each day**

| Month | ETo - Blaney-Criddle (in) | 181 trees per acre | 207 trees per acre | 242 trees per acre | 290 trees per acre | 303 trees per acre | 363 trees per acre |
|---|---|---|---|---|---|---|---|
| **2019** | | | | | | | |
| **Apr** | 0.21 | 0.37 | 0.43 | 0.50 | 0.60 | 0.62 | 0.75 |
| **May** | 0.24 | 0.38 | 0.43 | 0.51 | 0.61 | 0.63 | 0.76 |
| **June** | 0.25 | 0.38 | 0.44 | 0.51 | 0.61 | 0.64 | 0.77 |
| **July** | 0.25 | 0.33 | 0.38 | 0.44 | 0.53 | 0.55 | 0.66 |
| **Aug** | 0.23 | No irrigation | | | | | |
| **Sep** | 0.23 | 0.38 | 0.43 | 0.51 | 0.61 | 0.63 | 0.76 |
| **Oct** | 0.21 | 0.29 | 0.34 | 0.39 | 0.47 | 0.49 | 0.59 |
| **Nov** | 0.17 | 0.25 | 0.28 | 0.33 | 0.40 | 0.41 | 0.50 |
| **Dec** | 0.16 | 0.20 | 0.23 | 0.27 | 0.33 | 0.34 | 0.41 |
| **2020** | | | | | | | |
| **Jan** | 0.15 | 0.25 | 0.28 | 0.33 | 0.40 | 0.41 | 0.50 |
| **Feb** | 0.17 | 0.30 | 0.34 | 0.40 | 0.48 | 0.50 | 0.60 |
| **Mar** | 0.16 | 0.50 | 0.58 | 0.67 | 0.81 | 0.84 | 1.01 |
| **Apr** | 0.25 | 0.40 | 0.46 | 0.54 | 0.65 | 0.67 | 0.81 |
| **May** | 0.25 | 0.43 | 0.49 | 0.58 | 0.69 | 0.72 | 0.87 |
| **June** | 0.25 | 0.39 | 0.44 | 0.52 | 0.62 | 0.64 | 0.77 |
| **July** | 0.25 | 0.40 | 0.46 | 0.53 | 0.64 | 0.66 | 0.80 |
| **Aug** | 0.25 | 0.37 | 0.42 | 0.49 | 0.59 | 0.62 | 0.74 |
| **Avg** | 0.22 | 0.35 | 0.40 | 0.47 | 0.56 | 0.58 | 0.70 |

# Citrus tree leaves nutrition - 2018

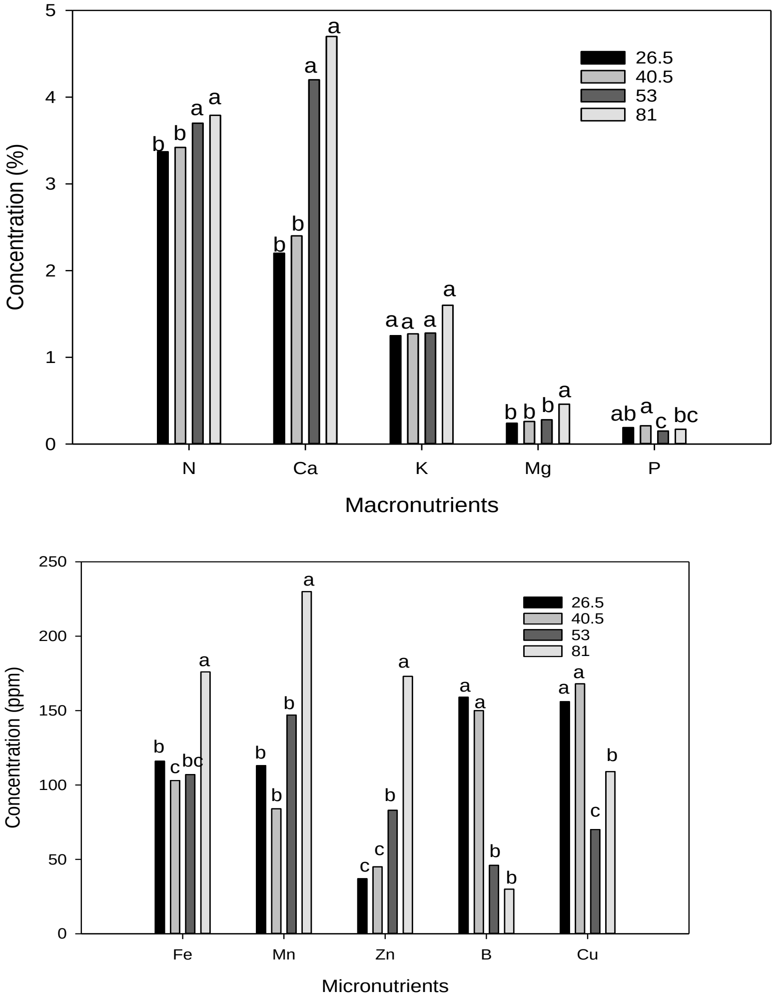




Irrigation rates effect on micro-nutrients concentration in citrus leaves

**Both macro- and micronutrients were equal the during the first year of the experiment indicating a consistent nutrient starting point.**

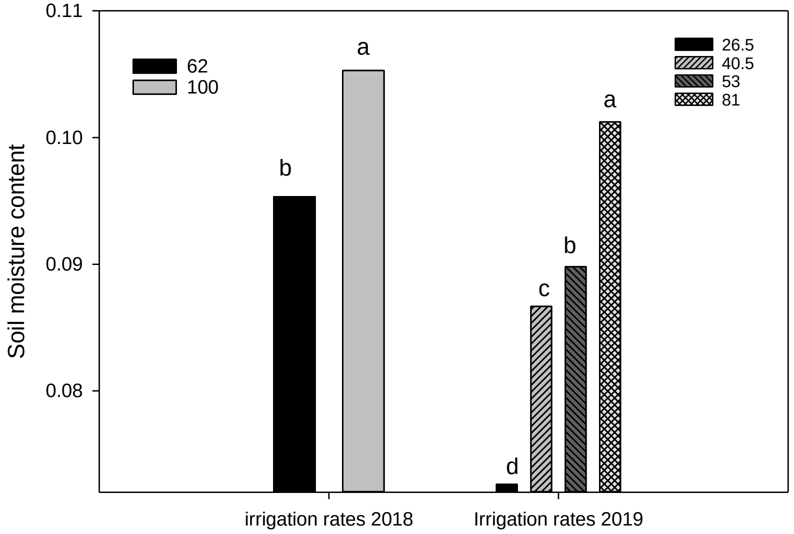
# Citrus tree leaf nutrient concentration- 2019



Irrigation rates impact on micronutrient concentrations in young citrus leaves

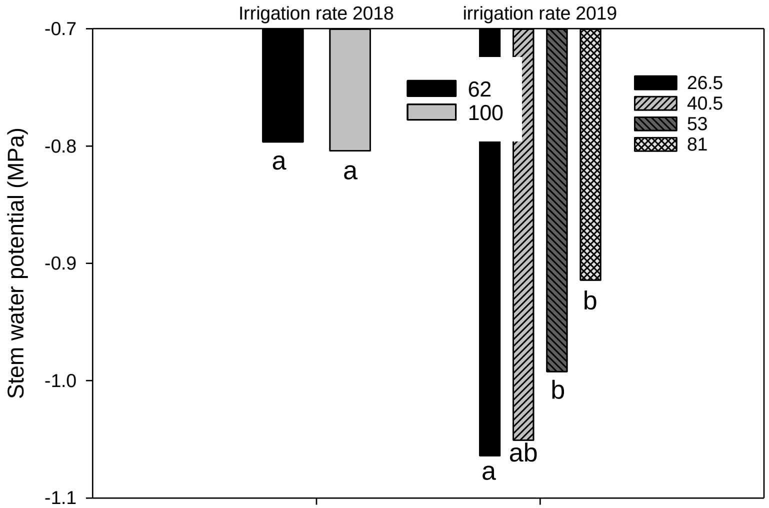
- Macronutrients increased with irrigation rate the second year and third.
- Highest irrigation resulted in greater macronutrient uptake.
- Only the highest irrigation rate resulted in higher micronutrient uptake.

# Soil moisture contents and stem water potential



Irrigation rate effect of soil moisture content

Effect of irrigation rates on stem water potential of citrus trees



- As expected, soil at higher irrigation rate resulted in soil moisture at or above field capacity (0.10).
- Stem water potential is used as an indication of stress with lower (more negative) values.
- Less stress was indicated at higher irrigation rates.

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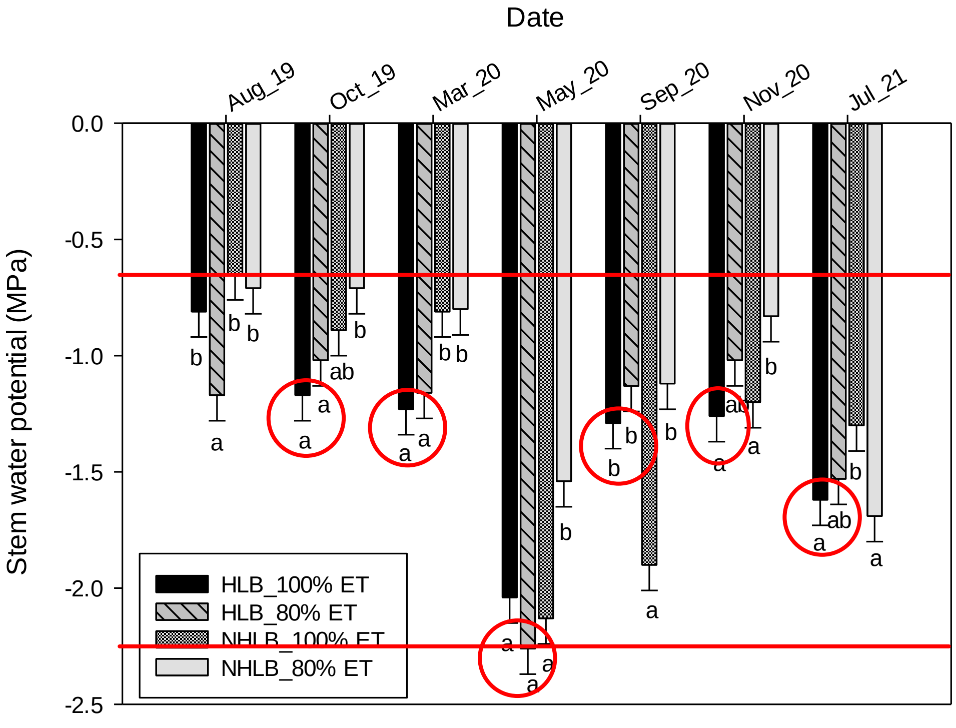
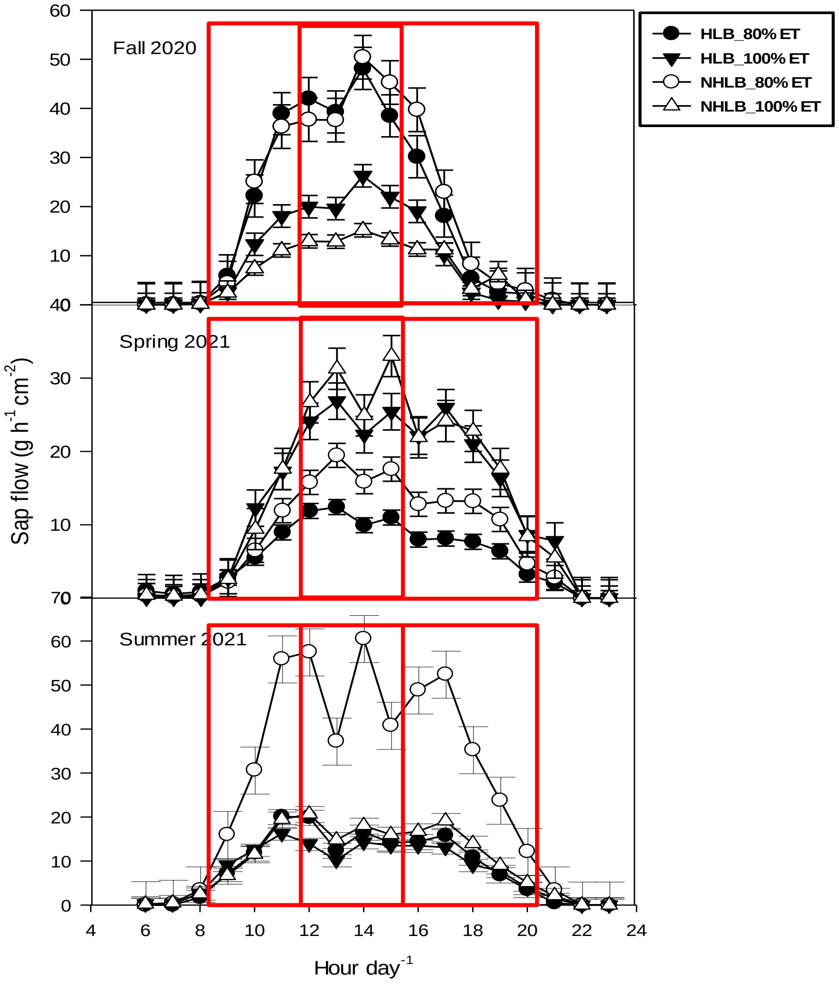
# Example of applications (3)

## Effect of treatments on stem water potential



- SWP was significantly different (P <0.001) among treatments
- SWP ranged from 2.4 and -0.6 MPa
- The HLB-affected trees under both 80% and 100% ET had similar SWP for all but Aug_2019



# Effect on sap flow

- Generally, sap flow occurred between 8 and 20 h daily.
- Sap flow (g $h^{-1}$ $cm^{-2}$) peaked around 12 and 15 h
- Trees under 80% ET had at least 30% greater sap flow than those under 100% ET in Fall 2020
- However, in Spring 2021 trees under 80% ET had at least 28% greater sap flow than those under 100% ET for both HLB and NHLB trees

# Summary

Tools are available for irrigation management including plant-based and soil-based sensors.

Optimal irrigation is possible using these tools and can lead to great water savings.

Most soils for crop production are sandy and need good management to optimize water use.

# ACKNOWLEDGEMENTS

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- UF/IFAS SWFREC: **Dr. Kelly Morgan, Dr. Ayankojo**

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# QUESTIONS/COMMENTS?

E-mail: dkadyampakeni@ufl.edu

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