Basics of Irrigation Scheduling

K. T. Morgan
Southwest Florida Research & Education Center
Outline

- Objectives of irrigation management.
- Factors affecting irrigation scheduling.
- Effect of Florida’s population increase on state water use.
- Crop water use calculations.
- Irrigation requirements.
- Overview of soil water status sensors.
- Demonstration of web and site-specific irrigation scheduling tools.
Objectives of Irrigation Scheduling

- Maximum yield per acre
- Maximum yield for amount of water applied
- Maximum yield per unit of fuel or electricity
- Maximize nutrient uptake.
- Minimize nutrient leaching.
6 key questions in irrigation scheduling

- How deep to irrigate?
- How deep do my roots grow?
- How much water does the soil contain now?
- How dry does the soil need to be to irrigate?
- How long do I wait to irrigate?
- How much water do I need to apply?
Factors affecting irrigation scheduling
Factors that affect irrigation depth and timing

- Soil type – water holding capacity, hydraulic conductivity.
- Where and how deep do my roots grow?
- Depth to water table.
Florida Sandy Soils

Soil Water Tension (kPa)

Soil Water Content (cm³ cm⁻³)

50% Depletion
25% Depletion
Field Capacity

Loam
Sand

Florida Sandy Soils
Soil Types

Entisol

Spodosol
<table>
<thead>
<tr>
<th>Soil Layer</th>
<th>Thickness (Inches)</th>
<th>Organic Matter</th>
<th>Clay Content</th>
<th>Available Water</th>
<th>Permeability (in/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A horizon</td>
<td>3-6</td>
<td>0.5-2%</td>
<td>&lt; 5%</td>
<td>7-10%</td>
<td>6-20</td>
</tr>
<tr>
<td>E horizon</td>
<td>18-30</td>
<td>&lt; 0.5%</td>
<td>&lt; 5%</td>
<td>5-7%</td>
<td>6-20</td>
</tr>
<tr>
<td>Bh horizon</td>
<td>6-12</td>
<td>2-8%</td>
<td>1-8%</td>
<td>12-26%</td>
<td>0.6-2</td>
</tr>
</tbody>
</table>

Source: USDA, NRCS, Soil Survey of Hendry County, Florida
# Entisols (Candler, Tavares, Zolfo, Pomello)

<table>
<thead>
<tr>
<th>Soil Layer</th>
<th>Thickness (Inches)</th>
<th>Organic Matter</th>
<th>Clay Content</th>
<th>Available Water</th>
<th>Permeability (in/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A horizon</td>
<td>3-6</td>
<td>0.5-2%</td>
<td>&lt; 3%</td>
<td>4-8%</td>
<td>6-20</td>
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<tr>
<td>C horizon</td>
<td>&gt; 80</td>
<td>&lt; 0.5%</td>
<td>&lt; 3%</td>
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<td>6-20</td>
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<tr>
<td>B horizon</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

Source: USDA, NRCS, Soil Survey of Polk County, Florida
Soil Effects on Root Density (Spodosol)

- Citrus trees form dense mat of fibrous roots immediately below the soil surface.
- Generally one-third of root system on furrow side of bed, remaining two-thirds on crown side.
- The A horizon appears to play the most important role in root size and quantity.
- Thickness of the A horizon critical in defining thickness of root system.

Source: Rootstock and Soil Interactions Project, Bauer, Castle, Boman, and Obreza
Soil Effects on Root Density (Entisol)

- Root density decreases with distance from the tree and depth
- Changes in rooting pattern is predictable with increase in tree size
- Citrus trees form dense mat of fibrous roots 12 to 18 inches below the soil surface

Source: Morgan et al. 2005
Effect of Florida’s population increase on state water use.
Total Agricultural Irrigation Water Withdrawals
2000

Million Gallons Per Day

- 0 to 5
- 5 to 50
- 50 to 100
- 100 to 950

Total Public Supply Water Withdrawals
2000

Million Gallons Per Day

- 0 to 1
- 1 to 10
- 10 to 50
- 50 to 100
- 100 to 400

USGS Florida Integrated Science web site http://fl.water.usgs.gov/WaterUse/
Florida
Population = 14,149,317
Water Use = 22,790 Ml/d
1995

- Public 35%
- Agriculture 53%
- Commercial 12%

Florida
Population = 15,982,378 (+12.9%)
Water Use = 26,204 Ml/d (+15.0%)
2000

- Public 35%
- Agriculture 57%
- Commercial 8%

USGS Florida Integrated Science web site http://fl.water.usgs.gov/WaterUse/
Orange County
Population = 758,962
Water Use = 891 Ml/d

1995
Agriculture 22%
Commercial 8%
Public 70%

2000
Agriculture 10%
Commercial 9%
Public 81%

Lee County
Population = 376,702
Water Use = 425 Ml/d

1995
Public 36%
Agriculture 56%
Commercial 8%

2000
Public 41%
Agriculture 47%
Commercial 12%

Orange County
Population = 896,344 (+18.1%)
Water Use = 995 Ml/d (+11.8%)

Lee County
Population = 440,888 (+17.0%)
Water Use = 488 Ml/d (+14.6%)

USGS Florida Integrated Science web site http://fl.water.usgs.gov/WaterUse/
Crop water use calculations.
Reduction of Soil Water Content with Time after Application

May 2000

Soil Water Content (cm cm\(^{-1}\))

Field Capacity

25% Depletion

Time

10 cm  20 cm  40 cm  80 cm
Crop Evapotranspiration (ET\textsubscript{c})

\[ ET_c = ET_o \times K_c \times K_s \]

Where,

\( ET_o \) = Reference ET.
\( K_c \) = Crop Coefficient,
\( K_s \) = Soil water extraction factor.
Effect of Time of Year

Source: Morgan et al. 2005
Effect of Soil Drying

Source: Morgan et al. 2005
Irrigation requirements.
Irrigation Trigger Point

- Irrigation should be started at a specific soil water content.
- The soil water content used depends on the stage of crop growth.
Irrigation Trigger Point

- Spring (Feb.- May) Flowering, Flush, and Fruit set.
- Summer, Fall, and Winter (June - Jan.) Flush and Fruit Enlargement.
- Citrus recommendation are:
  25-33% Depletion Feb. - May
  50-66% Depletion June - Jan.
Soil Water Now = Soil Water Yesterday - ET
Example of Irrigation Scheduling  
Month = June

<table>
<thead>
<tr>
<th>Historic ET&lt;sub&gt;c&lt;/sub&gt;</th>
<th>AW at Field Capacity</th>
<th>Depletion</th>
<th>Days between irrigations</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% Depletion</td>
<td>0.21</td>
<td>1.65</td>
<td>0.41</td>
</tr>
<tr>
<td>50% Depletion</td>
<td>0.21</td>
<td>1.65</td>
<td>0.83</td>
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</tbody>
</table>
Irrigation Scheduling Methods

- Published Guidelines.
  - Not Specific to Grove
- Soil Water Status.
  - Can be Expensive
  - High Labor Requirement
- Soil Water Balance Models.
  - Requires Information about field and irrigation system
  - Computer Based
## Irrigation Schedule

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ET (in/day)</td>
<td>0.07</td>
<td>0.11</td>
<td>0.13</td>
<td>0.18</td>
<td>0.20</td>
<td>0.21</td>
<td>0.20</td>
<td>0.19</td>
<td>0.16</td>
<td>0.12</td>
<td>0.09</td>
<td>0.06</td>
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<tr>
<td>Interval (days)</td>
<td>7-10</td>
<td>3-4</td>
<td>3-4</td>
<td>2-3</td>
<td>2-3</td>
<td>2-3</td>
<td>3-4</td>
<td>3-4</td>
<td>3-5</td>
<td>4-6</td>
<td>5-8</td>
<td>7-10</td>
</tr>
<tr>
<td>Duration (hours)</td>
<td>5-6</td>
<td>3-4</td>
<td>3-4</td>
<td>3-5</td>
<td>4-5</td>
<td>4-5</td>
<td>4-6</td>
<td>4-6</td>
<td>4-6</td>
<td>4-6</td>
<td>4-6</td>
<td>4-6</td>
</tr>
</tbody>
</table>


Assumptions:
- Field Capacity = 0.08 to 0.10 in/in
- Rooting Depth = 18 inches
- Application Rate = 0.1 to 0.15 in/hr
- Depletion = 25% Spring, 50% summer - Winter
## Effect of Rooting Depth

<table>
<thead>
<tr>
<th></th>
<th>12 in. depth</th>
<th>18 in. depth</th>
<th>24 in. depth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field Capacity (in/in)</strong></td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Available Soil Water (in)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb. – June. (25%)</td>
<td>0.27</td>
<td>0.41</td>
<td>0.54</td>
</tr>
<tr>
<td>July- Jan. (50%)</td>
<td>0.54</td>
<td>0.81</td>
<td>1.08</td>
</tr>
<tr>
<td><strong>Irrigation Schedule</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan. (ET= 0.08)</td>
<td>6-7 days</td>
<td>10-11 days</td>
<td>13-14 days</td>
</tr>
<tr>
<td></td>
<td>3-4 hours</td>
<td>5-6 hours</td>
<td>7-8 hours</td>
</tr>
<tr>
<td>May (ET=0.20)</td>
<td>1-2 days</td>
<td>2-3 days</td>
<td>2-3 days</td>
</tr>
<tr>
<td></td>
<td>1-2 hours</td>
<td>2-3 hours</td>
<td>3-4 hours</td>
</tr>
<tr>
<td>August (ET=0.22)</td>
<td>2-3 days</td>
<td>3-4 days</td>
<td>4-5 days</td>
</tr>
<tr>
<td></td>
<td>3-4 hours</td>
<td>5-6 hours</td>
<td>7-8 hours</td>
</tr>
</tbody>
</table>
Overview of soil water status sensors.
Soil Water Status

- **Soil Water Content – Electronic Sensors**
  - Most accurate method to determine irrigation scheduling and application amount
  - Highest cost

- **Soil Water Tension - Tensiometers**
  - Measures status not soil water content
  - Must know soil characteristic to determine irrigation schedule and application amount
Soil Water Content

Multi Sensor Arrays

Single Sensor Probes

Access Tube Sensor

Time Domain Reflectometry
Soil Water Potential

Resistance Sensors

Tensiometers
Web and site-specific irrigation scheduling tools.
Soil Water Balance

  - Evaporation from soil surface.
  - Transpiration from citrus trees.
- Calculate ET for the crop.
  - Table of historic ET values for the crop.
  - Calculate from reference ET (FAWN)
Computer Programs

- Web based
  - schedule based on nearest station
  - Enter: Field capacity, tree spacing, irrigation specifications
- PC Irrigation program
  - Select FAWN site
  - Same information required
  - Stores irrigation data
  - Print reports
Florida Automated Weather Network
(http://FAWN.IFAS.UFL.EDU)

Latest Temperatures
Saturday October 22, 2005 10:23 AM EDT

Rollover temperature for complete station data.
Click on temperature for a graphical display of station data.

Stations updated. Next update at 10:27 AM
**Web-based Tool**

- **Required Information**
  - FAWN station for ET.
  - Tree spacing, irrigation depth, irrigation specifications.
  - Soil field Capacity (can be selected from list).
  - Allowable seasonal depletion (can select default values).

- **Outputs**
  - Crop ET.
  - Interval between irrigations.
  - Duration of irrigation.
PC-based Site Specific Management System

Add New Block

For Grove: CentrHiland, Enter New Block Name (4-6 characters)

In Row Distance
Between Row Distance
Number of Acres
Tree Age

In ft
In ft
In yr

Wetted Diameter
Spray Pattern
Flow Rate
Irrigation Efficiency

In ft
In 0
In g/hr
In pct

Soil Type

Apopka

Irrigation Depth Source

Manual 1.97 ft

Allowed Soil Water Depletion...

Manual
Default by Soil Type

Jan 50
Feb 25
Mar 25
Apr 25
May 25
Jun 50
Jul 50
Aug 50
Sep 50
Oct 50
Nov 50
Dec 50

Enter a new or select an exist Rainfall Station

rg001

ET Source

FAWN

Manual Entry

Note: If Fawn data are not available, the historic ET will be used.

Save
Cancel

Status:
PC-based Site Specific Management System

Subject: WC
Profile Type: Irr
X: Date
Profile #: 1 (1 ~ 4)
Y: value
Layer #: 1 ~ 10 (1 ~ 40)

Water Content

WC
0.140
0.135
0.130
0.125
0.120
0.115
0.110
0.105
0.100
0.095
0.090
0.085
0.080
0.075
0.070
0.065
0.060
0.055
0.050

Date
PC-based Irrigation Management System

- Site Specific (Multiple Fields) Information
  - Estimated soil water content by soil layer.
  - Crop water uptake and stress index.
  - Field specific irrigation schedule.
  - Water use by field.

- Irrigation Schedule
  - Date specific.
  - Duration to fill each soil layer to irrigation depth to field capacity.
  - Alternate irrigation dates and durations.
Conclusions

- Soil type is key to root distribution.
- Depth of rooting is key to irrigation scheduling decisions.
- Water quantity and quality issues will impact agricultural water use in areas of increasing development.
- Irrigation scheduling varies seasonally by weather conditions.
- Three methods of irrigation scheduling are: tables, sensors, and models.
Infiltration Depth of Water Applied

\[ I = \frac{A}{FC} \]

Where:
- \( I \) = Infiltration depth of applied water (in)
- \( A \) = Depth of water applied (in)
- \( FC \) = Field capacity of soil (in/in or % divided by 100)
Total Soil Depth to Field Capacity

\[ I_t = \frac{A + W}{FC} \]

Where:

- \( I_t \) = Total water depth to field capacity (in)
- \( A \) = Depth of water applied (in)
- \( W \) = Depth of water to infiltration depth (in)
- \( FC \) = Soil field capacity (in/in or % divided by 100)
Depth of 1.0 inch of Rainfall

Assume:

Candler Fine Sand – FC = 8%
Soil Water Content – 6% (1/3 depletion)
Rainfall - 1.0 Inches

\[
I = \frac{A}{FC} = \frac{1.0}{0.08} = 12.5 \text{ inches}
\]

\[
W = I \times SWC = 12.5 \times 0.06 = 0.75 \text{ inches}
\]

\[
I_t = \frac{A + W}{FC} = \frac{1.0 + 0.75}{0.08} = 21.87 \text{ inches}
\]
Depth of 0.5 inch of Irrigation

Assume:

- Candler Fine Sand – FC = 8%
- Soil Water Content – 6% (1/3 depletion)
- Irrigation Depth - 0.5 Inches

\[
I = \frac{A}{FC} = \frac{0.5}{0.08} = 6.25 \text{ inches}
\]

\[
W = I \times SWC = 6.25 \times 0.06 = 0.375 \text{ inches}
\]

\[
I_t = \frac{A + W}{FC} = \frac{0.5 + 0.375}{0.08} = 10.94 \text{ inches}
\]
Weak Tree with Damaged Root System

Healthy Tree with Normal Root System
Weak Tree with Damaged Root System

Healthy Tree with Normal Root System
Severely Damaged Roots

Recovering Root System
Effect of Canopy Volume on Root Length Density

Source: Morgan et al. 2005
Effect of Canopy Volume on Root Length Density

Source: Morgan et al. 2005
Effect of Canopy Volume on Root Length Density

Source: Morgan et al. 2005
y = 0.111x^{-1.5686}

$R^2 = 0.9625$

Soil Water Retention

Soil Water Content (cm$^3$ cm$^{-3}$)

Soil Water Tension (kPa)

- 66% Depletion
- 50% Depletion
- 33% Depletion
- 25% Depletion
- Field Capacity

Soil Water Retention
### Alfisols (Pineda, Riviera, Wabasso, Winder)

<table>
<thead>
<tr>
<th>Soil Layer</th>
<th>Thickness (Inches)</th>
<th>Organic Matter</th>
<th>Clay Content</th>
<th>Available Water</th>
<th>Permeability (in/hr)</th>
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<tbody>
<tr>
<td>A horizon</td>
<td>3-6</td>
<td>1-4%</td>
<td>&lt; 5%</td>
<td>7-10%</td>
<td>6-20</td>
</tr>
<tr>
<td>E horizon</td>
<td>18-24</td>
<td>&lt; 0.5%</td>
<td>&lt; 5%</td>
<td>5-7%</td>
<td>6-20</td>
</tr>
<tr>
<td>Bt horizon</td>
<td>12+</td>
<td>&lt; 0.5%</td>
<td>10-30%</td>
<td>12-16%</td>
<td>&lt; 0.2</td>
</tr>
</tbody>
</table>

Source: USDA, NRCS, Soil Survey of St. Lucie County, Florida
Ridge Soil Types

Entisol
Water Table Depth Monitoring

- Soil water status
  - Tensiometers
  - Soil water content sensors
- Water table wells
  - Recording depth measurement devices
  - Manual (float) gauges
Water Table Observation Well

Source: Circular 1409, Florida Cooperative Extension Service, IFAS, University of Florida, Boman and Obreza
<table>
<thead>
<tr>
<th>Soil Profile#</th>
<th>Layer#</th>
<th>Root Section#</th>
<th>RootLength pct</th>
<th>WC(%)</th>
<th>NH4 Concentration</th>
<th>NO3 Concentration</th>
<th>Ks used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1.95</td>
<td>0.06952</td>
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<td>-</td>
<td>0.3659</td>
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<tr>
<td>1</td>
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<tr>
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<td>0.08785</td>
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<td>0.7538</td>
</tr>
</tbody>
</table>
### CWMS Daily Report for February, 2005

<table>
<thead>
<tr>
<th>Soil Profile#</th>
<th>Layer#</th>
<th>Root Section#</th>
<th>Root Length pct</th>
<th>WC (%)</th>
<th>NH4 Concentration (%)</th>
<th>NO3 Concentration (%)</th>
<th>Total Root Length:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>2</td>
<td>1</td>
<td>1</td>
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</tbody>
</table>

### Non-Irrigation Zone

### Monthly Report for February, 2005

<table>
<thead>
<tr>
<th>Day</th>
<th>Interval (day)</th>
<th>Duration (hours)</th>
<th>ETo Source</th>
<th>ETo Used (inches/day)</th>
<th>Ks used</th>
<th>Kc Used</th>
<th>ETc Used (inches/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb. 1</td>
<td>3</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Feb. 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Yearly Report (Monthly data used) for year 2005

<table>
<thead>
<tr>
<th>Month</th>
<th>Set Point Depth Source</th>
<th>Set Point Depth (cm)</th>
<th>Irrigation Depth Source</th>
<th>Irrigation Depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Decision Support Systems

#### Add New Block

<table>
<thead>
<tr>
<th>Grove</th>
<th>Block</th>
<th>Zone</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>In Row Distance</th>
<th>ft</th>
<th>Wetted Diameter</th>
<th>ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Row Distance</td>
<td>ft</td>
<td>Spray Pattern</td>
<td>°</td>
</tr>
<tr>
<td>Number of Acres</td>
<td>ft</td>
<td>Flow Rate</td>
<td>g/hr</td>
</tr>
<tr>
<td>Tree Age</td>
<td>&gt;15 yr</td>
<td>Irrigation Efficiency</td>
<td>%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Apopka</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Irrigation Depth</th>
<th>3 ft</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Allowed Soil Water Depletion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crop Coefficient</th>
</tr>
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<tbody>
<tr>
<td>Jan</td>
</tr>
<tr>
<td>0.85</td>
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<table>
<thead>
<tr>
<th>Rainfall Station</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>ET Source</th>
<th>Manual Entry</th>
<th>Historic Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAWN</td>
<td>ALACHUA</td>
<td></td>
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</table>