Irrigation Efficiency, Uniformity & Crop Response

System performance evaluation

Crop Water Stress Conference
February 23, 2016

Florence Cassel S. Bill Green
Assessing Irrigation System Performance

- 3 components:
  - Irrigation system efficiency
  - Uniformity of water application (Distribution uniformity)
  - Response of crop to irrigation

- Interrelated & vary with time and location
  - Location: field or farm scale
  - Time: irrigation event or growing season
Irrigation System Efficiency

- Effectiveness of system & operating decisions to deliver water from a source to a crop.

⇒ How much of the applied irrigation water is actually used by the crop?

Irrigation Efficiency (%) = \( \frac{\text{Water beneficially used}}{\text{Water applied}} \times 100 \)
What are the beneficial uses?

- Water used by crop (Evapotranspiration – ET)
- Water needed for:
  - Leaching salts
  - Crop establishment
  - Chemigation
  - Frost protection

⇒ Goal is to make all applied water a beneficial use (or as much as possible) and limit runoff/percolation
What are the possible losses?

- Conveyance losses from water source to field:
  - Leaks in headgates, pipelines, fittings, etc.

- Application losses in field:
  - Leaks in manifolds, laterals.
  - Wind drift
  - Evaporation from crop canopy & soil surface
  - Runoff, percolation below rootzone
  - Also depends on type of irrigation system, its design, and irrigation scheduling

→ Application efficiency
How can we improve irrigation efficiency?

- Reduce leakages
  - Perform regular maintenance on system

- Improve irrigation scheduling
  - Frequency and duration of irrigation events

- Reduce runoff, percolation below rootzone

↔  Irrigation Scheduling +

  Good knowledge, operation, & maintenance of Irrigation System
What is irrigation scheduling?

Applying **right amount** of water at **right time**

- Making appropriate decisions on two major questions:
  1. **WHEN** to irrigate?
  2. **HOW MUCH** to irrigate?
Benefits of irrigation scheduling

- Minimizes crop stress.
- Improves crop yield and quality.
- Improves water and energy usage
  - Water Use Efficiency (more crop per drop)
  - Energy Use Efficiency.
- Can save water, fertilizers, and energy
- Can improve net profits.
Main methods of irrigation scheduling

1. Climate-based

2. Soil-based

3. Plant-based
1. Climate-based methods

- Rely on weather and crop information to estimate amount of water depleted from rootzone.
- Focus on estimation of **crop water use**, i.e. **crop evapotranspiration (ET\textsubscript{c})**.

\[ \text{ET}_c = \text{Reference ET (ET}_o) \times \text{Crop coefficient (K}_c) \]

**CIMIS**

www.cimis.water.ca.gov
1. Climate-based methods

- Follows water budgeting method ("checkbook")
- Monitor ET (inches/day)
- Irrigate when ET over several days/weeks has reached maximum soil depletion level (management decision)
- Irrigation amount = total ET
Climate-based methods

**Advantages**
- ET Information is easily available and free (no need to install sensors)
- Easily computerized
- Answer both questions: WHEN and HOW MUCH to irrigate

**Disadvantages**
- Calculations can be difficult
- Need accurate local weather estimates
- Need accurate crop information (crop coefficient)
- Calculations should be verified with field checks
2. Soil-based methods

- Rely on sensors that monitor soil moisture level or soil water potential at appropriate locations and depths.
- As plant uses water, soil moisture is being depleted from rootzone.
- Soil moisture sensors measure amount of water remaining in soil.
  - When sensors indicate that soil has reached a critically low value (threshold) → apply irrigation (management decision).
Soil-based methods

**Advantages**

- Ease of use once measurement and calibration parameters have been determined.
- Commonly used in commercial fields – many sensors & monitoring services available.
- Most sensors can be automated (download data to datalogger, cell phone, etc)
Disadvantages

- Effectiveness is subject to representative placement of sensors (site selection) and good understanding of the crop root zone (depth).
- Some sensors measure soil water content and other measure soil water potential (more indicative of plant stress).
- Calibration required to determine “threshold”.
- When automated, can generate large amounts of data.
- Most sensors only answer: WHEN to irrigate (How much to irrigate is derived indirectly).
Soil-based methods

Sensor placement
(bigger challenge for drip & microsprinkler)
3. Plant based methods

- Rely on sensors that measure certain plant physiological traits, related to plant water stress:
  - Leaf water potential
  - Stomatal conductance
  - Canopy temperature
  - Sap flow
  - Stem diameter change

- Used to measure or estimate presence and/or degree of stress.

- Relatively new approach of scheduling.
Plant-based methods

**Advantages**
- Measures plant stress response directly
  - Most direct measure of plant water stress.
- Integrate environmental effects.
- Some methods can be used remotely.

**Disadvantages**
- Timing of measurements
  - If stress has been determined – might be too late, stress has already caused some yield loss.
Plant-based methods

Disadvantages (cont’)

More complex/time consuming than other methods.
  Require sophisticated equipment
    - Require high level of technical skills
    - Require calibration to determine “threshold” limits

- Some methods are invasive or destructive.

- Measurements may not be representative of entire field (large leaf-to-leaf or plant-to-plant variation).

- Only answers question: WHEN to irrigate
  (How much to irrigate is derived indirectly)
Selecting a Method

- Availability of data to determine crop water use
- Ability to measure water applied
- Time required to make decisions
- Value of expected benefits
- Climate-based methods (ET) are best since they provide information on HOW MUCH to irrigate.
- Ideally, best to use ET scheduling backed up with soil and/or plant monitoring.
Irrigation Scheduling Tool
WATERIGHT

○ Free program available to growers
www.wateright.org
Agricultural Irrigation Scheduling

Field Data Summary

Field Name: Almond First

Choose Station

CIMIS Station - 0
City - County -

Scheduling Basis and Criteria (choose one):

- Management Allowed Depletion 50 %
- Set Time/Irrigation Set
- Set Days in Rotation

Choose Crop

None selected

Choose Soil >> Avail H2O (in/ft) - Soil
.45 - Coarse Sand/Gravel

Choose System>>

Drip Tape

System Parameters

Irrigation Efficiency - %
Gross Application Rate - 0.000 in/hr

Field Data Summary

CIMIS Stn: Fresno State #80
City of Fresno in Fresno County

Field Number 1
Description North Field
Crop Almonds
Crop Season 3/1 - 10/15
Stop Irrigating 10/15
Soil Coarse Sand/Gravel
Maximum RootZone (ft) 5
Irrigation System Microsprinkler
Irrigation Efficiency 85%
Gross Application Rate (in/hr) 0.012
Scheduling Basis Hours/Irrigation Set
Desired Hours per Set (hrs) 18
Gross Applied per Set (in) 0.21875192027224

Seasonal Irrigation Schedule

<table>
<thead>
<tr>
<th>For Week Ending</th>
<th>Average Year ETo</th>
<th>Average Year Rain</th>
<th>This Year ETo</th>
<th>This Year Rain</th>
<th>Averages for Week Root Zone</th>
<th>Change This Yr vs Avg Yr</th>
<th>Total ETo to Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In/Day In/Wk</td>
<td>In/Day In/Wk</td>
<td>In/Day In/Wk</td>
<td>In/Day In/Wk</td>
<td>In/Dy Ft Hr:mm %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/8/2013</td>
<td>0.09 0.21</td>
<td>0.13 0.00</td>
<td>0.57 0.05</td>
<td>5.00 34:19</td>
<td>44 0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/15/2013</td>
<td>0.10 0.01</td>
<td>N/A N/A</td>
<td>0.60 0.06</td>
<td>5.00 39:55</td>
<td>N/A 0.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/22/2013</td>
<td>0.11 1.71</td>
<td>N/A N/A</td>
<td>0.63 0.07</td>
<td>5.00 44:46</td>
<td>N/A 1.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/29/2013</td>
<td>0.12 0.46</td>
<td>N/A N/A</td>
<td>0.66 0.08</td>
<td>5.00 54:28</td>
<td>N/A 1.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/5/2013</td>
<td>0.14 0.35</td>
<td>N/A N/A</td>
<td>0.69 0.09</td>
<td>5.00 64:19</td>
<td>N/A 2.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/12/2013</td>
<td>0.15 0.47</td>
<td>N/A N/A</td>
<td>0.72 0.11</td>
<td>5.00 74:10</td>
<td>N/A 3.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/19/2013</td>
<td>0.17 1.13</td>
<td>N/A N/A</td>
<td>0.74 0.12</td>
<td>5.00 84:37</td>
<td>N/A 4.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/26/2013</td>
<td>0.18 0.06</td>
<td>N/A N/A</td>
<td>0.77 0.14</td>
<td>5.00 95:15</td>
<td>N/A 5.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/3/2013</td>
<td>0.20 0.04</td>
<td>N/A N/A</td>
<td>0.80 0.16</td>
<td>5.00 106:19</td>
<td>N/A 6.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/10/2013</td>
<td>0.21 0.03</td>
<td>N/A N/A</td>
<td>0.83 0.17</td>
<td>5.00 118:08</td>
<td>N/A 7.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/17/2013</td>
<td>0.22 0.13</td>
<td>N/A N/A</td>
<td>0.86 0.19</td>
<td>5.00 131:04</td>
<td>N/A 8.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/24/2013</td>
<td>0.24 0.00</td>
<td>N/A N/A</td>
<td>0.89 0.21</td>
<td>5.00 144:00</td>
<td>N/A 10.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/31/2013</td>
<td>0.25 0.02</td>
<td>N/A N/A</td>
<td>0.92 0.23</td>
<td>5.00 157:02</td>
<td>N/A 11.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/7/2013</td>
<td>0.26 0.55</td>
<td>N/A N/A</td>
<td>0.95 0.25</td>
<td>5.00 170:33</td>
<td>N/A 13.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/14/2013</td>
<td>0.28 0.00</td>
<td>N/A N/A</td>
<td>0.98 0.27</td>
<td>5.00 183:16</td>
<td>N/A 15.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/21/2013</td>
<td>0.29 0.00</td>
<td>N/A N/A</td>
<td>1.01 0.29</td>
<td>5.00 195:26</td>
<td>N/A 17.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/28/2013</td>
<td>0.29 0.00</td>
<td>N/A N/A</td>
<td>1.03 0.30</td>
<td>5.00 202:09</td>
<td>N/A 19.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7/5/2013</td>
<td>0.29 0.00</td>
<td>N/A N/A</td>
<td>1.03 0.30</td>
<td>5.00 203:04</td>
<td>N/A 21.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7/12/2013</td>
<td>0.29 0.00</td>
<td>N/A N/A</td>
<td>1.03 0.30</td>
<td>5.00 202:31</td>
<td>N/A 23.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7/19/2013</td>
<td>0.29 0.00</td>
<td>N/A N/A</td>
<td>1.03 0.30</td>
<td>5.00 201:06</td>
<td>N/A 25.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7/26/2013</td>
<td>0.28 0.00</td>
<td>N/A N/A</td>
<td>1.03 0.29</td>
<td>5.00 198:49</td>
<td>N/A 27.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/2/2013</td>
<td>0.28 0.00</td>
<td>N/A N/A</td>
<td>1.03 0.29</td>
<td>5.00 195:53</td>
<td>N/A 30.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/9/2013</td>
<td>0.27 0.00</td>
<td>N/A N/A</td>
<td>1.03 0.29</td>
<td>5.00 192:09</td>
<td>N/A 31.90</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
② Uniformity of water application

- Irrigation Efficiency does not tell you where water was applied on field.

- Distribution Uniformity (DU) = Measure of how evenly water is distributed over a field.

⇒ Important to know if same amount of water/chemicals are applied throughout field, i.e., if emission devices discharge same amount of water
Distribution Uniformity (DU)

- Every pressurized irrigation system should be designed, installed, and maintained with the goal of achieving good DU.
- Good DU can save water, fertilizer, and energy.
- Once good DU is achieved, Irrigation, Fertigation, and Energy Efficiency can be maximized.
What are some causes of Non-Uniformity?

- Poor system design
  - Inadequate sprinkler overlap
  - Long laterals - high friction losses, etc.

- Poor equipment selection
  - Wrong or different emission devices used in same field
  - Wrong operating pressure
  - Wrong pipe diameter

- Manufacturing variations (small)
What are some causes of Non-Uniformity?

- Pressure differences - due to elevation changes & pressure losses due to friction losses (can be minimized with good design).
- Poor maintenance
  - Leaks, Clogging (emitters, filter)
  - Pressure valves not calibrated properly
- Wear and tear of irrigation equipment
- Pump flow and pressure do not match system design
- Wind effects on water distribution
Assessing Distribution Uniformity (DU) in field

- Conduct audit – field test using catch cans.

- Most Irrigation Systems audits use **Distribution Uniformity of the low quarter (low-1/4 DU)**-
  Developed by the Irrigation Training and Research Center (ITRC) at Cal Poly, SLO

**DU** = \( \frac{\text{avg volume of low 25% of measurements}}{\text{avg volume of all measurements}} \)
High Pressure Volume Test
Mid Pressure Volume Test
Low Pressure Volume Test

From K. Vang
Auditing the irrigation system to determine DU (con’t)

Measurements commonly obtained using catch cans or ...buckets
Calculating Distribution Uniformity

Arranged by increasing depth collected

Low Quarter

Average = 0.5 inches

Average = 0.8 inches

\[ DU_{lq} = \frac{0.5}{0.8} \times 100 = 63\% \]
\[ DU = \frac{AvgLowQuater}{Avg} \]
Relationship between efficiency and uniformity

- A high DU does not necessarily mean a high Irrigation Efficiency.
- But a high Irrigation Efficiency is not possible without a high DU.

✓ Irrigation efficiency is greatly influenced by uniformity of applied water.
  → You need a uniform irrigation system to be an efficient irrigator.

✓ Achieving high irrigation efficiency ultimately depends on system management.
Poor DU, uneven irrigation

Under-irrigation
Good DU but ..... 

**Efficient:** Correct amount of water applied

GOAL: Apply just enough to meet crop water needs

**Not Efficient:** Overwatering, potential for leaching
③ Evaluate response of crop to irrigation

Crop water use efficiency (CWU)
- CWU = Yield / ET

Irrigation water use efficiency (IWU)
- IWU = Yield / depth of applied irrigation water

Benefits of irrigation management

Why is Efficiency important?

Why is Uniformity important?

- Crop yields and quality are very strongly correlated with irrigation water management (scheduling, efficiency, distribution uniformity, maintenance)
  - Better yields
  - Improved crop quality (more uniform)
  - Less water used = $$ savings
  - Less energy used = $$ savings
  - Less fertilizers used = $$ savings and protect groundwater quality
Consequences of Over-Irrigating

- Increased incidence of plant diseases
  - Blights, molds, rots, wilts
- Increased weed pressure
- Less oxygen in root zone, yield loss
- Difficulty with harvesting and cultural operations
- Additional labor, pumping, fertilizer costs
Improve System Performance By:

- Getting a good design
- Maintaining your system
  - Replace worn/clogged nozzles, emitters (with same specifics as originally designed)
  - Fix leaky pipes
  - Flush system (mainlines, submains, laterals)
  - Maintain good filtration system (clean filter regularly, acidify water if calcium carbonates present, add chlorine if biological clogging)
- Improving management
  - Irrigation Scheduling
  - Operate at designed pressure and flow
  - Use flow meters and pressure regulators
How do we become efficient irrigators?

**Summary**

- Know when and how much water to apply
- Apply correct amount of water with a good irrigation system
  - Use flow meters to measure applied water
- Perform regular checks, maintenance & repairs on system
  - Determine uniformity

*Good Irrigation Uniformity + Good Irrigation Scheduling Leads to Good Irrigation Efficiency.*
How do you determine uniformity?

Summary

Field measurements

- Measure pressure
  - Big pressure differences often indicate uniformity problems
- Discharge of emission devices
  - Perform DU test
  - Install flow meters (lateral line preferably)
  - If variability can’t be explained by pressure differences, then probably clogging problems
Thanks!

Any Questions?

Florence Cassel S.
559-278-7955
fcasselss@csufresno.edu