Irrigation 101 +
Precision Ag Research

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Irrigation101+ Precision Ag Research

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We survived droughts in the past but have things changed?

Bruce Lampinen
UC Davis Plant Sciences
Second generation mule light bar

Adjustable from 8 to 32 feet in width

Adjustable from 2 to 11 meters in width
We have found that you can produce about 50 kernel pounds for each 1% of the total incoming light you can intercept.
Relationship between light interception and yield potential

Food safety risk increases above 80% interception due to difficulty in drying nuts and lack of sun to orchard floor.
Trees per acre from 1986 to 2013 in California

112 trees/ac in 2013
(~18.5’ x 21’)

$r^2 = 0.995$
Per acre yield from 1982 to 2013 in California

Increasing at a rate of 46 lbs/acre per year

Year:
- 1980
- 1985
- 1990
- 1995
- 2000
- 2005
- 2010
- 2015

Yield (kernel lbs/acre):
- 0
- 500
- 1000
- 1500
- 2000
- 2500
- 3000

$r^2 = 0.67$

2280 lbs/acre
Midday PAR interception versus estimated water needs and yield potential

<table>
<thead>
<tr>
<th>Midday PAR interception</th>
<th>Applied plus stored water (inches)</th>
<th>Yield potential (kernel lbs/ac)</th>
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<tbody>
<tr>
<td>10</td>
<td>(\frac{1}{1.43} = 7)</td>
<td>(7 \times 71.43 = 500)</td>
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<tr>
<td>20</td>
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<td>4000</td>
</tr>
<tr>
<td>90</td>
<td>63</td>
<td>4500</td>
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</table>

Midday PAR/1.43 = applied plus stored water

Applied plus stored water \(\times 71.43\) = yield potential

Note:
This analysis is based on microirrigation data only
Increases in yield potential result in increased water needs

Increase of 1424 lbs/acre over 31 years or 46 pounds per acre per year.

This means an increased water requirement of about 20” over the last 31 years or an increase of 0.64” per year.
While water demand has increased, changes in irrigation practices have increased efficiency as well.

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<td>47.57</td>
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<td>UC Drought Management - Historical Almond ET Updated to new almond crop coefficients, new coefficients in:</td>
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</table>
Best orchards are yielding in 4000 kernel pound per acre range at 80% PAR interception
Water needs based on yield potential

Best orchards need 56 inches (80% canopy cover)

Average orchard needed 36 inches
It is difficult to put on 56” of water on most soils without causing tree health problems particularly during high evaporative demand periods in July and August.
Dryland orchard in Yolo County

~30% interception
Dryland yield potential

Average rainfall ~20 inches in areas of Yolo County where dryland almonds still exist

20" of rain = 1420 kernel lbs/ac yield potential at 30% PAR int.

Try this in western Kern County with 5" of rain

5" rain = 350 kernel lbs/ac yield potential at 7% PAR interception
Ground cover also uses water

~35% PAR interception needs ~25 inches of water

~40% PAR interception from trees plus 40% from grass = 80% total needs ~56” of water
Higher yields per acre means more efficient production

Growing 3800 pounds on 80 acres is much more efficient than growing 1950 and 1850 pounds on 160 acres

Less light for weeds and groundcover, less fuel for mowing, spraying, harvest, etc., less land cost

39% (1950 lbs/ac)                 37% (1850 lbs/ac)                 76% (3800 lbs/ac)

3800 lbs/ac
Drought impacts

Drought will have much larger impacts in 2014 versus in 1991-1992

Impact on your orchards will depend on winter rainfall and canopy cover/productivity

1991-1992

State Water Project water deliveries were 50% of normal
Average almond orchard was producing 1200 kernel pounds per acre so would have required about 17 inches of water

2014

Average almond orchard producing in range of 2500+ kernel pounds per acre so would require about 35 inches of water
Best orchards producing about 4000 kernel pounds per acre so would require about 56 inches of water

If State Water project delivered 50% of normal (actually only delivered 40% in 2013)

Average orchard deficit 1991-1992 17/2 = 8.5 inches
Average orchard deficit 2013 35/2 = 17.5 inches
Best orchard deficit 2013 56/2 = 28 inches
Blake Sanden, UCCE-Kern County
Irrigation 101: 5-point sermon

• Canopy cover (PAR)/yield/ET, calculating almond ET, soil water holding capacity, –Lampinen, Sanden

• Irrigation uniformity, system mechanics, salt accumulation & leaching – Fulton

• Soil moisture & plant monitoring options – Dave Doll

• What do we know about plant stress, deficit irrigation impacts on plant growth and yield? – Shackel

• High tech plant/field monitoring – Upadhaya
SO WHAT’S ESSENTIAL for EFFICIENT IRRIGATION, OPTIMAL WATER BALANCE & CROP PRODUCTIVITY?
Irrigation & soil management are the essential foundations of crop production. The engineering factors are the ones we have the most control over.

**Factors having greatest variability**

- STEPS
- RETREAT
- CENTER
- CROP
- CULTIVATION

**NATURAL FACTORS**

- CLIMATE CONSIDERATIONS
  - HEAT UNITS/CHILLING
  - FROST-FREE DAYS/RADIATION
  - MIN-MAX TEMPS/ETo

- SITE SOIL CONSIDERATIONS
  - TOPOGRAPHY
  - TEXTURE/DRAINAGE
  - CHEMISTRY/AMNDMNT/COST

- WATER CONSIDERATIONS
  - RELIABILITY OF SUPPLY
  - CHEMISTRY/AMNDMNT/COST

**PROPOSED CROP**

- LIFE CYCLE & WATER USE
- ROOTING CHARACTERISTICS
- DESIRED STRUCTURE & SPACING
- HARVEST REQUIREMENTS
- FIELD TRAFFIC
- TRAINING/COST

**IRRIGATION / SOIL / FERTILITY**

- IRRIGATION METHOD
- DISTRIBUTION PATTERN
- IRRIGATION FREQUENCY
- PRESSURE REGULATION
- FILTRATION
- DURABILITY
- MONITORING

- AMENDMENT APPLICATION
- MAINTAINENCE / REPAIR
- SYSTEM CAPITAL COST
- ENERGY COST
Where do I start?

1. Pray for miracles. We need all the help/rain we can get!

2. Get all the information you can! (That’s why you’re here.)

3. Get down on your knees (Similar to Step 1, but now this is work.) so you can check the soil profile, emitter flowrates, adjust pressure regulators and optimize uniformity!
Creating the efficient field water balance – your soil moisture checking account!

- How big is the cup (soil AWHC)?
- How thirsty is the crop (ET)?
- How often/much do you fill the cup (Scheduling)?

![Water Budget Method of Irrigation Diagram]

- ET Loss to the Atmosphere
- ET inches/day: 0.25, 0.25, 0.30, 0.30, 0.35, 0.35, 0.30
- Days: 1, 2, 3, 4, 5, 6, 7

Soil Available Water
Allowable Depletion

IRRIGATE
1. When?-------After 7 days
2. How much?--Apply 2.10 inches of water + losses (Efficiency consideration)
Check your dirt! It has more secrets than the CIA.
Estimating soil texture by a “ribbon” test from a moistened ball. Sandy Clay Loam – Westside Kern County
Backhoe Pits – the Worm’s Eye View!
Hand-powered twist augers
($150 - $300)
Micro-irrigation system capable of injecting fertilizer and applying 0.6 to 1.5 inches/day.
How do I calculate total available water with microsprinklers @ 1.5 in/day…
Irrigation evaluation for application patterns & rootzone subbing  4/23/09

Bowsmith A-40 microsprinkler
Interpolated pattern of applied water from 2 Fanjets/tree
Summed 0-6 ft water content 6/24/09 after 24 hour irrigation
... or account for “subbing” in a double-line drip?
## Water Holding Capacity & Microirrigation Set Times for Orchards

### 1Irrigation Time to Refill & Moisture Reserve of 4 Foot Wetted Rootzone @ 50% to 100% Available

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Available Soil Moisture (in/ft)</th>
<th>Avg Drip Subbing Diameter from 1 to 4' Depth (ft)</th>
<th>Dble-Line Drip 1-gph, 10 per tree (irrig hrs)</th>
<th>Moisture Reserve @ 0.30&quot;/day (days)</th>
<th>10 gph Fanjet, 1 per tree (irrig hrs)</th>
<th>Moisture Reserve @ 0.30&quot;/day (days)</th>
<th>14 gph Fanjet, 1 per tree (irrig hrs)</th>
<th>Moisture Reserve @ 0.30&quot;/day (days)</th>
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<tr>
<td>Sand</td>
<td>0.7</td>
<td>2</td>
<td>2.2</td>
<td>0.3</td>
<td>11.6</td>
<td>1.4</td>
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<td>Loamy Sand</td>
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<td>1.4</td>
<td>4</td>
<td>17.5</td>
<td>2.1</td>
<td>26.9</td>
<td>3.3</td>
<td>28.3</td>
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<td>1.8</td>
<td>5</td>
<td>35.9</td>
<td>4.4</td>
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<td>4.5</td>
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<tr>
<td>Silt Loam</td>
<td>1.8</td>
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<td>43.1</td>
<td>5.3</td>
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<td>10.7</td>
<td>62.3</td>
<td>7.6</td>
<td>61.5</td>
<td>10.5</td>
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</table>

1Based on a tree spacing of 20 x 22’. Drip hoses 6’ apart. 10 gph fanjet wets 12’ diameter. 14 gph fanjet @ 15’ diameter.

Note: Peak water use @ 0.30”/day and 20 x 22’ spacing = 82 gallons/day/tree. 0.20”/day = 55 gallons/day/tree.

Table takes into account merging water patterns below soil surface for drip irrigation.
What’s the critical process that keeps the crop growing?

- **Optimal photosynthesis**
- **Maximum carbon dioxide uptake**
Reduced water, deficit irrigation, causes less turgor pressure in the plant, reduces the size of stomatal openings; thus decreasing the uptake of carbon dioxide and reducing vegetative growth.
6/3-9/30/14 average almond plot water conductance by 2014 applied irrigation

![Graph showing water conductance](image)

**Canopy Temp/Water Stress by Irrigation Treatment** (CERES Spectral Imaging 6-3-14, Shackel, et al. Yield Production Function Trial)
Crop water use is made up of **EVAPORATION** (E) from the soil, and **TRANSPIRATION** (T), water moving through plant to evaporate from the leaves, hence ET.
We haven’t been out of the cave that long regarding a scientific understanding of crop water use and “Normal Year” ET.
From 1968 to 1993 detailed records of Class A pan evaporation were recorded in dozens of locations around the SJV by the Dept of Water Resources. Using $ETo = 0.85$ Evaporation, a 20 year average $ETo$ of 49.3 inches was published by CA Dept of Water Resources.
The ET number from CIMIS is “potential” ET (ETo) which equals the water use of a non-stressed cool season grass.
CIMIS station locations around California as of 2002
The whole Central Valley covers Zones 12 to 16: for an “normal year” ETo of 53.3 to 62.5 in/yr, with most land @ 53 to 58 inches.
Comparing 1993 and 1999 estimates of Potential Evapotranspiration (ETo) for SJV (Potential ETo, reference crop ET, is water use by a tall cool-season non-stressed pasture grass)
Calculating ET for crops:

$$ET_{crop} = ET_o * K_c * E_f$$

$ET_o =$ **reference crop** (tall grass) ET

$K_c =$ **crop coefficient** for a given stage of growth as a ratio of grass water use. May be 0 to 1.3, standard values are good starting point.

$E_f =$ an **“environmental factor”** that can account for immature permanent crops and/or impact of salinity. May be 0.1 to 1.1, determined by site.
<table>
<thead>
<tr>
<th>Week</th>
<th>Normal Year Grass ETo (in)</th>
<th>Mature Crop Coefficient (Kc)</th>
<th>Almond ET -- Minimal Cover Crop, Mircosprinkler (inches, S. San Joaquin Valley)</th>
<th>Monthly Total</th>
<th>Daily Avg</th>
<th>20X22 Spacing Gallon / day / tree</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>1st Leaf @ 40%</td>
<td>2nd Leaf @ 55%</td>
<td>3rd Leaf @ 75%</td>
<td>4th Leaf @ 90%</td>
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<tr>
<td>1/6</td>
<td>0.21</td>
<td>0.40</td>
<td>0.03</td>
<td>0.05</td>
<td>0.06</td>
<td>0.08</td>
</tr>
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<td>1/13</td>
<td>0.28</td>
<td>0.40</td>
<td>0.04</td>
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<td>0.13</td>
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<td>0.29</td>
<td>0.39</td>
<td>0.47</td>
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<td>11/10</td>
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<td>0.71</td>
<td>0.16</td>
<td>0.22</td>
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<td>0.37</td>
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<td>0.29</td>
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<td>0.05</td>
<td>0.06</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>12/22</td>
<td>0.25</td>
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<td>0.04</td>
<td>0.06</td>
<td>0.08</td>
<td>0.09</td>
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<tr>
<td>12/29</td>
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<td>0.40</td>
<td>0.03</td>
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<tr>
<td>Total</td>
<td>57.90</td>
<td></td>
<td>20.91</td>
<td>28.75</td>
<td>39.20</td>
<td>47.05</td>
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Measured Brown Fertility Trial ET compared to 2002 Sanden & 1968 UC Almond ET

- Older UC Published Kc (1968)
- Sanden SSJV Kc (released 2002)
- 2008 - 12 Measured Kc (Brown fertility trial)

Avg Kc 4/1 - 11/15
- Older Avg Kc = 0.81
- Sanden Avg Kc = 0.93
- Measured Avg Kc = 1.05

Calculated Avg ET
- 42.3 in (4/1 - 11/15)
- 52.3 in (year)
- 59.6 in (year)

(Using CIMIS Zone 15 "Historic Eto" = 57.9 in)
Trends in Kern County Almonds

<table>
<thead>
<tr>
<th>Years</th>
<th>Cultural Practice</th>
<th>Yield (lb/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980-86</td>
<td>Short Prune</td>
<td>1371</td>
</tr>
<tr>
<td>1987-01</td>
<td>Long Prune</td>
<td>1569</td>
</tr>
<tr>
<td>2002-11</td>
<td>More Water &amp; N</td>
<td>2306</td>
</tr>
</tbody>
</table>
Do you get 6,000 lb/ac with 60” ET?

![Graph showing the relationship between Single Tree Kernal Yield (lb/ac) and Single Tree Yearly ET by Soil Water Depletion (in) for different years (2008, 2009, 2010, 2011, 2012). Each year is represented by different markers: 2008 (diamonds), 2009 (triangles), 2010 (squares), 2011 (x marks), 2012 (x marks). The x-axis represents the Single Tree Yearly ET by Soil Water Depletion (in), ranging from 48 to 64. The y-axis represents the Single Tree Kernal Yield (lb/ac), ranging from 0 to 6,000.]
Current findings on almond ET and yield impacts in Kern County

Westside Longevity trial (15th leaf 2013)

- Interactions and 95.0 Percent LSD Intervals
- Irrigation Target: 48, 56
- 16% less water reduced yield 9%

Eastside ET Production Function (8th leaf 2013)

- Interactions and 95.0 Percent LSD Intervals
- Irrigation Target: 48, 56
- 30% less water reduced yield 19%

2014 final totals:
- 48" Irrigation = 44.0"  
- 56" Irrigation = 51.8"

- 15% less water reduced yield 6% (2014 not significant)
- 30% less water reduced yield 14% (2014 not significant)
"Benchmarking" almond yield by total applied water (rain + irrigation) in the Murray-Darling Basin of Australia

107 almond orchards, 10 different farms
• QUESTIONS:

1. A fanjet system wetting 40% of the orchard floor has more “E” than any double-line drip system? True/False

2. Rootzone moisture storage for a fanjet system is always greater than for a double-line drip? True/False

3. For a 1”/day microsprinkler system wetting 50% of the floor, which irrigation duration/orchard age combination has the lowest “E”?  
   a) 8 hrs – 6\textsuperscript{th} leaf  
   b) 24 hrs – 2\textsuperscript{nd} leaf  
   c) 24 hrs – 6\textsuperscript{th} leaf  
   d) 12 hrs – 10\textsuperscript{th} leaf  
   e) 48 hrs – 5\textsuperscript{th} leaf

4. 56” of water generates an 80-90% canopy cover and guarantees 4,000 lb/ac? True/False
Irrigation Scheduling 101

Allan Fulton
UC Cooperative Extension
Tehama, Glenn, Colusa, and Shasta Counties

Topics:

• Irrigation Distribution Uniformity
• Salinity Management
Important to the bottom line:

- water demand
- energy demand
- orchard production and tree health
- production per unit water and land
DU is not as simple to technically quantify

\[
\text{Distribution Uniformity (DU)} = \frac{\text{Average infiltrated water of low quartile of measurements in orchard}}{\text{Average infiltrated water whole field}}
\]

• Amount of infiltrated water is difficult to measure

Instead:

• With drip and micro irrigation: pressure and emission flow rates are measured
• With flood: inflow, border check dimensions, water advance rates and distances are measured along with tailwater and time for water to recede
Measuring DU is much simpler with drip and micro sprinkler
How to check pressures and flows
Putting the Value of Irrigation Distribution Uniformity into Perspective

Example: Target application 1.0 inch water

\[ DU = 90\% \quad 1.12'' \]

\[ DU = 70\% \quad 1.42'' \]
Example: Target application 1.0 inch water

<table>
<thead>
<tr>
<th>DU</th>
<th>Water Applied High ¼ of orchard</th>
<th>Water Applied Low ¼ of orchard</th>
<th>Difference across orchard one irrigation</th>
<th>Difference thirty irrigation cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>1.12</td>
<td>0.90</td>
<td>0.22</td>
<td>6.6</td>
</tr>
<tr>
<td>80</td>
<td>1.27</td>
<td>0.80</td>
<td>0.47</td>
<td>14.1</td>
</tr>
<tr>
<td>70</td>
<td>1.42</td>
<td>0.70</td>
<td>0.72</td>
<td>21.6</td>
</tr>
</tbody>
</table>
Example: Target 1.0 inch of water in low ¼ of orchard using a micro sprinkler system with 0.05 inch/hr application rate

<table>
<thead>
<tr>
<th>DU</th>
<th>Hours to apply 1” low ¼ of orchard</th>
<th>Total hours thirty irrigation cycles</th>
<th>Hours irrigation (pump) time increased between DU’s</th>
<th>Relative Increase %</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>20</td>
<td>600</td>
<td>Reference Point</td>
<td>----</td>
</tr>
<tr>
<td>90</td>
<td>22</td>
<td>660</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>80</td>
<td>24</td>
<td>720</td>
<td>120</td>
<td>20</td>
</tr>
<tr>
<td>70</td>
<td>26</td>
<td>780</td>
<td>180</td>
<td>30</td>
</tr>
</tbody>
</table>
Is there opportunity among the almond industry to improve DU?

Graph: Micro Irrigation DUs of Almonds by ITRC Ranking Method (103 Evaluations) MIL 2002-2014

- Excellent: 11% (Average System Age: 6.2 years)
- Good: 23% (Average System Age: 6.7 years)
- OK: 29% (Average System Age: 7.3 years)
- Low: 22% (Average System Age: 8.7 years)
- Poor: 15% (Average System Age: 10.4 years)
Keys to Achieving or Maintaining high DUs (what works well)

- Balanced pressures
- Sprinkler types – must match
- Nozzle sizes – must match
- Maintenance – filtering & flushing
- Maintenance – breaks and leaks
- Maintenance - chemigation
Plugs, leaks, and breaks
Salinity Management in Almonds
About Almond Salt Tolerance:

• Evidence of greater sodium and chloride tolerance in peach-almond hybrid rootstocks than peach rootstock

• Support that some almond varieties will express sodium leaf toxicity before others (i.e. Fritz will express toxicity before Nonpareil)

• Data suggests almond may tolerate higher root zone salinity than past research indicated (old threshold 1.5 ds/m versus newer suggesting a threshold of 2.5 to 3.0 ds/m)
On Reclaiming Salt Impacted Orchards

- Leaching is the primary step to manage salts but it is not necessary every irrigation or perhaps even every season, only when crop tolerances are approached.
- Periodic soil testing in the root zone will help determine when and how much leaching is needed.
- The soil water content must exceed field capacity in the root zone for leaching to occur.
- Leaching is most efficient in the winter when crops are dormant and ET is low. Also this timing does not coincide with critical periods of nitrogen fertilization and uptake.
- Intermittent periods of irrigation and rainfall will more efficiently leach salts and boron than continuous.
On Reclaiming Salt Impacted Orchards

- If an orchard has been impacted by salinity and boron, when the water supply improves, research based estimates can be made as to how much leaching may be needed to reclaim an orchard back to tolerable levels.

<table>
<thead>
<tr>
<th>Leaching Requirement</th>
<th>Proportion that orchard root zone salinity exceeds threshold salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.3X</td>
</tr>
<tr>
<td>Depth of water (inches) per foot of rootzone</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Thank You!
Ken Shackel, UC Davis
Irrigation 101: The Tree

How does it feel and react?

Cooperators:
Dave Doll
John Edstrom
Allan Fulton
Bruce Lampinen
Blake Sanden
Larry Schwankl
Gerardo Spinelli
Practice Question: Which plant needs irrigation?

(1)

(2)
First leaf almond orchard, Winters, CA, at the end of the first season of growth.
Question: how would you rate the level of water stress that you think might have been experienced during the growing season by this orchard?

1) Luxury water, no stress whatsoever.
2) Adequate water, no significant stress.
3) Mild water stress.
4) Moderate water stress.
5) Severe water stress.
Medium treatment:
average SWP about -12 bars (-1.2 MPa)
Dry treatment:
average SWP about -15 bars (-1.5 MPa)
Wet treatment: average SWP about -8 bars (-0.8 MPa)
Forest Gump principle: Stress is as stress does.

If you want to know whether a tree is under stress, then irrigate it. If it gives a beneficial response, then it was under stress. If not, it wasn’t. Either that, or it was, but there was nothing you could do about it.
For young orchards: filling the space quickly has great economic benefits, so growth is a beneficial response.

For mature orchards: the space is already filled, so excessive growth is not a beneficial response.

So, we need to understand how plants respond to water availability and water stress.
Pressure chamber method for measuring water stress

Like measuring the “blood pressure” of the plant

Peach ET response to SWP in a lysimeter

\[ y = 0.0557x + 1.3538 \]

\[ R^2 = 0.8107 \]

-11 bars difference gave about a 50% reduction in ET
For almonds we also see a similar reduction in stomatal conductance at the leaf level, but not at the canopy level using meteorological methods. We are now planting almonds in the lysimeter to test this.
Almond hull split
Proposed benefits of RDI for almonds during hull split:

1) Speed up Hull Split
2) Reduce Hull rot
3) Reduce Sticktights (Improve Harvestability)
4) Save Water

SWP recommendation: -14 to -18 bars during hull split
Corning RDI study (2002-4)
Corning: Prior to RDI

% Hull Split in Carmel (East/West difference similar in all varieties)

<table>
<thead>
<tr>
<th>Date, 2000</th>
<th>10 Aug</th>
<th>16 Aug</th>
<th>22 Aug</th>
<th>31 Aug</th>
<th>6 Sep</th>
<th>14 Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>East</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Average SWP = -8.4 bars)</td>
<td>0%</td>
<td>0%</td>
<td>5%</td>
<td>13%</td>
<td>32%</td>
<td>40%</td>
</tr>
<tr>
<td><strong>West</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Average SWP = -14.1 bars)</td>
<td>4%</td>
<td>23%</td>
<td>60%</td>
<td>83%</td>
<td>85%</td>
<td>91%</td>
</tr>
</tbody>
</table>

Problems with uneven hull split timing:
- Uncertain timing for hull split spray
- Irrigation management problems
- Uneven/delayed harvest
Starting in 2001, under RDI (East soil), Nonpareil hull split was the same for East and West soils

<table>
<thead>
<tr>
<th></th>
<th>Date</th>
<th>Jul 13</th>
<th>Jul 20</th>
<th>Jul 27</th>
<th>Aug 1</th>
<th>Aug 13</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2001</strong></td>
<td><strong>East (silt)</strong></td>
<td>2%</td>
<td>20%</td>
<td>45%</td>
<td>70%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td><strong>West (gravel)</strong></td>
<td>2%</td>
<td>25%</td>
<td>55%</td>
<td>75%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Date</th>
<th>Jul 29</th>
<th>Aug 7</th>
<th>Aug 15</th>
<th>Aug 22</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2003</strong></td>
<td><strong>East (silt)</strong></td>
<td>29%</td>
<td>95%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td><strong>West (gravel)</strong></td>
<td>29%</td>
<td>88%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Corning Location – Irrigation Summary (RDI)

<table>
<thead>
<tr>
<th>Soil</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water applied</td>
<td>Cutoff date</td>
<td>Water applied</td>
</tr>
<tr>
<td>East</td>
<td>24”</td>
<td>10-Jul</td>
<td>14”</td>
</tr>
<tr>
<td>(silt)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>40”</td>
<td>25-Aug</td>
<td>41”</td>
</tr>
<tr>
<td>(gravel)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ETc</td>
<td>43”</td>
<td></td>
<td>40”</td>
</tr>
</tbody>
</table>

Very long cutoff/cutback OK on East (silt) soil
“West Side story”
Some unfortunate west side trees
growing the east side
Drought Study in Almonds, 2009

Main questions:

1) How much water does it take for an almond tree to survive?

2) Will application of small amounts of water (5”, 10”) over the season help?

3) Is there a critical level of tree water stress that will cause tree death or dieback?
June 29, 2009

Control tree

- 9.8 bars SWP
June 29, 2009

10” tree

- 25 bars SWP
June 29, 2009

0" tree

- 40 bars SWP
This tree had reached -63 bars on July 14, 2009, and by July 28 was completely defoliated. But notably, did not die!
Yield: The biggest reduction occurred in the year following the stress (i.e. carryover effect)
Water Production Function Yields and SWP’s: Year 2
At most locations, irrigation treatments are causing the expected and statistically significant (but not large), differences in SWP. The story is not so clear yet in yield.

<table>
<thead>
<tr>
<th>Kern</th>
<th>Merced</th>
<th>Tehama</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (#/ac) SWP June-August</td>
<td>Yield (#/ac) SWP June-August</td>
<td>Yield (#/ac) SWP June-August</td>
</tr>
<tr>
<td>%ET Mean</td>
<td>%ET Mean</td>
<td>%ET Mean</td>
</tr>
<tr>
<td>90 1960 110 -16a</td>
<td>110 2910 110 -14a</td>
<td>74 2340 116 -12a</td>
</tr>
<tr>
<td>110 1890 100 -17a</td>
<td>100 2900 100 -15ab</td>
<td>100 2315 100 -15 b</td>
</tr>
<tr>
<td>100 1870 80 -19ab</td>
<td>80 2640 90 -16ab</td>
<td>116 2260 86 -16 b</td>
</tr>
<tr>
<td>80 1840 90 -19ab</td>
<td>90 2540 80 -18 bc</td>
<td>86 2260 74 -17 b</td>
</tr>
<tr>
<td>70 1610 70 -21 b</td>
<td>70 2420 70 -19 c</td>
<td></td>
</tr>
</tbody>
</table>
Take home points:

1) Biology is complex - almonds have many responses to water stress.
2) Most responses are expected to reduce yield, but some may have beneficial side effects (i.e., hull split RDI), and there may be a ‘sweet spot’ for sustainable water management.
3) The severity of the response will depend on the level of stress (SWP).
4) Early symptoms are reduced growth and defoliation of lower leaves.
5) Almonds can survive very high levels of stress, but severe stress will reduce yield this year and especially next.
6) We are scratching the surface – many practical questions remain!

Thanks for your attention and support
Plant and Soil Monitoring for Efficient Irrigation Management

David Doll UCCE Merced
-or- Allan Fulton, UCCE Tehama
Why Should I Monitor the Soil and Plant?

Increases Efficiency of Water Applications by:

- Determining proper timing of irrigation in a variable environment,
- Making sure water stays within the root-zone (and reducing application amounts if it doesn’t),
- Applying stress at specific periods to reduce water use (and provide disease control benefits)
Monitoring Applications

Soil Based Monitoring

• Provides an idea on movement and depth of water within soil
• Able to identify duration of irrigations based on movement of water within the soil
• Hard to interpret when salt or disease comes into the picture

Plant Based Monitoring

• Indicates plant stress levels, regardless of soil conditions;
• Useful in troubleshooting irrigation schedules, managing RDI;
• With exception of pressure chamber, not much work done in other systems;
Soil Moisture Monitoring Tools

Feel Method

Capacitance/TDR

Electrical Resistance

Tensiometer

Neutron probe
### Soil Moisture Monitoring

<table>
<thead>
<tr>
<th></th>
<th>&quot;Feel&quot;</th>
<th>Tensiometers</th>
<th>Dielectric Sensors</th>
<th>Electrical Resistance</th>
<th>Neutron Probes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic Operation</strong></td>
<td>Soil between fingers</td>
<td>Measures the suction</td>
<td>Measures dielectric constant</td>
<td>Measures resistance</td>
<td>Measures neutrons slowed by water</td>
</tr>
<tr>
<td><strong>Requirement for Calibration</strong></td>
<td>Experience</td>
<td>Minimal</td>
<td>Yes, soil dependent</td>
<td>Moderate</td>
<td>Yes, soil dependent</td>
</tr>
<tr>
<td><strong>Monitoring Frequency</strong></td>
<td>Manual, Once</td>
<td>Manual or Automatic</td>
<td>Automatic</td>
<td>Automatic</td>
<td>Manual, once</td>
</tr>
<tr>
<td><strong>Zone of Measurement</strong></td>
<td>Size of Auger bucket</td>
<td>2&quot; off of sensor</td>
<td>About 1&quot; from outside edge</td>
<td>1&quot; off of sensor, less in heavy, wet soils</td>
<td>10&quot; diameter</td>
</tr>
<tr>
<td><strong>Replacement, Maintenance</strong></td>
<td>None</td>
<td>Annual (check of vacuum and gauges), some require removal</td>
<td>Annual Maintenance</td>
<td>Annual, replacement every 3-7 years</td>
<td>Replace batteries, transport rules, annual radiation safety check</td>
</tr>
<tr>
<td><strong>Affected by Salinity, Alkalinity</strong></td>
<td>None</td>
<td>No</td>
<td>Yes, but depends on sensor type</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Soil Type Most Suitable</strong></td>
<td>All</td>
<td>All</td>
<td>Sand – Sandy Clay Loam (Non-cracking Soils)</td>
<td>Sandy Loam – Clay</td>
<td>All</td>
</tr>
<tr>
<td><strong>Common Companies</strong></td>
<td>Hortau, Irrometers</td>
<td>Decagon, Aquacheck, EnviroSCAN</td>
<td>Watermarks</td>
<td>Contracted Services</td>
<td></td>
</tr>
</tbody>
</table>

Comparison of Capacitance to Neutron Probe

Water Content (total mm to 1.5 m depth)

- PureSense 0-1.5m
- Weekly NP 0-1.5 m

Date: 2/1 2/22 3/15 4/5 4/26 5/17 6/7 6/28 7/19 8/9 8/30 9/20 10/11 11/1
## Plant Base Monitoring

<table>
<thead>
<tr>
<th></th>
<th>&quot;Look and Feel&quot;</th>
<th>Sap Flow Sensors</th>
<th>Dendrometers</th>
<th>Pressure Chamber</th>
<th>Aerial Imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Operation</td>
<td>Look at newer growth</td>
<td>Measures Sap &quot;flow&quot;</td>
<td>Measures Expansion, Contraction</td>
<td>Measures Stem Water Potential</td>
<td>Measures canopy temperature</td>
</tr>
<tr>
<td>Requirement for Calibration</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Monitoring Frequency</td>
<td>Except when blinking</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Manual</td>
<td>Manual</td>
</tr>
<tr>
<td>Zone of Measurement</td>
<td>Few trees</td>
<td>Single Tree</td>
<td>Single Tree</td>
<td>Single to few trees</td>
<td>Entire Orchard</td>
</tr>
<tr>
<td>Replacement, Maintenance</td>
<td>None</td>
<td>Yes, 2-3 years</td>
<td>Yes</td>
<td>Minimal</td>
<td>None</td>
</tr>
<tr>
<td>Major Challenges</td>
<td>Too Late</td>
<td>Not refined for Almonds</td>
<td>Lack of Calibration</td>
<td>Time involved</td>
<td>Not refined for Almonds</td>
</tr>
</tbody>
</table>

Plant Based Monitoring Tools

Pressure Chamber

Aerial Imaging

Dendrometers

Sap Flow Sensors

Source: http://www.dynamax.com
Many plant based tools lack “real-time” understanding of readings – except pressure chamber
Soil Variability = Monitoring Variability

http://Earth.google.com;
Soil Overlay: http://casoilresource.lawr.ucdavis.edu/drupal/
Soil Variability = Monitoring Variability

Veris with Core sampling
Soil Variability = Monitoring Variability

<table>
<thead>
<tr>
<th>Soil Zone</th>
<th>Tree Loss</th>
<th>% of Tree Loss</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22/168</td>
<td>13</td>
<td>Wet feet/Disease, Blow-Over</td>
</tr>
<tr>
<td>2</td>
<td>8/420</td>
<td>1.9</td>
<td>Blow-Over</td>
</tr>
<tr>
<td>3</td>
<td>11/504</td>
<td>2.1</td>
<td>Blow-Over</td>
</tr>
</tbody>
</table>

Veris with Core sampling
Soil Variability = Monitoring Variability

Not Managing Variability Leads to Crop Loss!
Soil Variability = Monitoring Variability

How to Manage?

• Plant based – sample trees in differing soils

• Soil based:
  – Large plots: Place Multiple Sensors
  – Small plots:
    • Coarse soil: Place sensor in lowest holding capacity soil, short, frequent irrigations
    • Heavy Soil: Sensor in soil with lowest infiltration rate, longer, low GPM irrigation
Shrini Upadhyaya, UC Davis
Precision Canopy and Water Management of Specialty Crops through Sensor-Based Decision Making

(SCRI-USDA-NIFA-NO. 2010 – 01213)


- Plant Water Status Sensing
- Field Computer
- Soil Water Status Sensing
- Canopy Reflectance Measurement by Drone Copter
- Canopy PAR Absorption Measurement
- Canopy Shape Measurement by LIDAR
- Variable Rate Irrigation Management
Light Interception Information – What can it do for us?

- Assist in canopy management – Optimize light capture
- Assist in row spacing and tree spacing within the row (-replanting)
- Provide an idea of optimum yield (-nutrient management)
- Provide an estimate of potential transpiration (-irrigation management)
Nickels Estate – PAR Interception Study
The integrated light interception over the whole season can be shown to be related to potential yield and transpiration.
Estimation of Canopy Light Interception Using UAV
Shadow’s Area Estimated by UAV and Zenith Angle. (diurnal data was used)

\[ R^2 = 0.8132 \]

<table>
<thead>
<tr>
<th>Area Measured with lightbar (m²)</th>
<th>UAV estimated shadow area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td>80</td>
<td>170</td>
</tr>
<tr>
<td>100</td>
<td>220</td>
</tr>
<tr>
<td>120</td>
<td>270</td>
</tr>
<tr>
<td>140</td>
<td>320</td>
</tr>
<tr>
<td>160</td>
<td>370</td>
</tr>
<tr>
<td>180</td>
<td>420</td>
</tr>
</tbody>
</table>

PAR intercepted (Zn < 50)

\[ y = 1x - 0.0375 \]

\[ R^2 = 0.9219 \]
Plant water status indicates the current stress level in the plant and can be a valuable piece of information for irrigation management.

- Because of extensive root zone of orchard/vineyard crops, soil moisture measured at a particular depth may not be sufficient to indicate the amount of moisture available for crop growth.
Sensor Suite System

- Leaf temperature
- Air temperature + RH
- PAR
- Wind speed

Results for shaded almond leaves
Further Developments

Mobile sensor suite
- Anemometer
- Temp. and RH probe
- Pressure chamber
- IRT
- PAR sensor
- Data logger

Hand-held sensor suite
- Leaf Temperature
- PAR
- Air Temp. and Relative humidity
- Wind speed

Continuous monitoring of leaf temperature
- Leaf Temperature
- PAR
- Air Temp. and Relative humidity
- Wind speed
Installation of Leaf Monitor

Leaf monitor in almond orchard

Almond leaf close up
Wireless Mesh Network of Leaf Monitors
Management Zones based on Light Interception, Leaf Temperature and Yield.

Spatial variability

Three treatments in each zone:
- (i) Grower based, (ii) Stress based, and (iii) Deficit ET (60%)

* Number represent trees
Remote Access of Data

(Tair – Tleaf) data following irrigation

Irrigation

Tree getting water stressed after irrigation
Comparison with Actual Water Stress

- **Graph 1**: MCWSI vs. Days after Irrigation for 2013, 2014, and both years combined.
- **Graph 2**: Deficit SWP (MPa) vs. MCWSI.
- **Graph 3**: MCWSI_Irr vs. DSWP with linear equations:
  - $y = 0.4511x^2 - 0.145x + 0.0805$, $R^2 = 0.7049$
  - $y = 0.2516x^2 + 0.2178x + 0.0796$, $R^2 = 0.7184$
  - $y = 0.4759x^2 - 0.1861x + 0.0663$, $R^2 = 0.8083$
### Water Use Efficiency and Precision Irrigation Management

#### Preliminary Results

<table>
<thead>
<tr>
<th>Irrigation treatment</th>
<th>Liters</th>
<th>%age of ET</th>
<th>Yield (kg/tree)</th>
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</thead>
<tbody>
<tr>
<td>60% ET</td>
<td>11303.1</td>
<td>60.00</td>
<td>25.84</td>
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<tr>
<td>Stress based</td>
<td>15243.3</td>
<td>80.91</td>
<td>26.89</td>
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<tr>
<td>Grower based</td>
<td>19278.8</td>
<td>102.33</td>
<td>30.22</td>
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</table>

![Graph showing efficiency with different irrigation treatments]
Economics

<table>
<thead>
<tr>
<th>$ per Pound</th>
<th>1400</th>
<th>1800</th>
<th>2200</th>
<th>2600</th>
<th>3000</th>
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</thead>
<tbody>
<tr>
<td>$1.00</td>
<td>(1,136)</td>
<td>$(758)</td>
<td>$(380)</td>
<td>$(2)</td>
<td>$376</td>
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<tr>
<td>$1.50</td>
<td>(436)</td>
<td>142</td>
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<td>2,842</td>
<td>4,020</td>
<td>5,198</td>
<td>6,376</td>
</tr>
</tbody>
</table>

Effect of Price per pound and yield/acre if one node is used for 50 trees
Thank you for your attention!

http://ucanr.edu/sites/PCWM/
Clark Seavert
Oregon State University