Precision Irrigation Management: What’s Now and What’s New (Part 1)

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Precision Irrigation Management: What’s Now and What’s New (Part 1)

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Almond Board of California
Plant Water Status- Overview of Existing Tools
Bruce Lampinen, UC Davis Plant Sciences
## Water potential in the soil-plant-atmosphere continuum

<table>
<thead>
<tr>
<th>Location</th>
<th>Fully watered (bars)</th>
<th>Stressed (bars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air above tree</td>
<td>-95</td>
<td>-95</td>
</tr>
<tr>
<td>Air near leaf</td>
<td>-70</td>
<td>-80</td>
</tr>
<tr>
<td>Air in leaf</td>
<td>-12</td>
<td>-18</td>
</tr>
<tr>
<td>Xylem in leaf (6m)</td>
<td>-10</td>
<td>-16</td>
</tr>
<tr>
<td>Xylem in scaffold</td>
<td>-8.0</td>
<td>-14</td>
</tr>
<tr>
<td>Xylem in trunk</td>
<td>-7.5</td>
<td>-12</td>
</tr>
<tr>
<td>Xylem in root</td>
<td>-1.2</td>
<td>-3.0</td>
</tr>
<tr>
<td>Soil</td>
<td>-0.3</td>
<td>-0.7</td>
</tr>
</tbody>
</table>
As an almond tree becomes stressed from lack of water, several things happen:

- Stem water potential becomes more negative
- Leaf temperature increases
- Increased shrinking of trunk at midday
- Water flow in xylem slows
- Leaf characteristics change

These are the characteristics that can be used to estimate plant water status.
Stem water potential becomes more negative
Leaf temperature increases
Increased shrinking of trunk at midday
Water flow in xylem slows
Leaf characteristics change

Soil Moisture Equipment
Plant Pressure Chamber

ICT stem psychrometer
Stem water potential becomes more negative
Leaf temperature increases
Increased shrinking of trunk at midday
Water flow in xylem slows
Leaf characteristics change

Soil Moisture Equipment
Plant Pressure Chamber

Midday stem water potential (bars)
T1 (+water, +nitrogen)
T2 (+water, -nitrogen)
T3 (-water, +nitrogen)
T4 (-water, -nitrogen)
April May June July Aug Sep
-35
-30
-25
-20
-15
-10
-5
0
**
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*
* *
* *
*
*
* **
Stem water potential becomes more negative

Leaf temperature increases

Increased shrinking of trunk at midday

Water flow in xylem slows

Leaf characteristics change
Stem water potential becomes more negative

**Leaf temperature increases**

Increased shrinking of trunk at midday

Water flow in xylem slows

Leaf characteristics change
Stem water potential becomes more negative

**Leaf temperature increases**

Increased shrinking of trunk at midday

Water flow in xylem slows

Leaf characteristics change
Stem water potential becomes more negative

Leaf temperature increases

Increased shrinking of trunk at midday

Water flow in xylem slows

Leaf characteristics change

Kern Almond Water Production Trial (blue least stressed, red most stressed)

On any given day can show variability across orchard but calibration varies over season
Stem water potential becomes more negative
Leaf temperature increases
**Increased shrinking of trunk (or leaf?) at midday**
Water flow in xylem slows
Leaf characteristics change
Stem water potential becomes more negative
Leaf temperature increases
Increased shrinking of trunk at midday
Water flow in xylem slows
Leaf characteristics change

Phytec dendrometer

Dendrometer (microns)
Volumetric water content (%)
Stem water potential becomes more negative
Leaf temperature increases
Increased shrinking of trunk at midday
Water flow in xylem slows
Leaf characteristics change

Edaphic Scientific
Sap Flow Sensor

ICT Sap Flow Sensor

Dynamax Dynagage
Sap Flow Sensor
Stem water potential becomes more negative
Leaf temperature increases
Increased shrinking of trunk at midday
Water flow in xylem slows
Leaf characteristics change
Stem water potential becomes more negative
Leaf temperature increases
Increased shrinking of trunk at midday
Water flow in xylem slows
Leaf characteristics change- normalized difference vegetation index (NDVI)
Set up NDVI cameras aimed at individual trees
Set up NDVI cameras aimed at individual trees
Set up NDVI cameras aimed at individual trees

NDVI tracked changes in MSWP with a 10 day delay

In other words, NDVI told you what MSWP was 10 days ago
Usefulness of these techniques

Leaf temperature increases
   Varies with wind, air to leaf temp differences, etc.
Increased shrinking of trunk at midday
   Can be useful but need a fully watered tree to calibrate
   Difficult (expensive) to monitor large number of trees
Water flow in xylem slows
   Can be useful but need a fully watered tree to calibrate
   Difficult (expensive) to monitor large number of trees
Leaf characteristics change (NDVI)
   Can show orchard variability
   Different calibration through season
   Lags behind tree water status by about 10 days
Usefulness of these techniques

Whichever of these techniques you use, be sure to calibrate it against stem water potential

Soil Moisture Equipment
Plant Pressure Chamber
Thanks to the Almond Board of California for funding various aspects of this work.
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A Leaf Monitor to Continuously Monitor Plant Water Status

Shrini K Upadhyaya
Professor
UC Davis
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Mr. Alexander Schramm, Junior Specialist
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Dr. Changjie Han, Visiting Scholar, China
Dr. Bruce Lampinen, Plant Sciences
Dr. Ken Shackel, Plant Sciences
Dr. Mike Delwiche, Bio. and Agr. Eng
Dr. Franz Niederholzer
What Plant Physiologists recommend -

- For almonds it is important to manage plant water status
  - Between 12 to 14 bars pre- and post-hull split period, and
  - Between 14 to 18 bars during the hull split period
- To achieve good quality, water use efficiency, and disease resistance
Stomatal Conductance and Leaf Temperature

- Plant has enough water
  - Opens stomata
  - More CO$_2$ for Photosynthesis
    - More water vapor loss - transpiration
      - More cooling of leaf
        - Cooler leaf temperature

- Leaf temp. less than air temp.
- Plant is under no water stress

Is it that simple?
Sensor Suite System

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

Data logger
Multiple Linear Regression Results of Extensive Field Tests during 2010 and 2011

**Almonds**

\[ T_L = -2.619 + 0.809 T_a - 2.487 \text{ SWP} + 0.044 \text{RH} \]

\[ R^2 = 0.90 \]

**Walnuts**

\[ T_L = -3.028 + 0.817 T_a - 2.424 \text{ SWP} + 0.050 \text{RH} \]

\[ R^2 = 0.86 \]

**Grapes**

\[ T_L = -15.92 + 1.38 T_a - 3.81 \text{ SWP} + 0.029 \text{PAR} \]

\[ R^2 = 0.86 \]
Further Developments

Still bulky and needs field visit

Leaf Temperature

PAR

Air Temp. and Relative humidity

Wind speed
Wireless Mesh Network of leaf monitors
Status of a Plant

- A fully saturated tree/vine:

- A not so happy tree/vine:

- Representative tree/vine:

\[
CWSI = \frac{(T_L - T_A) - (T_L - T_A)_{Sat}}{(T_L - T_A)_{Dry} - (T_L - T_A)_{Sat}}
\]
Management Zone based Precision Irrigation in Almond Crop

Soil Characteristics (Digital elevation & texture) influenced management zones the most
Plant water Status

Harvest preparation

Average SWP, bar

Pre Hull Split

Post Hull Split

Zone 1 (bar) Zone 2 (bar)
Cumulative water applied per tree

Inches of water applied:
- Grower: 21.6 (94.0% of ET)
- Zone 1: 16.1 (70.0% of ET)
- Zone 2: 18.6 (81.0% of ET)

Cumulative ET corrected for rainfall starting May 1st = 23.0 in

Overall water application:
- Zone #1: 74.6%
- Zone #2: 86.3%
## Yield and Quality

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield, lb/acre</th>
<th>Mass, g/50</th>
<th>Length/Width/Height, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1 - Grower</td>
<td>2643</td>
<td>64.8</td>
<td>23.8/13.7/8.5</td>
</tr>
<tr>
<td>Zone 1 - Stress</td>
<td>2551</td>
<td>65.0</td>
<td>24.0/13.5/8.5</td>
</tr>
<tr>
<td>Zone 2 - Grower</td>
<td>2869</td>
<td>65.1</td>
<td>24.3/13.7/8.4</td>
</tr>
<tr>
<td>Zone 2 - Stress</td>
<td>2496</td>
<td>65.8</td>
<td>23.9/13.6/8.5</td>
</tr>
</tbody>
</table>

- Mold percentages were also not significant.
Thank You
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Ken Shackel

Water production function research
Question: how does almond yield respond to water?

Best estimate so far: about 70 kernel pounds per acre increase for every inch of water.
Summary (c/o B. Lampinen) of Previous Almond Research Relating Yield to PAR and Applied Irrigation Water

**PAR (shade):**

- More shade on the ground means that trees are collecting and using more sunlight to grow the crop.
- Good orchards can achieve about 50 kernel pounds for every 1% of ground shaded (PAR).
- Average orchards are around 38 kernel pounds per 1% PAR
Summary (c/o B. Lampinen) of Previous Almond Research Relating Yield to PAR and Applied Irrigation Water

Applied Water:

• Yield and PAR both increase more-or-less in a straight line as irrigation increases.

• Example: 50” of water should give about 70% PAR and about 3,500 kernel pounds.

• At some point, too much irrigation should cause problems and reduce yield, not to mention environmental issues, but the ‘too much’ water point has yet to be determined.
Almond Water Production Function Project

• 3 sites.
• 3-4 irrigation levels per site, range: 70% to 110% ET.
• Irrigation treatments since 2013.
• Yield since 2012 (pre-treatment).
Almond yields from 2012 to 2016 at the **Kern** site

2 highest irrigation treatments (around 45”) compared to 2 lowest (around 28”)

- Clear trend of separation only in 2015 & 2016.
Almond yields from 2012 to 2016 at the **Merced** site

2 highest irrigation treatments (around 45”) compared to 2 lowest (around 28”)

- Trend of separation started in the first treatment year (2013).
Almond yields from 2012 to 2016 at the Tehama site
2 highest irrigation treatments (around 45”) compared to 2 lowest (around 28”)

- Clearly no trend whatsoever.
Almond yield response to water at the Kern site (2014-2016)

- Upward trend every year, with more-or-less the same response to water (parallel lines) each year.
Almond yield response to water at the **Merced** site (2014-2016)

- Narrower range of treatments, but the same response to water (parallel lines) each year.
Almond yield response to water at the Tehama site (2014-2016)

- Relatively flat response (little to no response)
Sites varied in response. All sites show a lower yield and **less** of a response to water than expected.
Reminder: Previous Almond Research Relating Yield to PAR and Applied Irrigation Water

**Applied Water:**

- Yield and PAR both increase more-or-less in a straight line as irrigation increases.
- Example: 50” of water should give about 70% PAR and about 3,500 kernel pounds.
- At some point, too much irrigation should cause problems and reduce yield, not to mention environmental issues.

![Graph showing relationship between applied water and yield](image)
Sites had a very similar response. As in yield, less of a response to water than expected, but in many cases points were above the expected value.

For our amounts of water (35” – 60”) we have a canopy, but it is underperforming at all the sites.
• Orchards with the same PAR should require about the same amount of irrigation.
• These data indicate that yields for the same PAR can be substantially different.
• Making gains in water productivity will probably require us to determine why orchards with a sufficient canopy are not generating high yields.
Conclusions

• At all sites, the trees have consistently responded to irrigation in terms of their physiological water stress levels starting on the first year of irrigation treatments.

• Despite this, across a relatively wide range of seasonal water regimes (35” to 60””) we have only seen modest increases in yield, on average giving about 35 kernel pounds of additional yield per acre for every additional inch of water.

• Nonpareil yield at the Tehama site has been largely unresponsive to water, but the Monterey yield at that location has shown a similar response to Nonpareil at the other sites.

• Together, these indicate that a factor/s other than water stress may be preventing yields from reaching their potential.
Thanks to my cooperators:

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Sam Metcalf

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Questions?