Yield as a function of evapotranspiration and irrigation

(Original title: Correlation of individual tree nut yield, evapotranspiration, tree stem water potential, total soil salinity and chloride in a high production almond orchard)

Blake Sanden – Irrigation/Soils Advisor, University of California, Kern County
Blake Sanden is the Irrigation and Agronomy Farm Advisor with the University of California Cooperative Extension, stationed in Kern County at the southern end of the San Joaquin Valley. He conducts county-based, applied research and extension programs focusing on irrigation system management, salinity/fertility management for all crops, and agronomic field crop production of alfalfa, dry beans and oil crops.

Blake has a BS in International Agricultural Development & Agronomy and MS in Irrigation and Drainage from UC Davis and 35 years of experience in production ag, international ag development and extension. Significant projects include: development of salt tolerance thresholds for pistachios in the San Joaquin Valley, soil moisture monitoring and irrigation efficiency assessment on 12,000 acres in Kern County, deficit irrigation in early citrus navels and almond water use/fertilizer management for optimal yield.
Co-investigators
S. Muhammad – UC Davis, Pakistan Agricultural Extension
P.H. Brown – UC Davis, Pomology/Fertility
K.A. Shackel – UC Davis, Pomology/Plant-Water Relations
R.L. Snyder – UC Davis, Extension Specialist Biometeorology

Cooperators
Paramount Farming Company / Roll International
Kern County farmers and almond growers

Funding: Almond Board of California
Development of pistachios & almonds on the Westside of the San Joaquin Valley have yielded spectacular results.
Much former flood irrigated cotton ground prone to water logging and salinity problems has been converted to pistachios on drip irrigation. Better ground has been planted to almonds – but this is no guarantee of escaping salt problems.
Boron, chloride and sodium accumulation killing marginal leaf areas at end of season.
Excessive Na, Cl and especially B can burn and desiccate almonds.
Observation: Many orchards would stress and exhibit some defoliation as early as July on through harvest.
Chloride toxicity causes marginal burn, general chlorosis at lower levels, near complete defoliation in more sensitive varieties when combined with water stress which also causes mites to increase egg laying.
Lime-induced Iron Chlorosis in Almonds
Wood Colony almonds on vigorous Hanson rootstock (every $4^{th}$ row) overcomes lime-induced Fe chlorosis
What about salinity buildup under super efficient irrigation when the salt load is ~ $\frac{1}{2}$ mt/ML?
Micro-irrigation system capable of injecting fertilizer and applying 0.6 to 1.5 inches/day
Salinity is the greatest threat to orchard production in California.
Our understanding is still limited.
Considerable potential to improve management strategies particularly irrigation and leaching strategies.
Without mitigation (leaching and/or improved water quality), it can only get worse.

Kandelous, Unpublished

Model of salt accumulation under microsprinkler / spray (Fanjet) irrigation.

What Next:
... or account for "subbing" in a double-line drip?
Problem: You can be too efficient. Chloride and salt accumulation contributing to chlorosis and early leaf senescence after harvest cutoff.
CA Aqueduct (or borehole) water salinity

= 0.41 mt / ML  (0.46 t/ac-ft, 0.53 ds/m EC, 339 ppm tds)

=1.6 dS/m EC increase to 3 m depth of soil over 20 years @ 14 ML/ha/yr (55.1 inches)

=8.0 dS/m increase for 40% drip volume to 1.5m

1 ML/ha =100 mm depth water

(CA Water Plan Update 2009: Vol2 Chap18: Salt and Salinity Management)
Intensive monitoring site with 5 neutron probe access tubes, Watermark/Irrometer logger, Surface Renewal and Sonic Anemometer heat flux estimates of ET.

Possible PureSense Probe
Patrick Brown fertility trial 2008-2012

12 treatments total

- 4 N levels, 2 sources
  125, 200, 275, 350 lb/ac

- 3 K levels, 3 sources
  100, 200, 300 lb/ac
Comparison of University of California Almond ET/Kc Curves

- Older Published Kc
- Sanden SSJV Kc
- 2008 - 11 Measured Kc

Avg Kc 4/1 - 11/15
- Older Avg Kc = 0.81
- Sanden Avg Kc = 0.93
- Measured Avg Kc = 1.04

Calculated Avg ET
- 1070 mm (4/1 - 11/15)
- 1320 mm (year)
- 1510 mm (year)

(Using CIMIS Zone 15 "Historic Eto" = 57.9 in)
2008 Kern Almond Crop Coefficients (Kc) Using Satelites & SEBAL 156 Fields

Co-PI: David’s Engineering, SEBAL International
Differential N rates affected yield but had no effect on individual tree SWP or ET.

### 2010

<table>
<thead>
<tr>
<th>Treatment (N-K lb/ac)</th>
<th>Stem Water Potential (MPa)</th>
<th>Soil Water to 2.7 m (%)</th>
<th>Total Neutron Probe ET (in)</th>
<th>SWP-NP Tree Kernel Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drip</td>
<td>Fanjet</td>
<td>Drip</td>
<td>Fanjet</td>
</tr>
<tr>
<td>125-200</td>
<td>-0.98 a</td>
<td>-1.11 a</td>
<td>14.7 ab</td>
<td>13.3 a</td>
</tr>
<tr>
<td>200-200</td>
<td>-0.97 a</td>
<td>-1.19 b</td>
<td>15.9 b</td>
<td>13.9 a</td>
</tr>
<tr>
<td>275-200</td>
<td>-0.97 a</td>
<td>-1.25 b</td>
<td>16.4 b</td>
<td>15.0 a</td>
</tr>
<tr>
<td>275-300</td>
<td>-1.01 a</td>
<td>-1.21 b</td>
<td>15.5 ab</td>
<td>13.5 a</td>
</tr>
<tr>
<td>350-200</td>
<td>-0.97 a</td>
<td>-1.19 b</td>
<td>13.6 a</td>
<td>14.2 a</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>-0.98</td>
<td>-1.19</td>
<td>15.2</td>
<td>14.0</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>0.05</td>
<td>0.06</td>
<td>2.3</td>
<td>2.6</td>
</tr>
</tbody>
</table>

### 2011

<table>
<thead>
<tr>
<th>Treatment (N-K lb/ac)</th>
<th>Stem Water Potential (MPa)</th>
<th>Soil Water to 2.7 m (%)</th>
<th>Total Neutron Probe ET (in)</th>
<th>SWP-NP Tree Kernel Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drip</td>
<td>Fanjet</td>
<td>Drip</td>
<td>Fanjet</td>
</tr>
<tr>
<td>125-200</td>
<td>-0.93 b</td>
<td>-1.03 a</td>
<td>15.8 ab</td>
<td>14.3 a</td>
</tr>
<tr>
<td>200-200</td>
<td>-0.95 a</td>
<td>-1.04 a</td>
<td>16.2 ab</td>
<td>14.4 a</td>
</tr>
<tr>
<td>275-200</td>
<td>-0.93 b</td>
<td>-1.05 a</td>
<td>18.0 b</td>
<td>16.7 a</td>
</tr>
<tr>
<td>275-300</td>
<td>-0.93 b</td>
<td>-1.04 a</td>
<td>16.3 ab</td>
<td>14.9 a</td>
</tr>
<tr>
<td>350-200</td>
<td>-0.90 c</td>
<td>-1.05 a</td>
<td>14.2 a</td>
<td>15.3 a</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>-0.93</td>
<td>-1.04</td>
<td>16.1</td>
<td>15.1</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>0.02</td>
<td>0.02</td>
<td>2.5</td>
<td>2.7</td>
</tr>
</tbody>
</table>
Rootzone salinity profiles with depth

FANJET Chloride Concentration (saturation extract, meq/l)

DRIP Chloride Concentration (saturation extract, meq/l)

FANJET Soil EC (saturation extract, dS/m)

DRIP Soil EC (saturation extract, dS/m)
Almond Relative Yield (%) = \[100 - 19 \times (\text{Soil } \text{EC}_e - 1.5)\] = 52.5% @ ECruz = 4 dS/m

CA groundwater depletion: 1962-2003

Trends in Kern County Almonds

<table>
<thead>
<tr>
<th>Years</th>
<th>Cultural Practice</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980-86</td>
<td>Short Prune</td>
<td>1537</td>
</tr>
<tr>
<td>1987-01</td>
<td>Long Prune</td>
<td>1759</td>
</tr>
<tr>
<td>2002-11</td>
<td>More Water &amp; N</td>
<td>2584</td>
</tr>
</tbody>
</table>
Trends in individual tree salinity and almond kernel yield

Fig. 2.a. All years average rootzone ECe to 1.5 m by tree number approximately west to east.

Fig. 2.b. All years tree kernel yield by tree number approximately west to east.
Pearson Product “R” Correlation Values of Various Salinity, Water and Almond Yield Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Chloride</th>
<th>SWP</th>
<th>NP-ET</th>
<th>Yield</th>
<th>Previous Year EC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2008 EC</strong></td>
<td>0.970*</td>
<td>-0.451</td>
<td>0.189</td>
<td>0.014</td>
<td>--</td>
</tr>
<tr>
<td><strong>2009 EC</strong></td>
<td>0.926*</td>
<td>-0.571*</td>
<td>-0.188</td>
<td>-0.294</td>
<td>0.786*</td>
</tr>
<tr>
<td><strong>2010 EC</strong></td>
<td>0.899*</td>
<td>-0.306</td>
<td>-0.045</td>
<td>-0.120</td>
<td>0.550*</td>
</tr>
<tr>
<td><strong>2011 EC</strong></td>
<td>0.866*</td>
<td>-0.454*</td>
<td>0.170</td>
<td>-0.007</td>
<td>0.507*</td>
</tr>
<tr>
<td><strong>All Years Avg</strong></td>
<td>0.920*</td>
<td>-0.533*</td>
<td>0.063</td>
<td>-0.266</td>
<td>--</td>
</tr>
</tbody>
</table>

(*Probability < 0.05)
Comparison of “relative yield” as a function of salinity for a 0.9 m and 1.5 m rootzone

Fig. 3. Relative kernel yield as a function of average rootzone salinity (0-0.9 m) for all years and the “classic” almond salt tolerance curve (Ayers and Westcott, 1985).

Fig. 3.b. Relative kernel yield as a function of average rootzone salinity to 1.5 m for all years and the “classic” almond salt tolerance curve (Ayers and Westcott, 1985).
Growth and Salt Tolerance of Nonpareil on Different Rootstocks

Current Patrick Brown salinity trials at UC Davis
So how consistent is yield as a function of applied water and ET?
Do you get 6,000 lb/ac with 60” ET?
(Brown fertility trials, 275 lb/ac N yields)

1200 – 1600 mm ET

Single Tree Yearly ET by Soil Water Depletion (in)

Single Tree Kernal Yield (lb/ac)
"Benchmarking" almond yield by total applied water (rain + irrigation) in the Murray-Darling Basin of Australia

107 almond orchards, 10 different farms
Almond yield by light (PAR) & water

- Multi year plot averages
- Single year orchard or plot average
- Single tree reps

Graph showing the relationship between kernel yield, applied water, and PAR interception.
The white line is the maximum potential yield. Any number of factors can decrease your orchard yield relative to its potential including water stress (excess or deficit), disease pressure, poor bloom weather, poor nutrient management etc.

Production potential is about 50 kernel pounds/ac of almond for every 1% of incoming light intercepted- so to produce 4000 kernel pounds per acre you need to intercept ~80% of the incoming PAR (Bruce Lampenin data for California).
CERES website image (6/17/2015) of CONDUCTANCE water stress for ETPF trial
Aerial Imagery can identify irrigation/stress non-uniformity.

3/25-9/22/2015 average almond plot Conductance by 2015 applied irrigation (10 flyovers)

Canopy Temp/Water Stress by Irrigation Treatment (CERES Spectral Imaging 6/17/2015)
NDVI (vigor/biomass) not as strongly correlated with applied water

\[ y = 0.0038x + 0.3761 \]
\[ R^2 = 0.2639 \]

3/25-9/22/2015 average almond plot NDVI by 2015 applied irrigation (10 flyovers)

NDVI/Biomass by Irrigation Treatment

(CERES Spectral Imaging 6/17/2015, Shackel, et al. Yield Production Function Trial)
Both CONDUCTANCE & APPLIED WATER were poorly correlated to final kernel yield. Bloom density and other factors can be just as important as stress on your final yield.
Conclusions

• Almonds are capable of much higher yields under even more saline conditions than old published standards.

• The presence of clay exchange sites, good to high levels of free Ca in the field soil and better attention to optimal irrigation help overcome toxicity problems documented in earlier sand tank and field studies.

• Development of new almond salinity thresholds should somehow include these variables.
The Global Perspective: Paul Ehrlich’s “Population Bomb” has not disappeared

- Global food production will need to increase by 38% by 2025 and 57% by 2050.

- It is estimated that about 15% of the total land area of the world has been degraded by soil erosion and physical and chemical degradation, including soil salinization.