Managing Orchard Salinity During and After Drought

December 9, 2015
Speakers

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David Doll,
UCCE – Merced County
Understanding and Managing Salinity for Almonds

David Doll, UCCE Merced
Understanding Salinity within Almond Orchards
Salinity Tolerance of Almond

- How Tough are Almonds?
  - Sodium Sensitive
  - Every dS/m above 1.5 = 18-21% growth rate decrease

Fig. 2. Relative yield (RY) of various crops as a function of soil ECₑ (Sanden, et al., 2004).

<table>
<thead>
<tr>
<th>Salinity of:</th>
<th>Degree of Growth/Yield Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. root zone¹</td>
<td>None</td>
</tr>
<tr>
<td>Irrigation water¹</td>
<td>Unit</td>
</tr>
<tr>
<td></td>
<td>dS/m</td>
</tr>
<tr>
<td></td>
<td>&lt;1.1</td>
</tr>
</tbody>
</table>

* Source: Adapted from E.V. Maas (1990), p. 280. Guidelines assume a 15 percent leaching fraction.
Salt Accumulation

- Why does salt accumulation occur?

Even good water can create salt issues!

Salt exclusion happens at the root.
### Almond Salinity Issues: Plant Effects

<table>
<thead>
<tr>
<th></th>
<th>Degree of Restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
</tr>
<tr>
<td>Sodium (%)</td>
<td>&lt;0.25</td>
</tr>
<tr>
<td>Chloride (%)</td>
<td>&lt;3.0</td>
</tr>
<tr>
<td>Boron ppm</td>
<td>&lt;30</td>
</tr>
</tbody>
</table>
Almond Salinity Issues: Plant Effects

By the time you see toxicity:

- Trees are already experiencing osmotic effects prior to showing symptoms
- Can occur rapidly (especially with chloride)
- Takes 2-3 years of effective leaching to reduce tissue levels, regain productivity
Almond Salinity Issues: Plant Effects

Low Salinity: Movement of Water from Osmotic Effects

- = Salt Cation
- = Water Molecule
- = Plant Compound
Almond Salinity Issues: Plant Effects

High Salinity:
Movement of Water from Osmotic Effects

= Salt Cation
= Water Molecule
= Plant Compound
Almond Salinity Issues: Plant Effects

High Salinity: Movement of Water from Osmotic Effects

= Salt Cation

= Water Molecule

= Plant Compound
Almond Salinity Issues: Plant Effects

Plant expends energy to create compounds to maintain osmotic gradient; reduces energy for crop

At some level, salt levels increase above the roots capacity to exclude--uptake occurs
Salinity Tolerance of Almond

Sources of Salts in CA ag:

Present in soils
Fertilizer and composts
Irrigation water
  - Surface – tends to be cleaner
  - Well – variable quality

Water analysis needs to be conducted to know the quality of water!
### Well Water Analysis: Interpretation

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH</th>
<th>Ecw (dS/m)</th>
<th>Ca (meq/L)</th>
<th>Mg</th>
<th>Na</th>
<th>HCO3 (meq/L)</th>
<th>SO4</th>
<th>Cl</th>
<th>SAR</th>
<th>SARadj</th>
<th>B (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>7.79</td>
<td>2.88</td>
<td>10.10</td>
<td>14.4</td>
<td>12.0</td>
<td>4.71</td>
<td>26.8</td>
<td>4.55</td>
<td>3.43</td>
<td>8.13</td>
<td>0.77</td>
</tr>
<tr>
<td>UC</td>
<td>&lt;7.0</td>
<td>&lt;1.1</td>
<td>SAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;4.0</td>
<td>&lt;3.0</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

Water is not ideal!

---

*Source: Adapted from E.V. Maas (1990), p. 280. Guidelines assume a 15 percent leaching fraction.*
### Well Water Analysis: Interpretation

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<table>
<thead>
<tr>
<th>Degree of Restriction</th>
<th>SAR</th>
<th>Chloride (meq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>&lt;3.0</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Increasing</td>
<td>3-9</td>
<td>5-15</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt;9.0</td>
<td>&gt;15</td>
</tr>
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</table>

*Water is not ideal!*

\[
SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}
\]
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</table>

**Acidifying water will drop adjusted SAR closer to reported SAR**

**Water is too hot!**

**pH dependent:** Indicates that Ca2+ or Mg2+ will not remain free in soil solution
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<td>0.77</td>
</tr>
<tr>
<td>OK</td>
<td>7.89</td>
<td>1.20</td>
<td>4.33</td>
<td>3.5</td>
<td>6.42</td>
<td>1.77</td>
<td>10.1</td>
<td>0.99</td>
<td>3.25</td>
<td>5.44</td>
<td>0.46</td>
</tr>
<tr>
<td>UC</td>
<td>&lt;7.0</td>
<td>&lt;1.1</td>
<td>SAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;4.0</td>
<td>&lt;3.0</td>
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</tr>
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Not the best water, but workable:
Adjust pH to free up calcium
Additional gypsum (500 lbs/acre foot = 2 meq Ca increase)
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<td>0.99</td>
<td>3.25</td>
<td>5.44</td>
<td>0.46</td>
</tr>
<tr>
<td>???</td>
<td>7.66</td>
<td>0.86</td>
<td>1.91</td>
<td>2.9</td>
<td>4.48</td>
<td>6.3</td>
<td>0.36</td>
<td>1.69</td>
<td>2.91</td>
<td>6.74</td>
<td>2.6</td>
</tr>
<tr>
<td>UC</td>
<td>&lt;7.0</td>
<td>&lt;1.1</td>
<td>SAR</td>
<td>&lt;4.0</td>
<td>&lt;3.0</td>
<td>&lt;0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Degree of Restriction

<table>
<thead>
<tr>
<th>Boron (mg/L)</th>
<th>None</th>
<th>Increasing</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.5</td>
<td></td>
<td>0.5-3.0</td>
<td>&gt;3.0</td>
</tr>
</tbody>
</table>
Water Modification

• Lowering pH of Irrigation Water:
  – Titration for water must be performed to determine amounts needed.
  – Send water plus acid of choice to a local lab.

• Calcium Amendments
  – Vary;
  – Can be applied or injected
## Water Modification

<table>
<thead>
<tr>
<th>Salt</th>
<th>Formulation</th>
<th>Solubility (distilled water @20°C, at pH=7)</th>
<th>Soil Rxn and effect on pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium nitrate</td>
<td>Ca(NO₃)₂</td>
<td>121</td>
<td>Highly soluble, Gradual, Neutral</td>
</tr>
<tr>
<td>Calcium chloride dihydrate</td>
<td>CaCl₂·2H₂O</td>
<td>98</td>
<td>Highly soluble, Gradual, Neutral</td>
</tr>
<tr>
<td>Calcium chloride</td>
<td>CaCl₂</td>
<td>74</td>
<td>Highly soluble, Gradual, Neutral</td>
</tr>
<tr>
<td>Calcium acetate</td>
<td>C₄H₆CaO₄</td>
<td>34.7</td>
<td>Highly soluble, Increase pH of acid soils</td>
</tr>
<tr>
<td>Gypsum</td>
<td>CaSO₄·2H₂O</td>
<td>0.26</td>
<td>Moderately soluble, Gradual, Neutral</td>
</tr>
<tr>
<td>Dolomite</td>
<td>CaMg(CO₃)₂</td>
<td>0.03 (depends on soil pH)</td>
<td>Low solubility, Increase pH of acid soils</td>
</tr>
<tr>
<td>Lime</td>
<td>CaCO₃</td>
<td>0.005 (depends on soil pH)</td>
<td>Very low solubility, Increase pH of acid soils</td>
</tr>
<tr>
<td>By-product ash</td>
<td>CaO or Ca(OH)₂</td>
<td>Variable (depends on soil pH)</td>
<td>Very low solubility, Increase pH of acid soils</td>
</tr>
</tbody>
</table>

*Source: CRC Handbook of Chemistry and Physics, 56th Edition*
Water Modification

Adding Calcium to Water

- In solution: ~ 250 lbs of gypsum/acre ft to increase one meq/l of calcium
- Land grade applications made monthly – but need 6x more to get the same effect
### Almond Salinity Issues: Soil Effects

<table>
<thead>
<tr>
<th>Water Source</th>
<th>pH</th>
<th>EC dS/m</th>
<th>Sodium (meq/l)</th>
<th>Calcium (meq/l)</th>
<th>Mg (meq/l)</th>
<th>SAR/adj SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atwater</td>
<td>7.6</td>
<td>0.32</td>
<td>6.35</td>
<td>2.10</td>
<td>5.59</td>
<td>3.2/6.15</td>
</tr>
<tr>
<td>UC RECS</td>
<td>&lt;1.1</td>
<td>&lt;3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Westside</td>
<td>8.3</td>
<td>1.24</td>
<td>7.6</td>
<td>3.5</td>
<td>0.7</td>
<td>5.2/11.1</td>
</tr>
</tbody>
</table>
Almond Salinity Issues: Soil Effects

Low Exchange Capacity Soils will show sodium toxicity before high exchange capacity soils.

WHY?
Almond Salinity Issues: Soil Effects

Soil with high CEC

Soil with low CEC
Almond Salinity Issues: Soil Effects

Soil Sampling may not provide answer in low CEC soils:

<table>
<thead>
<tr>
<th></th>
<th>E.C. (dS/m)</th>
<th>Sodium (meq/L)</th>
<th>Chloride (meq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1’</td>
<td>0.19</td>
<td>0.55</td>
<td>0.31</td>
</tr>
<tr>
<td>2’</td>
<td>0.19</td>
<td>0.82</td>
<td>0.30</td>
</tr>
<tr>
<td>3’</td>
<td>0.81</td>
<td>3.12</td>
<td>0.94</td>
</tr>
<tr>
<td>4’</td>
<td>1.25</td>
<td>5.05</td>
<td>1.24</td>
</tr>
<tr>
<td>5’</td>
<td>0.93</td>
<td>3.96</td>
<td>0.93</td>
</tr>
<tr>
<td>UC Value</td>
<td>&lt;1.5</td>
<td>&lt;5.0</td>
<td>&lt;5.0</td>
</tr>
</tbody>
</table>
Almond Salinity Issues: Soil Effects

Salinity that root is exposed to is not the same as volume sampled for LOW CEC SOILS
Managing Salinity within Almond Orchards
Almond Salinity Issues: Soil Sampling

Soil Sampling should occur in the fall after the completion of the irrigation season

• Samples should be taken within the wetting profile;

• A complete soil profile should be pulled at even increments down to a minimum depth of five feet (e.g. 0”-12”, 13”-24”, 25”-36”, 37”-48”, and 49”-60”);

• Multiple locations can be pooled within a block, but each block/irrigation set should have an analysis;

• If struggling with infiltration, consider pulling a 0-6” sample to look for chemical imbalances;

• If average root system salinity is over 1.5 dS/m, than a leaching program should be considered;

• Follow up the leaching program with another round of sampling to determine the effectiveness of the program.
Almond Salinity Issues: Management

4 Utilized Principles:

- Managing Salt Build-up
- Displacement of Salts
- Leaching of Salts
- Rootstock Resistance

- In-Season Leaching Fractions
- Water Amendments
- Dormant Leaching
- Pre-plant decision
Almond Salinity Management: In-Season Leaching

• Dependent upon the salinity of the soil and water applied.
• Requires salinity analysis of soil and water

\[ E \text{Ce} = \text{Salinity of the Soil (dS/m)} \]

\[ E \text{Ciw} = \text{Salinity of Irrigation Water (dS/m)} \]

\[ E \alpha = \text{irrigation system application efficiency} \]

\[ \text{Leaching Requirement (LR)} = \frac{E \text{Ciw}}{(5 \times E \text{Ce}) - E \text{Ciw}} \]

\[ \text{Net Inches Required} \]
\[ \text{Gross Inches} = \frac{1}{(1 - \text{LR}) \times E \alpha} \]
Almond Salinity Management: In-Season Leaching

• Example: 2.33 net inches of water needed, $E_a=80%$

$$E_{Ce} = \text{Salinity of the Soil (dS/m)} = 4.0$$

$$E_{Ciw} = \text{Salinity of Irrigation Water (dS/m)} = 2$$

$$\text{Leaching Requirement (LR)} = \frac{E_{Ciw}}{5 \times E_{Ce} - E_{Ciw}} = \frac{2}{5 \times 4.0 - 2} = 0.11$$

$$\text{Net Inches Required} = \frac{2.33}{(1 - LR) \times (E_a)} = \frac{2.33}{(1 - 0.11)(0.8)} = 3.69$$

$$\text{Gross Inches} = \frac{2.33}{(1 - LR) \times (E_a)} = \frac{2.33}{(1 - 0.11)(0.8)} = 3.69$$
Almond Salinity Management: In-Season Leaching

Generalized LC:

• If want soil EC (ECe) = water EC (ECw) = 33%
• ECe = 2X ECw, LF = 10%
• ECe = 3X ECw, LF = 5%
Almond Salinity Management: In-Season Leaching

Risks of in-season leaching programs:

• Too wet of soils for proper root development
  – Encourages root disease
• May encourage vigor, increased timing of fruit development, risk of hull-rot;
• May leach nitrate;
• Dry down will pull salts back into the rootzone (e.g. hull-split RDI or harvest).

Is this the best strategy?
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.

Leaching is most efficient in the winter when crops are dormant and ET is low. Timing does not coincide with critical periods of nitrogen fertilization and plant activity, reducing leaching risk and disease;
Almond Salinity Management: Dormant Leaching

- The soil water content must exceed field capacity in the root zone for leaching to occur;
- Intermittent periods of irrigation and rainfall will more efficiently leach salts and boron than continuous;
- During rain events, drip systems, or limited pattern microsprinklers should be ran to help keep salts out of rootzone;
- Low CEC soils (sands, loamy sands) will require less water than higher CEC soils due to reduced salt concentration/cation “tie up”
Almond Salinity Management: Dormant Leaching

<table>
<thead>
<tr>
<th>Proportion that rootzone salinity exceeds threshold</th>
<th>1.0X</th>
<th>1.3X</th>
<th>2X</th>
<th>2.6X</th>
<th>3.3X</th>
<th>4X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peach (dS/m)</td>
<td>1.5</td>
<td>1.95</td>
<td>3</td>
<td>3.9</td>
<td>4.95</td>
<td>6</td>
</tr>
<tr>
<td>PxA Hybrid (dS/m)</td>
<td>2</td>
<td>2.6</td>
<td>4</td>
<td>5.2</td>
<td>6.6</td>
<td>8</td>
</tr>
<tr>
<td>Inches of water/Foot</td>
<td>0</td>
<td>0.6</td>
<td>1.8</td>
<td>3</td>
<td>4.2</td>
<td>5.4</td>
</tr>
</tbody>
</table>

Assumes that rootzone is at field capacity
Dormant leaching programs for sodium will most likely reduce chloride and boron

- Managing chloride is easier due to being an anion, and less water will be needed;
- If managing boron (weak anion/neutral), more water will be needed than chloride (about twice the amount);
- Amounts will vary based on soil and chloride load, but would start with about ½ the amount required for sodium
Almond Salinity Management: Displacement

Increasing cation concentrations can help to displace sodium;

• Use of calcium or magnesium containing amendments;
  – Generally rely on calcium as it has other plant benefits;
  – Some sources may precipitate with water source.

• Acidifying the soil to decrease soil pH, increasing hydrogen ions;

• Not needed for chloride;

• May not be as useful for low CEC soils.
## Almond Salinity Management: Overview

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<th>Higher CEC Soils (&gt; 12 meq/100 g)</th>
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<tbody>
<tr>
<td>Sand, Loamy sands</td>
<td>Textures</td>
</tr>
<tr>
<td>0.4”-1.5” per foot</td>
<td>Water Holding Capacity</td>
</tr>
<tr>
<td>High</td>
<td>Severity of Uptake Burn</td>
</tr>
<tr>
<td>Low</td>
<td>Difficulty to Leach</td>
</tr>
<tr>
<td>2-4 times the WHC, (8”- 15”)</td>
<td>Leaching Amounts</td>
</tr>
<tr>
<td>Low rates</td>
<td>Amendments</td>
</tr>
<tr>
<td></td>
<td>High rates (CEC)</td>
</tr>
</tbody>
</table>

- Low CEC Soils: Low rates
- Higher CEC Soils: High Rates (CEC)

- **Texture**: Sandy loams, loams, silts, and clays
- **Water Holding Capacity**: >1.5” per foot
- **Severity of Uptake Burn**: Increases with salinity
- **Difficulty to Leach**: High due to WHC, CEC
- **Leaching Amounts**: 3”-15” plus profile fill (~10-22”)
- **Amendments**: High Rates (CEC)
Almond Salinity Management: Rootstock Selection

Trial was established in 1989 on a sandy soil with low exchange capacity (3.1 meq/100g of soil)

- Irrigated with solid set sprinklers with low quality groundwater
  - moderately high sodium, 6.35 meq/L (SAR= 3.06)
  - low chloride 0.75 meq/
- 6 Rootstocks: Brights Hybrid, Halford, Hansen, Lovell, Nemaguard, Nemared,
- 5 blocks of 5 trees established in RCBD planted 24’x24’
Almond Salinity Management: Rootstock Selection

Around the orchards 10\textsuperscript{th} year, marginal leaf scorching started to appear on peach rootstocks

Possible differences in salt tolerance?
Almond Salinity Management: Rootstock Selection

Sodium % within leaf tissues

- Severe
- Increasing

P<0.05

- Carmel
- Nonpareil

<table>
<thead>
<tr>
<th>Variety</th>
<th>Sodium %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brights</td>
<td>A</td>
</tr>
<tr>
<td>Halford</td>
<td>C</td>
</tr>
<tr>
<td>Hansen</td>
<td>B</td>
</tr>
<tr>
<td>Lovell</td>
<td>B</td>
</tr>
<tr>
<td>Nemaguard</td>
<td>B</td>
</tr>
<tr>
<td>Nemared</td>
<td>B</td>
</tr>
</tbody>
</table>

A indicates a higher sodium percentage compared to B and C.
Almond Salinity Management: Rootstock Selection

Chloride % within leaf tissues

Increasing

<table>
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<th>Nonpareil</th>
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</tr>
<tr>
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</tr>
</tbody>
</table>

P<0.05
Almond Salinity Management: Rootstock Selection

20th Leaf Yields, Nonpareil

![Bar graph showing 20th leaf yields for different rootstocks.]

- Brights: A
- Halford: B
- Hansen: A
- Lovell: B
- Nemaguard: A B
- Nemared: B

P = 0.05
Almond Salinity Management: Rootstock Selection

Lovell Rootstock

Carmel Nonpareil
Almond Salinity Management: Rootstock Selection

Carmel Rootstock

P/A Hybrid Rootstock

Nonpareil
Rootstock selection does impact salinity tolerance with P/A hybrids appearing more tolerant to SODIUM/CHLORIDE than peach rootstocks.

Roger Duncan, UCCE Stanislaus
Methods: ‘Nonpareil’ nursery grafted trees on eight rootstocks were planted Feb, 2011, at 22’ x 18’. Twenty Titan SG1s were added April, 2011, but not in the replicated trial.

The trial is located in Yolo County north of Cache Creek. The soil is Marvin silty clay loam. Boron in the irrigation water ranges from <1mg/l to 3.1 mg/l, depending on year and month.
Almond Salinity Management: Rootstock Selection

K. Pope, UCCE
Yolo/Solano
Almond Salinity Management: Rootstock Selection

Yield Per Acre 2014

- Titan
- Nickels
- FxA
- Hansen
- Brights
- Rootpac
- Viking
- Lovell
- Krymsk

Yield Per Acre
PAR %

K. Pope, UCCE
Yolo/Solano

R² = 0.7266
Almond Salinity Management: Variety Influence

Roger Duncan, UCCE Stanislaus
Almond Salinity Management

• Spend some time to improve distribution uniformity in orchard
• Be careful with too salty of water – may do more harm than good!
• Know your water, soil, and utilize a leaching program
• Monitor tissue levels consistently
Quick Notes on DU Improvement

- Micro-irrigation systems decline in DU as they age (most dramatically after 5 years);
- Clean or remove hose screens, flush lines monthly, replace emitters with the same emitter;
- Use amendments that won’t precipitate – dependent upon water quality;
- Check pressures and flows at the emitter, risers, and pump.

These practices help reduce the impacts of salinity!