Managing Pistachio Tree Health Under Saline Conditions

Advances in Pistachio Production – Short course

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Pistachios are salt tolerant but elevated salinity....

- degrades soil structure
- decreases water uptake
- stunts growth
- can lead to salt accumulation in tissues and decrease nut crop quality
- tree nutrition, soil, and water monitoring and management is key!

What is salinity?

Dissolved salts in irrigation water or soil solution

Cations: Ca\(^{2+}\), Mg\(^{2+}\), Na\(^{+}\), K\(^{+}\)
Anions: SO\(_4\)^{2-}, Cl\(^{-}\), HCO\(_3\)^{-}, CO\(_3\)^{2-}, NO\(_3\)^{-}
B (H\(_3\)BO\(_3\) (boric acid) and H\(_2\)BO\(_3\) (borate))
Saline-sodic or sodic soil

- Crusting/infiltration issues
- High sodium, pH and bicarbonates
- Managed with soil and water amendments and leaching

Normal or saline soil

- Little to no infiltration problems
- Generally good soil structure
- Managed with leaching water

Salinity impacts on pistachio

Osmotic:
- Elevated salts require more energy to move water from roots to transpiring tissues
- ET decreases
- Growth limited

Specific Ion Toxicity:
- Salts absorbed by roots accumulate in woody tissue and leaves
- Leaf burn on margins
- Nutritional disorders

Tree sensitivity increases with time

Osmotic

Specific Ion toxicity

= Na⁺, Cl⁻, B
Mechanisms of salt tolerance

- High salt in soil leads to a decrease in water potential between the soil and tree.
- Tree makes physiological adjustments to maintain an osmotic gradient for water movement from root to transpiring tissues.
- Sodium (Na+) and chloride (Cl-) concentrations decrease along the transpiration stream through the tree.
- Salt storage in the stem's xylem structures and circulation in the phloem prevent ions accumulation in leaves (Godfrey et al. 2019).

Osmotic impacts: reduced water use

Osmotic impacts: reduced vigor

Prolonged or severe salinity may overcome trees ion exclusion strategies, leading to leaf necrosis and declining yields.

Specific Ion Impacts:
B levels in leaf tissue of Kerman scion

Yield Impacts
Pistachios are salt tolerant but....

- 4.5 to 6 dS/m EC irrigation water may not be sustainable for long-term productivity if salinity challenges are coupled with poor drainage
- Soil and water chemistry, and soil structure must be managed to improve drainage and leaching

Soil ECe: average 7.1 dS/m
Low EC, high SAR ground water

Dormant Season Salinity Management:

improve water penetration and leach enough salt for efficient use of water next season

**Salinity Management Timeline:**

**November:**
- Sample irrigation water and soil from 1’ to 5’
- Determine EC, pH, Na+ (SAR), B
- Calculate and apply soil and/or water amendments if needed
- Calculate depth of reclamation: Determine depth of water (inches per foot depth soil) needed to achieve desired salinity
- Determine timeline for completing leaching program

**November to March:**
- **Leach in dormant season**
  - 1st fill profile to field capacity (3-6 inches over 3-4 days), then 2-4 days drainage...then begin leaching applications

**March:**
- Re-sample irrigation water and soil from 1’ to 5’ to determine effectiveness of applied leaching and starting point for growing season

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**Key things to look for in water and soil analyses:**

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Threshold for caution</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>&gt; 8 acidifying amendments likely necessary</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>&gt; 4.5 water, &gt; 6-8 soil (potential reduced vigor and production)</td>
</tr>
<tr>
<td>Saturation percentage (Sat %)</td>
<td>Soil texture estimate</td>
</tr>
<tr>
<td>Na+ and Cl− (meq/L)</td>
<td>&gt; 20* soil and water</td>
</tr>
<tr>
<td>Boron (mg/L)</td>
<td>&gt; 3 soil and water</td>
</tr>
<tr>
<td>SAR water</td>
<td>&gt; 5x ECw, likely infiltration problems</td>
</tr>
<tr>
<td>Exchangeable sodium % soil</td>
<td>&gt; 6% likely infiltration problems</td>
</tr>
<tr>
<td>Bicarbonate (HCO₃⁻) water (meq/L)</td>
<td>&gt; 2.5, acid forming amendments recommended</td>
</tr>
<tr>
<td>% Lime (CaCO₃) soil</td>
<td>&lt;1% add Ca amendments, &gt;1% use acid forming amendments</td>
</tr>
</tbody>
</table>

*Source: B.L. Sanden, H.C. Reyes, and S.C. Grattan. 2004

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**Resources:**

- [Managing Salinity, Soil, and Water Amendments](http://cekern.ucanr.edu/files/88609.pdf)
- [Analytical Conversions and Leaching Calculations](http://cekern.ucanr.edu/Irrigation_Management/ANALYTICAL_CONVERSIONS_AND_LEACHING_CALCULATIONS)
- [ANRI Catalog's details](https://anrcatalog.ucanr.edu/Details.aspx?itemNo=3375)
Soil salinity amendment, unit conversions and leaching calculations

Cnvrsn-Infilt-LeachCalc
http://cekern.ucanr.edu/Irrigation_Management/ANALYTICAL_CONVERSIONS_AND_LEACHING_CALCULATIONS/

Key Salinity measurements: EC and TDS

Electrical Conductivity (EC) (soil and water)
- driven by concentration of salts
- some ions conduct electricity more than others
- Units: decisiemens per metre (dS/m) and millimho per centimeter (mmho/cm)
  - 1 dS/m = 1 mmho/cm

Total dissolved solids (TDS) water
- total mg of salt remaining if one-liter water evaporated to dryness
- Units: (mg/L or ppm)

Convert EC to TDS, or vice versa:

\[ \text{TDS (mg/L or ppm)} = \text{EC (dS/m)} \times 640 \quad (\text{EC from 0.1 to 5 dS/m}) \]
\[ \text{TDS (mg/L or ppm)} = \text{EC (dS/m)} \times 800 \quad (\text{EC 5 to 10 dS/m}) \]

Soil and water analyses unit conversions: meq/l, mg/l, ppm...

- Milligrams per liter (mg/L) = parts per million (ppm)
- mg/L = milliequivalents per liter (meq/L) × equivalent weight

\[ \text{meq/L} = \frac{\text{mg/L}}{\text{equivalent weight}} \]

Equivalent weights of selected cations

<table>
<thead>
<tr>
<th>Cation</th>
<th>Equivalent weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>23</td>
</tr>
<tr>
<td>Calcium</td>
<td>40</td>
</tr>
<tr>
<td>Magnesium</td>
<td>24</td>
</tr>
<tr>
<td>Potassium</td>
<td>39</td>
</tr>
<tr>
<td>Barium</td>
<td>56</td>
</tr>
<tr>
<td>Carbonate (Ca²⁺)</td>
<td>30</td>
</tr>
<tr>
<td>Chloride (Cl⁻)</td>
<td>35</td>
</tr>
<tr>
<td>Sulfate (SO₄²⁻)</td>
<td>96</td>
</tr>
<tr>
<td>Nitrate (NO₃⁻)</td>
<td>62</td>
</tr>
<tr>
<td>Phosphate (PO₄³⁻)</td>
<td>97</td>
</tr>
</tbody>
</table>
Calculate soil applied rates

Simplified Goal: replace Na⁺ with Ca⁺ and leach the Na⁺ out

- determine calcium requirement (meq Ca/100 g soil needed to displace Na⁺) and amendment rates from soil analysis, use:
  - SAR
  - Exchangeable sodium
  - Exchangeable sodium percentage (ESP)
  - CEC

Example Calculations: see Hanson and Gratton pages 116-118

Gypsum is a salt that adds to osmotic pressure that limits water uptake through the roots

Broadcasting or injecting gypsum into the water is only necessary if:
Sodium > 5 * Calcium

<table>
<thead>
<tr>
<th>Gypsum (100%)</th>
<th>Sulfuric Acid</th>
<th>Sulfur (100%)</th>
<th>Lime sulfur (9% Ca, 24%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1.7</td>
<td>1.0</td>
<td>0.3</td>
</tr>
<tr>
<td>1.5</td>
<td>2.6</td>
<td>1.6</td>
<td>0.5</td>
</tr>
<tr>
<td>2.0</td>
<td>3.4</td>
<td>2.1</td>
<td>0.7</td>
</tr>
<tr>
<td>2.5</td>
<td>4.2</td>
<td>2.6</td>
<td>0.8</td>
</tr>
<tr>
<td>3.0</td>
<td>5.2</td>
<td>3.2</td>
<td>1.0</td>
</tr>
<tr>
<td>3.5</td>
<td>6.0</td>
<td>3.7</td>
<td>1.2</td>
</tr>
<tr>
<td>4.0</td>
<td>6.9</td>
<td>4.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Adapted from Hanson and Gratton University of California, Pub 3375, 2006.

Caution: do not exceed 1500 lbs in a single application in established orchards
Calculate water applied rates

Ibs of amendment per acre ft water

<table>
<thead>
<tr>
<th>meq/L</th>
<th>Gypsum Sulfate</th>
<th>Sulfuric Acid</th>
<th>Salicylic Acid</th>
<th>Lime Sulfur</th>
<th>Nitro Sulfur</th>
<th>Sulfate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>234</td>
<td>131</td>
<td>44</td>
<td>191</td>
<td>109</td>
<td>242</td>
</tr>
<tr>
<td>2.0</td>
<td>468</td>
<td>266</td>
<td>87</td>
<td>382</td>
<td>218</td>
<td>484</td>
</tr>
<tr>
<td>3.0</td>
<td>702</td>
<td>399</td>
<td>131</td>
<td>573</td>
<td>327</td>
<td>706</td>
</tr>
<tr>
<td>4.0</td>
<td>936</td>
<td>532</td>
<td>178</td>
<td>764</td>
<td>430</td>
<td>960</td>
</tr>
<tr>
<td>5.0</td>
<td>1170</td>
<td>665</td>
<td>218</td>
<td>955</td>
<td>545</td>
<td>1210</td>
</tr>
<tr>
<td>6.0</td>
<td>1404</td>
<td>798</td>
<td>262</td>
<td>1146</td>
<td>654</td>
<td>1452</td>
</tr>
</tbody>
</table>

Low to moderate rate

Moderate to high rate

$EC_w = (Na^+ + Ca^{++} + Mg^{++}) ÷ 10$

$SAR = \frac{Na^+}{Ca^{++} + Mg^{++}} \sqrt{2}$

Need Ca^{++} to raise EC<sub>w</sub> and lower SAR

Example water meq Ca/L calculations in Pistachio Production Manual p. 148 – 149

Calculate Amendment Rates

<table>
<thead>
<tr>
<th>Salinity of Applied Water (dS/m)</th>
<th>Severe reduction</th>
<th>Slight to moderate reduction</th>
<th>No reduction in infiltration rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

$Na + Ca + Mg = 9.6 + 0.5 + 0.1 = 10.2$ meq/l

$EC = 10.2 ÷ 10 = 1.0$ dS/m

$SAR = 9.6 ÷ ((0.5 + 0.1) ÷ 2)^{0.5} = 17.5$

See Pistachio Production Manual pages 148 – 149

Calculate Amendment Rates

New $Ca + Mg = 3.5 + 0.1 = 3.6$ meq/l

New cation concentration = $9.6 + 3.6 = 13.2$ meq/l

New $EC = 13.2 ÷ 10 = 1.3$ dS/m

New $SAR = 9.6 ÷ ((3.5 + 0.1) ÷ 2)^{0.5} = 7.2$
Calculate water applied rates

Ibs of amendment per acre ft water

<table>
<thead>
<tr>
<th>Gypsum Sulfate (23% Ca, 19% S)</th>
<th>Acid Sulfate (100% S)</th>
<th>Lime sulfur (100% S, 24% S)</th>
<th>Nitro sulfur (20% N, 40%Mg)</th>
<th>Sulfate (10% N, 10% Fe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 234 131 44 191 109 242</td>
<td>2.0 468 268 87 382 218</td>
<td>3.0 602 309 111 575 327</td>
<td>4.0 736 380 174 764 430</td>
<td>5.0 870 441 237 950 532</td>
</tr>
<tr>
<td>Low to moderate rate</td>
<td>Moderate to high rate</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{EC}_w = \left( \text{Na}^+ + \text{Ca}^{++} + \text{Mg}^{++} \right) \div 10 \]

\[ \text{SAR} = \frac{\text{Na}^+}{\sqrt{\left( \text{Ca}^{++} + \text{Mg}^{++} \right) / 2}} \]

Need Ca++ to raise ECw and lower SAR

Example water meq Ca/L calculations in Pistachio Production Manual p. 148 – 149

Calculate the depth of reclamation

http://cekern.ucanr.edu/Irrigation_Management/ANALYTICAL_CONVERSIONS_AND_LEACHING_CALCULATIONS/

Soil texture and depth of leaching water requirement
Calculate depth of water for reclamation

Required Leaching Ratio* (depth water/depth soil) = \( K / (\text{Desired EC/Original EC}) \)

* Assumes leaching water is ≈ 1.0 dS/m

Use K factor of 0.15 for sprinkling, drip or repeated flooding. Boron use 0.6 leaching coefficient 3x greater than other salts

Average salinity: 6.5 dS/m

In-season leaching fraction to maintain desired rootzone salinity

Leaching fraction required over long-term irrigation with a given salinity of water to obtain a desired rootzone salinity. (Ignoring precipitation/dissolution reactions in the soil.)

\[ \text{Applied water needed} = 1/(1-\text{LF}) \]
Calculated feet to hours

- Gallons to apply = depth of water (inches) x (trees per acre) X (0.622 gal/in. ft²)
- Depth of water inches = 0.98 feet x 12 inches per foot = 11.8 inches
- Acre inches per hour = (trees per acre) x (gph output per tree) ÷ 27,154 gallons per acre-inch
- 128 trees x 8 gph ÷ 27,154 gallons = 0.038 acre in/hr

11.8 inches ÷ 0.038 in/hr = 310 hours or 13 days

Monitoring progress with continuous soil EC measurements:
The effect of micro-spray application of non-saline water on soil electrical conductivity (EC) at different depths in 2002 pistachio block near Firebaugh 2020

Tree health in saline conditions summary.....

- Pistachio is more tolerant than other tree crops but elevated salinity degrades soil structure, decreases water uptake, stunts growth, eventually accumulates salt in tissues and decreases nut crop quality
Tree health in saline conditions summary:

- Keep soil salt levels below 4.5 dS/m
- Soil and water sample
- First address sodicity then salinity
  - Fall apply gypsum before rain and leaching
- Best approach: leach salts in dormant period
  - lowest ET and maximum salt accumulation post season
- If possible complete leaching before spring root flush

THANK YOU!

QUESTIONS?