Salinity Issues in Soils and Irrigation Water: 
Leaching needs and issues

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Sources of Salts and Trace Element Issues

Primary / Natural Salinity:
- From weathering of soil parent materials containing salts and trace elements (including soluble salts – chlorides of Na, Ca, Mg + Sulfates and Carbonates/Bicarbonates)

Secondary Salinity (caused by our human activities):
- Replace native vegetation with irrigated ag, use of salt-containing groundwater or surface water sources; shallow groundwater impacts
- Additional salts from fertilizers, composts, other amendments
- Combined with inadequate drainage and limited plan/ability to export salts
How much salt added with irrigated agriculture?

Example (in semi-arid and arid irrigated areas):

If irrigated with 0.8 dS/m water (CA Aqueduct, others) with the following quantities, how much salt added?

2 feet of water (0.8 dS/m) = 1.25 Tons salt/year/acre
4 feet of water (0.8 dS/m) = 2.5 Tons salt/year/acre
How much salt added with irrigated agriculture?

Not only a question of **HOW MUCH SALT** has been added to the root zone with irrigation water, from the shallow groundwater, or other sources ...

Another set of questions relate to the **COMPOSITION** of the salts in the salt-affected ground (**WHAT TYPE OF SALTS**)?
Different Types of Salt-Affected Soils
(ways of characterizing salt-affected soils):

- **Saline Soils** - high enough soluble salts to injure plants, reduce growth, reduce availability of water to plants, sometimes direct specific ion toxicity issues as well

- **Saline-Sodic Soils** – both high in soluble salts and specifically also in sodium. Differ from saline soils in proportion of Na to Ca and Mg (Na higher). High EC irrig water would result in better soil structure, but more high salinity impacts on crop. For reclamation, must first deal with sodicity, increase Ca/Mg and reduce Na levels.

- **Sodic Soils** – can be low to moderate in total soluble salts, but have relatively high amounts of sodium adsorbed onto soil particles. This results in dispersed soil particles and generally poor tilth and low water permeability, aeration issues, high pH.
**SALT-AFFECTED SOIL CLASSIFICATIONS (NRCS)**

<table>
<thead>
<tr>
<th>Salt -affected soil classification</th>
<th>Electrical conductivity (EC)</th>
<th>Sodium Absorption Ratio (SAR)</th>
<th>Exchangeable Sodium Percentage (ESP)</th>
<th>Resulting Soil Physical / Soil Structure Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not salt-affected</td>
<td>Less than 4</td>
<td>Below 13</td>
<td>Below 15</td>
<td>Flocculated</td>
</tr>
<tr>
<td>Saline</td>
<td>Greater than 4</td>
<td>Below 13</td>
<td>Below 15</td>
<td>Flocculated</td>
</tr>
<tr>
<td>Sodic</td>
<td>Less than 4</td>
<td>Above 13</td>
<td>Above 15</td>
<td>Dispersed</td>
</tr>
<tr>
<td>Saline-sodic</td>
<td>Greater than 4</td>
<td>Above 13</td>
<td>Above 15</td>
<td>Flocculated</td>
</tr>
</tbody>
</table>

Can “assign” soils a certain classification based on this chart, but salinity issues occur over time, so there often is a progression from “not salt-affected” to some level of salinity impact.
Leaching Practices Needed – *dependence on salt sources*

Keep in mind that the salt buildup problem occurred over time, and will also take time to reduce.

**Where did the salt come from? What caused salt accumulations? Do you have any control over continuing additions to problem?**

- Originated with salt-containing irrigation water
  - Did accumulations occur over long time with low/moderate salinity waters?
  - Or ... result from short-term use of high salinity waters?
  - Is there a lower salinity water available for reclamation?
- Originated from shallow water table
  - Can you exert some control over water table depth at specific times of year through drainage, or with other crops able to use shallow groundwater?
  - Or ... is shallow groundwater control/depth mostly out of your local control ... a recurring issue in high rainfall years, etc.?
Saline Soil Management - *timing, impacts of amendments*

- **Drainage out of surface layers needed** - Leaching over time provides best ability to manage saline soils, provided that either drainage is available to carry away higher salinity drainage waters, or shallow gw buildups can be managed.

- For many annual crops, plants are most sensitive to salinity during germination and early seedling development. For this reason, dormant season leaching and winter rainfall can be most effective in combination to reduce surface soil salinity.

- **Soil amendments** (elemental S, gypsum, other Ca-amendments, etc.) can actually add salts, and use should be restricted to specific situations where they may help. Make sure you know composition of manures, composts and what you are adding.

- Problems with sodicity are a different situation.
Sodic Soil Management – *amendments as part of process*

✓ Can be difficult and costly to reclaim a truly sodic soil
✓ Generally drainage also required for effective reclamation effort

✓ In some situations, can utilize tillage and organic matter additions to help break up high-sodium layers affecting soil structure, water infiltration & movement - can be hard to do in orchard settings under micro-irrigation

✓ **How improve water infiltration rates in sodic soils?**
  ✓ Ca levels need to be increased for sodic soil reclamation, since this displaces Na & reduces ESP
  ✓ example: can inject gypsum into irrig water early on during reclamation, this increases salinity and calcium levels & helps stabilize soil structure
  ✓ Practices help reduce Exch. Sod. Percentage (reduction needed depends on soil texture & irrigation method)
Sodic Soil Management – *irrigation water supply issues*

✓ Be careful to consider chemical composition of irrigation waters, especially if you change routinely from irrigation district water to deep gw wells.

✓ It is important to know some details of irrigation water chemistry to make good choices:

✓ **SALINE – SODIC SOIL MANAGEMENT** options:
  ✓ For reclamation, treat these soils first for sodicity problems (addition of Ca first, followed by leaching practices)
  ✓ If try to leach with good quality water first, while Na still high (relative to Ca + Mg) and not soluble, will:
    ✓ Reduce salinity
    ✓ Increase sodicity problems since you haven’t removed Na, and
    ✓ Make soil structure and infiltration problems worse
Sodic Soil Management – *irrigation water supply issues*

- Be careful to consider chemical composition of irrigation waters, especially if you change from irrigation district water to deep groundwater wells.
- It is important to know some details of irrigation water chemistry to make good choices:

**EXAMPLES:**
- Waters high in bicarbonate with a high SAR (ratio of sodium to Ca + Mg) can essentially help create a sodic soil given enough time.
- Large concentrations of bicarbonates or carbonates in water react with soil Ca & Mg to form compounds such as calcium carbonate that precipitate out of solution. This removal of Ca & Mg increases the sodium hazard, and a relative indicator of this hazard is the "adjusted SAR"
Sodic Soil Management – *amendments as part of process*

**GYPSUM:**
- Common choice to supply Calcium for sodic soil reclamation, also high in S but this is not generally a problem for crops
- Dissolves well at high pH; quantity needed can be quite high, so often recommend split applications or only treat worst-affected areas

**ELEMENTAL S:** *(can also consider adding acids directly for similar affect)*
- Adding S does not add Calcium – it oxidizes to form sulfuric acid, which can dissolve free lime (CaCO3) in arid-zone soils
- It helps speed process, treat more soil volume if S can be incorporated

<table>
<thead>
<tr>
<th>Amount to treat one ft soil (Tons/acre)</th>
<th>Exchangeable Sodium you want to replace with Calcium (meq Na / 100 g soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Gypsum</td>
<td>1.75**</td>
</tr>
<tr>
<td>Elem. Sulfur*</td>
<td>0.325</td>
</tr>
<tr>
<td>Sulfuric acid*</td>
<td>0.99</td>
</tr>
</tbody>
</table>

*assumes soil contains adequate amounts of free lime  

**split amounts higher than 2T/ac into separate applications**
### Crop Issues with salts and specific ions

<table>
<thead>
<tr>
<th>Measurements in soil or water</th>
<th>Resulting Potential Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical conductivity (EC)</td>
<td>Quantitative indicator of amounts of dissolved salts. Can impact germination and crop growth</td>
</tr>
<tr>
<td>Exch. Sodium Percentage (ESP)*, Sod. Abs Ratio (SAR)</td>
<td>With increasing ESP / SAR, aggregate structure breaks down, can result in reduced infiltration &amp; Water movement. High Na can be toxic to plants</td>
</tr>
<tr>
<td>pH (acidity measure)</td>
<td>Availability of Fe, Mn, micronutrients reduced; if pH greater than 8 – 8.5, monitor SAR, ESP more closely</td>
</tr>
<tr>
<td>Chloride</td>
<td>Leaf tip burns, leaf drop</td>
</tr>
<tr>
<td>Boron</td>
<td>Leaf yellowing, spotting, variable with growth stage</td>
</tr>
<tr>
<td>Carbonates, bicarb.</td>
<td>Interveinal yellowing, assoc. with Fe, Zn deficiencies</td>
</tr>
<tr>
<td>sodium</td>
<td>Leaf burn, necrotic edges</td>
</tr>
</tbody>
</table>

SAR measured in water or soil sat. extract; ESP is % of CEC filled by Na (used in gypsum application rate calculations)
LEACHING REQUIREMENT – Generalized calculations

*Depends on having some data from soil & irrigation water samples so chemistry known – keep past & future records of data to determine how leaching & any amendment trts are working!

Leaching Requirement (LR) = \( \frac{EC_{iw}}{5 \times EC_{e}} - EC_{iw} \)

Amount to Apply (inches) = \( \frac{ET_{c} \text{ replacement}}{1 - LR} \times AE \)

Where: \( EC_{iw} = \) irrig water EC; \( EC_{e} = \) soil EC in rootzone; \( AE = \) irrigation distribution efficiency (as a fraction of 1)

Example: \( ET_{c} = 1.2 \text{ inches for 4 days}; \ AE = 0.85; \ EC_{iw} = 1.8; \ EC_{e} = 3.5 \)

\[ LR = \frac{1.8}{5 \times 3.5} - 1.8 = .1146 \]

Amount to Apply (inches) = \( \frac{1.2}{1 - 0.1146} \times 0.85 = 1.59 \text{ inches} \)

(instead of the 1.2 inches to meet \( ET_{c} \) requirements)
**GENERALIZED TABLE FOR LEACHING FRACTIONS (LF) - BASED ON THE APPROACH JUST DESCRIBED**

(Ayers and Westcot, 1985) - UCCE Kern Co. bulletin Sanden, B., Fulton, A.E., Ferguson, L.

<table>
<thead>
<tr>
<th>Irrig Water EC (dS/m)</th>
<th>Desired Average Rootzone Salinity (ECe) (dS/m)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td></td>
<td>10</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td>33</td>
<td>10</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1.5</td>
<td></td>
<td>20</td>
<td>10</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td>33</td>
<td>17</td>
<td>10</td>
<td>7</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>3.0</td>
<td></td>
<td>33</td>
<td>20</td>
<td>14</td>
<td>10</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>4.0</td>
<td></td>
<td>33</td>
<td></td>
<td>23</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td></td>
<td></td>
<td></td>
<td>33</td>
<td>24</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**In General:**
- For soil ECe to remain about=ECiw, LF = **33 percent**
- For ECe to end up 2 times ECiw, LF = **10 percent**
- For ECe to end up 3 times ECiw, LF = **5 percent**
Leaching Ratio \((depth\ water/depth\ soil)\)
= \(K / (\text{target ECe} / \text{measured ECe})\)

Where:
\(\text{measured ECe}\) = soil EC average or zone within rootzone;
\(\text{target ECe}\) = desired ECe for soil after leaching
\(K\) = variable factor based on irrigation water application rate & characteristics
\((K = 0.15\ for\ sprinklers,\ drip,\ repeated\ flood/furrow;\ 0.3\ for\ continuous\ flood;\ and\ if\ Boron\ a\ big\ problem,\ K\ may\ be\ raised\ to\ 0.6\ since\ difficult\ to\ leach)\)

Example: Leaching Ratio \((\text{depth of water/depth of soil})\) = 
\(K / (\text{target ECe} / \text{measured ECe})\)
target ECe = 2.5; measured ECe = 5.5; drip used so \(K = 0.15\); for 3 feet depth

\text{Leaching ratio} = 0.15 / (2.5/5.5) = 0.33
\text{Depth of Leaching Water for 3 feet of profile} = 0.333 \times 3\ ft = 1\ foot
## In-Season Leaching versus Dormant-Season – *some pros & cons*

### In-Season Leaching:  
**Pros:**
- Calculations of leaching needs tied to weekly ETc calculations  
- If effective, lower salt & trace element exposure during peak growth periods  

**Cons:**
- Some soils unable to infiltrate full amounts to meet ETc plus leaching requirements  
- Localized soil volumes can be under conditions of anoxia – possible direct plant damage, disease impacts  
- Increase potential for fertilizer nutrient leaching

### Dormant Season Leaching:  
**Pros:**
- Leaching can be done during low ET time of year, potentially more effective leaching  
- Potentially more effective for Boron, Chloride leaching  
- Avoids anaerobic conditions during active growth, less disease  
- Less ponding, higher infiltration  
- Better separation from timing of soluble nutrient applications  

**Cons:**
- Soil water content must be brought back up to field capacity for leaching to occur (can be an issue low rainfall yr)
Observations – *studies related to leaching in orchard setting*

B. Hanson, D. May. Univ. CA. 2011. UC-ANR publ. #8447. Drip Irrigation Salinity Management for Row Crops

**Discussions: maintenance and reclamation in-season leaching**

- Discussed zones of salt accumulation with limited soil volume drip, and leaching fraction estimates from different studies were reviewed, including:
    - Almonds irrigated at 50, 100, 150% estimated ETc using double line drip
    - Water balance method of estimating leaching fraction would suggest no leaching for 50 & 100% trts., and 50% leaching for 150% treatment
    - Actual estimates were 4-6% for 50% ETc trt, 10-22% for 100% trt, and 31-36% for 150% ETc treatment.
  - Hanson et al (2009) and Hanson and May (2004)
    - processing tomatoes & cotton under drip with and without shallow GW
    - In bed systems & widely-spaced drip lines, there was substantial localized leaching concentrated in zones around drip lines, with significant remaining salt accumulations at fringes of wetted zones
    - Simulations suggested primary wetted zone leaching fractions of about 8%, 25% and 31% for water applic. of 60, 100 and 115% estimated ETc for processing tomatoes
**Observations** – *studies related to leaching in orchard setting*

C. M. Burt, B. Isbell, Cal Poly SLO. 2005. Trans ASAE. And ITRC paper P 05-001

**Approach: for reclamation leaching**

- Pistachio orchard in Westhaven (Fresno Co.) series soils, silt loam & clay loams – experiment done during dormant season
- Multiple lines low flow drip tape, to try to minimize bypass flow & ponding
- Concentrated application in 1.8 m (6 ft) wide area down tree rows
- Leaching water applied in zone where irrigation water applied & where salt concentrated
- Water applied to about 1/3 of the ground area @ about one-half the water used if trying to leach full ground area

**Equivalent depth of leaching**

= net depth of leaching water (after soil at FC, and covering ET) divided by Depth of a soil zone

<table>
<thead>
<tr>
<th>Equivalent leaching depth (ft)</th>
<th>Approx. fraction of original salt remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>0.8 to 0.6</td>
</tr>
<tr>
<td>0.4</td>
<td>0.57 to 0.38</td>
</tr>
<tr>
<td>0.6</td>
<td>0.43 to 0.28</td>
</tr>
<tr>
<td>0.8</td>
<td>0.36 to 0.23</td>
</tr>
<tr>
<td>1.0</td>
<td>0.30 to 0.20</td>
</tr>
</tbody>
</table>
Summary – *Suggested Approaches*

- Be willing to sample irrigation waters & have basic chemical suitability analyses done for all water sources used for irrigation.

- Depending on salinity, sodicity or specific trace element issues at your site(s), sample soils to assess developing problems & impacts of your leaching or amendment treatments.

- Consider basic limits of salt and trace element tolerance issues for the crops grown (i.e., what can you get away with & for how long?)

- Adjust leaching & amendment application practices (gypsum, acid, S, etc.) for type / combination of conditions in salt-affected ground.

- When soil type & chemistry result in low capacities to infiltrate water, consider emphasis on dormant-season (winter +) leaching to reduce plant damage assoc. with anoxia, & reduce chances of nutrient leaching. Some studies suggest this can be a more effective, efficient use of limited water available for leaching.
Thank you