Salts in Soils: From Fertilizer to Tidewater

Jarrod O. Miller
What are Salts?

• Ionic Compounds
  – Inorganic
  – Dissolve easily into cations and anions
  – Example: KCl $\rightarrow$ K$^+$ and Cl$^-$

• Salts that don’t dissolve easily (carbonates) are not necessarily an issue in agriculture
Types of Salts in Soils and Groundwater

- **Cations:** Na$^{+1}$, K$^{+1}$, Ca$^{+2}$, Mg$^{+2}$, NH$_4^+$

- **Anions:** Cl$^{-1}$, NO$_3^{-1}$, SO$_4^{-2}$, HCO$_3^-$, CO$_3^{-2}$, PO$_4^{-2}$

*Cations will bond with anions, either in soluble (ionic) or less soluble (covalent) forms*
Commonly Known Salts

- **NaCl** - Sodium Chloride – Table Salt
- **KCl** – Potassium Chloride – Muriate of Potash
- **K₂SO₄** – Potassium Sulfate – Muriate of Sulfate
- **CaSO₄** – Calcium Sulfate – Gypsum
- **NH₄NO₃** – Ammonium Nitrate
- **NH₄SO₄** – Ammonium Sulfate
- **CaCO₃** – Calcium Carbonate - Lime
- **NaHCO₃** – Sodium Bicarbonate – Baking Soda

*Salts are only a problem at high concentrations*
How do we measure soil salts?

- An electrical conductivity (EC) meter
  - Two probes with a current

- Dissolved salts (ions) have a charge
  - It will conduct electricity
  - More salts = more conductance

- EC units of measurement
  - mmhos/cm
  - dS/M
  - They are the same
EC meters for precision agriculture

- Probes measure across the machine in the ground
- Clay has a strong conductance, so you can measure texture
Cation Exchange Capacity and Salts

Soil is the anion, attracting the cations

So its natural for soils to have “salts”

Some soil bonding is ionic, some is covalent
Cation Exchange Capacity and Salts

We tend to worry about salts that are exchangeable:

- Na, K, Ca, Mg, Cl, SO$_4$

Those that bond tightly to the soil won’t bother plants as much

- PO$_4$, Micronutrients
Higher CEC Holds More Total Salts

**Good** = adsorbs and holds salts away from plant roots

*(also means it holds more nutrients)*

**Bad** = If you need to correct salt content, take more effort
Salt Effects on Plant Roots

Osmotic Pressure

Pressure needed to prevent osmosis, or when solution moves from higher to lower concentration.
Salt Effects on Plant Roots

In Other Words

If salt concentration is higher in the soil than the plant root, water will want to move out of the root, and into the soil.

*Excess soil salts cause roots to dehydrate and die.*
Normal Salinity and Turgor Pressure

• There should naturally higher concentration of ions in the plant compared to soil
  • Ions are the nutrients and building blocks

• This draws water into the plant and causes osmotic pressure
  • Turgor pressure
  • Keeps plants upright
Salt Effects on Plant Roots

- Na is not an essential nutrient, and can be toxic to plants
- So high salts cause osmotic stress, while high Na is toxic
Salinity and Soil Structure

- Positive (+) charged salts allow negatively (-) charged soil particles to get closer
- Helps build soil structure
- Charge and concentration of salt is important though

For simplicity Ca/Mg > K > Na at doing this
Sources of Soil Salts: Minerals

Common Salts in Red

- Quartz – $\text{SiO}_2$, plus impurities (Fe, Mn, etc)
- Feldspars
  - $\text{KAlSi}_3\text{O}_8$, $\text{NaAlSi}_3\text{O}_8$, $\text{CaAl}_2\text{Si}_2\text{O}_3$
- Mica –
  - Muscovite ($\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{F,OH})_2$)
  - Biotite ($\text{K(Mg,Fe)}_3(\text{AlSiO}_{10})(\text{F,OH})_2$)

They weather from rocks
Ridge and Valley Limestone

Limestone is Mg and Ca carbonates

Can leave “salts” on the soil surface
All rocks weather and produce salts. Wetter climates cause them to leach out.
Sources of Salts: Poor Drainage

Salts can accumulate if there is poor drainage

- High water table
- Poor drainage due to clay, impervious layers

*In the east, it’s a bigger issue with tidal soils that received high salts*
Sources of Salts: Irrigation

- If salts can leach from soils, they can move down to groundwater.
- Irrigation has been a major source of salinization in the past.
- This will be a bigger issue in areas with less rainfall.
  - If your drainage water has a lower concentration than the irrigation water, the soil will salt.
Sources of Salts: Fertilizers

- Most fertilizers will be highly soluble and produce salts
  - *Otherwise they aren’t that useful*

- Salt Index (SI) measures the salt concentration that a fertilizer adds to the soil

- SI is a relative Comparison to $\text{NaNO}_3$
  - Common fertilizer at the time (Chili Saltpeter)
  - Represents value of 100
    - *Anything above 100 is more “salty” than saltpeter*
Sources of Salts: Coastal Sprays

- Breaking ocean waves can create sea spray
  - Can contain salts of Na, Mg, Ca, Cl, SO$_4$
- Mostly stays near shoreline
  - May travel up to 15 miles from shore

NASA
Sources of Salts: Tidal Inundation

- High tides can bring saltwater onto lands
- Hurricanes often push saltwater further
- Rising sea levels on the coast and Chesapeake Bay also increase saltwater issues
Salts in Seawater/Tidal/Brackish

- Freshwater salts are close to zero
- Brackish waters can range from 0.5 to 35 parts per thousand
- Saltwater can be 35 parts per thousand
Chesapeake Bay

- Saline at the mouth (25-30 ppth)
- Brackish throughout the middle
- Freshwater in northern regions and rivers (<5ppth)
- Moves with the weather
National Geographic

Subsidence and Sea Level Rise

- Saline soils should be uncommon in the east, however......
- Groundwater drawdown causes subsidence
- Climate change causes sea level rise
Saltwater Intrusion

These changes are bringing higher salt levels than crops can tolerate.
## Some Plant Tolerance to Salts

<table>
<thead>
<tr>
<th>Crop</th>
<th>10% Loss</th>
<th>25% Loss</th>
<th>50% Loss</th>
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<tbody>
<tr>
<td>Barley</td>
<td>9.6</td>
<td>13.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Rye</td>
<td>7.7</td>
<td>12.1</td>
<td>16.5</td>
</tr>
<tr>
<td>Wheat</td>
<td>6.0</td>
<td>8.0</td>
<td>10.0</td>
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<tr>
<td>Sorghum</td>
<td>5.1</td>
<td>7.1</td>
<td>10.0</td>
</tr>
<tr>
<td>Corn</td>
<td>3.9</td>
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<tr>
<td>Orchardgrass</td>
<td>3.1</td>
<td>5.5</td>
<td>9.6</td>
</tr>
<tr>
<td>Tomato</td>
<td>3.5</td>
<td>5.0</td>
<td>7.6</td>
</tr>
<tr>
<td>Sweet Corn</td>
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<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Watermelon</td>
<td>2.5</td>
<td>3.5</td>
<td>4.5</td>
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</table>
Plant Tolerance to Soil Salts

- Osmotic stress can be limited by reducing water loss
  - Plant may close stomata to reduce evaporation
  - Plant may take up more water to lower salt concentrations

- Na and Cl uptake can also cause stress, so plants can use exclusion mechanisms in their tissues
  - Exclude them from uptake
  - Compartmentalize them in tissue
Crop Response to Salinity

1. Starts with osmotic phase, where water uptake is inhibited
   - May dominate when EC > 25 dS/m

2. The second phase attempts to exclude ion uptake to prevent an imbalance (K) or toxic levels (Na, Cl)
   - This phase may be more important over longer time periods.
   - Osmotic effect will dominate when salts are high!

* Rengasamy, 2010
Crop Yield and Salts

- As salt content increases, so does EC and the osmotic pressure

- Yield drops off dramatically at higher levels of salts

- 1500 kPa is also known as the permanent wilting point

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* Rengasamy, 2010
Soil Water Content and Salts

- As a soil dries out, salt concentration (mg/L) gets higher
- Due to less water (same total amount of salts)
- So drier soils will have a larger osmotic effect
Soil Response to Salts: Structure

- Ions in the soil can help form structure
- Calcium is one of the best
- Sodium (Na) is one of the worst
- Na can disperse soil particles
- Without structure/bonding soil can crust over
- Makes infiltration difficult
Soil Response to Salts: pH

- Most soluble salts are basic cations and increase the pH
- When Ca concentration is high enough it precipitates as a carbonate (lime)
  - pH never rises above 8.2
- As Na increases so does pH
  - Na salts are soluble, so pH can go above 9
What Happens with pH > 9?

- Aluminum becomes soluble (again) and is toxic to plant roots

- Other metals like Fe, Mn can also become soluble
  - Can be toxic if levels are high enough
  - These are also micronutrients, so if the soil has low conc, this may be good for plants
Summary of Negative Salt Effects

• Excess Salts
  – Increase osmotic pressure, making it difficult for plants to take up water
  – Raises pH > 7-8

• Excess Sodium
  – Toxic to plants
  – Disperse soil particles, creating a surface crust, making water infiltration and seed germination difficult
  – Raises pH >9
Classification of Salty Soils

- EC = electrical conductivity
  - Measures the activity of all salts

- ESP = Exchangeable Sodium Percentage
  - Na vs [Ca, Mg, K] on the CEC

- SAR = Sodium Adsorption Ratio
  - Na / \sqrt{(Ca+Mg)/2}
  - 0.015(SAR) = ESP/(100-ESP)

Obviously, they find Na to be a major issue.
Classification of Salty Soils

<table>
<thead>
<tr>
<th>Classification</th>
<th>EC</th>
<th>Soil pH</th>
<th>ESP</th>
<th>SAR</th>
</tr>
</thead>
<tbody>
<tr>
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<td>&gt;4.0</td>
<td>&lt;8.5</td>
<td>&lt;15</td>
<td>&lt;13</td>
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<tr>
<td>Sodic</td>
<td>&lt;4.0</td>
<td>&gt;8.5</td>
<td>&gt;15</td>
<td>&gt;13</td>
</tr>
<tr>
<td>Saline-Sodic</td>
<td>&gt;4.0</td>
<td>&lt;8.5</td>
<td>&gt;15</td>
<td>&gt;13</td>
</tr>
</tbody>
</table>

- So saline soils have an overall salt issue, probably osmotic effects on water
- Sodic soils will have toxic Na levels and poor soil structure
- Saline sodic have the worst of both worlds, but still have good structure
Classification of Salty Soils

Saline

- Excessive salts for plant growth

Sodic

- Excessive sodium on the CEC. Not high in overall salts

Saline-Sodic

- Excessive salts, high sodium. Ca still controls pH.
Remediation of Salty Soils

**Saline**
- Wash the soil with freshwater

**Sodic**
- Add gypsum (CaSO₄)
- Wash with freshwater

**Saline-Sodic**
- Add gypsum (CaSO₄)
- Wash with freshwater
Managing Salts: Fertilizers

• Fertilizers are meant to be soluble and dissolve into salts
  • So plants can take them up

• High concentrations near germinating seeds is the larger issue
  • Mature plants may have other roots to count on
  • Foliar applications can also “burn” leaves, without killing the plant

• Use the salt index of a fertilizer and think about placement, texture, and moisture
Managing Salts: Fertilizers

- Higher clay and organic matter means higher CEC
  - These soils can sorb more of the salts, keeping them from roots

- Placement – Broadcasting spreads the salts out, while banding next to the seed will increase the chance of salt injury

- Use the salt index combined with management to determine the best way forward
  - Don’t use a liquid fertilizer with SI > 20 near the seed
  - Don’t use more than 10-20lbs N+K₂O in furrow
Managing Salts: Irrigation

- This is a bigger issue out west, as we probably have enough rainfall to leach out salts
- Test irrigation water for salts
- Make sure soils have good drainage
- Make sure that drainage water has a higher salt concentration than what is going in through irrigation
Managing Salts: Tidal Inundation

The source of the problem will determine the solution
1. Tidal surge from hurricanes?
2. Tides moving up drainage ditches?
3. Saline groundwater from rising seas?
Tidal Storm Surges

- Bring in excess salts to the soil surface
- Can include Na, Ca, Mg, SO$_4$
- Most likely produces saline soil
  - Wash out with freshwater/rainfall
  - Unless you have poor drainage!
High Tides Coming up Drainage Ditches

- Higher sea levels/land subsidence increases this chance

- Salts come in more often and can build up
  - Waiting on rain may not be good enough

- If soils are high in Na, you can remediate with gypsum (still need freshwater)
If groundwater is saline, drainage is necessary to remediate.

Some soils cannot recover.
Washing Salts from the Soil

- Highly saline soil could need over 40 inches/acre of freshwater
  - Should be added in increments so it doesn’t pond

- Soils high in Na become a problem, as crusts prevent leaching
  - You can add gypsum
  - Maybe not as big a deal with seawater, which includes Ca and Mg

- Soils that can’t drain will build up in salts
Quick Clay

- Some areas of Norway are old sea floor, high in salts
- When the salts washout with rainfall, landslides occur
Saline Soil Summary

- Most likely salt issue in the Mid-Atlantic is going to be fertilizer burn
- Irrigation issues are unlikely if we keep getting 60+ inches of rainfall
- Landowners along the shoreline will experience tidal inundation
  - Prevent tidewater if possible
  - Drain soils
  - Add gypsum
  - Plant salt tolerant crops
  - Convert to wetlands
Questions?