# Salts in Soils: From Fertilizer to Tidewater

Jarrod O. Miller

University of Delaware

# What are Salts?

- Ionic Compounds
  - Inorganic
  - Dissolve easily into cations and anions
  - Example: KCl -> $K^+$ 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:** $Cl^{-1}$, $NO_3^{-1}$, $SO_4^{-2}$, $HCO_3^{-}$, $CO_3^{-2}$, $PO_4^{-2}$

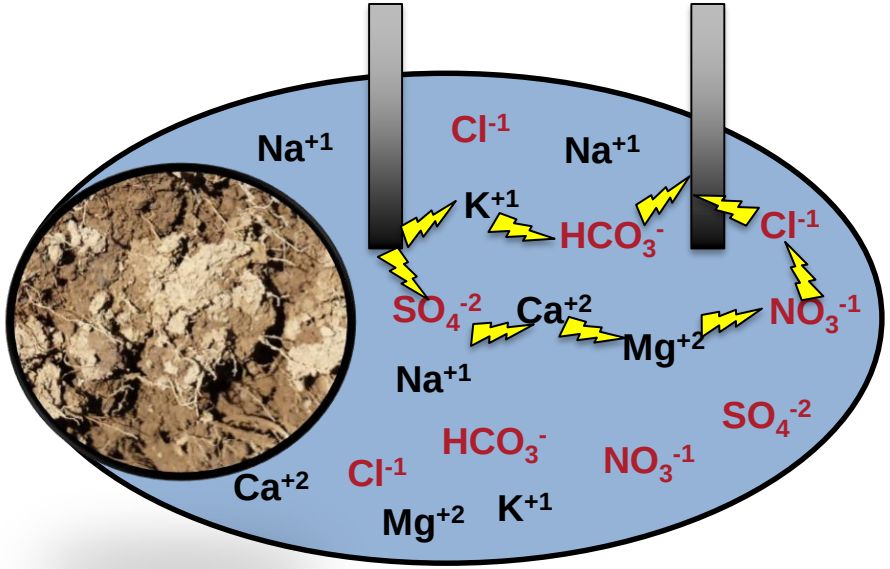
*Cations will bond with anions, either in soluble (ionic) or less soluble (covalent) forms*

# Commonly Known Salts

- **NaCl** - Sodium Chloride – Table Salt
- **KCl** – Potassium Chloride – Muriate of Potash
- **$K_2SO_4$** – Potassium Sulfate – Muriate of Sulfate
- **$CaSO_4$** – Calcium Sulfate – Gypsum
- **$NH_4NO_3$** – Ammonium Nitrate
- **$NH_4SO_4$** – Ammonium Sulfate
- **$CaCO_3$** – Calcium Carbonate - Lime
- **$NaHCO_3$** – Sodium Bicarbonate – Baking Soda

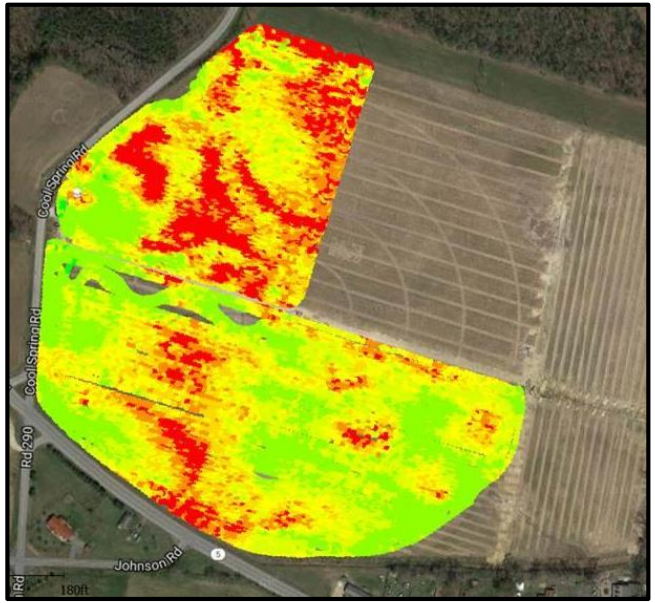

***Salts are only a problem at high concentrations***

# How do we measure soil salts?



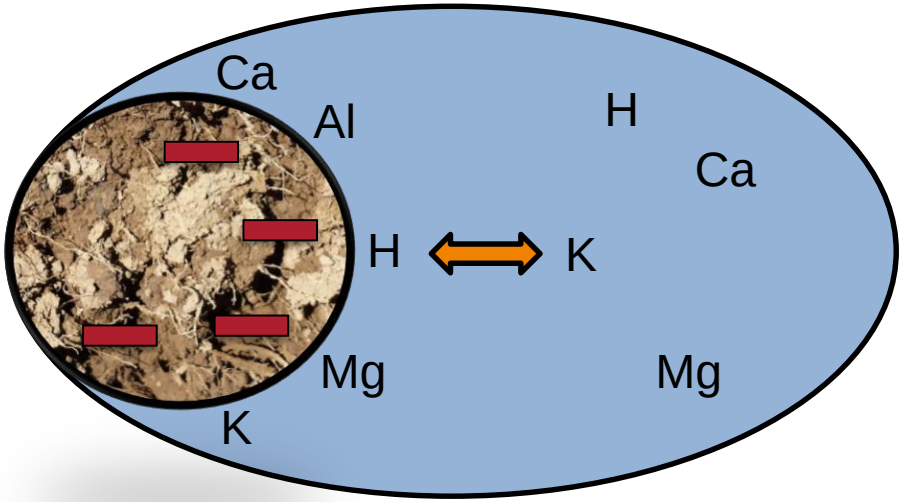

- An electrical conductivity (EC) meter
  - Two probes with a current
- Dissolved salts (ions) have a charge
  - It will conduct electricity
  - More salts = more conductance
- EC units of measurement
  - mmhos/cm
  - dS/M
  - They are the same

# 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

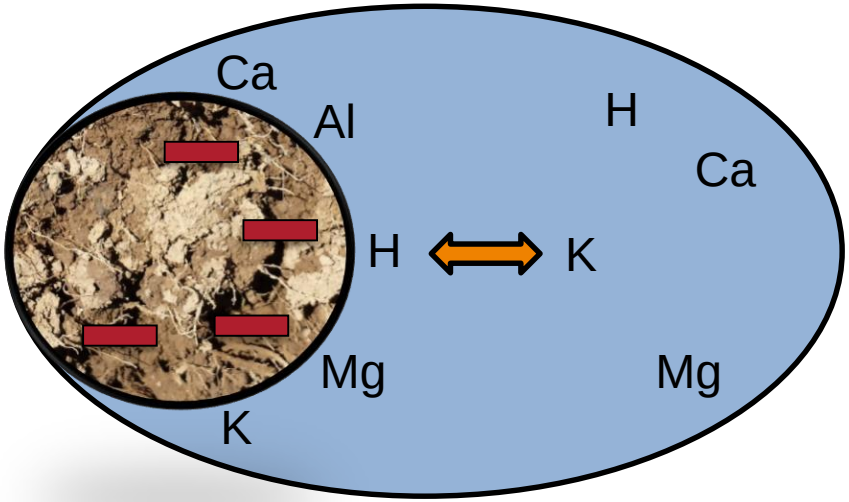



Soil is the anion, attracting the cations

So its natural for soils to have “salts”

Some soil bonding is ionic, some is covalent

# Cation Exchange Capacity and Salts



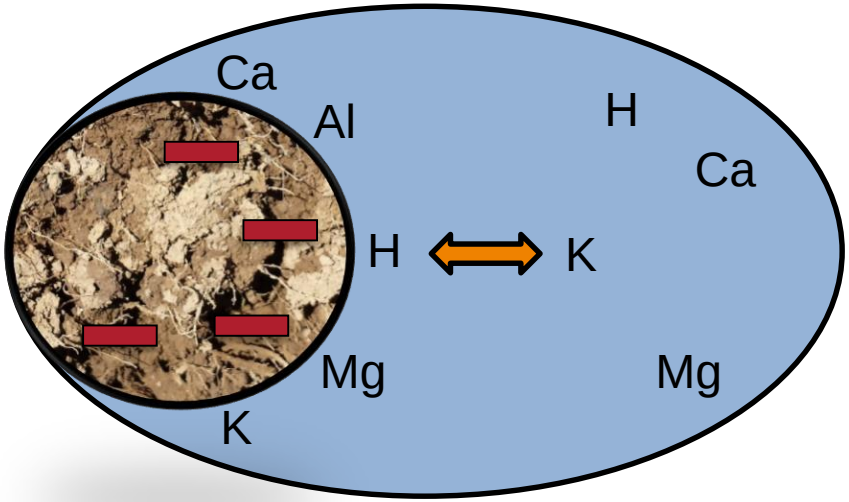

**We tend to worry about salts that are exchangeable:**

- 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

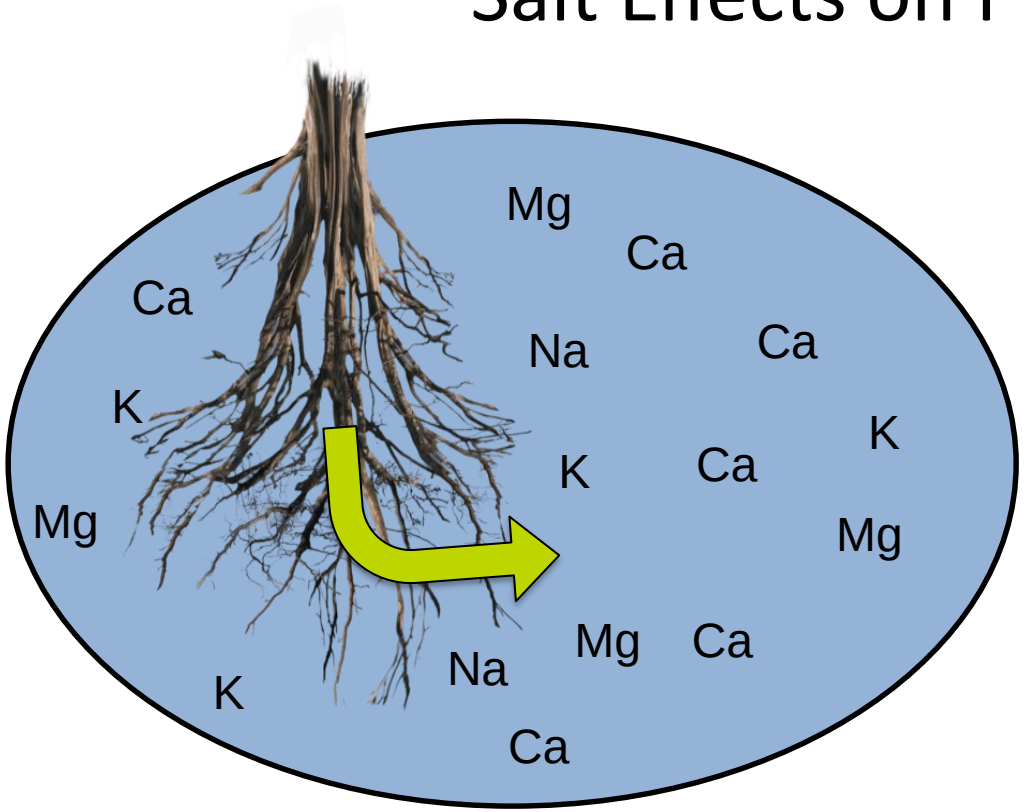



**Good** = adsorbs and holds salts away from plant roots

*(also means it holds more nutrients)*

**Bad** = If you need to correct salt content, take more effort

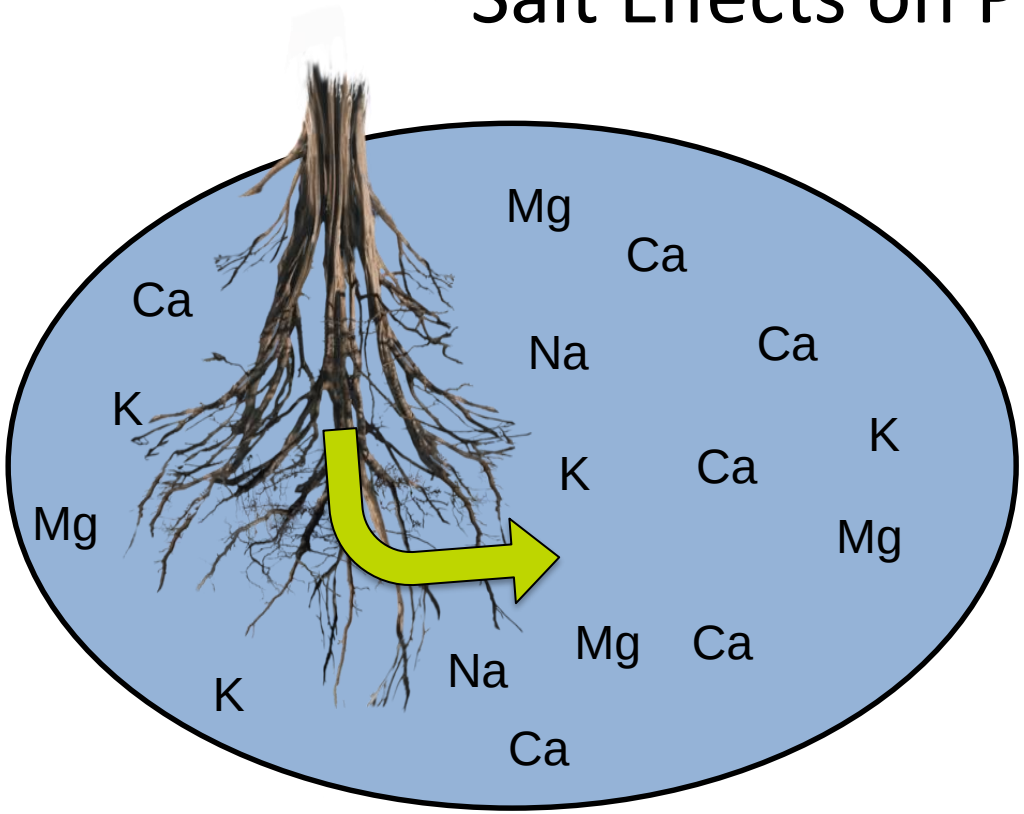
# Salt Effects on Plant Roots




## 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.

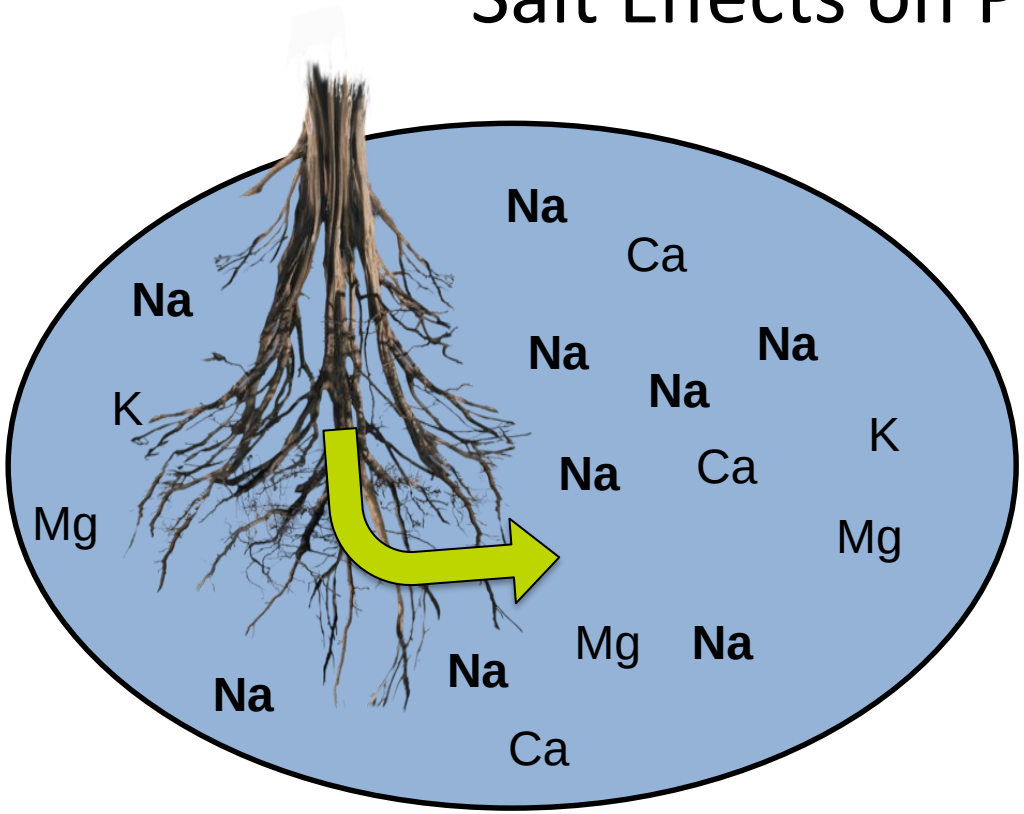
*Excess soil salts cause roots to dehydrate and die.*

# 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

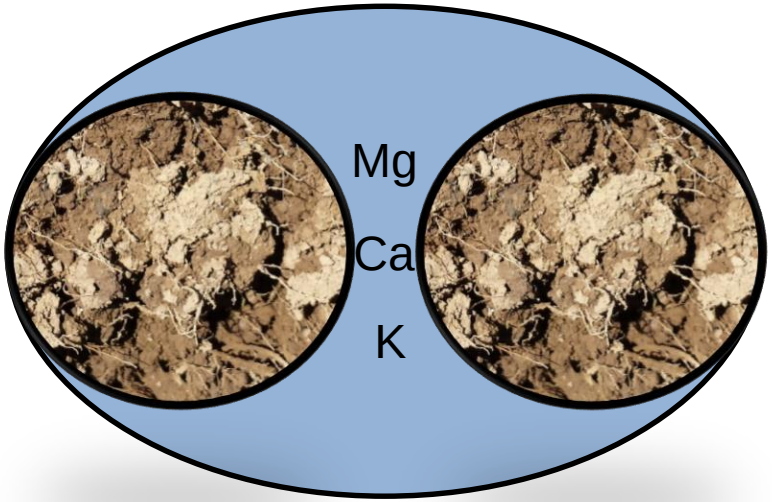
- This draws water into the plant and causes osmotic pressure
  - Turgor pressure
  - Keeps plants upright

# 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

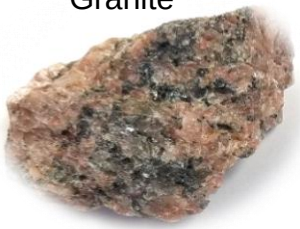
***Common Salts in Red***

- Quartz – $SiO_2$, plus impurities (**Fe, Mn**, ect)
- Feldspars
  - **K**$AlSi_3O_8$, **Na**$AlSi_3O_8$, **Ca**$Al_2Si_2O_3$
- Mica –
  - Muscovite (**K**$Al_2(AlSi_3O_{10})(F,OH)_2$)
  - Biotite (**K**(**Mg,Fe**)$_3(AlSiO_{10})(F,OH)_2$

*They weather from rocks*

Quartz

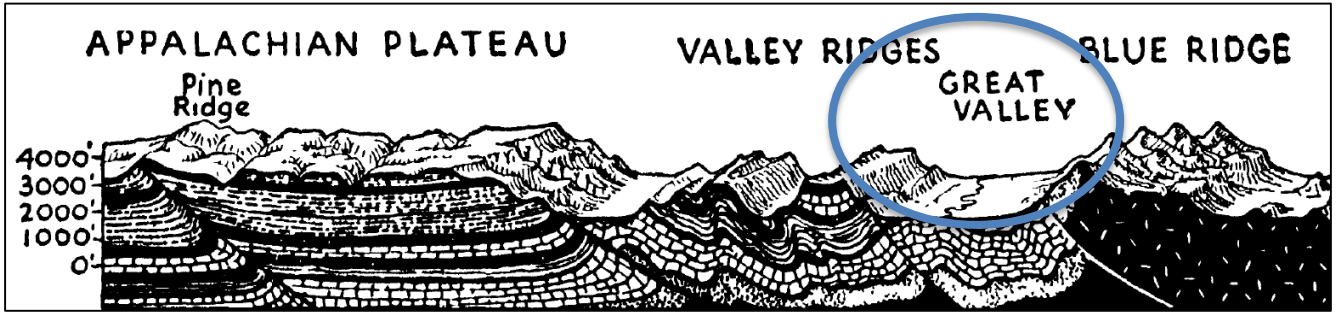
Granite



K Feldspar

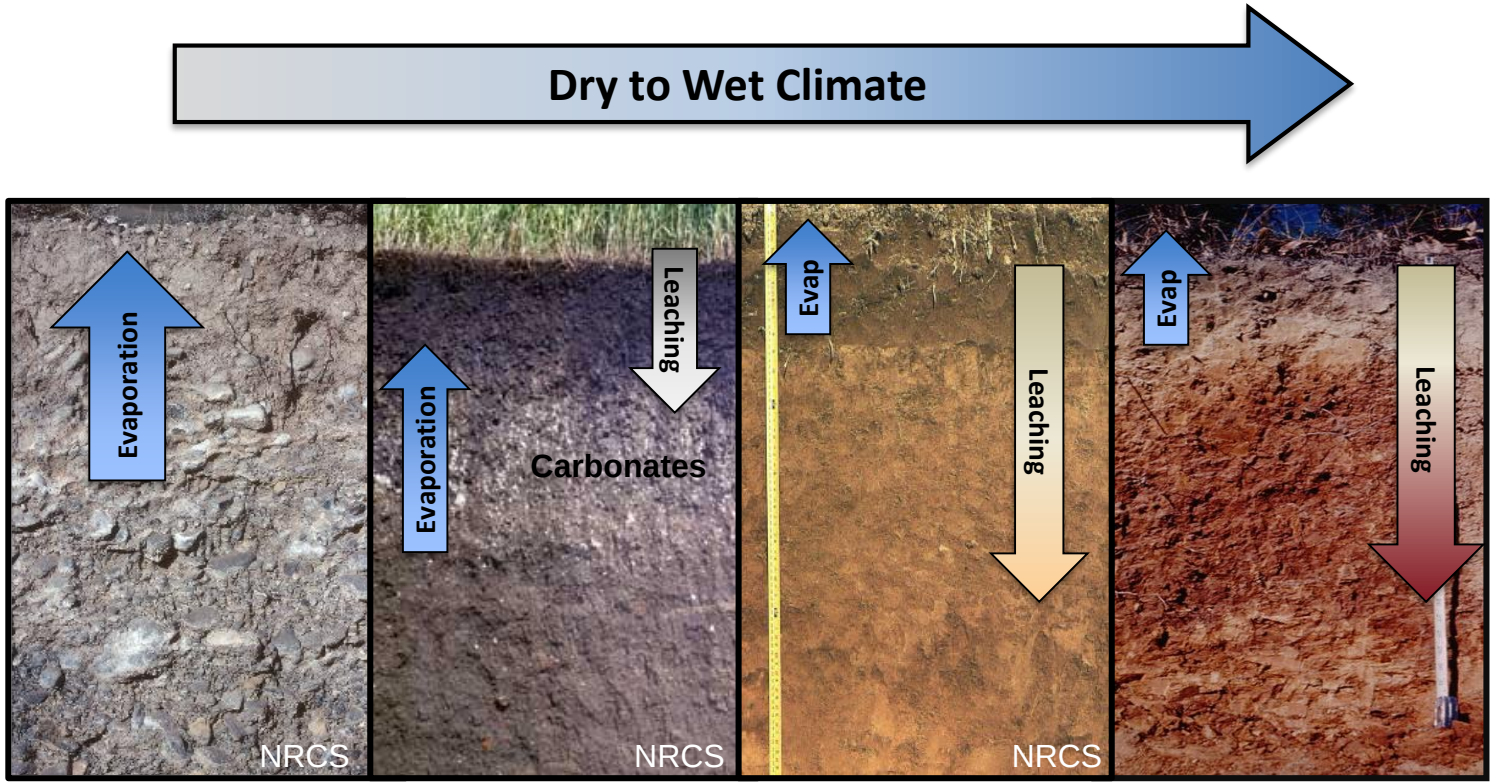
Biotite

# Ridge and Valley Limestone



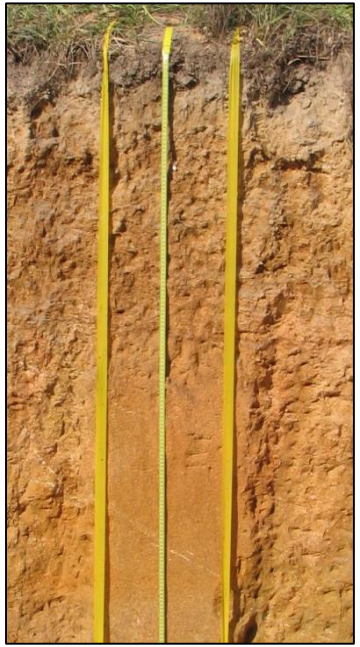

Limestone is Mg and Ca carbonates

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



**Well drained**

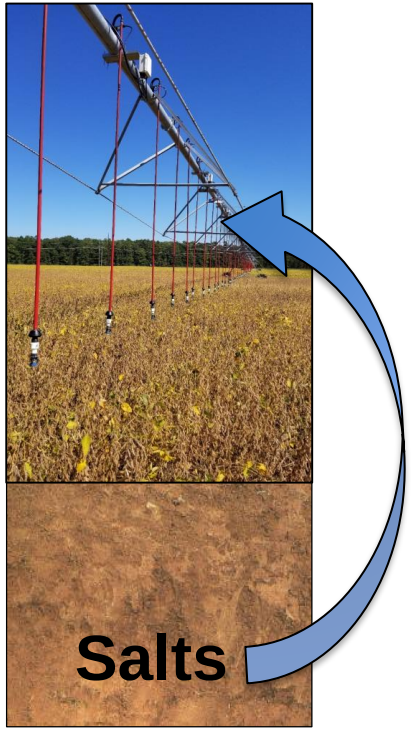

**Poorly drained**

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*

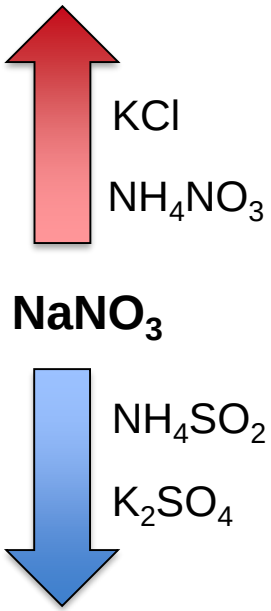
# Sources of Salts: Irrigation




- 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 with salinize*

# 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 $NaNO_3$
  - Common fertilizer at the time (Chili Saltpeter)
  - Represents value of 100
    - *Anything above 100 is more "salty" than saltpeter*



# Sources of Salts: Coastal Sprays

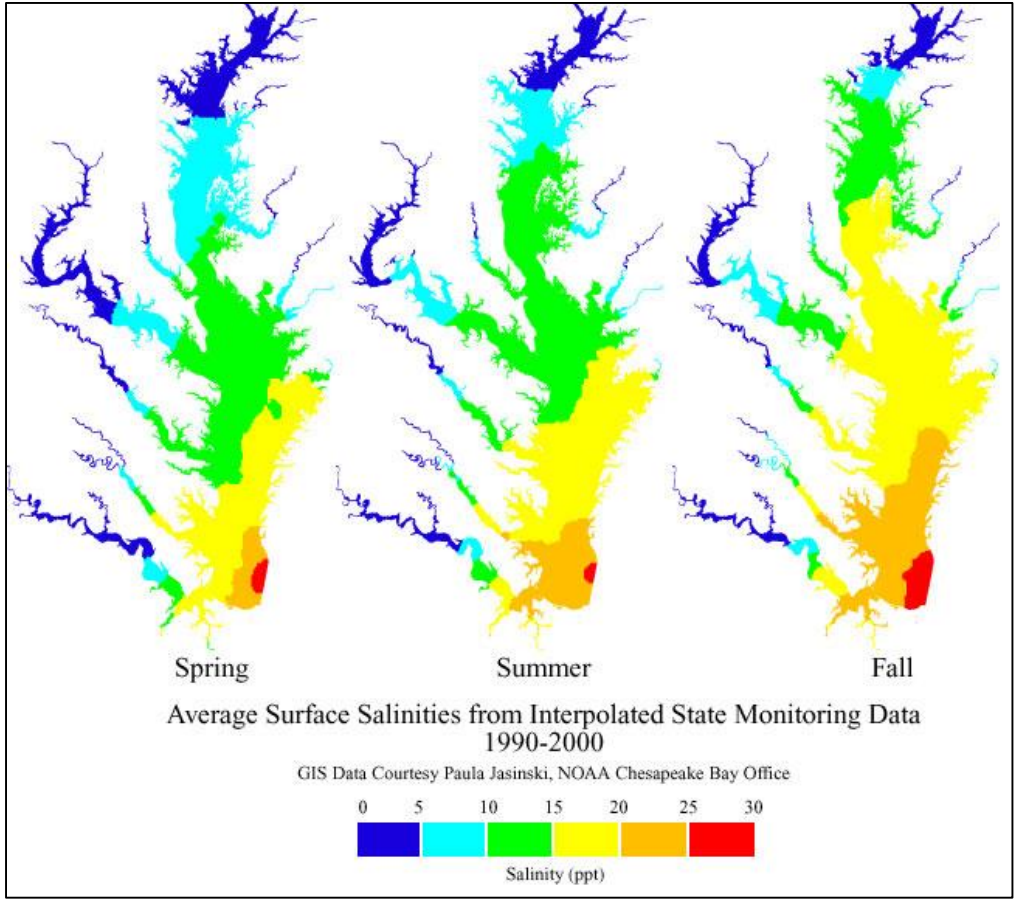

- Breaking ocean waves can create sea spray
  - Can contain salts of Na, Mg, Ca, Cl, $SO_4$
- Mostly stays near shoreline
  - May travel up to 15 miles from shore

# 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




Maryland Department of Natural Resources

# Chesapeake Bay

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


# 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

| Crop | 10% Loss | 25% Loss | 50% Loss |
|---|---|---|---|
| | ----------EC (dS/m)---------- | | |
| Barley | 9.6 | 13.0 | 17.0 |
| Rye | 7.7 | 12.1 | 16.5 |
| Wheat | 6.0 | 8.0 | 10.0 |
| Sorghum | 5.1 | 7.1 | 10.0 |
| Corn | 3.9 | 6.0 | 7.0 |
| Orchardgrass | 3.1 | 5.5 | 9.6 |
| Tomato | 3.5 | 5.0 | 7.6 |
| Sweet Corn | 2.5 | 4.0 | 6.0 |
| Watermelon | 2.5 | 3.5 | 4.5 |

*Utah State University Extension, 2000*

# 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

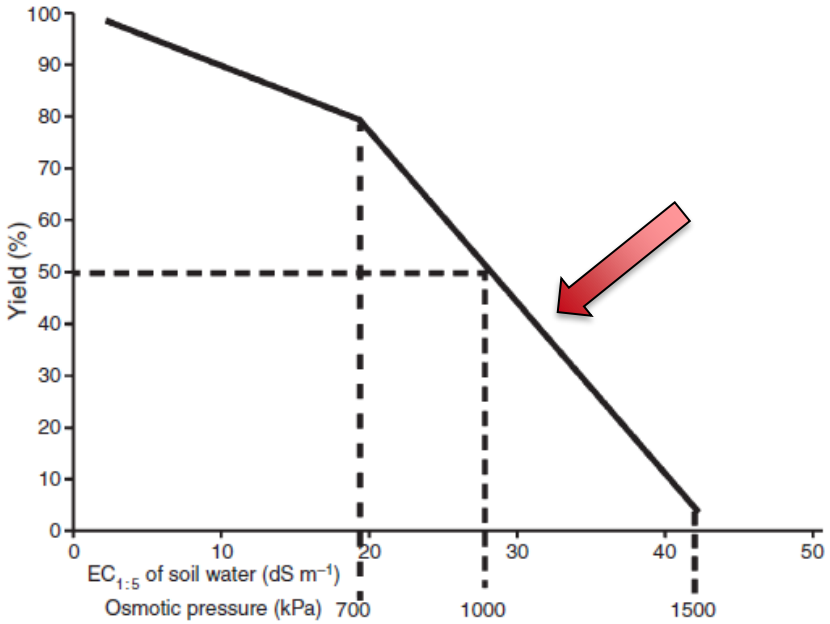


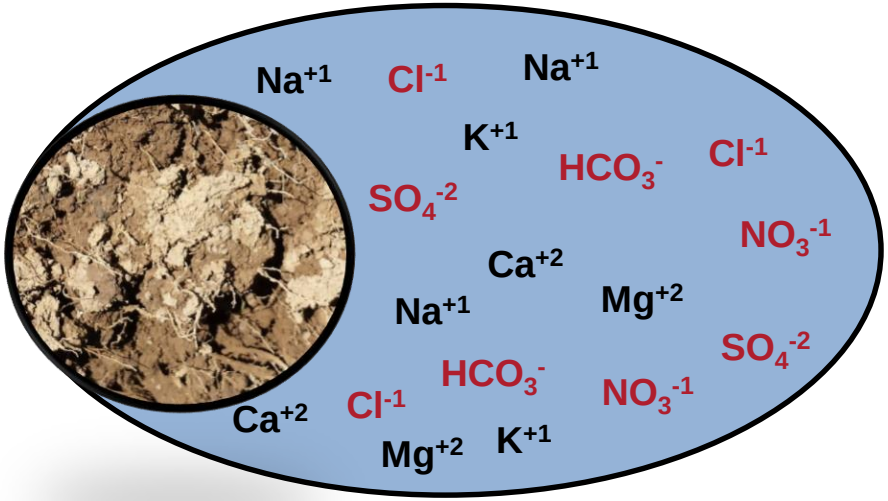

**Fig. 2.** Schematic diagram of the effect of electrical conductivity (EC) and osmotic pressure of the soil solution on the yield of wheat (from Kelly and Rengasamy 2006).

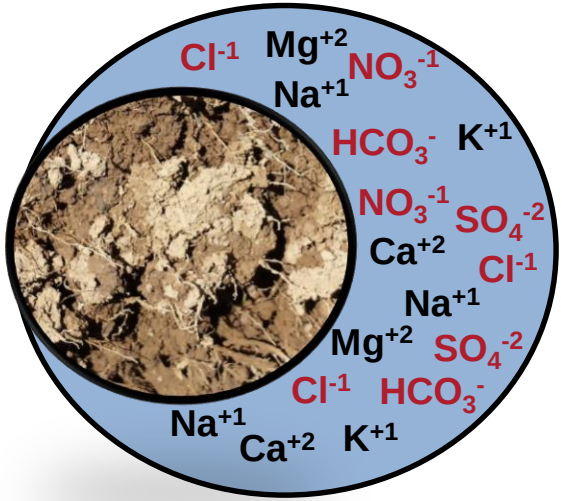
- As salt content increases, so does EC and the osmotic pressure
- Yield drops off dramatically at higher levels of salts

-1500 kPa is also known as the permanent wilting point

* 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

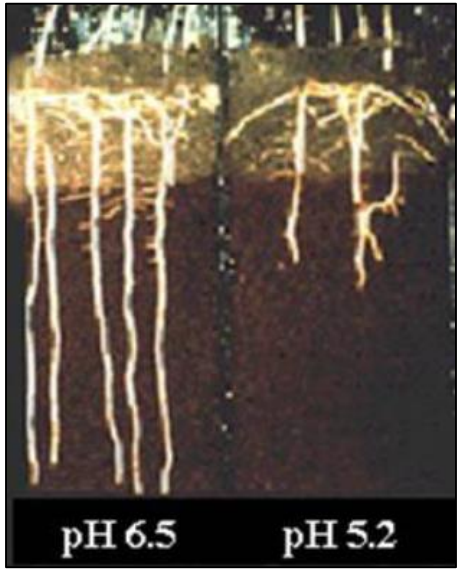
Carbonates precipitated on a soil ped

- 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




+ pH > 9

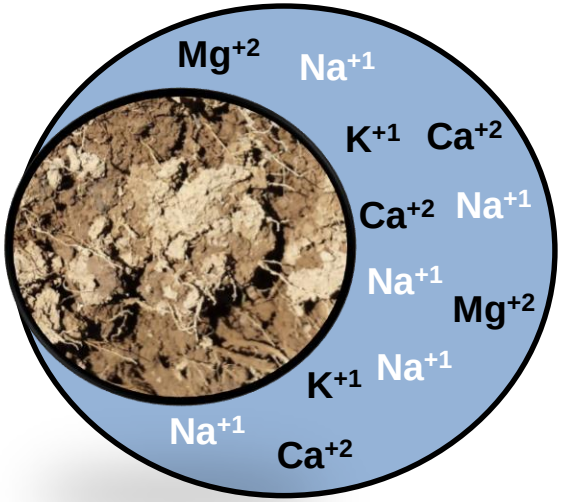
# Summary of Negative Salt Effects

- 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

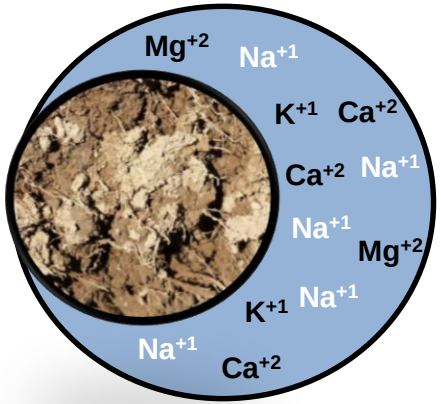
# Classification of Salty Soils

- 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

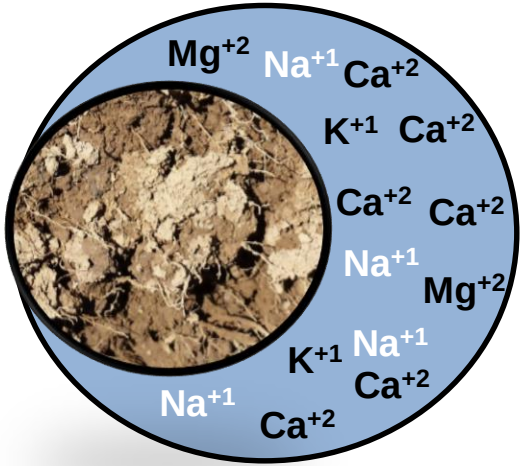



| Classification | EC | Soil pH | ESP | SAR |
|---|---|---|---|---|
| Saline | > 4.0 | <8.5 | <15 | <13 |
| Sodic | <4.0 | >8.5 | >15 | >13 |
| Saline-Sodic | >4.0 | <8.5 | >15 | >13 |

- 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

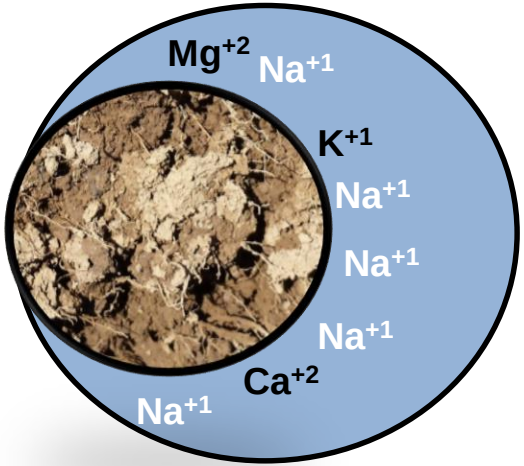
# Classification of Salty Soils

**Saline**



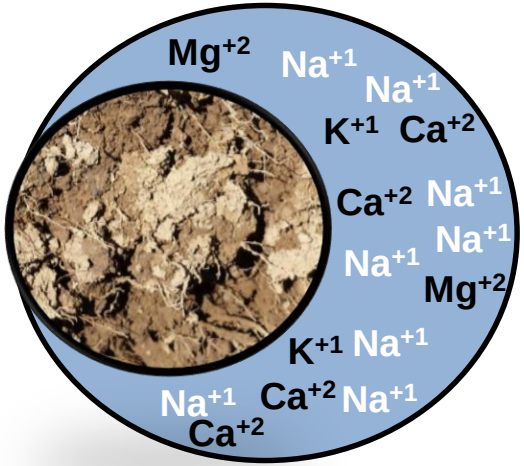

Excessive salts for plant growth

**Sodic**




Excessive sodium on the CEC. Not high in overall salts

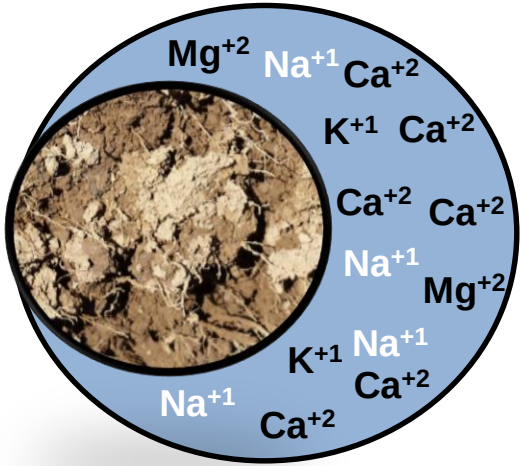
**Saline-Sodic**




Excessive salts, high sodium. Ca still controls pH.

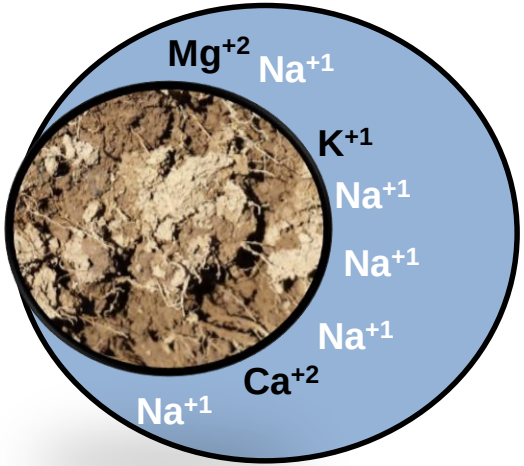
# Remediation of Salty Soils

**Saline**



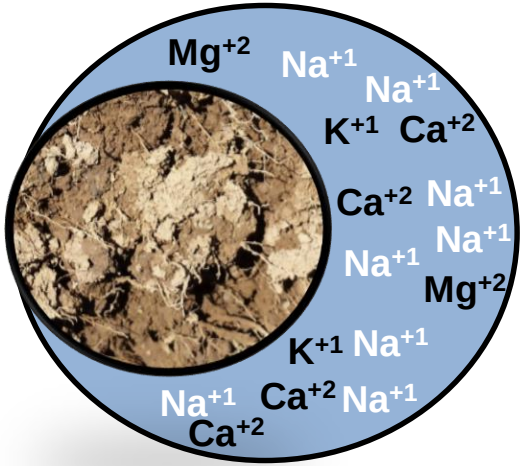

Wash the soil with freshwater

**Sodic**




Add gypsum ($CaSO_4$)
Wash with freshwater

**Saline-Sodic**




Add gypsum ($CaSO_4$)
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

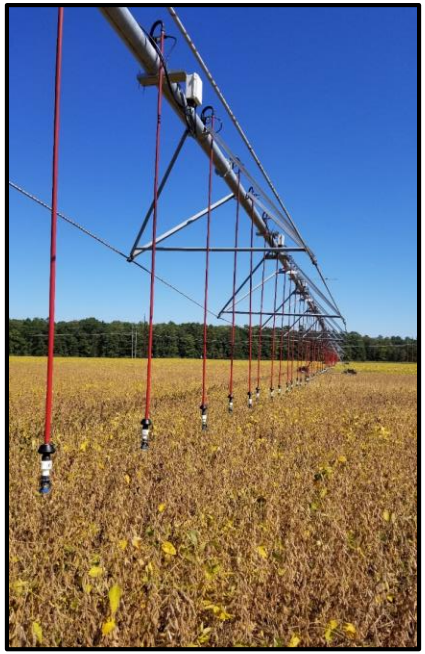
# Managing Salts: Fertilizers

- 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 $N+K_2O$ in furrow

# Managing Salts: Irrigation

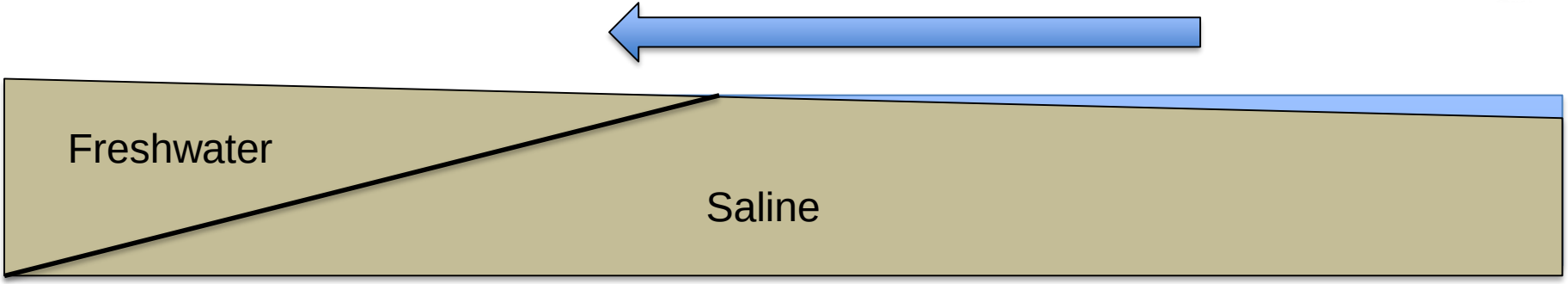


- This is a bigger issue out west, as we probably have enough rainfall to leach out salts
- Test irrigation water for salts
- Make sure soils have good drainage
- Make sure that drainage water has a higher salt concentration than what is going in through irrigation

# Managing Salts: Tidal Inundation

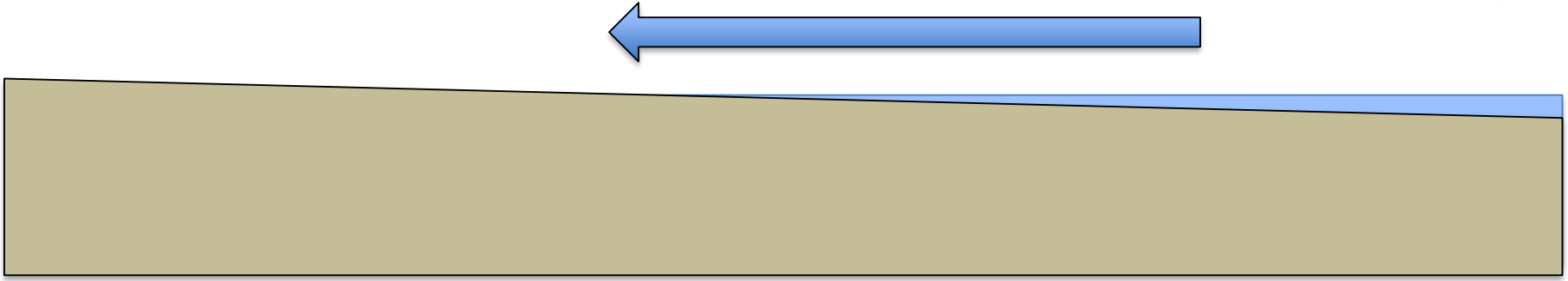
The source of the problem will determine the solution

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!

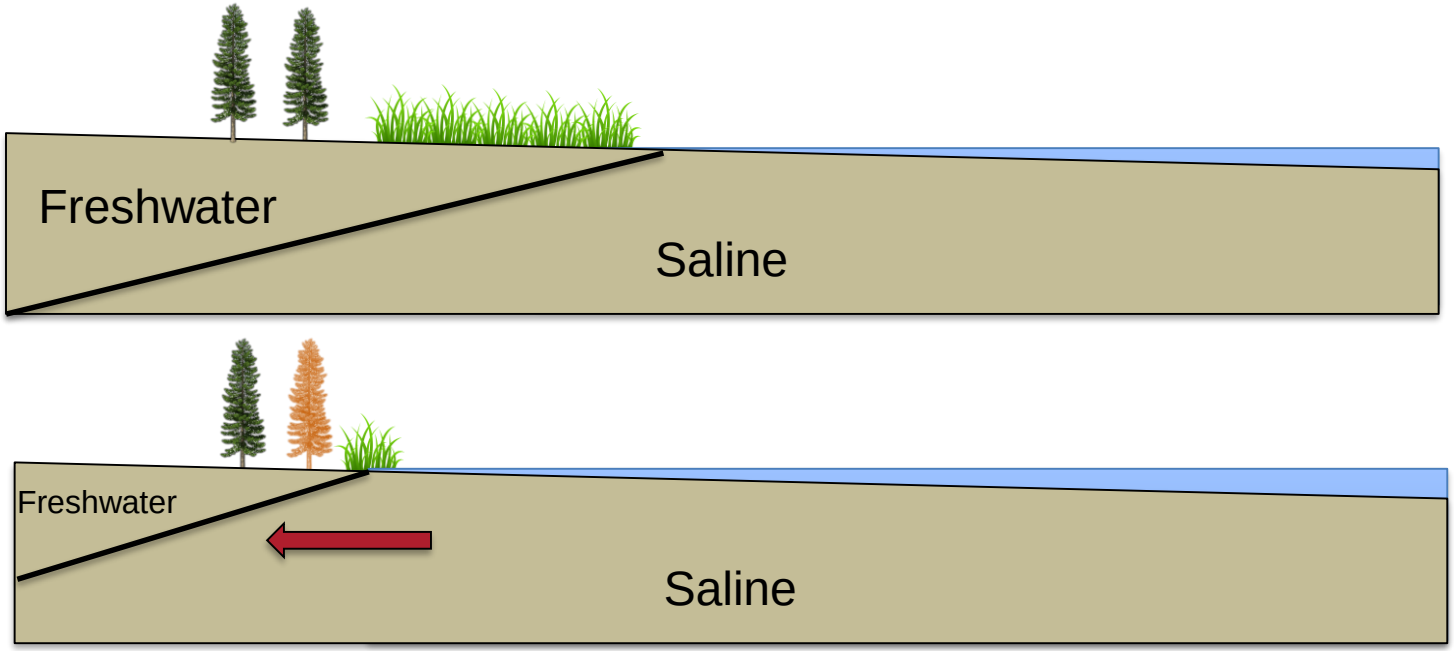


# High Tides Coming up Drainage Ditches

Saltwater intrusion follows ditches (yellow lines)

- 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)

# Saline Groundwater



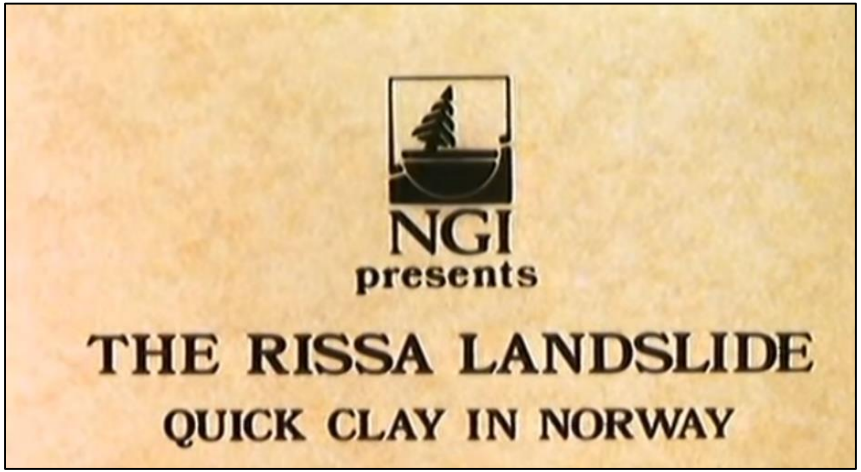

Rising water levels

- 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?