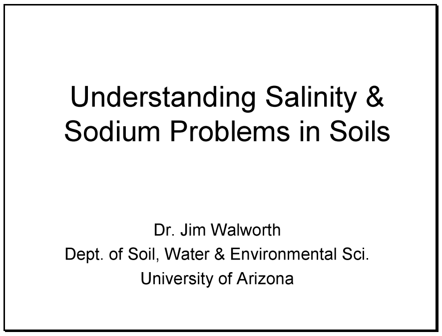
Slide 1




Feel free to contact me:

Dr. Jim Walworth

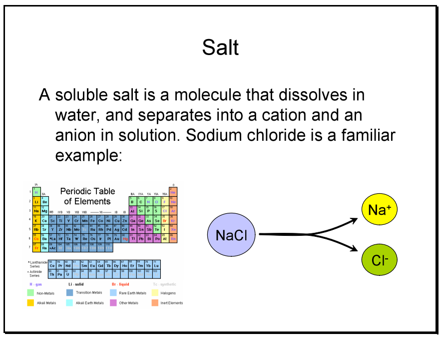
Walworth@ag.arizona.edu

(520) 626-3364

Additional material is available at:

http://ag.arizona.edu/swes/soil_fertility/

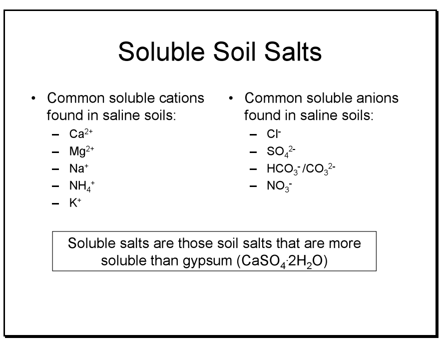
Slide 2




First, we need to define exactly what we mean when we use the words salt and salinity. For our purposes a salt is a material composed of a cation (often an alkali metal and alkaline earth metal – columns IA and IIA on the periodic table) and an anion (often a halogen – column VIIB on the periodic table). These compounds form solid crystals when dry. Soluble salts dissolve in water, and once dissolved, the anion (negatively charged molecule) and cation (positively charged molecule) separate, and act as individual ions, or charged particles.

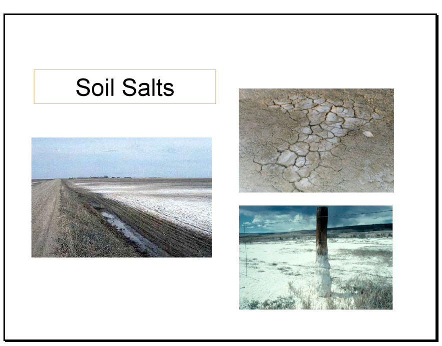
The most familiar example is sodium chloride (NaCl) or table salt, but numerous other salts are common in soils, such as calcium carbonate ($CaCO_3$), potassium sulfate ($K_2SO_4$), magnesium carbonate ($MgCO_3$), or ammonium chloride ($NH_4Cl$). In fact, just about every possible cation-anion pairing is found in nature. Salinity is a measure of the combined concentration of salts in soil or water.

Slide 3




The common cations in our soils are calcium ($Ca^{+2}$), magnesium ($Mg^{+2}$), sodium ($Na^{+}$), ammonium ($NH_4^{+}$), and potassium ($K^{+}$); the common anions are chloride ($Cl^{-}$), sulfate ($SO_4^{-2}$), bicarbonate and carbonate ($H_2CO_3^{-2}$ and $HCO_3^{-}$), and nitrate ($NO_3^{-}$). The term salt refers to a cation-anion pair formed by any combination of these ions. We also use the term salts to refer to all such anion-cation pairs. Soluble salts are those salts with greater solubility than gypsum ($CaSO_4 \cdot 2H_2O$), and are of most interest to us because of their strong influence on soil chemical, physical, and biological properties.

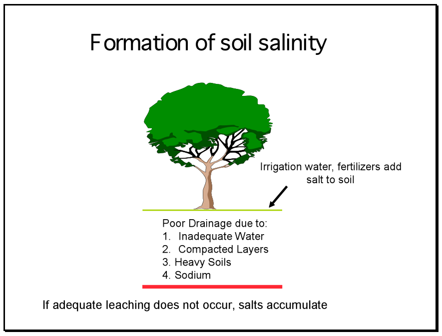
Slide 4




In the desert southwest, salt accumulation is one of the most important soil and land management issues. In soils, dissolved and soluble cations and anions are collectively called soil salts; we don't worry about who's pairing with who. In fact, we're more interested in the positively-charged cations than the negatively-charged anions. You will notice that we will spend considerable time here discussing cations (particularly sodium and calcium) and almost none talking about anions.

If salts and salt behavior are understood, irrigation water and soil salts are relatively easy to manage. But management options can diminish as salt accumulates. Unfortunately, mismanagement of soil salts can cause a long-lasting or even permanent reduction in soil productivity.

Slide 5



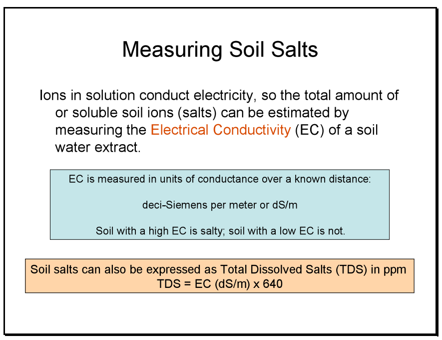

Why do soils get salty?

Salts are continually added to soil by

- weathering of soil minerals
- additions from rain, dust, and irrigation water
- fertilizer additions

Unless salts leave the soil at the same rate as they are added, salts will accumulate. Salts leave soils by leaching out of the soil, carried by water draining through the soil profile. If there is inadequate drainage water to carry away salts, they accumulate. The main reason for inadequate drainage in native desert southwest soils is lack of precipitation. In some soils, compacted layers, clay horizons, or high sodium layers impede soil drainage and lead to salt accumulation.

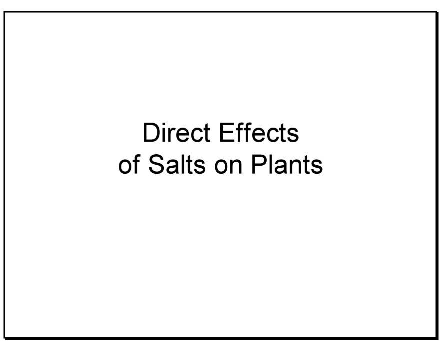
Slide 6




Salts, when dissolved in water, cause the water to become a better electrical conductor. Knowing this, we can estimate the amount of salt in water by measuring the electrical conductivity, or EC. The higher the EC, the greater the salt concentration. To measure soil EC, we make a water extract and measure the EC of the extract.

The units of EC are decisiemens per meter (dS/m) or, in older literature, millimhos per centimeter (mho/cm). These units are identical. EC measurements can be converted into parts per million (ppm) of salt by multiplying EC (in dS/m) x 640.

Slide 7




We'll look at salts from two points of view. The first is concerned with the effects of salts on plants growing in the soil. The second is an examination of the ways in which salts affect the soil itself.

Slide 8


Although we handle and consume salt daily, salts are quite toxic in large concentrations. For many centuries salt has been used to cure meats, fish, and vegetables. At one time, salt was the world's most valuable trading commodity because of its preservative properties. If allowed to accumulate in soils, salts will eventually kill all growing plants. Willcox Playa is a good place to see the effects of excessive salts, although there are many such basins around Arizona that collect salts from surrounding lands.

Slide 9

## Salt Effects on Plants

- Excess soluble salts can be harmful to plant growth because:
  - Salts lower the osmotic potential energy of soil water. Water is less available to plants.
  - Some soluble salt ions can have specific toxic effects on plants, such as:
    - $Na^+$, $Cl^-$ , $H_3BO_3$

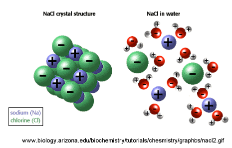
The dissolved anions and cations of salts in water are surrounded by water molecules. These water molecules are strongly attracted to dissolved ions, making the water molecules less available to plant roots.

However, some salts (boron is the best example) are directly toxic to plants instead of affecting water availability.

Slide 10

## Salt Effects on Plants

- When soluble salts dissolve in water, and anions and cations separate, they are surrounded by water molecules and become hydrated.
  - This lowers the osmotic potential energy of soil water because the water is tied up by the anions and cations.
  - This water is less available to plants.
  - Plants become stressed, even when the soil is moist.



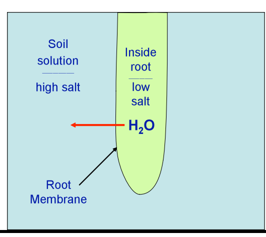

www.biology.arizona.edu/biochemistry/tutorials/chemistry/graphics/nacl2.gif

The dissolved anions and cations of salts in water are surrounded by water molecules. These water molecules are strongly attracted to dissolved ions, which makes the water molecules less available to plant roots.

Slide 11

## Too Much Salt

- Water is drawn from regions of low salt concentration to regions of high salt concentration:




Salts draw water out of plant roots, causing water-stress of the plants.

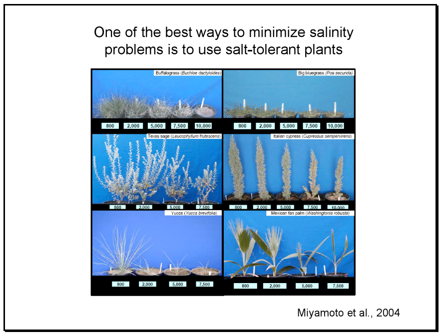
The pull of salt molecules on water is extremely strong. Salt can pull water out of tissues and cells, a process used in curing animal hides and food preservation. Most cell walls are more permeable to water than they are to salt molecules. These are described as semi-permeable membranes. If a high and a low salt solution are put together, but separated by a semi-permeable membrane, then water is drawn from the low salt solution to the high salt solution. This is because the salt molecules in the saltier solution are pulling the cleaner water through the membrane to establish equilibrium. This is osmosis. (In reverse osmosis (RO), salty water is pushed through a semi-permeable membrane, leaving salts behind, and producing de-salinized water.)

A plant root is a semi-permeable membrane. Salts pass through root cell walls much more slowly than does water. If a root is surrounded by salty water, the salty water will try to pull water out of the root. So salty soil water is less available to plants than is clean water.

Slide 12

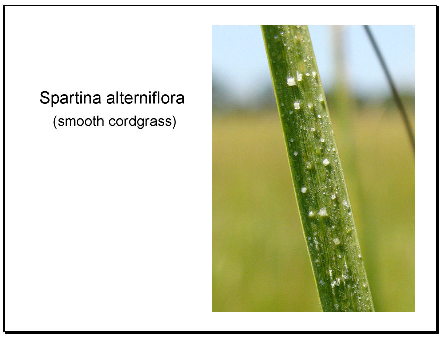
Salt-affected plants sometimes appear to be water-stressed. Plant growth generally declines as soil salinity increases. In broad-leaved plants, leaf margins appear burned, usually in a fairly uniform pattern throughout the plant. The level of salinity that causes stunting is dependent on the species, and even variety, of plant. Some halophytes (salt-loving plants) actually grow better in salty than in un-salty conditions.

Slide 13



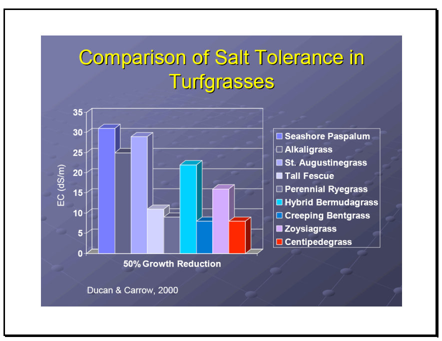

These slides show the effects of varying levels of salt on the growth of several landscaping plants. Notice the difference in sensitivity between plant species.

Slide 14




Salt tolerant plants utilize an array of mechanisms to survive salty conditions.  Some can absorb excess salt and excrete it from leaf or stem tissues, as seen in the photograph shown here.

Slide 15




There is a wide range of salt tolerance in turf grass species and cultivars.  The electrical conductivity values shown on the vertical axis of this graph provide only rough guidelines for salt tolerance of turfgrasses.

Slide 16

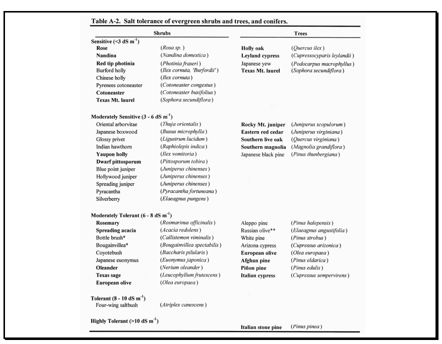


**Table A-2. Salt tolerance of evergreen shrubs and trees, and conifers.**

| Shrubs | | Trees | |
|---|---|---|---|
| **Sensitive (<3 dS m$^{-1}$)** | | | |
| **Rose** | (*Rosa sp.*) | **Holly oak** | (*Quercus ilex*) |
| **Nandina** | (*Nandina domestica*) | **Leyland cypress** | (*Cupressocyparis leylandii*) |
| **Red tip photinia** | (*Photinia fraseri*) | Japanese yew | (*Podocarpus macrophyllus*) |
| Burford holly | (*Ilex cornuta, 'Burfordii'*) | **Texas Mt. laurel** | (*Sophora secundiflora*) |
| Chinese holly | (*Ilex cornuta*) | | |
| Pyrenees cotoneaster | (*Cotoneaster congestus*) | | |
| **Cotoneaster** | (*Cotoneaster buxifolius*) | | |
| **Texas Mt. laurel** | (*Sophora secundiflora*) | | |
| **Moderately Sensitive (3 - 6 dS m$^{-1}$)** | | | |
| Oriental arborvitae | (*Thuja orientalis*) | **Rocky Mt. juniper** | (*Juniperus scopulorum*) |
| Japanese boxwood | (*Buxus microphylla*) | **Eastern red cedar** | (*Juniperus virginiana*) |
| Glossy privet | (*Ligustrum lucidum*) | **Southern live oak** | (*Quercus virginiana*) |
| Indian hawthorn | (*Raphiolepis indica*) | **Southern magnolia** | (*Magnolia grandiflora*) |
| **Yaupon holly** | (*Ilex vomitoria*) | Japanese black pine | (*Pinus thunbergiana*) |
| **Dwarf pittosporum** | (*Pittosporum tobira*) | | |
| Blue point juniper | (*Juniperus chinenses*) | | |
| Hollywood juniper | (*Juniperus chinenses*) | | |
| Spreading juniper | (*Juniperus chinenses*) | | |
| Pyracantha | (*Pyracantha fortuneana*) | | |
| Silverberry | (*Elaeagnus pungens*) | | |
| **Moderately Tolerant (6 - 8 dS m$^{-1}$)** | | | |
| **Rosemary** | (*Rosmarinus officinalis*) | Aleppo pine | (*Pinus halepensis*) |
| **Spreading acacia** | (*Acacia redolens*) | Russian olive** | (*Elaeagnus angustifolia*) |
| Bottle brush* | (*Callistemon viminalis*) | White pine | (*Pinus strobus*) |
| Bougainvillea* | (*Bougainvillea spectabilis*) | Arizona cypress | (*Cupressus arizonica*) |
| Coyotebush | (*Baccharis pilularis*) | **European olive** | (*Olea europaea*) |
| Japanese euonymus | (*Euonymus japonica*) | **Afghan pine** | (*Pinus eldarica*) |
| **Oleander** | (*Nerium oleander*) | **Piñon pine** | (*Pinus edulis*) |
| **Texas sage** | (*Leucophyllum frutescens*) | **Italian cypress** | (*Cupressus sempervirens*) |
| **European olive** | (*Olea europaea*) | | |
| **Tolerant (8 - 10 dS m$^{-1}$)** | | | |
| Four-wing saltbush | (*Atriplex canescens*) | | |
| **Highly Tolerant (>10 dS m$^{-1}$)** | | | |
| | | **Italian stone pine** | (*Pinus pinea*) |

Similar information is also available for landscaping plants.

Slide 17

**Table A-4. Salt tolerance of plants native to the Southwest.**

| Shrubs/Agave | | Trees | |
|---|---|---|---|
| **Sensitive (<3 dS m$^{-1}$)** | | | |
| **Yucca** | (*Yucca brevifolia*) | Western red bud | (*Cercis occidentalis*) |
| **Bird of paradise** | (*Caesalpinia mexicana*) | **Arizona sycamore** | (*Platanus wrightii*) |
| **Texas Mt. laurel** | (*Sophora secundiflora*) | **Desert willow** | (*Chilopsis linearis*) |
| Guayule | (*Parthenium argentatum*) | **Texas vitex** | (*Vitex agnus-castus*) |
| **Moderately Sensitive (3 - 6 dS m$^{-1}$)** | | | |
| | | **Cottonwood** | (*Populus fremontii*) |
| Silverberry | (*Elaeagnus pungens*) | **Desert olive** | (*Forestiera neomexicana*) |
| | | Seep willow | (*Baccharis salicifolia*) |
| **Moderately Tolerant (6 - 8 dS m$^{-1}$)** | | | |
| Coyotebush | (*Baccharis pilularis*) | | |
| **Agave** | (*Agave parryi*) | | |
| **Tolerant (8 - 10 dS m$^{-1}$)** | | | |
| **Texas sage** | (*Leucophyllum frutescens*) | **Piñon pine** | (*Pinus edulis*) |
| **Century plants** | (*Agave americana*) | Honey mesquite | (*Prosopis glandulosa*) |
| **Highly Tolerant (>10 dS m$^{-1}$)** | | | |
| Pickleweed | (*Allenrolfea occidentals*) | Screwbean mesquite | (*Prosopis pubescens*) |

Landscape Plant Lists for Salt Tolerance Assessment, Miyamoto et al., 2004
http://www.plantanswers.com/Landscape_Plant_Lists_for_Salt_Tolerance_Assessment.pdf

And for some southwestern desert plants.

Slide 18

## Salts can also be good for plants

- Many plant nutrients are soil salts
  - Cation nutrients
    - $Ca^{2+}$
    - $Mg^{2+}$
    - $NH_4^+$
    - $K^+$
    - $Fe^{+2}$
    - $Mn^{+2}$
    - $Cu^{+2}$
    - $Ni^{+2}$
    - $Zn^{+2}$
  - Anions nutrients
    - $Cl^-$
    - $SO_4^{2-}$
    - $PO_4^{-3}$
    - $NO_3^-$
    - $MoO_4^{-2}$

The other side of the coin is that plants need soil salts. Consider that all the anions and cations listed above are essential plant nutrients. Without these ions dissolved in the soil solution, plant life is not sustainable.

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That's why some salts, in proper amounts, are good for plants and why too much salt is bad for plants.

Salts also affect soil. And as with plants, the effects of salts on soil can be either good or bad.

Earlier, we indicated that salts affect both plants and soils. We've reviewed the ways in which salts affect plants. Salts directly affect both physical and chemical soil properties.

Slide 20

## Salt, Sodium, and Soil Structure

The effects of salts on soil physical properties such as soil structure are most critical. Here, you see sodium accumulation inhibiting water infiltration and drainage.

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## Soil Structure

- Structure is the arrangement of soil particles (sand, silt, clay) into stable secondary units called aggregates.
- Aggregates are composed of sand, silt, and clay particles, and are held together by cations, organic matter, oxides, carbonates, or clays.
- Aggregates influence important soil properties, including porosity, aeration, and water movement.

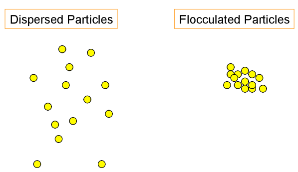
In most soils, individual soil particles are cemented into aggregates or clumps made up of many individual sand, silt, and clay particles. Aggregates can be cemented together by cations, carbonates, clays, or organic matter.

Slide 22

## Soil Structure - Aggregates

Aggregates consist of flocculated particles

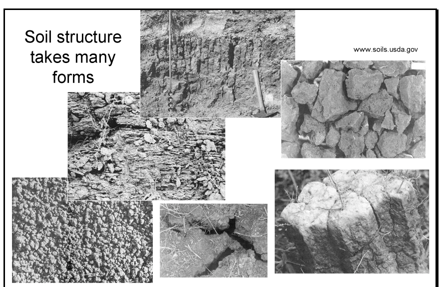
Soil clay particles can be unattached to one another (*dispersed*) or clumped together (*flocculated*).




Clay particles act independently under some soil conditions. We say that these particles are dispersed. If conditions are right, however, soil particles will flocculate and form aggregates.

Slide 23

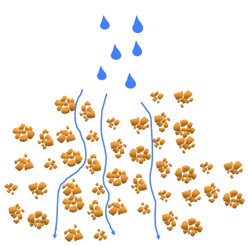
Soil structure takes many forms




Soil particles can be arranged in many ways, resulting in some very distinct kinds of soil structure. This is an important topic, but not one we will cover here.

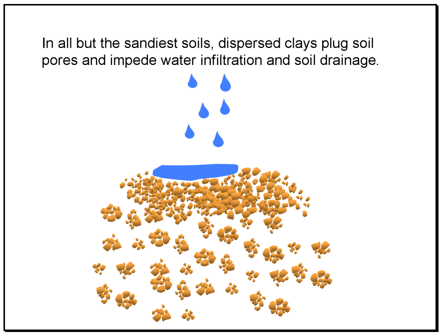
Slide 24

Flocculation is important because water moves mostly in large pores between aggregates. Also, plant roots grow mainly between aggregates.



In finer-textured (clayey) soils, the large pores between aggregates (macropores) are critical for water flow, root growth, and drainage.

Slide 25




If soils disperse, small particles will plug up the macropores in the soil. Water can not infiltrate, and will pond on top of the soil. This is good for pond construction, but not for growing plants.

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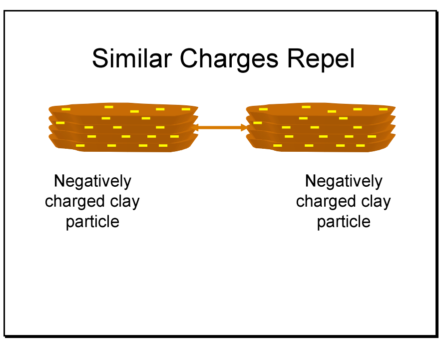
## Dispersed Soils

- Dispersed soils absorb water very slowly
  - More runoff is likely
  - Water is used less efficiently
  - Erosion is more likely
- Plant roots can not easily penetrate dispersed soils
  - Shallow-rooted plants
  - Less efficient water use
  - Less efficient nutrient utilization

In dispersed soils, water infiltrates and drains slowly. Water is much more likely to run off of the soil, increasing the potential for erosion and limiting the amount of water available for growing plants. These soils are likely to be poorly aerated because they lack the large pores necessary for exchange of soil air with atmospheric air. Large, inter-aggregate pores are also important for root penetration. Therefore, plants growing in dispersed soils are likely to be shallow-rooted.

Dispersed soils tend to form impermeable crusts at the surface when they dry. This can impede seedling emergence. Poor stand establishment is common in these soils.

Slide 27




Most soil clay particles are electrically negatively charged. This is largely a function of the structure of clay minerals. Like-charged particles or molecules repel each other - cations repel cations, and anions repel anions. Clay particles repel one another.

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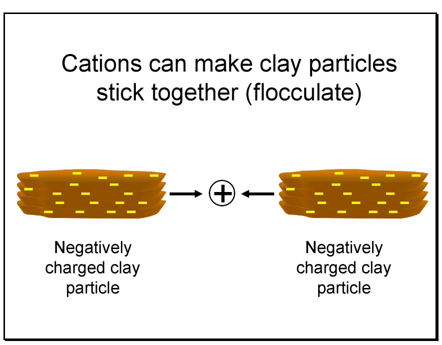


The ‘same charge’ repulsion between two negative clay particles can be bridged by cations. The soil solution surrounding clay particles contains cations that can attract nearby clay particles. In this way, the clay particles can get close enough together to bond into aggregates, or to flocculate.

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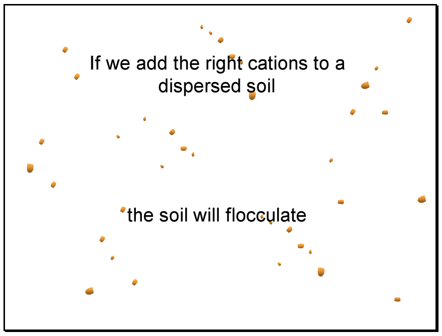
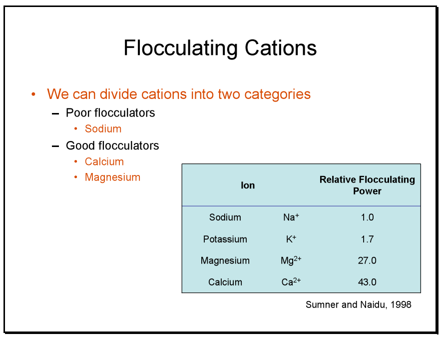



Addition of flocculating cations can aggregate a dispersed soil. This is a basic management tool for irrigated soils.

Slide 30




Some cations are much better flocculators than others. Flocculating ability is related to strength of attraction of cations to clay particles; the most weakly attracted are the worst flocculators ($Na^+$, for example) and those most strongly attracted to clay particles are the best flocculators ($Ca^{2+}$):

Worst $\leftarrow$ $Na^+ < NH_4^+ = K^+ < Mg^{2+} < Ca^{2+} < Al^{3+}$ $\rightarrow$ Best

Of the cations commonly found in desert soils sodium is the weakest flocculator. Potassium is slightly better. Magnesium and calcium are 27 and 43 times better, respectively, than sodium.

Soils with lots of good flocculators, like calcium, are likely to have much better structure than soils with lots of poor flocculators, like sodium. We can evaluate a soil's tendency to disperse or flocculate by looking at relative amounts of 'poor flocculators' versus 'good flocculators'.

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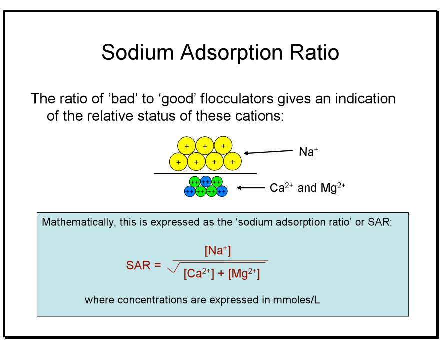
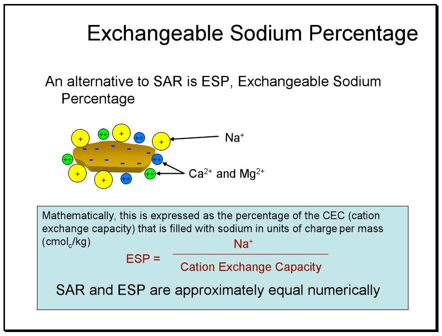



One way of doing this is by the <u>sodium adsorption ratio</u>, or <u>SAR</u> for short. This ratio compares the amount of sodium to the amount of calcium plus magnesium. There are a couple of ways of writing the formula for SAR. The simplest uses cation concentrations of millimoles per liter (mmol/L) and is shown here. SAR equals the sodium concentration divided by the square root of the sum of the calcium and magnesium concentrations.

The higher the SAR, the more likely the soil is to disperse. In general, we would like to see SAR values less than 9 or 10, better yet, below 3. However, the exact SAR at which a soil will disperse is dependent on the amount and types of clay present. A very sandy soil might be okay with a high SAR, and some clay soils may disperse with very low SARs.

SAR can be used to evaluate both soils and irrigation waters.

Slide 32




An alternative measure of a soil's tendency to disperse or flocculate is the exchangeable sodium percentage, or ESP.

This is a measure of the amount of sodium on the soil cation exchange sites. It is calculated as the amount of sodium divided by the cation exchange capacity. Units are centimoles of positive charge per kilogram of soil ($cmol_c$/kg). Old units are milliequivalents per 100 g of soil (meq/100g). These two units are identical.

ESP can be used only with soil because water has neither cation exchange capacity nor exchangeable sodium. SAR is the appropriate measure for waters.

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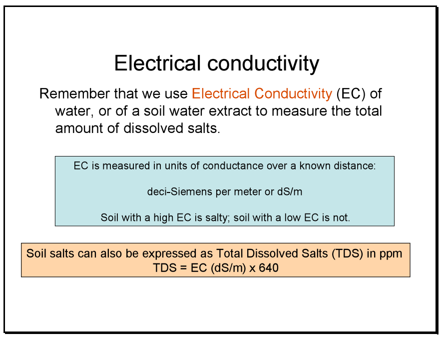
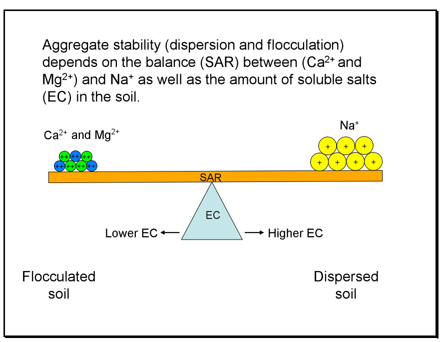



Slide 34




Actually, two factors are critical in determining the tendency of a soil to disperse or flocculate. These are relative *sodium* versus *calcium plus magnesium* levels (expressed either as SAR or ESP), and soil salinity (measured by EC).

We can combine these two aspects of soil salinity into a simple conceptual model, represented as a see-saw. On one end of the see-saw sit *calcium plus magnesium* cations; *sodium* cations sit on the other end. This represents the soil SAR. The position of the fulcrum or balancing point represents the level of soil salinity, or EC. If the left end of the see-saw tilts downward, the soil is flocculated. If the right end tilts downward the soil is dispersed.

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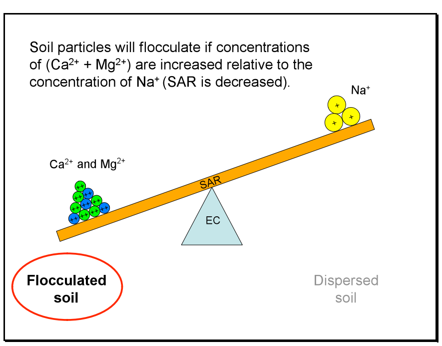
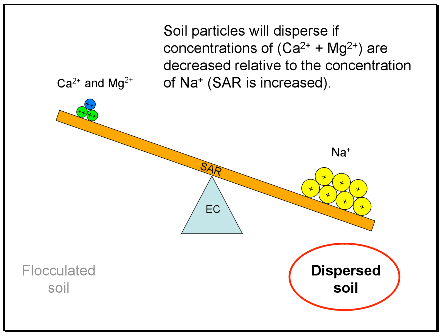



If the left side of the see-saw is loaded up with calcium or magnesium, and the sodium side (the right side) is unchanged, the left side of the see-saw is heavier and tilts downward. This means the soil is flocculated. This makes sense because both calcium and magnesium are good flocculators.

Also, as calcium and magnesium levels increase, SAR decreases. Therefore, another way to describe this situation is to say that as SAR drops, soil tends to flocculate.

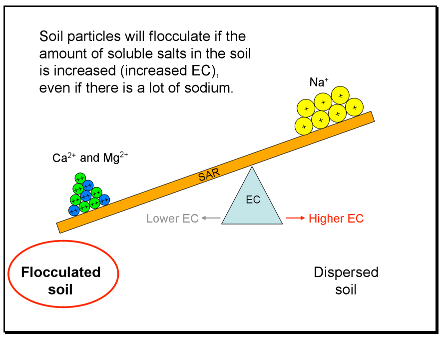
Slide 36




If the right side of the see-saw is loaded up with sodium, and the calcium/magnesium side (the left side) is unchanged, the right side of the see-saw is heavier and tilts downward. This means the soil is dispersed. This makes sense because sodium is a very poor flocculator.

Also, as the sodium level increases, SAR increases. (Soil sodium levels are also referred to as sodicity). Another way to describe this situation is to say that as SAR increases, soil tends to disperse. This is one way salts can damage soils.

Slide 37




What happens if the relative calcium, magnesium, and sodium proportions are unchanged, but the EC of the soil increases (the soil becomes saltier)? Now the fulcrum or balancing point has moved to the right, so the left side of the see-saw tilts downward. The soil flocculates.

This happens even though the SAR did not change. Salty soil tends to flocculate even when it contains high levels of sodium. In this respect, salt is good for the soil.

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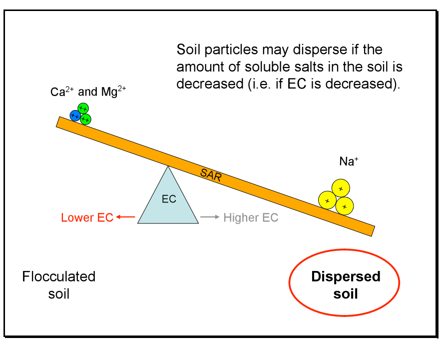


Conversely, let's see what happens if the relative calcium, magnesium, and sodium levels are unchanged, but the EC of the soil decreases (the soil becomes less salty). Now the fulcrum has moved to the left, so the right side of the see-saw tilts downward. The soil disperses.

Again, this happens even though the SAR did not change. Soil with a low salt level can disperse even when the sodium level and the SAR are low.

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Dispersed soil can become impermeable to water. It can form crusts that impede seedling emergence.

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## Salt and soil chemistry

- One of the most important chemical properties affected by soil salts is pH
  - In soil desert soils, the pH is controlled by the presence and absence of certain salts.
  - Many soil salts that accumulate in desert soils are alkaline. Therefore, most desert soils are alkaline.

Alkaline soils are those with pH levels greater than 7. Alkaline soils are uncommon in most of the United States, but very common in the desert southwest. In fact, it is unusual to find desert soils that are not alkaline. Most desert soils have a pH close to 8, due to the presence of calcium carbonate. This is a relatively insoluble salt that naturally accumulates under desert conditions.

Sometimes we find soils with pH levels well over 8, which generally indicate the presence of sodium salts.

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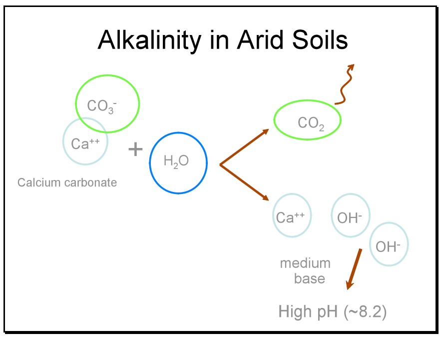


Calcium bicarbonate is a common salt in arid region soils. It combines with water (hydrolyzes) to form carbon dioxide and calcium hydroxide, a moderately strong base. Soils with calcium bicarbonate can have pH's as high as 8.3.

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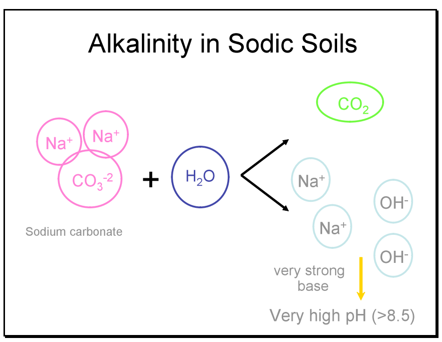


Sodium bicarbonate is another common salt in sodic soils. It combines with water, forming sodium hydroxide, a very strong base. Soils with sodium bicarbonate can have pH's greater than 9.0.

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## What does soil alkalinity do?

- Except in cases of extreme alkalinity (pH greater than 9.0), pH itself has little direct effect on plant growth, however pH does affect availability of many plant nutrients.
  - Availability of many nutrients is affected by soil pH.
  - Reactions of fertilizer nutrients (N, P, Fe, Zn for example) are controlled by soil pH.

Plants don't care too much about pH, but they *are* affected by pH because of the effects of pH on plant nutrients and other elements in the soil.

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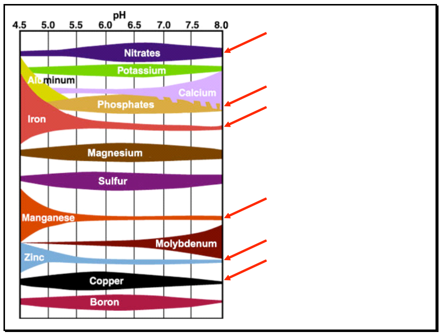


In this diagram the thickness of the colored bands represents availability of the nutrients.

Notice that the metal micronutrients, iron, manganese, zinc, and copper all become unavailable at high pH's (indicated by the narrowness of their respective bands at the right side of the diagram). Our high pH soils generally contain lots of iron, manganese, zinc, and copper, but these metals are in insoluble forms that many plants can not access.

Other nutrients unavailable in high pH soils include phosphorus and nitrogen. Phosphorus, like the metals, is present in sufficient quantities in many desert soils, but is insoluble at high pH levels. In contrast, desert soils actually contain very low levels of nitrogen because they contain little organic material.

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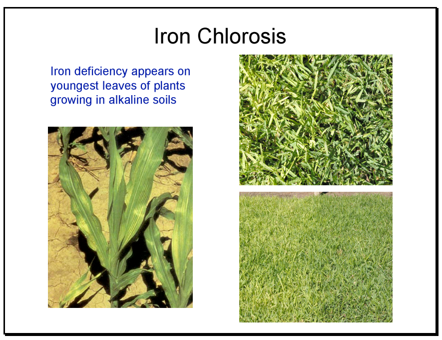


Because of the low solubility of iron in high pH soils, iron deficiency (also called iron chlorosis - chlorosis means yellowing) is common in the desert. Iron deficiency appears first on the youngest leaves. Usually the interveinal areas (the areas between the veins) on these leaves become bleached or whitish.

Iron chlorosis is uncommon in native desert plants because they are adapted to high pH soils, and have developed specific mechanisms to allow them to absorb iron from soil very efficiently.

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This is a negative consequence of certain soil salts which are, unfortunately, ubiquitous in desert soils.