Alkaline, Saline & Sodic Soils

Alkaline (high pH) soils are found in arid and semiarid areas. There is not enough rainfall in these areas to leach the base forming cations like calcium, magnesium, potassium and sodium. Natural weathering rock forms of these minerals keep the soil colloids "loaded", not allowing hydrogen (H) to accumulate and form acid soils.

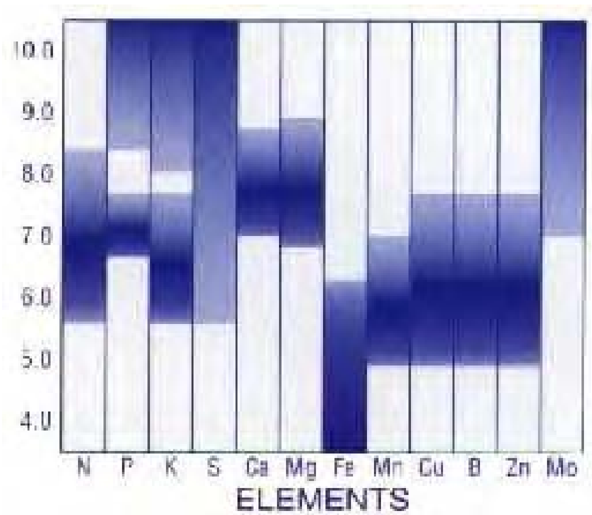
Unfortunately, in many areas, this condition of low rainfall and poor drainage leads to the accumulation of sodium and its salts ($NaSO_4$ and NaCl). When high sodium is present in the soil as a soluble salt, the soil is referred to as *saline*. With a high pH it would be both saline and alkaline. If the sodium is attached on the soil colloids but is over 5% of CEC, it can be considered as a *sodic* soil.

The primary problem associated with high pH soils and plant nutrition is the reduced availability of trace minerals (such as Zn, Fe, Mn & Cu), phosphates and boron.

Trace Elements

Although it is sometimes beneficial to apply trace minerals such as zinc, manganese and iron to soils, they are usually tied up quickly. Fortunately, most plants require only small amounts of these minerals and they can be easily supplied by foliar applications. This is especially efficient when foliars are properly mixed and chelated.

However, in high pH soils, plants can produce, and excrete, large amounts of organic acids from their roots which acidifies the area in the immediate root to soil interface, releasing insoluble minerals.



Above: The blue lines indicate that the nutrient is available at a specific pH range. The lighter blue indicates less availability and white, VERY LOW.

Calcareous Soils

The problem of high pH is complicated by an accumulation of calcium carbonate at some level of the soil profile. These accumulations are referred to as being *calcareous*. When these layers are shallow, roots of many plants have trouble growing through this layer. In the Northwest USA, apple trees have a problem what is referred to as calcium carbonate induced iron deficiency.

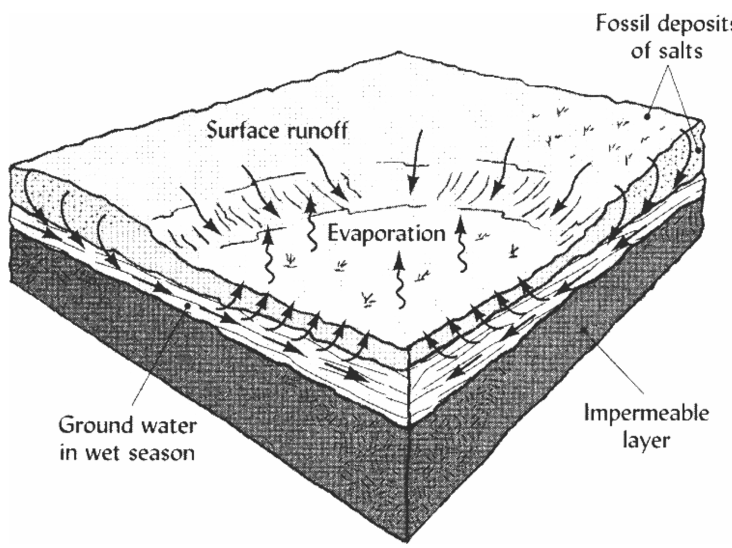
Phosphates & High pH
In high pH soils, applied phosphate fertilizers are made insoluble by calcium and magnesium. In some soils up to 80% of applied phosphates can be converted into mono-calcium and di-calcium phosphate forms within 2 – 3 days after application.

Proper management of phosphate applications in high pH, calcareous soils are important.

Saline & Sodic Soils

This is one of the most common, yield-limiting problems associated with high pH soils. Remember that soils have a high pH because they do not have the structure or rainfall to continuously wash out the available calcium and magnesium compounds. These base forming compounds (base = high pH = OH^-) keep the pH alkaline. Part of the problem with poor water movement and drainage is that salts (mostly sodium) begin to accumulate.

Natural Salt Accumulation



Salts are formed from natural weathering of rocks and minerals or they are brought into the soil by rainfall or irrigation. Some areas also contain high levels of salts from previous geological times when the land was a bottom of a lake or ocean. These salts are dissolved and leaches along impermeable layers to a low spot were by evaporation they tend to accumulate.

Irrigation has further complicated these problems by provided excess water for salt leaching and movement. Irrigation water itself can also contain high levels of sodium, which adds to the problem of salt accumulation in soils. In irrigated areas, the accumulation of salts arises from poor drainage of fields and also from "reel" or "flood" irrigation. In flood irrigation, the water comes into the field relatively clean; however, as it runs down the field, it picks up salts, becomes saturated, and then redeposits the salts on the lower end of the field.

This natural accumulation of soluble salts (usually sodium sulfates or chlorides) is called *saline* soils. Many plants cannot tolerate a very high level of these soluble salts. There is a key difference between *saline* and *sodic* soils that must be understood in order to manage salts more effectively.

Saline Soils

As already stated, the sodium in saline soils is found as a soluble "salt", usually as a sulfate or a chloride. This salt accumulation occurs when there is either very low cation exchange capacity of colloids (sandy soils) or adequate levels of calcium or magnesium. Soil colloids "prefer" calcium and magnesium over sodium. The result is that saline soils usually have good aeration and aggregate stability. The problem is the level of the soluble salts and the effect on plant growth and water uptake.

Plants respond differently to high sodium levels. For example, beans when subjected to high levels of NaCl wilt due to the effect of sodium on the ability of the plant to take up water. In this case, the root cells lose water by osmosis, because of the high level of salts around the root. In a short time, the lack of water and nutrient uptake causes the cell to collapse, thereby leading to death of the plant by drought.

Other plants are very sensitive to the chloride ions usably found in saline soils. Grapevines, apples and citrus develop growth inhibition, marginal chlorosis and necrosis on mature leaves. With these plants it is not water deficiency that is the constraint, but chloride sensitivity (especially in citrus).

In some instances the high levels of sodium cause a deficiency of another nutrient. For example, barley plants grown with high sodium sulfate levels showed much better growth and development when supplied with manganese.

In cotton, with low levels of phosphates and higher levels of NaCl, the uptake and translocation of phosphates is severely hampered. Some crops, like tomatoes, the presence of high salts causes a depression of phosphorus utilization by the leaf. Research shows that a tomato plant grown in high salts requires up to two times the level of leaf phosphates to achieve the same yield as plants grown in lower levels of salts.

Saline Management

The number one method of managing saline soils is drainage and the use of a clean water supply to leach out accumulated salts. This method is effective in well-drained soils. Drainage of soils can also be affected (and improved) by recognizing when a soil is partially sodic as will be explained later.

Nutrient management of saline soils depends on the crop variety. However, calcium is the most effective nutrient in increasing the salt tolerance of many plant species. Calcium applications on saline-sodic soils have a dual effect:

1) It improves the soil structure and thus soil aeration and drainage and
2) It improves the Ca:Na ratio and thus supports the capacity of the roots to restrict sodium uptake.

With some crops like potatoes, the application of adequate amounts of calcium and increase the tolerance to sodium salts by a factor of 10 times. In citrus the application of calcium suppresses the uptake of sodium chlorides into the leaves. This mechanism is the role of calcium in cell membrane stability and the control of ion uptake and transport. Calcium binds the phospholipid compounds that make up the membrane (filter) of the cell wall. Properly formed with adequate levels of calcium, this membrane will keep Na and Cl out of the cell. This function is extremely critical for the development of strong root cells and selectivity of Ca over Na at the root level.

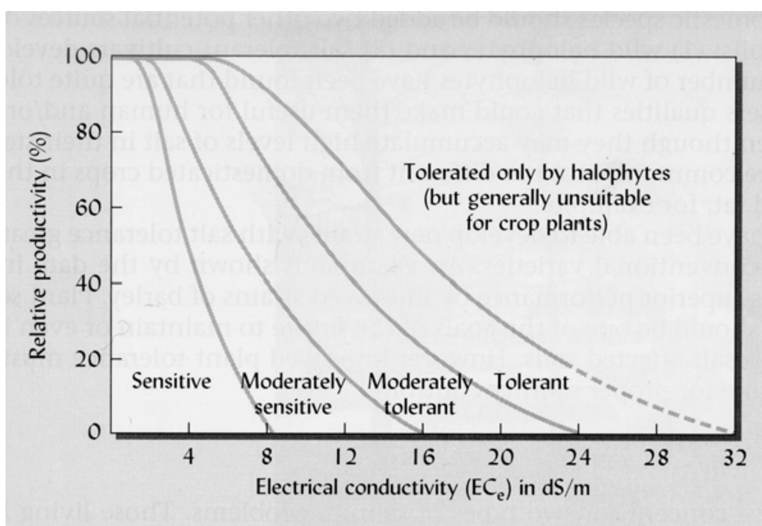
In vegetable crops like tomatoes and lettuce, high sodium levels cause calcium related growth problems such as blossom end rot and tipburn, respectively. Under these conditions it may be necessary to completely analyze the calcium contents of the soil and sodium content of the irrigation water. In some cases, addition of calcium to the soil may not be appropriate, except under the conditions where the calcium can be concentrated as with drip irrigation.

Application of gypsum or small amounts of finely ground lime, are probably the best available methods of suppressing the negative effects of saline soils.

Saline Measuring – the level of soluble salts is usually expressed on soil tests as EC, or electrical conductivity. This is based on the fact that pure water is not a good conductor of electricity, but conductivity increases dramatically as more and more salt is dissolved in the water. The test for salinity (saturated paste method) is done by saturating soils with distilled water, allowing setting overnight, and measuring the water with an EC meter. On many tests in the USA the results are expressed in mmhos/cm (millimhos per centimeter). In international circles the unit of measurement is expressed as deci-siemens per meter (dS/m). Not too worry, 1 mmhos/cm = 1 dS/m!

A soil is considered as saline with the EC is above 4 mmhos/cm (4 dS/m). However, because of the sensitivity of certain crops to high soluble salts, some labs prefer to show 2 mmhos/cm as saline. The follow chart and table will help determine the sensitivity and levels of many crops to soluble salts.

This chart can be used with the table on the following page. Chart & table taken from "The Nature & Properties of Soils", 11th edition. EC in dS/m at even low levels partially effects the yield potential of sensitive or moderately sensitive crops.



Relative Tolerance of Certain Plants to Saline Soils

Tolerant	Moderately Tolerant	Moderately Sensitive	Sensitive
Barley, grain	Barley, forage	Alfalfa	Almond
Bermuda grass	Beet, garden	Arborvitae	Apple
Bougainvillea	Broccoli	Boxwood	Apricot
Cotton	Brome grass	Broad bean	Azalea
Date	Cow pea	Cauliflower	Bean
Elm	Fescue, tall	Cabbage	Blackberry
Locust	Fig	Celery	Boysenberry
Natal plum	Harding grass	Clover, alsike	Burford holly
Nutall alkali grass	Honeysuckle	Ladino, red,	Carrot
Oak	Hydrangea	Strawberry	Celery
Olive	Juniper	Berseem	Dogwood
Rescue grass	Kale	Corn	Grapefruit
Rosemary	Mandarin	Cucumber	Hibiscus
Rugosa	Orchard grass	Dallis grass	Larch
Salt grass	Oats	Grape	Lemon
Sugar beet	Pomegranate	Juniper	Linden
Tamarix	Privet	Lettuce	Onion
Wheat grass, crested	Rye, hay	Pea	Orange
Wheat grass, fairway	Ryegrass, perennial	Peanut	Peach
Wheat grass, tall	Safflower	Radish	Pear
Wild rye, altai	Sorghum	Rice, paddy	Pineapple
Wild rye, Russian	Soybean	Squash	Plum, prune
Willow	Squash, zucchini	Sugarcane	Potato
	Sudan grass	Sweet clover	Raspberry
	Trefoil, birdsfoot	Sweet potato	Rose
	Wheat	Timothy	Star jasmine
	Wheat grass, western	Turnip	Strawberry
		Vetch	Sugar maple
		Viburnum	Tomato

Sodic Soils

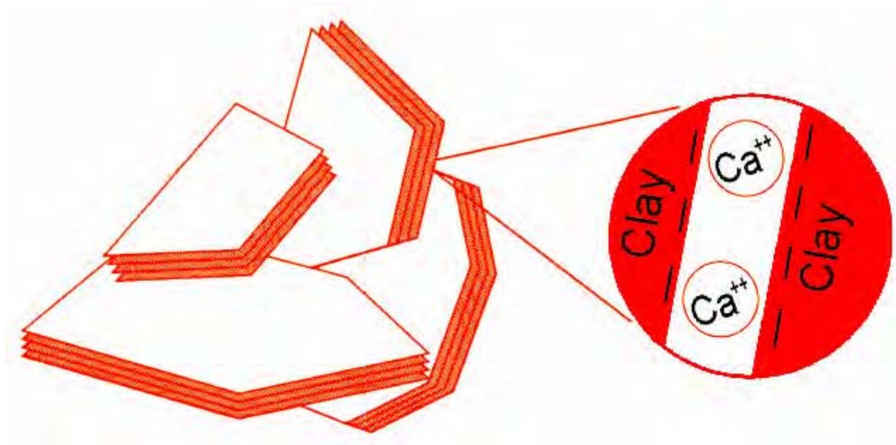
In sodic soils, or saline-sodic soils, leaching does not help without the addition of calcium to displace the sodium held by the soil colloid. Unlike saline only soils, sodic soils actually have high amounts (percentage) of sodium on the colloid. This is good in that the sodium is not "available" as a salt to salt intolerant plants, but a problem in that high sodium on the colloid causes soil compaction and crusting.

$$SAR = \frac{[Na^+]}{\sqrt{½\,([Ca^{2+}] + [Mg^{2+}])}}$$

Sodic soils are determined by two methods. First the ESP (exchangeable sodium percentage) is calculated by dividing the exchangeable sodium into the total cation exchange capacity. A soil with an ESP of over 15 is considered sodic. This level also means that the pH is usually 8.5 and higher. The second method that is being used widely is calculation of the SAR (sodium adsorption ratio). This is done by the formula expressed as with soils have a SAR of greater that 13 being considered sodic.

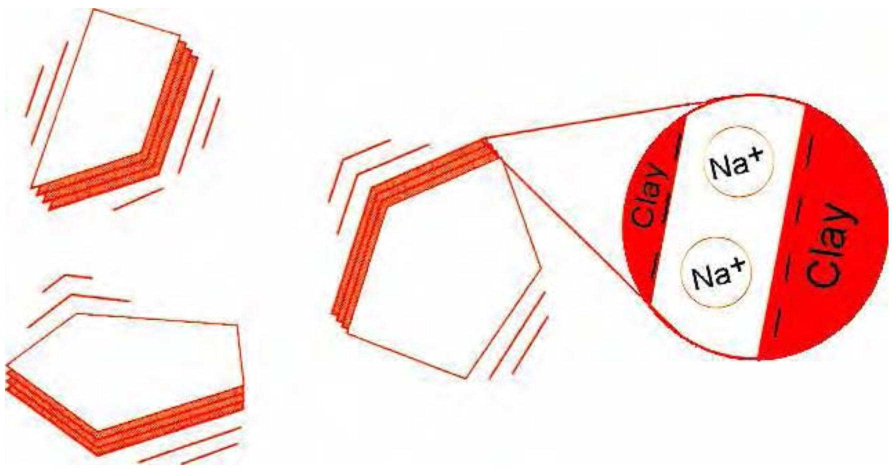
Fully understanding the negative effect of high sodium levels on the colloid is important in properly recommending soil additives to negate the effects.

The role of cations in the flocculation of soil clays is that di & trivalent cations like Ca^{++} and Al^{+++} are strongly bound (absorbed) to the negative surfaces of the colloid. This effectively neutralizes the negative charge of clay. As the diagram also illustrates, calcium has a positive charge on "both sides", therefore it acts as an effective bridge between two clay particles, holding them a part.



When adequate calcium is present on the clay surface, this helps "hold" the tiny clay particles in aggregate structures. This mechanism is especially important in low organic matter, low microbiologically active soils as these organic's also play a critical role in soil aggregation.

On the other hand, when the sodium percentage is high, sodium does not effectively neutralize the negative charges of the clay. Na^{+} is a large hydrated ion in soils (has lots of water "hooked" to it) and it cannot get close enough to the clay to bind tightly like Ca^{++}. This cause an excess of negative charges and the soil particles tend to repel each other, causing dispersion. When it rains, the small separated particles tend to wash down and clog soil pores. The second negative effect of high sodium levels attached to the colloid is that Na^{+} is monovalent (has only one charge). This leads to poor "bridging" of soil particles and the soil structure also collapses.



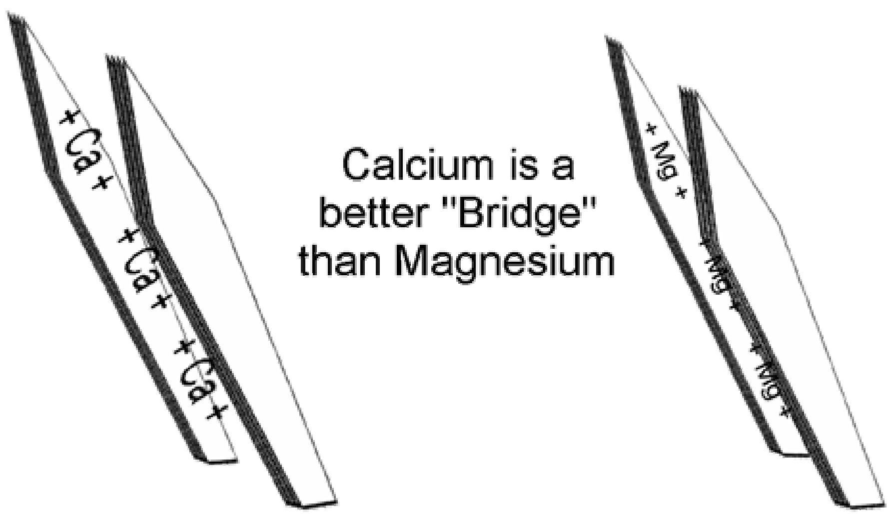
Fortunately, this condition is very reversible in that Na^{+} is easily replaced by Ca^{++} and with proper management this condition can be easily reversed by the addition of soluble forms of calcium.

Magnesium Ratios

While on the subject of calcium and sodium effects on clay soils, it is a good time to point out the cause of soil compaction in high magnesium to calcium ratio soils. For most clay types, a good ratio of calcium to magnesium is about 3 – 5 to 1. When this ratio gets to 2 to 1 or 1 to 1, high magnesium can cause the soil to become very compacted by the same "bridging" method that helps keep a apart with calcium is involved. Although calcium (Ca^{++}) and magnesium (Mg^{++}) are both divalent, there are two differences between them.

	Ionic Radii	
	Non-hydrated	Hydrated
Calcium	0.099 nm	0.96 nm
Magnesium	0.066 nm	1.08 nm

As the table illustrates, calcium has a greater radius as a dry ion than magnesium. Also calcium is less hydrated (carries less water) than magnesium. The effect of "size" and amount of water make magnesium a little less effective at holding a part soil colloids and a little less effective and neutralizing the negative charges.



The ratio of calcium to magnesium is much harder to change than the calcium to sodium ratio. The reason is that the magnesium does bind to clay much harder than sodium, therefore is much harder for calcium to "replace." A reason for magnesium buildup can be high magnesium irrigation water. In this case it is important to monitor calcium levels and be sure not to use sulfuric acid based materials to acidify the irrigation water. High magnesium only becomes a serious problem in high CEC clay based soils, especially those with depleted organic matter.

Irrigation Water Quality

The salt level of the irrigation water is the most important factor regulating soil quality in many problem soils. No sodium related soil problem would ever be corrected without analyzing and fully understanding the contents of the irrigation water available for the problem area.

How to take a sample:

- Collect a representative sample of 4 – 8 ozs.
- Well Water – collect only after 30 minutes of pumping, to assure that the sample is not contaminated from pumping system and the sample is representative of well contents.
- Monitor well levels closely during the irrigation system. It is possible for levels to change dramatically as water elevation in well drops.
- Canals – collect flowing water from the surface.
- Make sure sample containers are very clean. (Don't expect an accurate pH measurement when sample is collected in orange juice container.)
- If it is not possible to send sample in on the same day taken, immediately refrigerate to reduce changes in EC and concentrations of calcium and bicarbonate levels due to formation of lime ($CaCO_3$).

In evaluating water quality, the same parameters of sodium forms arise as that in the soil. "Free" sodium (*salinity*) in the form of NaCl (sodium chloride) would not affect the stability of soil aggregates, as would *sodic* sodium in the water.

To determine if the water is saline or sodic, one must know the SAR (sodium adsorption ratio) of the water. This number should also be adjusted to account for the amount of calcium in the water that will be lost to the formation of lime. A good lab analysis and lab service will do all these calculations for you. If they don't, build a spreadsheet that does the calculations, or hire a lab that does.

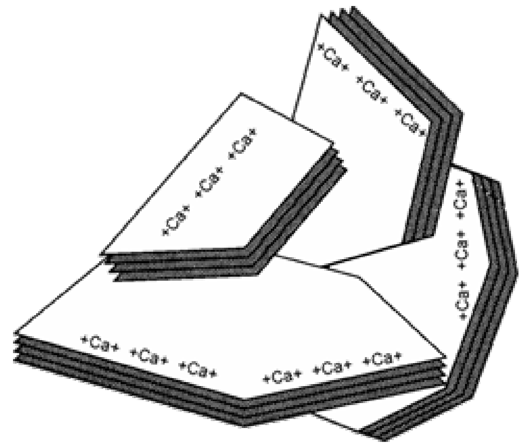
$$SAR = \frac{[Na^+]}{\sqrt{½ ([Ca^{2+}] + [Mg^{2+}])}}$$

The SAR rating for water is the same as it is for soils. What this means is that the lower the amount of calcium and magnesium in the water, in comparison to the sodium level, the higher the SAR number is and therefore, the greater the problem. For water SAR calculations it is also important to adjust SAR rating by having the lab figure out how much of the calcium in the water will turn to lime (related to carbonate and bicarbonate concentrations in water) and be unavailable to "knock off" sodium from the soil colloid. If a water contains 1.85 meq/l of Ca, 1.76 meq/l of Mg and 0.95 meq/l of Na the following the formula would work out as follows:

1.85 Ca plus 1.76 mg divide by 2 equals 1.805. The square root is 1.3435. Divide the sodium level as 0.95 divide by 1.3435 equals 0.72 SAR.

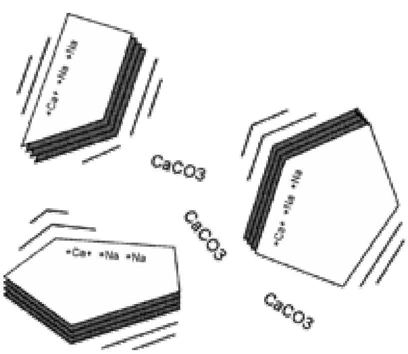
Let us say that the water contained only ½ as much Ca and Mg and 2 X's the Na. Therefore, 0.93 Ca plus 0.88 mg divide by 2 equals 0.905. The square root is 0.951. Divide the sodium level as 1.9 divide by 0.951 equals 1.99 SAR.

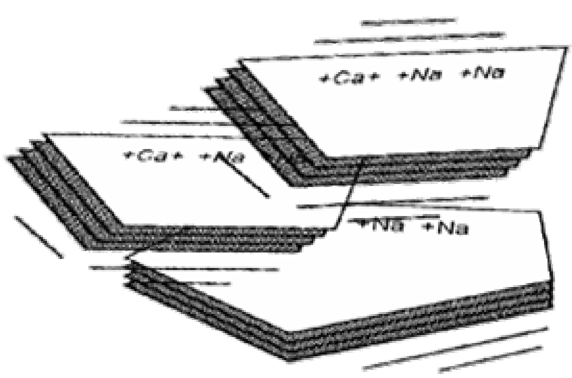
To further illustrate the issue of water quality and dealing with saline and sodic soils let's look at a practical situation. The soil colloids to the right contain an adequate amount of calcium. Calcium is divalent (2 positive charges) and it "hooks" up tightly with the negative clay. Therefore, the calcium helps the clay form an aggregate structure that holds water and air and gives the soil good porosity and structure. Irrigation water will penetrate, help leach down salts and grow a good healthy plant. Furthermore, as we have already learned, "free" sodium in water as Na_2SO_4 or NaCl is soluble so it easily leaches and will not accumulate in the soil structure and cause growing problems.



However, the canal runs dry and now the grower has to start irrigating with well water that has a high SAR rating. This means that it has lots of sodium and limited amounts of calcium or magnesium. There is also another problem; the water also has lots of bicarbonate and carbonate in it.

As the field is irrigated, the bicarbonates and carbonates "tie up" the available calcium and precipitate it in an insoluble form. The excess sodium will loosely bind to the clay colloids, but as we learned, they do not tie up the negative charges on the colloids as well as calcium does and the soil aggregate structure "flies" apart. This then begins a cycle of soil destruction.

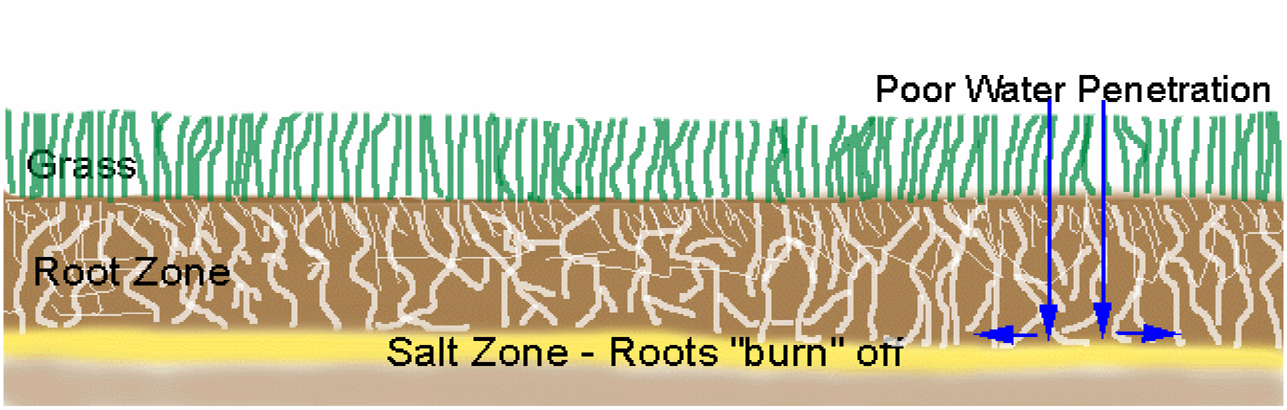




The soil has no structure, so therefore the water droplets hit the soil and begin to compact it. The lack of calcium and excess sodium on the colloid (sodic soils) causes the soil to "collapse".

The result is less water movement downward, less water movement equals an accumulation of more salts in both "free" state (saline) and "bond" state (sodic). There is also no aggregate structure to "hold" water. The small particles also tend to wash and clog the soil pores.

Before we can begin working on the solution to this problem, we have to summarize the effect of this condition on the growth of many plants. One of the worst effects is the high sodium levels (especially free Na) cause a reduction of root growth and development. This causes a plant & root system that is weak and susceptible to disease. The lack of plant growth (in both shoot & root) takes away from the system a very important tool in self-correcting the problem.



Dealing with Saline/Sodic Soils

The situation is that we have high carbonate/bicarbonate water that has tied up the calcium and made it insoluble and unavailable for the soil colloid. The high sodium is weakly attached to the soil colloid. The soil aggregate structures have fallen apart and now the soil has no structure. Water does not penetrate and wash the free sodium down. The pH of the soil is increasing leading to further calcium deficiency. Because of poor water movement, the salts are not leaching away from the roots and the roots are burning off.

There are three important ingredients needed:

1. Available Calcium
2. Acidity (hydrogen – H^+)
3. If at all possible some Organic Matter

In dealing with calcium additions to saline/sodic soils, gypsum (calcium sulfate) is what is recommended the most. This gives important calcium and a salt that will help the sodium leach out.

Sodium bicarbonate + Gypsum = Sodium Sulfate + Calcium carbonate + Carbon dioxide
($2\ NaHCO_3 + CaSO_4 = Na_2SO_4 + CaCO_3 + CO_2$)

However, if the soil is truly SODIC (has high pH) the problem is not solved here. Remember that the calcium became insoluble when the high bicarbonate/carbonate water was applied ($CaCO_3$ formed). We need another important ingredient, acidity.

Chemically, it is simple to add acidity to the soil. The problem in many areas is cost per acre. When the sulfur is added as pure sulfur, it must be oxidized by soil microbes in order to give acidity. This takes a microbe, some oxygen present in the soil and some water, it gives acidity as follows;

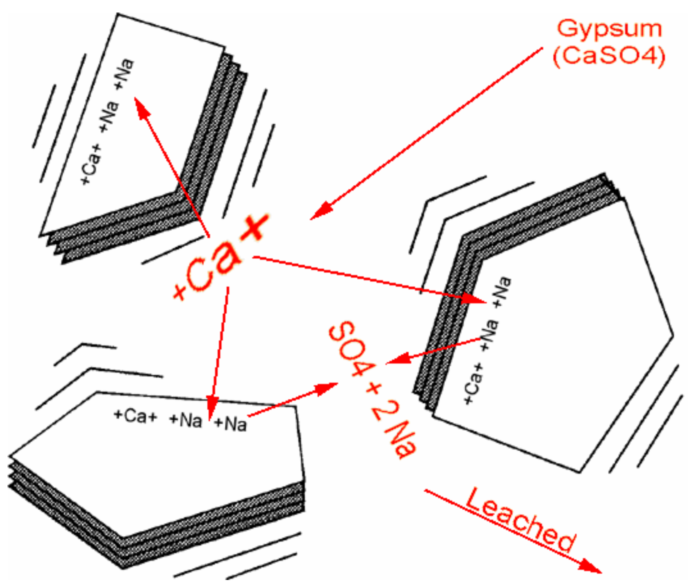
Thiobacillus + Sulfur + 3 oxygen + 2 water = 2 sulfuric acid = 4 hydrogen + 2 sulfates
Thiobacillus + $S + 3\ O_2 + 2\ H_2O = 2\ H_2SO_4 = 4\ H^+ + 2\ SO_4^-$

Another method is to add sulfuric acid. This is expensive, but in some conditions it is the most effective method. In both additions the important part of the equation is the addition of acids, which lowers the pH of the soil and increases the solubility of the calcium carbonate, which has formed and caused the problem in the first place.

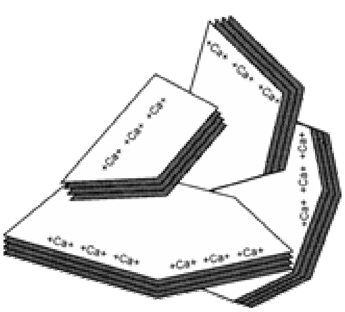
Note: The addition of gypsum and sulfur both require good tillage and distribution in the soil profile. With permanent crops and turf this is impossible. Therefore, it is recommended to add sulfuric acid to the water, make sure sufficient calcium carbonates are available in the soil and sufficient water (and soil profile) is available to leach out the sodium sulfate.

A soil test will be needed to determine the following:

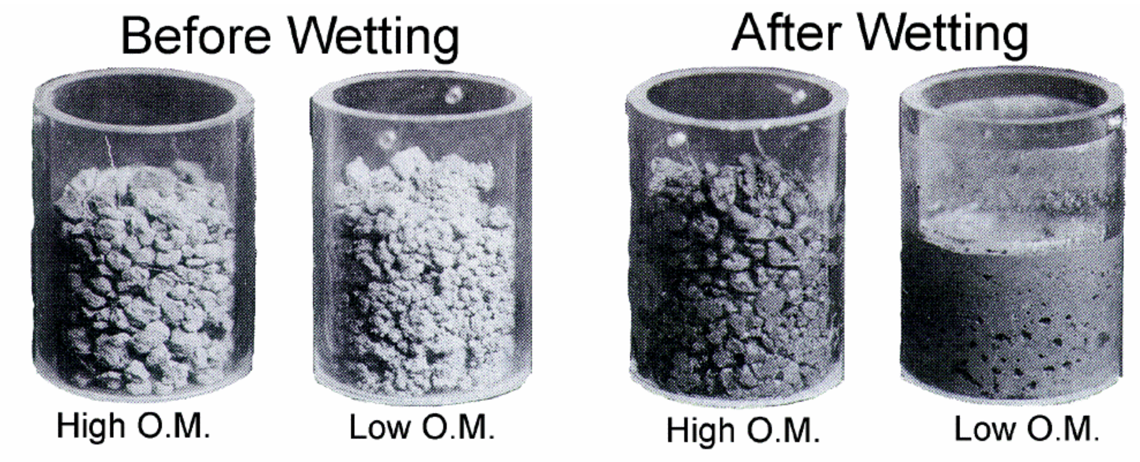
1. Soil pH
2. Cation Exchange Capacity (CEC)
3. % of Ca, Mg & Na on CEC



From these figures the total amount of gypsum required to displace the desired amount of sodium can be calculated. The gypsum must be applied and well mixed into the soil profile. The reaction outlined to the right will occur (with water present). The gypsum gives calcium to the colloid, the sodium is leached as sodium sulfate and then the soil gets back its structure.



This change in soil structure brought about by displacing the sodium with calcium and creating a condition for the soil particles to aggregate is called "flocculation". However, these flocculated soil particles are still not STABILIZED. To build and maintain soil fertility, the factors that go into stabilizing and maintaining a soil structure are of utmost importance and this belongs to the biological fertility cycle.



Addition to Saline Levels

Research shows that the levels of free sodium in soils as determined by a soil test may not be a totally accurate indication of the levels of Na accumulation in the immediate vicinity of the root hair.

As the water uptake rate (transpiration) increases, the level of sodium in the loosely adhering soil (rhizosphere) and the closely adhering soil (rhizoplane) can be much higher then that of the bulk soil.

Relationship between Water Uptake per Unit Length of Root and Sodium and Chloride Accumulation around Maize Roots (Sinha & Singh, 1974)

H20 uptake	Chloride (mg/100 gram)			Sodium (mg/100 gram)			EC
Transpiration (100 ml/cm)	Bulk Soil*	Loose**	Close***	Bulk Soil*	Loose**	Close***	Close*** Mmhos/cm
0.38	31	41	58	22	34	41	1.38
0.46	36	43	65	28	33	45	2.28
0.82	43	66	97	36	49	68	3.79
0.95	44	64	128	38	57	90	5.02

* Soil away from roots ** loosely adhered to roots *** closely adhered to roots