NDSU
Extension Service
North Dakota State University

Saline and Sodic Soils

Background:

The wet climate during the last 20 years has increased salinity acres. As per a recently published report there are nearly 5.8 million acres in North Dakota which are affected by soil salinity (Brennan, J., and M. Ulmer, 2010, Salinity in the Northern Great Plains, Natural Resources Conservation Service, Bismarck, N.D.). With more acres affected each year by salinity and sodicity, the management and alleviation of saline and sodic soils cannot be stressed more. Even though closely related and having many characteristics in common, soil salinity and sodicity are two different problems, which should be dealt with differently and require slightly different management practices. This publication is intended to help the farm producer or landowner to understand the fundamental differences between these two problems.

Difference between Saline and Sodic Soils:

Saline soil is a term used to describe excessive levels of soluble salts in the soil water (soil solution), high enough to negatively affect plant growth, resulting in reduced crop yields and even plant death under severe conditions (Figure 1).

Figure 1. A typical saline spot along state Highway 17 East, N.D.

The primary effect of excessive soluble salts on plants is to limit the ability of plant roots to absorb soil water even under wet soil conditions. Soil water flows from higher osmotic potential (low salt concentration) to lower osmotic potential (high salt concentration). A soil solution with low osmotic potential due to the higher concentration of soluble salts compared to the plant cells, will not allow plant roots to extract water from soil (figure 2), causing drought-like symptoms in the plants (Seelig, 2000). That process is called "osmotic effect".

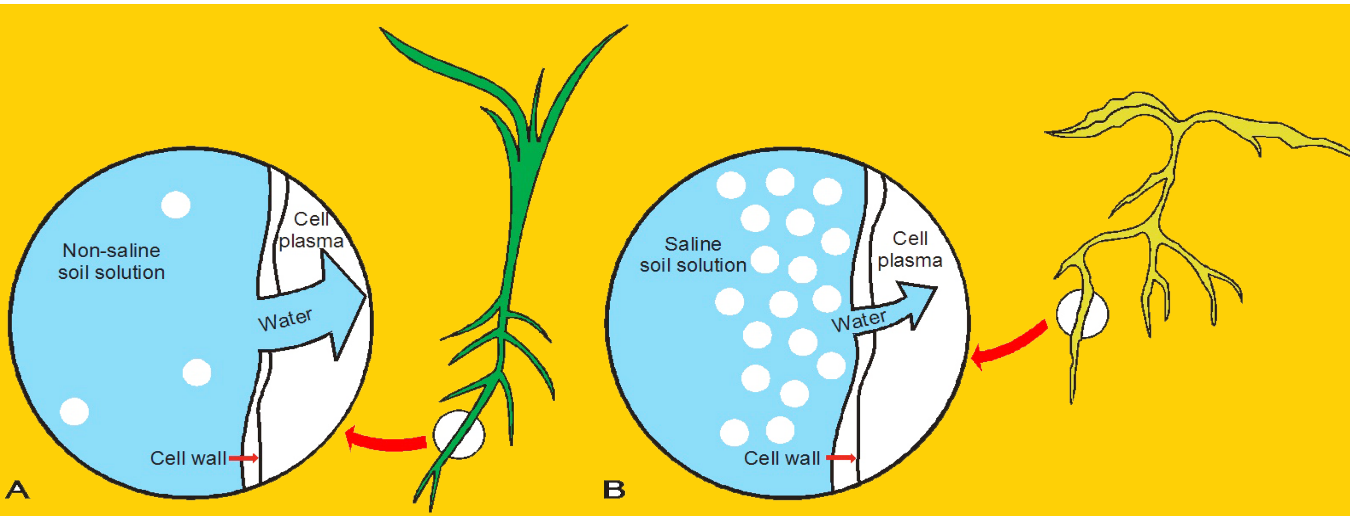

Figure 2. Excessive soluble salts causing drought-like symptoms in plants.

The most common soluable salts in North Dakota soils are sulfates of sodium, calcium and magnesium (Keller et al., 1984). However, saline soils in the northern Red River Valley have high amounts of chlorides of sodium, calcium and magnesium (Seelig, 2000). The third most common group of salts is carbonate based. As the word soluble indicates, these salts can easily be leached out of the upper 2-3 feet of surface soil under good soil moisture and drainage conditions.

In contrast to saline soils, sodic soils have excessive levels of sodium (Na+) adsorbed at the cation exchange sites (Figure 3). Soil sodicity causes degradation of soil structure. That process is called soil dispersion.

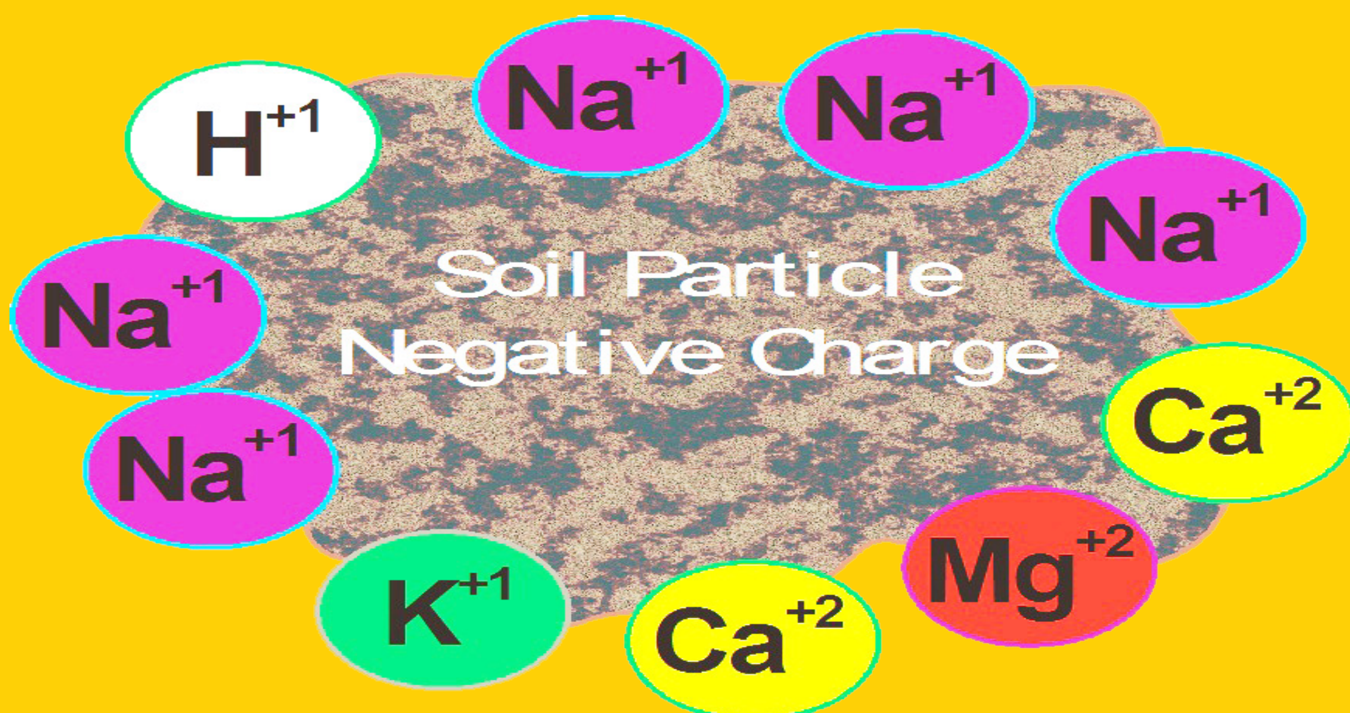

Figure 3. Example of a sodic soil aggregate with more than 15 percent of its cation exchange sites occupied by sodium ions.

The forces that hold clay particles together are greatly weakened when excessive sodium is adsorbed at the negative charges of clay particles, forming sodium-clay particles (Seelig, 2000). When wet, sodium-clay particles get easily disintegrated or dispersed from the larger soil aggregates (Figure 4). Once dry, sodium-clay particles clog the soil pores (especially macro-pores) and settle down in dense layers (Figure 5).

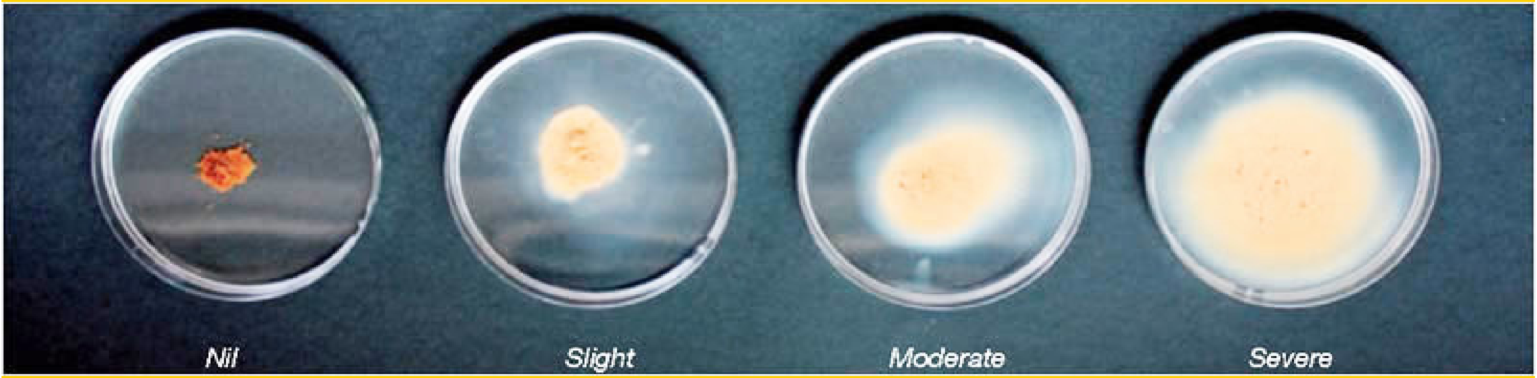

Figure 4. Degrees of soil dispersion due to soil sodicity through the disintegration of soil particles (Photo courtesy of Alison Lacey, Copyright Western Australian Agriculture Authority, 2009).

Poor physical structure (figure 5) then results in soils difficult to till, poor seed germination and restricted plant root growth. Due to the poor physical structure, sodic soils are also susceptible to wind and water erosion compared to saline soils. Soil dispersion effect will be more severe on expanding-type of clays as their degree of swelling increases, causing the clogging of the larger soil pores. In saline and saline-sodic soils though, higher concentrations of salts provide excess cations like calcium and magnesium which promote flocculation (opposite of dispersion) by moving in close to the negatively charged particles, thereby reducing their tendency to disintegrate or disperse from each other (The Nature and Properties of Soils, 14th Edition, Revised).

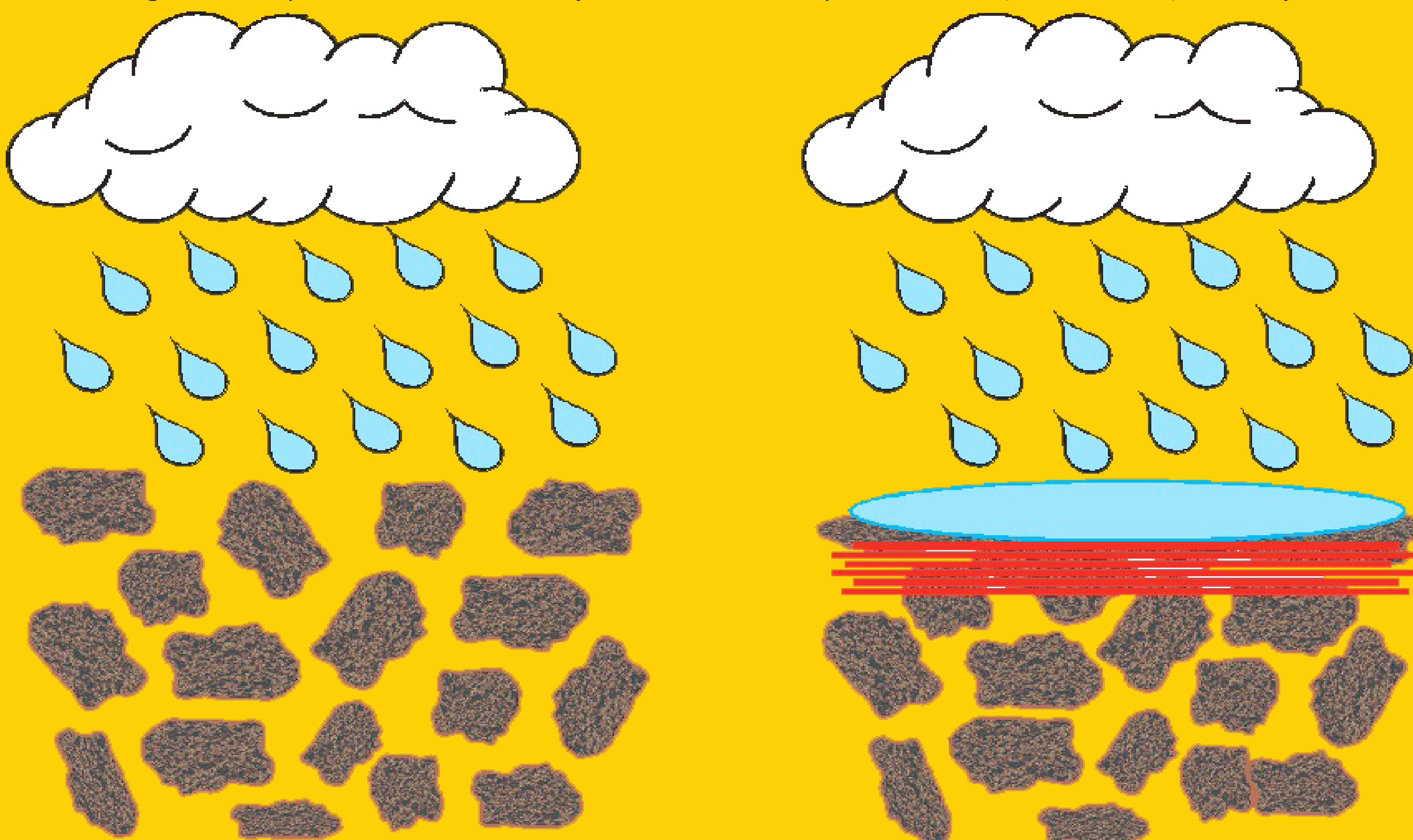

Figure 5. Soil with good physical structure (left) versus a dispersed soil with poor physical structure on the right.

Main Causes:

The causes for saline and sodic soils in the northern Great Plains are natural, but both conditions can be affected by management. The primary natural cause for these two is the parent material of the soils within the state and the underlying sodium-rich shale that is present in the bedrock below the soil sediments.

The severity of soil salinity or sodicity occurs where there is shallow saline or sodic groundwater level (Figure 6). Groundwater levels in relation to the soil surface fluctuate depending upon the precipitation received and the evapotranspiration of the vegetative cover. Groundwater levels that average about 6 feet or less in depth are highly susceptible to salinity or sodicity development (Seelig, 2000). Groundwater within 6 feet of the surface can move through capillary action to or near the soil surface resulting in very low or no downward movement of excessive soil water and soluble salts, very low soil oxygen content along with bringing in salts with it. The water evaporates, leaving behind the salts. The longer the groundwater level is close to the surface, the greater level of salts or sodium will develop. In rolling topography, with soil texture discontinuity or hard layers, such as coal seams, saline seeps can develop during periods of high rainfall.

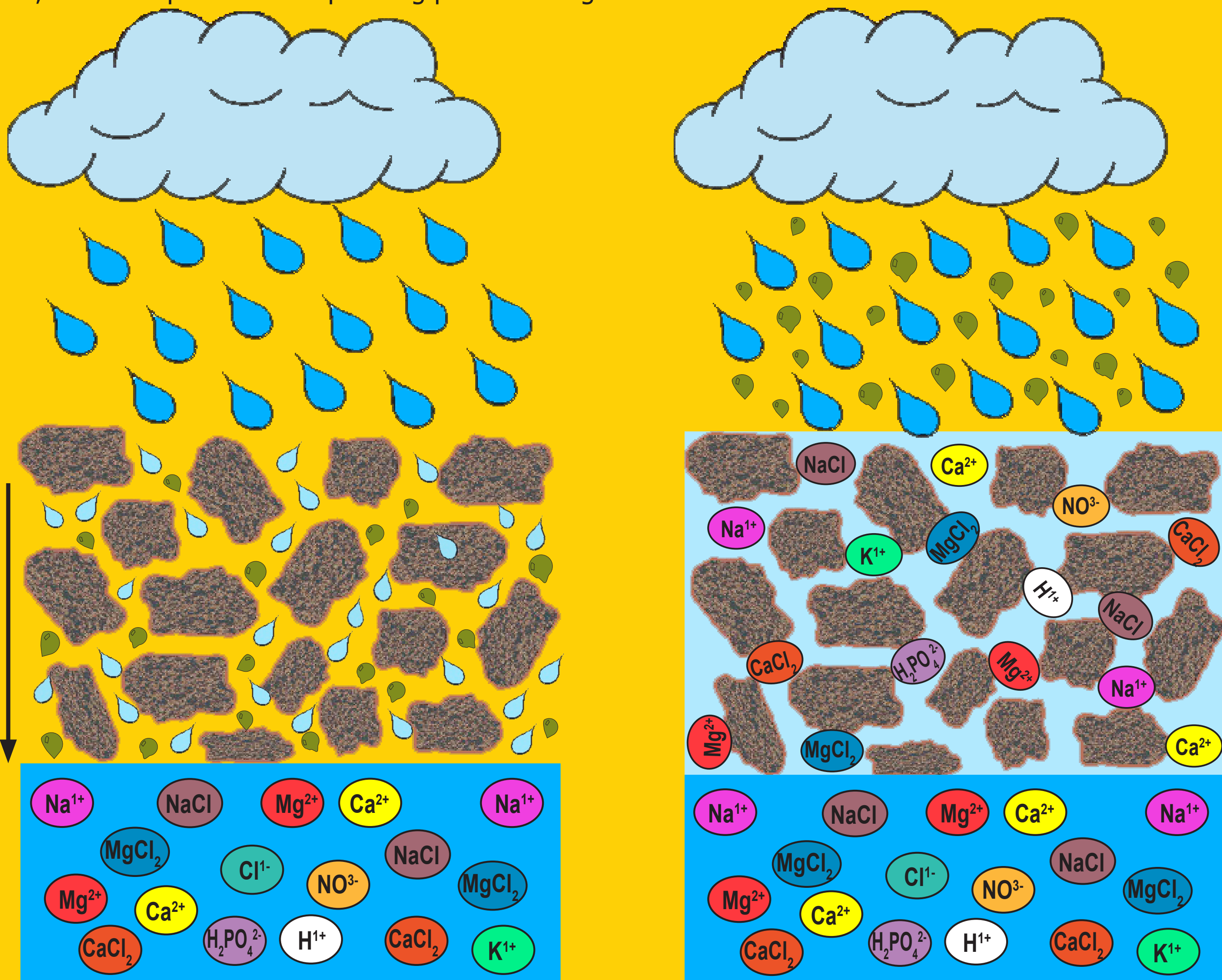

Figure 6. A well-drained soil with low groundwater level (left) versus a saturated soil with very shallow groundwater level on the right.

Another major reason for bringing in excessive salts in the plant root zone is the use of excessive irrigation water or having very wet weather conditions (excessive rains), which are man-made and natural respectively. In North Dakota though, predominantly it is the wet cycle which creates ideal conditions for shallow groundwater level, thus causing soil salinity and sodicity.

Indicators:

In soils suspected as being saline or affected by sodium, the extent of the problem and its management are difficult to determine unless the soil is analyzed using laboratory procedures. Soils should be sampled to at least 2 feet depth in 6-inch increments. Soil salinity can be diagnosed by measuring the salt concentration in soil water (solution) by analyzing it for Electrical Conductivity (EC). EC is the ability of a material to transmit electrical current, which in the case of a soil is the result of salt concentration.

A soil is classified as saline once its saturated paste extract EC will reach 4.00 deciSiemens/meter (dS/m), which will be equal to 4.00 millimhos/centimeter (mmhos/cm) using, the same saturated paste extract method. EC values measured through 1:1 by weight soil:water slurry method will result in lower values versus the saturated paste extract method. Variation among the EC values measured through these two methods will also differ for different soil textures. Following formulas in Table 1, can be used as a rough guide for the conversion of EC values.

Table 1. General conversion from 1:1 soil:water slurry method used by many commercial labs and the saturated paste extract method used in research applications.

x = EC of saturated paste extract   y = EC of 1:1 soil:water slurry

Soil Texture		
Coarse	Medium	Fine
X = 3.01y – 0.06	X = 3.01y – 0.77	X = 2.96y – 0.95
y = 0.33x + 0.06	y = 0.33x + 0.77	y = 0.375x + 0.97

Hogg, T.J., and Henry, J.L. 1984. Comparison of 1:1 And 1:2 Suspensions and Extracts with the Saturation Extract in Estimating Salinity in Saskatchewan Soils. Canadian Journal of Soil Science, 1984, 64(4): 699-704, 10.4141/cjss84-069.

The extent of soil sodicity is measured either through its Exchangeable Sodium Percentage (ESP) or Sodium Adsorption Ratio (SAR). Both measure the sodium content of the soils in relation to calcium and magnesium using specific mathematical formulas. Sodic soils are low in total soluble salts but high in exchangeable sodium, which tends to disperse soil particles and destroys soil structure (Management of Saline and Sodic Soils, Kansas State University, 1992). For taxonomic purposes, a soil will be interpreted as sodic if it has an Exchangeable Sodium Percentage of 15 or more or have Sodium Adsorption Ratio of 13 or more. Sodic soils often have a pH level of 8.5 or more in carbonate-rich soils, such as in northeastern North Dakota, but may also have very low pH, perhaps as low as 4.0 in southeastern North Dakota in soils with no carbonates. Soils having both, salinity as well sodicity problems are considered as saline-sodic soils and will have the characteristics of both. Typical characteristics of saline, sodic and saline-sodic soils are presented in Table 2.

Classification	Electrical Conductivity (mmohs/cm)	Soil pH	Exchangeable Sodium %	Sodium Adsorption Ratio	Soil Physical Condition
Saline	> 4.0	< 8.5	< 15	< 13	Normal
Sodic	< 4.0	> 8.5	> 15	> 13	Poor
Saline-Sodic	> 4.0	<8.5	> 15	> 13	Normal

= greater than, < = less than

Management of Saline and Sodic Soils, Kansas State University, 1992.

Management of Saline Soils:

Because salts can only be leached downward in the soils with soil water, attention to drainage is very important. Assessment of where the water comes from that result in the high water table is particularly important. Management might first be based on intercepting water coming into the problem area, with mitigation of the actual salinity as a secondary step. Improved use of in-field and boundary-field ditches can also improve soil drainage and facilitate leaching of salts (figure 7).

Figure 7. Example of a field ditch along state Highway 17, N.D.

Drainage might involve planting of water-use efficient crops, intercepting cropping with crops like alfalfa to use water before it enters the problematic area, use of cover crops in non-crop intervals or the installation of surface or subsurface drainage systems like tile drainage (figure 8).

Figure 8. Installation of tile drainage in progress in Ramsey County along state Highway 17 near Edmore, N.D. (Photo courtesy of Ronald Beneda, NDSU Cavalier County Extension agent).

A thorough analysis of EC and SAR or ESP should be conducted before the installation of any subsurface drainage system, as excessive leaching of divalent cations (calcium and magnesium) can lead to the sealing of soil layers either around or above the tiles, if placed within or under the sodic layers.

With improved soil permeability and infiltration achieved through drainage under good soil moisture conditions (rainfall or irrigation) desired results should be achieved through the continuous leaching of soluble salts.

In the absence of good soil drainage in place combined with a high groundwater levels, late-maturing, deep-rooted and salt tolerant crops, like alfalfa, sugarbeet and sunflower can also be excellent choices which withstand moderate salt levels and take water from deeper depths (Franzen, 2007). To avoid excessive recharge of groundwater levels through rain along with reducing the soil surface evaporation, continuous cropping can also be very effective.

Management of Sodic Soils:

In order to reclaim sodic soils, it is essential to first replace the excessive sodium from the cation exchange sites with large amounts of calcium supplements before starting the salt leaching process. Common examples of amendments are calcium sulfate and calcium chloride on alkaline soils and calcium carbonate on acidic soils (Sodic Soil Management. Vegetable Soilpak, Chapter D5., Government of Australia).

Management of sodic soils can also be very difficult and expensive depending upon the cost of calcium supplements. Like saline soils, sodic soils also require good soil drainage and low groundwater level. The only difference will be the application of calcium supplements (usually gypsum) and thoroughly mixing it into the soils (figure 8). Once sodium is displaced by calcium from the cation exchange sites, sodium (Na^+) converts into a salt (Na_2SO_4) and leach out of the rooting zone. Positive results can be achieved by applying 4 to 8 tons/acre of gypsum combined with thoroughly mixing it into the soil. Although gypsum costs may decrease in the future if in-state coal-fired power plants decide to make gypsum instead of calcium sulfite and landfilling the material, currently an 8 ton application would cost about $1,600 per acre.

Figure 9. Field gypsum application (photo courtesy of Keith Mount Liming of UK).

Some success has been reported using sugar beet processing waste lime, but controlled studies using the material have not been conducted. When the dominate soil salts are sulfates, use of calcium chloride might have greater effect, although this material is even higher in cost compared to gypsum (Franzen, 2007).

The exact quantities of gypsum or any other calcium supplement per acre depend upon the level of excessive sodium present in a soil. Reclamation of sodic soils will also be slow compared to the remediation of saline soils as the damaged soil structure in the sodic soils (due to dispersion) will take time to improve. In order to speed up the reclamation process, it is recommended to grow a salt-tolerant crops during the early stages and incorporating the plant residues to increase the soil organic matter level of the soils (Management of Saline and Sodic Soils, Kansas State University, 1992). That will counter soil dispersion by improving soil structure.

Management of Saline-Sodic Soils:

Management of salinity and sodicity becomes more complicated when both occur in the same soil together. A saline-sodic soil normally does not exhibit strong sodicity symptoms. However, as the soil salinity decreases through improved drainage or management, calcium and magnesium salts are preferentially leached away and sodium is more slowly leached and eventually dominates the soil. Its management will be very similar to sodic soils. Like sodic soils, remediation of saline-sodic soils requires an extra step of applying calcium (Ca^{++}) supplements (commonly gypsum) followed by salinity remediation practices of improving soil drainage and lowering down the water-table level.

Summary:

Though not always economically feasible due to the natural causes or heavy costs involved, it may be practical to bring saline and sodic soils back to productivity. First analyze the soils to determine the nature of the problem. If the soil is saline, determine where the water is coming from that is resulting in a shallow groundwater level. A combination of management practices using intercepting crops, improved physical drainage, use of better adapted crops and use of cover crops should improve the conditions. If the soil is sodic, determining whether the cost of amendment and drainage will be worth the investment is an important consideration. If the soil is both saline and sodic, perhaps living with the condition and growing salt-tolerant crops would be better than creating an expensive sodic problem.

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