The Basics of Salinity and Sodicity Effects on Soil Physical Properties

Information Highlight For The General Public

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<u>Table of contents</u>

Introduction to salinity and sodicity.

Saline irrigation water contains dissolved substances known as salts. In much of the arid and semi-arid United States (including Montana), most of the salts present in irrigation water are chlorides, sulfates, carbonates, and bicarbonates of calcium magnesium, sodium, and potassium. While salinity can improve soil structure, it can also negatively affect plant growth and crop yields. Sodicity refers specifically to the amount of sodium present in the irrigation water. Irrigating with water that has excess amounts of sodium can adversely impact soil structure making it difficult for plant growth. Highly saline and sodic water qualities can cause problems for irrigation, depending on the type and amount of salts present, the soil type being irrigated, the specific plant species and growth stage, and the amount of water that is able to pass through the root zone.

1. The effects of salinity on plant growth.

Salinity becomes a problem when enough salts accumulate in the root zone to negatively affect plant growth. Too many salts in the root zone hinder plant roots from withdrawing water from the surrounding soil. This lowers the amount of water that is available to the plant, regardless of the amount of water that is actually in the root zone. For example, when plant growth is compared in two identical soils with the same moisture levels, but one soil has salty water and the other soil has salt-free water, plants are able to use more water from the soil with the salt-free water. Although the water is not actually held tighter to the soil in saline environments; the presence of the salt in the water causes plants to use more energy to get water from the soil. **The main point is that excess salinity in soil water can decrease plant available water and cause plant stress.**

Soil water salinity is dependent on soil type, climate, water use and irrigation routines. For example, immediately after the soil is irrigated, plant available water is at its highest and soil water salinity is at its lowest. However, as plants use soil water, the remaining water is held tighter to the soil and it becomes progressively more difficult for the plants to use the remaining soil water. As the water is taken up by plants through transpiration or lost to the atmosphere by evaporation, the soil water salinity increases because the salts become more concentrated in the remaining soil water. Evapotranspiration (ET) between irrigation periods can further increase salinity. (Increased salinity due to ET is rarely taken into account in most salinity charts.)

2. The affects of salinity on soil physical properties.

Soil water salinity can affect soil physical properties by causing fine particles to bind together into aggregates. This process is known as flocculation. Flocculation is beneficial in terms of soil aeration, root penetration and root growth. Although increasing salinity of the soil solution has a positive effect on enhancing soil aggregation and stabilizing soil structure, at high levels salinity can have negative and potentially lethal effects on plants. As a result, **salinity cannot be increased to maintain soil structure without considering the impact the increased salinity will have on plants.**

3. The effects of sodium and sodicity on soil physical properties.

Sodium has the opposite effect on soils that salinity does. The primary physical process associated with high sodium concentrations is soil dispersion. Soil dispersion results from the break down of soil aggregates in water, leaving clay particles to disperse and settle into soil pore spaces between soil aggregates.

Another process associated with sodium is clay platelet and aggregation swelling. The forces that bind clay particles together are disrupted when too much sodium gets between clay particles. When this separation occurs, the clay particles expand and the soil disperses. Salts that contribute to salinity, such as calcium and magnesium, do not have this same effect because they are smaller and tend to cluster closer to the clay particles (Figure 1). Calcium and magnesium will generally keep the soil flocculated because they compete for the same spaces as sodium to bind to clay particles. **Increased amounts of calcium and magnesium can reduce the amount of sodium-induced dispersion.**

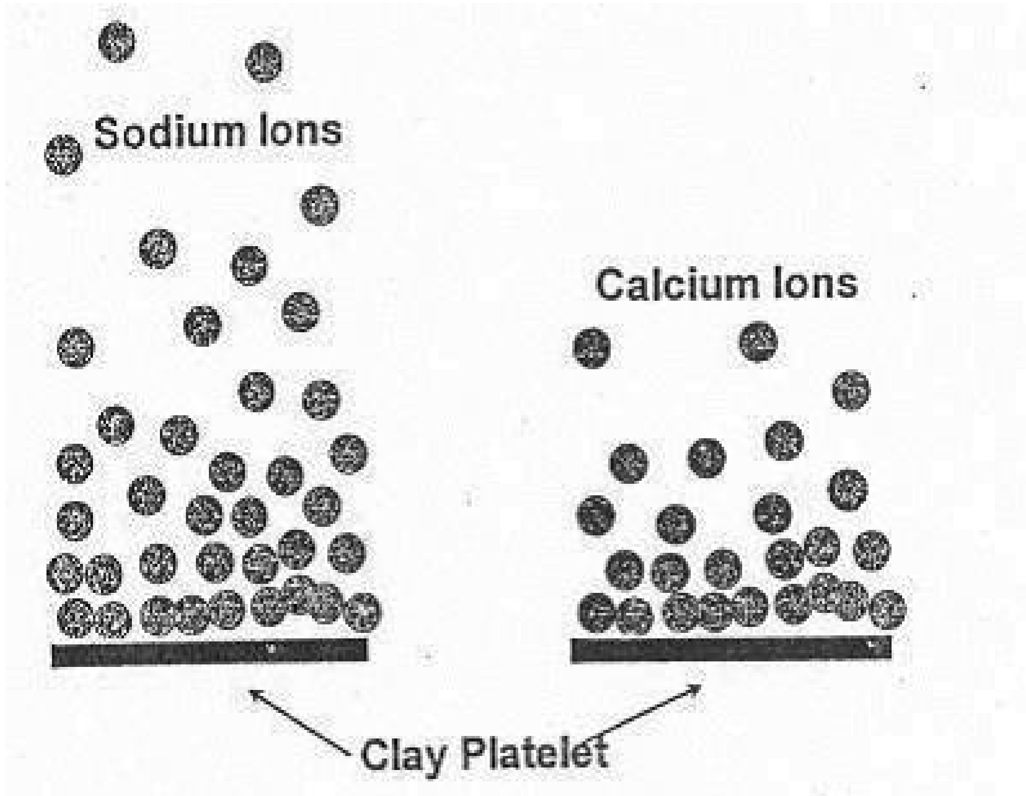

Figure 1. Behavior of sodium and calcium attached to a clay particles. (*After Hanson et al., 1999*).

Soil dispersion causes clay particles to plug the soil pores, resulting in a reduction in soil permeability. When the soil is repeatedly wetted and dried and clay dispersion occurs, the soil will then reform and solidify into almost cement-like soil with little or no structure. **The three main problems caused by sodium-induced dispersion are reduced infiltration, reduced hydraulic conductivity, and surface crusting.**

Infiltration

Soil dispersion hardens the soil and blocks water infiltration which makes it difficult for plants to establish and grow. The major implications associated with decreased infiltration due to sodium-induced dispersion include reduced plant available water and increased runoff and soil erosion.

Hydraulic Conductivity

Soil dispersion not only reduces the amount of water entering the soil, but it also affects the hydraulic conductivity of the soil. Hydraulic conductivity refers to the rate at which water flows through the soil. For instance, soils with well-defined structure will contain a large number of macropores, cracks, and fissures which allow for relatively rapid flow of water through the soil. When sodium-induced soil dispersion causes loss of soil structure, the hydraulic conductivity is also reduced. If the water cannot pass through the soil, then the upper layer can become swollen and water logged. This results in anaerobic soils which can reduce or prevent plant growth and decrease organic matter decomposition rates. The decrease in decomposition causes soils to become infertile, black alkali soils.

Surface Crusting

Surface crusting is a characteristic of sodium affected soils. The primary causes of surface crusting are: 1) physical dispersion caused by the impact of raindrops or irrigation water, and 2) chemical dispersion which depends on the ratio of salinity and sodicity of the applied water.

Surface crusting due to rainfall is greatly enhanced by sodium induced clay dispersion. When clay particles disperse within soil water, the dispersed clay particles plug macropores in the soil surface by two means. First, dispersed clay particles plug macropores in the soil surface blocking avenues for water and roots to move through the soil. Secondly, soil structure is lost during dispersion and a cement like surface layer is formed when the soil dries. The hardened upper layer, or surface crust, restricts water infiltration and plant emergence.

4. The relationship between salinity and sodicity and soil physical properties (EC/SAR).

The relationship between soil salinity and its flocculating effects and sodicity and its dispersive effects influence whether or not soil will stay aggregated or become dispersed under various salinity and sodicity combinations. As irrigation water with lower salinity is applied to the soil by irrigation or rainfall, this water will flow into the spaces (micropores) between the clay particles. The salinity of the applied water may then become low relative to the salinity of the soil aggregates. The water migration causes swelling and dispersion of the clay particles. In contrast, irrigation water with higher salinity tends to cause particles to stay together and soil structure is maintained.

More than fifty years of research have been conducted to determine the relationship between salinity (EC) and sodicity (SAR) of irrigation water and how it affects soil physical properties. This relationship is now understood well enough to make accurate predictions of how specific soils will behave when irrigated with different levels of salts and sodium. **The main concerns related to the relationship between salinity and sodicity of irrigation water are the effects on soil infiltration rates and hydraulic conductivities.**

The Swelling Factor

The ratio of salinity (EC) and sodicity (SAR) determines the effects of salts and sodium on soils. Salinity promotes soil flocculation and sodicity promotes soil dispersion. The combination of salinity and sodicity on soils is the swelling factor. The swelling factor is the amount a soil is likely to swell with different combinations of salinity and sodicity. **The importance of determining the swelling factor is to find out if sodium-induced dispersion or salinity-induced flocculation will affect the soil physical properties the most.**

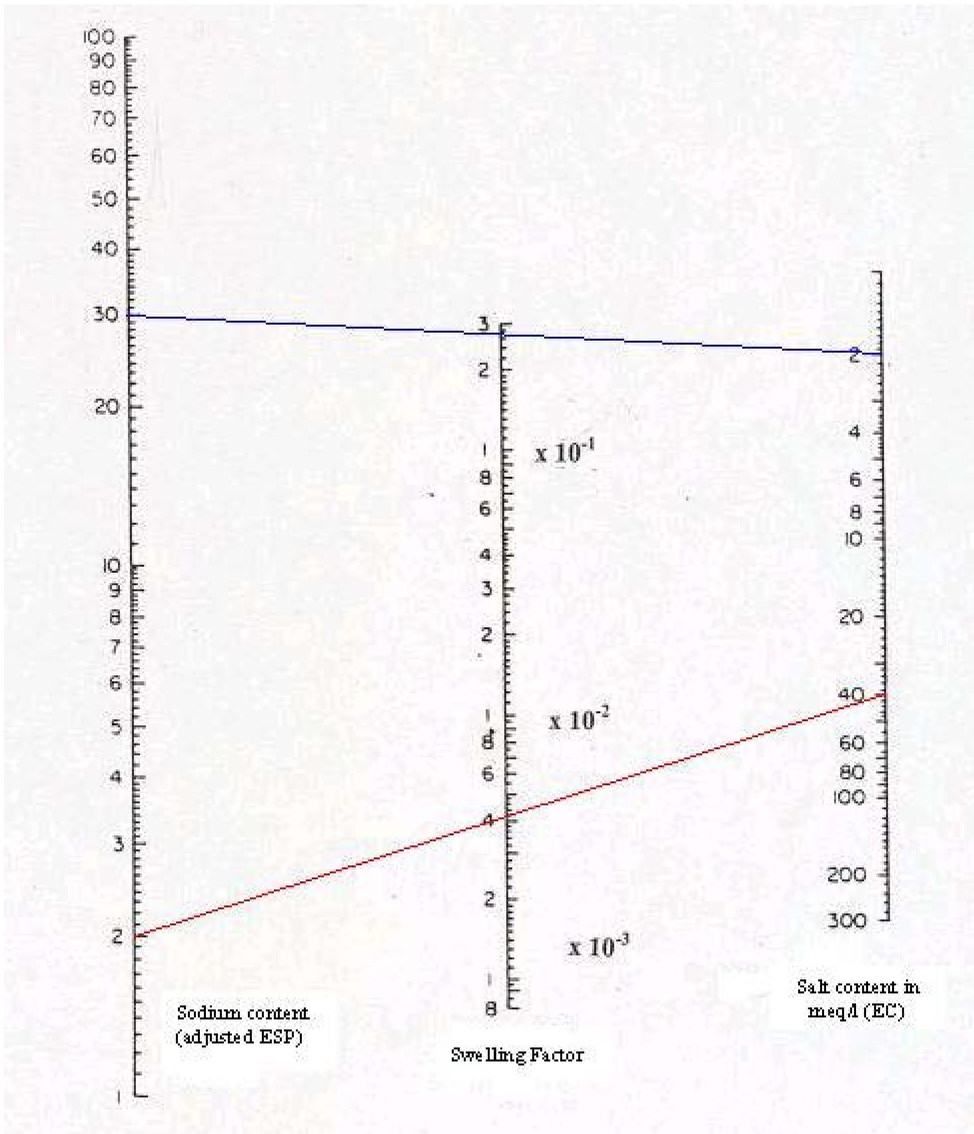

Figure 2. Swelling factor as a function of sodium content (adjusted ESP) of soil and salt concentration of soil water (*After McNeal, 1968*).

Scientists have been able to get a good idea of the swelling factor by using Figure 2. It is possible to draw a line from the sodium content (adjusted ESP) in the left column to the appropriate salt concentration in the right column. The line intersects the middle column, the swelling factor, indicating how much the soil will swell. For instance, drawing a line between adjusted ESP = 2 and an EC = 40 meq/L (red line) yields a swelling factor of 0.0041. In this example, the swelling factor of 0.0041 indicates that dispersion is not a problem. However, a combination of adjusted ESP = 30 and EC = 2 yields a swelling factor of 0.28 which indicates that dispersion is likely. In short, Figure 2 helps show how the dispersive effects of soils with high ESP can be lessened with the flocculating effects of irrigation water with high EC.

Infiltration Rates

Another approach to judging the effects of salinity (EC) and sodicity (SAR) on soil physical properties is to assess potential impacts of various irrigation water qualities on infiltration rates. Figure 3 demonstrates the relationship between salinity and sodicity and how different combinations affect infiltration rates. For example, severe problems are likely if the irrigation water has low salinity and high sodicity. Another example is at a SAR = 15, a severe reduction in infiltration will occur at an EC = 1 dS/m. An EC of 2.5 or less results in a slight to moderate reduction in infiltration. With an EC greater than 2.5, there will likely not be a reduction in infiltration. Similarly, Table 1 numerically defines the relationship between EC, SAR, and infiltration rates.

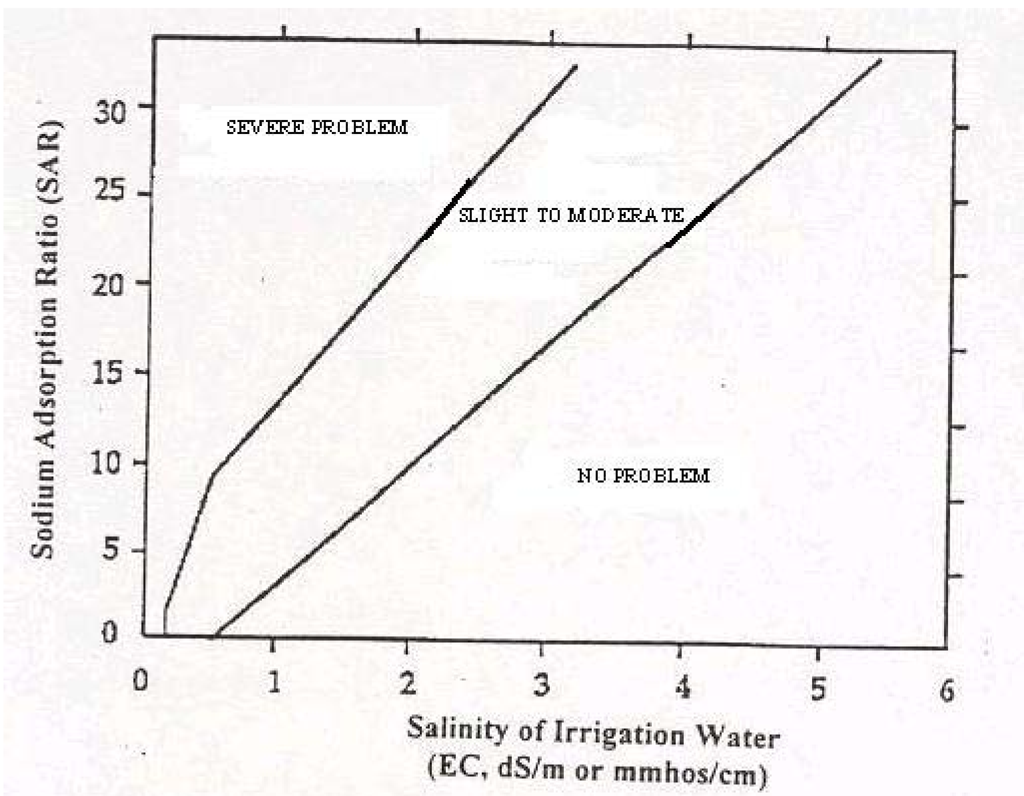

Figure 3. Potential for reduction in the rates of infiltration resulting from various combinations of EC and SAR of applied water (*After Hanson et al., 1999*).

Table 1. Guidelines for saline-sodic water quality suitable for irrigation in terms of reduced infiltration (*After Ayers and Tanji, 1981*).			
	EC dS/m		
SAR	No Problem	Slight to moderate	Severe problem
0 to 3	> 0.9	0.9 to 0.2	< 0.2
3 to 6	> 1.3	1.3 to 0.25	< 0.25
6 to 12	>2.0	2.0 to 0.35	< 0.35
12 to 20	> 3.1	3.1 to 0.9	< 0.9
20+	> 5.6	5.6 to 1.8	< 1.8

Factors such as climate, soil type, crop and plant species and management practices also need to be accounted for when determining acceptable levels of salinity and sodicity of irrigation water. Soil texture and rainfall also play important roles in the effects of salinity and sodicity of irrigation water on soil physical properties. Intense rainfall can flush salts beneath the root zone, but will not significantly reduce the amount of sodium bound to the soil. Therefore, **rainfall can reduce the potential for soil aggregation from salts and increase the likelihood that sodium-induced dispersion will happen.**

5. The role of soil texture.

Soil texture plays an important role in all aspects of irrigation, and the role of soil texture with respect to the effect of salinity and sodicity is no exception. Soil texture helps determine how much water will be able to pass through the soil, how much water the soil can store, and the ability of sodium to bind to the soil.

Clay soils can hold more water and are slower to drain because the particles are smaller. Smaller particles can pack closer together, block the spaces between the particles and prevent water from passing through. Sand particles are larger and have larger pore spaces for water to pass through. Under normal irrigation practices, sandy soils will naturally be able to flush more water through the root zone than clay soils. The end result is that sandy soils can withstand higher salinity irrigation water because more dissolved salts will be removed from the root zone. Less dissolved salt in the root zone is beneficial for plant growth because plants are able to use water more efficiently.

Another important aspect of soil texture is the fact that clays have more surface area for sodium to bind to. This simply means that clay soils have the greatest risk for excess sodium to bind to them and cause dispersion. Sands have a larger particle size, resulting in less surface area; correspondingly, they cannot accept as much sodium as clay particles can.

6. The role of clay type.

The three main clay types are montmorillonite, illite, and kaolinite clays. On the microscopic scale, each of these clays has a different lattice structures, i.e., different building blocks. This directly affects the ability for sodium to bind to the clay particles. Basically, the more sodium that a certain type of clay is able to hold, the more infiltration and hydraulic conductivity will be reduced. Montmorillonite clays are affected by sodium the most, while kaolinite is affected the least. This same pattern is also true for the swelling factor. Montmorillonites are the most prone to swelling and dispersion, whereas kaolinites are the least likely to swell and disperse.

This paper has been adapted for the understanding of the general public. Readers can access the technical version at: http://waterquality.montana.edu/docs/methane/basics.shtml

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