Jeffrey C. Silvertooth
Professor & Extension Specialist – Agronomy/Soil Science
Department of Environmental Science
University of Arizona

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Reclamation of Saline and Sodic Soils

In the late 19th and early 20th centuries, as people moved out to settle the open territories of the western U.S., the development of lands for agriculture was a primary objective. However, they encountered problems with lands and soils that were sometimes found to be unsuitable for irrigation and crop production, often due to salinity, sodicity, and drainage problems. It was immediately recognized that much of the land and soils in the western U.S. needed to be "reclaimed" from their natural condition. The "reclamation" of these lands became an important part of the process. All this development was dependent on the availability of water and good land and water management capacities. This required large tracts of land and large projects. As a result, the U.S. federal government became involved in the development of these western territories.

In response to these needs in the western U.S. territories, the Reclamation Act and the U.S. Reclamation Service (USRS) was formed within the US Geological Survey under the Secretary of the Interior Ethan Allen Hitchcock when Theodore Roosevelt signed The Reclamation Act on 17 June 1902. The new USRS was given the responsibility of studying potential water development projects in each western state with federal lands. In 1907, the Secretary of the Interior separated the USRS from the USGS and created the Bureau of Reclamation (BoR) as a distinct entity within the Department of the Interior.

Along with the USRS and BoR, the U.S. Department of Agriculture (USDA) sent agronomists (crop and soil scientists) out into the western territories to study the soils and climate to find crop plants that were well-suited for adaptation. Colleges of Agriculture with the Land Grant Universities, such as the University of Arizona, were also involved in this process.

In the arid and semi-arid regions of the western U.S. soils were commonly saline from the accumulation of soluble salts due to low rainfall and high evaporation demand from the climate.

Most of the soils suitable for crop production agriculture, such as in Arizona, are alluvial soils (deposited over time by water associated with rivers and streams) that are young geologically and very fertile and productive once they are reclaimed from salinity and sodicity. Salts had accumulated in these soils due to water being drawn out of the soils through evaporation. This repeated action over long periods of time resulted in high concentrations of soluble salts deposited in the upper portions of the soil profile. Soils were classified in terms of the salinity levels and today we commonly use the electrical conductivity (EC) of the soil solution as a standard measure. That is because solutions increase in electrical conductivity as the solute concentration, or salinity increases. The measure of EC is used for water (EC_w) and the soil solution or soil saturation extracts (ECe).

The international (SI) unit of conductivity is ‘Siemens’ with the symbol ‘S’ per meter. The equivalent non-SI unit is ‘mho’ and 1 mho = 1 Siemens. Thus, for those not familiar with the SI system, mmhos/cm can be read the same as dS/m without any numerical change. The use of mmhos/cm is still found with some laboratories and references.

By definition a saline soil is a non-sodic soil containing sufficient soluble salt to adversely affect the growth of most crop plants with a lower limit of electrical conductivity of the saturated extract (ECe) being 4 deciSiemens / meter (dS/m) or greater, which is equivalent to a value of 4 mmhos/cm . It is important to note that this is a lower limit by definition but the degree of soil salinity conditions are fully dependent upon the crop in question. Crop plant sensitivity to salinity varies tremendously among species (Tables 1 and 2).

Soil Salinity Class	**Conductivity of the Soil Saturation Extract EC_e (dS/m)**	**General Effect on Crop Plants**
Non-saline	0-2	Salinity effects negligible
Slightly saline	2-4	Yields of sensitive crops may be restricted
Moderately saline	4-8	Yields of many crops are restricted
Strongly saline	8-16	Only tolerant crops yield satisfactorily
Very strongly saline	>16	Only a few tolerant crops yield satisfactorily

Table 1. Soil salinity classes and crop growth.

Arid land soils are commonly naturally saline due to the process of soluble salt accumulations over long periods of time. Also, the rivers, streams, and aquifers used for irrigation also commonly carry significant concentrations of soluble salts. Dr. Wilford Gardner, one of my predecessors, colleagues, and friend from the UA, once state that "Successful irrigation schemes in arid regions carry the seeds of their own demise". This refers to the natural salinity of irrigation waters that will result in damaging salt accumulations over time if not managed properly.

Irrigation waters in Arizona commonly carry significant salt loads. As an example, by use of a simple conversion factor of 2.7 we can convert the concentration of any given solute in water to pounds (lbs.) of that solute delivered in each acre-foot (AF) of water. The following example uses water with a total solute (salt) concentration of 750 parts per million (ppm or mg/l), which is similar to Colorado River water quality. We can see that delivering five AF of this irrigation water in a single season delivers five tons of salt into that field. As a result, we must deal with this constant salt delivery in desert crop production systems.

Example: Solute Concentration (ppm) X 2.7 = lbs. of solute/AF-water

750 ppm X 2.7 = 2,032.5 lbs. salt/AF

2,032 lbs. salt/AF X 5 AF-water = 10,162.5 lbs. salt/acre

= (5.0 T salt/acre)

For the reclamation and management of soluble salts in a soil profile, leaching and the downward movement of the soluble salts through the crop root zone is the effective procedure needed. Leaching is accomplished by applying additional amounts of irrigation water to a soil profile that is already saturated. Leaching and the removal of soluble salts is effective when the soil-water moves below the root zone and good internal soil drainage carries the salts out of the soil-plant system in the field. Therefore, movement of water through the soil profile and root zone and good internal soil drainage are essential elements to this process of soil reclamation and management. Soil amendments are not needed for saline soil management. Additional water for salt leaching is needed.

A common question is "how much additional water is needed to accomplish sufficient leaching?". That is primarily dependent on the crop and the salinity level of the irrigation water. An effective and straightforward method of calculating a leaching requirement (LR) can be calculated with the following equation that was presented by the USDA Salinity Laboratory (Ayers and Westcot, 1989).

Leaching Requirement (LR) Calculation:

$$\mathbf{LR} = \frac{\mathbf{EC_w}}{5(\mathbf{EC_e}) - \mathbf{EC_w}}$$

Where:

EC_w = salinity of the irrigation water, electrical conductivity (dS/m)
EC_e = critical plant salinity tolerance, electrical conductivity (dS/m)

This is a good method of a LR calculation that has been utilized extensively and successfully in Arizona and the desert Southwest for many years. We can easily determine the salinity of our irrigation waters (EC_w) and we can find the critical plant salinity tolerance level from easily available tabulations of salinity tolerance for many crops (Ayers and Westcot, 1989). Additional direct references are from Dr. E.V. Maas' lab at the University of California (Maas, 1984: Maas, 1986; Maas and Grattan, 1999; Maas and Grieve, 1994; and Maas and Hoffman, 1997).

There are many methods to calculate the proper LR and the one shown here (Ayers and Westcot, 1989) is good in my view because it includes the specific salinity limits for the crop and salinity levels of the irrigation water. Also, it is very simple and straightforward to use and apply.

For example, we can see in Table 2 from a few selected crops commonly grown in Arizona the variation in salinity tolerance. For a given quality of water (EC_e) the LRs calculated from the equation above will increase with lower salinity tolerance levels. For example, lettuce will require a higher LR than cotton or barley using the same water for irrigation.

Table 2. Salinity tolerance for selected crops with soil solution salinity levels (ECe, dS/m at 25^{o}C) where yields will be reduced by 10, 25, and 50%.

Crop	10%	25%	50%
Lettuce (*Latuca sativa* L.)	2	3	5
Broccoli (*Brassica oleracea* L.)	4	6	8
Cotton (*Gossypium hirsutum* L.)	10	12	16
Barley (*Hordeum vulgare* L.)	12	16	18

Adapted from L. Bernstein, Salt Tolerance of Plants, USDA Bull. 283, 1964 and E.V. Maas, 1984.

The other major issue of reclamation and management of arid region soils is associated with high sodium (Na) concentrations. Sodic soils are often identified by problems with water infiltration and extensive soil crusting. By definition, a sodic soil is non-saline (ECe < 4.0 dS/m) but with relatively high levels of Na on the soil cation exchange complex (CEC). The Na in the soil is commonly measured by the Sodium Adsorption Ratio (SAR) from a soil analysis or the Exchangeable Sodium Percentage (ESP). The SAR is commonly used because it is a more direct and faster method of analysis in the laboratory.

By definition, sodic soils have an SAR ≥ 13 and a pH > 8.5. However, that is not a great diagnostic tool in itself since we have encountered cases in many arid regions, including Arizona, where that pH classification does not hold. Finer textured soils with higher clay content can express sodicity symptoms, soil crusting and infiltration problems with SAR values of 6-12. Thus, finer textured soils are more sensitive in this regard.

It is important to note that saline soils will be well-aggregated with good soil structure. On the other hand, sodic soils will be dispersed with poor aggregation and bad soil structure.

The SAR for a soil can be easily calculated from the laboratory analysis of a good soil sample from the field with the following equation:

<u>SAR = Sodium Adsorption Ratio</u>

when using concentrations of mmoles L^{-1}

$$\mathbf{SAR} = \frac{[\mathbf{Na}^{+}]}{[\mathbf{Ca}^{2+} + \mathbf{Mg}^{2+}]^{1/2}}$$

Sodic soil problems require a two-step process for reclamation that includes first a soil amendment, commonly a calcium (Ca) source to replace the Na on the CEC with materials such as Gypsum ($CaSO_4$). In Arizona and the desert Southwest, our soils are generally very calcareous, with high amounts of natural Ca in the form of $CaCO_3$, commonly known as caliche. Agricultural acid is often used to liberate free Ca in the soil from the caliche present that is then used to effectively exchange for the Na on the soil CEC. Following that chemical exchange, the soluble Na then needs to be leached out of the soil profile, Figure 2. Thus, sodic soil reclamation is a two-step process: 1) Exchange of Na with Ca and 2) leaching of soluble Na^+ from the crop root zone.

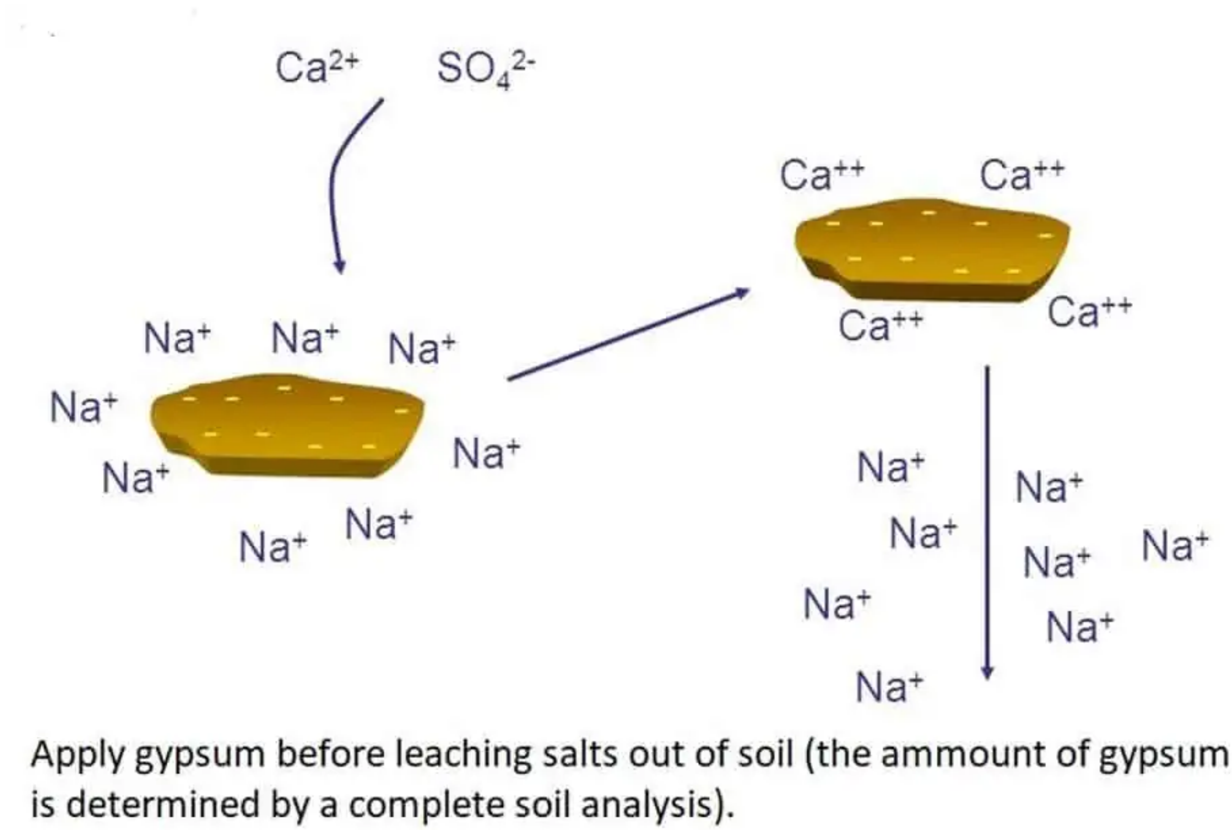

Figure 1. Calcium (Ca^{2+}) and (Na^{+}) exchange and leaching of soluble Na^{+}

Thus, in either case of dealing with a saline and/or sodic soil, leaching and additional water is needed for remediation and sustainable land management. This means additional irrigation water is needed above and beyond the requirement for crop water consumptive use.

For viable and sustainable crop production systems in the western U.S., appropriate agronomic (crop and soil) management of soil salinity and sodicity is essential. We need irrigation water to not only sustain crop water needs but also enough water to sufficiently leach the soluble salts from the soil profile. Accordingly, good soil drainage is also essential. There are many historical and present-day cases around the world in arid and semi-arid regions where this has been ignored or mis-managed and it has consistently served to the demise of those agricultural systems.

In summary, saline soils need sufficient leaching of soluble salts for reclamation and management. No soil amendments are needed for a saline soil management. Sodic soils will require an amendment to exchange the Na on the soil CEC with Ca or a similar ion. Then soluble Na in soil solution needs to be leached from the crop root zone. Thus, salinity management involves the basic process of adequate soil leaching and sodic soil reclamation is a two-step process: 1) Na exchange and 2) leaching of soluble Na from the crop root zone with sufficient irrigation water.

One of the best management practices in the field is to watch and monitor crop and soil conditions, take soil and water samples as part of the routine field monitoring effort, and manage irrigations and drainage systems to accommodate total water needs that our soil-plant systems and crop production operations depend on.

One concern that we should all be alert to in this time of water shortage, is the need to manage and budget sufficient irrigation water to manage our agricultural lands and soils for optimum crop water needs and also leaching to manage soil salinity. Arizona and desert Southwest agriculture has done a good job of this in the past by adequately managing salinity and sodicity in our crop production systems and it is important that we incorporate these points into our future management plans. Reclamation was important 120 years ago and it is still extremely important for us today in the management of western agriculture and crop production systems.

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