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DROUGHT TIP

Reclaiming Saline, Sodic, and Saline-Sodic Soils

Salt-affected soils cause poor plant growth, affect crop production, and reduce water use efficiency. Some salt-affected soils have physical problems that slow water infiltration and increase surface runoff. The reclamation of salt-affected soils can lead to better water management, water use efficiency, and crop production.

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The first step in reclaiming a salt-affected soil is diagnosis of the problem. There are three types of salt-affected soils: saline, sodic, and saline-sodic. Each of these three types of salt-affected soils has a different impact on plant growth and requires different reclamation strategies, so the type of salt-affected soil must be determined prior to cultivation and/or reclamation. The information in table 1 is used to classify salt-affected soils. Typically, either electrical conductivity (EC, a measure of total soluble salts) and exchangeable sodium percentage (ESP, the percentage of cation-exchange sites occupied by sodium) or EC and sodium adsorption ratio (SAR, a ratio of sodium to soluble calcium and magnesium) are used to determine which type of salt-affected soil is present. Physical condition/soil structure and pH can also be good indicators.

Table 1. Properties used to classify salt-affected soil

Soil salinity/sodicity type	Electrical conductivity (EC)	Exchangeable sodium percentage (ESP)	Sodium adsorption ratio (SAR)*	pH	Physical condition
	dS m^{-1}	%			
Typical agricultural soil	< 4	< 15	< 13	< 8.0	good
Saline soil	> 4	< 15	< 13	< 8.5	good
Sodic-only soil	< 4	> 15	> 13	> 8.5	poor
Saline-sodic soil	> 4	> 15	> 13	< 8.5	poor to good

SAR of the soil water extract

Saline Soils

Saline soils have a high amount of soluble salts, as indicated by an EC > 4 dS m^{-1} (table 1). Saline soils often exhibit white salt deposits or crusts, visible at the soil surface. Saline soils typically do not display poor soil structure, and as a result, they have adequate water infiltration rates.

Sodic Soils

Sodic soils have a high amount of exchangeable sodium on the cation-exchange sites. These soils are characterized by having ESP > 15% (table 1). A high sodium adsorption ratio (SAR > 13) can be used as a proxy for ESP. Sodic soils have low salinity (EC < 4 dS m^{-1}) and often a very high pH (> 8.5). They are typically very dark in color and are often called "black alkali" soils. Low-salinity irrigation water can increase soil dispersion/sealing and reduce water infiltration in sodic soils.

Sodic soils display poor physical condition because exchangeable sodium disperses clay minerals, causing soil structure to degrade. Dispersed clay minerals move with percolating water and eventually clog large soil pores that are critical for both aeration and water movement. This, in turn, decreases the soil's infiltration rate and permeability. These impenetrable layers are often at or near the soil surface.

Saline-Sodic Soils

There are also sodic soils with a lower pH and no dark coloration. Many of the soils on the west side of the San Joaquin Valley, often dominated by sodium sulfate salts, are both sodic and saline. Saline-sodic soils have high ESP (> 15%) and high salinity (EC > 4 dS m^{-1}) (table 1). These soils typically have better soil physical condition than non-saline sodic soils because their high soluble salt content keeps clay minerals flocculated (non-dispersed) and their soil structure stable. Similarly, the salt content buffers the pH to 8.5 or less. Reclamation processes must address both the salinity and the exchangeable sodium of saline-sodic soils. Low-salinity irrigation water can reduce infiltration in saline-sodic soils.

Salt-affected soils can cause a variety of problems. High salinity causes osmotic stress that makes the plant cells concentrate solutes, allowing water to move into the roots. This draws on the plants' energy and has the potential to reduce growth. High salinity in the root zone can drastically reduce crop yield. While saline soils have a threshold EC > 4 dS m^{-1}, salt-tolerant crops can grow in soils with higher salinity, though some crops are sensitive to EC values below this threshold. For a list of the salt tolerance rankings of some crops, see Hanson (2006) and other publications referenced at the end of this publication. High salinity is usually the combined result of the salt load of the soil's parent material and poor drainage. Salts will build up over time if water cannot be leached out of the soil profile. Similarly, saline soils can form where a high water table occurs together with irrigation water that is high in salts or even where irrigation water contains moderate to high levels of salts.

Excess sodium in sodic soils is toxic to some crops, particularly to trees that are exposed over several years. The sodium also competes with other cations such as potassium, calcium, and magnesium for plant uptake, and that can lead to plant nutrient deficiencies (Davis et al. 2014). The high pH characteristic of sodic soils decreases the availability of most essential plant nutrients.

Reclaiming Saline Soils

The most common reclamation strategy for saline soils is to flush the salts out of the root zone with good-quality water. Methods include continuous ponding, intermittent ponding, and sprinkling. The amount of water needed to reduce soil salinity to a specified level can be determined based on reclamation curves or equation 1 (Hanson, et al. 2006):

$$D_w = (k \times D_s \times EC_{ei}) \div EC_{ef} \qquad \text{(eq. 1)}$$

where:

D_w = depth of water infiltrated (feet)

D_s = depth of soil to be reclaimed (feet) k = 0.45 for organic soils, 0.30 for fine-textured soils and 0.10 for coarse-textured soils

EC_{ei} = initial soil salinity

EC_{ef} = final soil salinity desired

Continuous ponding

Continuous ponding involves the application of large volumes of standing water until enough salt has been removed from the root zone. The amount of water needed can be determined using equation 1.

The final desired salinity depends on the salinity tolerance of the crop. The actual amount of water required depends on soil type and the initial EC. Thus, monitoring the soil salinity over the reclamation period and afterwards is necessary to determining whether additional adjustments are needed.

Intermittent ponding or sprinkling reclamation

Intermittent ponding or sprinkling reclamation methods can be used to save water while reclaiming soils. Instead of ponding as a continuous application, several smaller amounts of water can be applied as ponded- or sprinkler-irrigation, followed by periods of dry down. The wetting and drying cycles efficiently leach salts from smaller soil pores using one-third to two-thirds less water than continuous ponding. To find the amount of water needed, you can use equation 1, substituting $k = 0.10$ for all soil types (Hanson et al. 2006).

One disadvantage of intermittent ponding and sprinkler application is the relatively long period required to complete the multiple wetting-and-drainage/drying cycles, as compared to continuous ponding, which is completed as a single event. Additionally, in areas with high evaporation, intermittent reclamation methods may be problematic because salts leached only to a shallow depth due to the small initial water applications can move back upward, toward the soil surface, during the drying period after water application. For this reason, leaching is much more effective when done during winter, when evaporation is at a minimum.

Drainage

Adequate drainage is needed to reclaim saline soils. Soils with a shallow water table require a subsurface drainage system so the drainage water will be able to leave the field. Otherwise, continuous ponding may saturate the soil up to its surface. With tile drains appropriately spaced in a field, the overall water table will be lowered, although the water table will be lowest just above the tile. If the water table remains too high between drainage lines, it is because the spacing between the drainage lines is too great and an additional line may need to be installed between the existing lines. Intermittent ponding or sprinkling will also improve leaching in areas that are distant from the drains. Sprinkling is usually the preferred reclamation method under these conditions.

Reclaiming Sodic and Saline-Sodic Soils

Sodic and saline-sodic soils are reclaimed by replacing the exchangeable sodium with calcium. This is commonly accomplished by adding gypsum, since it is relatively soluble and inexpensive. However, if the soils are naturally high in calcium carbonate (lime), fine-ground elemental sulfur or sulfuric acid can be applied without having to apply calcium directly to the soil. The sulfur, with the aid of soil microbes, will oxidize in the moist soil to form sulfuric acid, which will dissolve the lime, making its calcium available in solution to replace the sodium on the soil exchange sites. This is a fairly slow process, dependent on the exposed surface area of the sulfur particles. Sulfur should be mixed into the surface layer of the soil. Acid can be applied to the soil or injected into the irrigation water. Care must be taken to ensure that the calcium reaches all depths designated for reclamation. Saline-sodic soils should be leached with good-quality (low-sodium) water after treatment with calcium-bearing amendments or sulfur. As with saline soil reclamation, adequate drainage must be maintained for both sodic and saline-sodic soils to flush sodium out of the system (Horneck, et al. 2007).

Restoration of sodic and saline-sodic soils is a slow process. Reclamation will occur sequentially with depth as the calcium saturates the cation-exchange sites and moves down through the soil profile. Therefore, if deeper reclamation is desirable, you need to add sufficient gypsum to ensure that reclamation extends to the full desired depth. However, it is best not to apply the gypsum all at once. It is better and more effective to add the gypsum in annual increments until the desired exchangeable sodium percentage (ESP) is reached at the desired depth. Organic materials such as composts and manures as well as salt-tolerant cover crops can be helpful in maintaining surface soil structure/aggregation for adequate infiltration and completion of the reclamation process (Davis et al. 2014). Continued monitoring of salinity and sodicity is also recommended.

How Much Material to Apply for Saline-Sodic and Sodic Soil Reclamation

Gypsum

The amount of gypsum needed for reclamation depends on the soil's initial ESP, the final level desired for exchangeable sodium, the soil's capacity to adsorb sodium and calcium, the soil's bulk density, and the total depth of soil to be reclaimed. The amount of gypsum needed—called the gypsum requirement—is determined by laboratory analysis. In the absence of such an analysis, recommended rates range from 3 to 5 tons per acre. A rule of thumb for estimating the amount of water to apply is that about 3 inches of water per acre will dissolve 1 to 2 tons of gypsum.

Example 1. Gypsum requirement calculation:

Your soil has a CEC of 20 milliequivalents (meq) per 100 grams of soil and an ESP of 20%, and you desire a final ESP of approximately 5%. In these calculations it is acceptable to assume that SAR is roughly equivalent to ESP.

Calculate the percent exchangeable sodium that must be replaced with calcium:

20% (measured ESP) – 5% (desired ESP) = ESP of 15%,

meaning that 15% of exchangeable sodium must be replaced with calcium (Ca) to achieve the desired ESP.

Now convert the exchangeable sodium percentage that you want to replace into milliequivalents of sodium to be replaced:

0.15 (15%) × 20 meq of CEC/100g soil = 3 meq/100g soil

As a general rule, 1.7 tons of gypsum (100% equivalent purity) is required per milliequivalent of sodium per 100g soil for one acre-foot of soil:

3 meq/100g soil × 1.7 = 5.1 tons of gypsum needed to reclaim the 0-to-1-foot depth of soil on 1 acre of land.

Thus, about 5 tons of pure gypsum per acre would be required to reclaim the top 12 inches of this soil. It may also be better to incorporate half this amount into the soil in the fall the first year and the second half the following fall. If reclamation were desired to a greater depth, you would continue adding gypsum in similar amounts on an annual basis, making sure to collect soil samples to monitor the reclamation process as it reaches toward the target depth. Make sure to adjust this calculation for your specific grade of gypsum and soil depth.

Sulfur

Sulfur is sometimes used to reclaim sodic soils that contain lime. In this case, soil tests are needed to determine the amount of lime present in the soil. The reclamation process is time consuming since the sulfur must first be oxidized by soil bacteria (*Thiobacillus*) to form sulfuric acid. This, in turn, dissolves the lime. However, the oxidation process requires warm, well-aerated, moist soil conditions, and is limited to the surface area of the soil particles. Sulfur applied in the fall may have little effect until the following summer.

Sulfuric Acid

Sulfuric Acid, when directly mixed into the soil or added to the irrigation water, dissolves lime that is already present in the soil, thus releasing free calcium that can exchange for sodium in the soil. The process is relatively rapid, but sulfuric acid is difficult and dangerous to handle.

Other amendments

Calcium chloride, calcium nitrate, lime sulfur, and ferric sulfate are other soil amendments that can be used for sodic soil reclamation. Calcium chloride and calcium nitrate are highly soluble materials, but they are expensive.

Table 2. Tonnage equivalent to 1 ton of pure gypsum for various amendments

Amendment	Application equivalent to 1 ton of pure gypsum
	tons
Gypsum	1 ton applied = 1 ton gypsum
Sulfur	0.19 ton applied = 1 ton gypsum
Sulfuric acid	0.61 ton applied = 1 ton gypsum
Ferric sulfate	1.09 tons applied = 1 ton gypsum
Calcium chloride	0.86 ton applied = 1 ton gypsum
Calcium nitrate	1.06 tons applied = 1 ton gypsum
Lime sulfur	0.78 ton applied = 1 ton gypsum

The "gypsum requirement" can be calculated as explained above, and it is often included as part of a laboratory agricultural soil analysis. However, you must remember that commercially available gypsum is not 100 percent pure, and you must apply it at a higher application rate to compensate for the lack of purity. The application rates for other amendments can be estimated on the basis of the amendment's equivalent to 1 ton of pure gypsum. To estimate the amount of impure gypsum or the amount of other amendments, use table 2 and equation 2:

$$\text{Applied tons required} = 100 \div \%\ \text{purity} \times \text{tons equivalent} \qquad \text{(eq. 2)}$$

Example 2. How much gypsum (60% purity) should be applied if the gypsum requirement is 3 tons per acre?

Tons equivalent = 1.00 (from table 2)

Applied amount = $100/60 \times 1 = 1.67$ tons

If the gypsum requirement is 3 tons per acre, then $3 \times 1.67 = 5$ tons per acre of 60% pure gypsum should be applied.

Example 3. How much sulfuric acid (80%) purity) should be applied if the gypsum requirement is 4 tons per acre?

Tons equivalent = 0.61 (from table 2)

Amount applied = $100/80 \times 0.61 = 0.76$ ton

For every ton of gypsum required, 0.76 ton of 80% pure sulfuric acid should be applied. The total amount to be applied is $4 \times 0.76 = 3$ tons per acre of sulfuric acid.

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For More Information

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