Determining the gypsum requirement for reclamation of sodic and sodium-impacted soils

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Gypsum application in an Arizona pecan orchard. Photo by Jim Walworth.

Recently, one of the authors received a question about determining the gypsum requirement (GR) for reclamation of sodic and sodium-impacted soils. The purpose of this article is to provide information to aid in understanding the laboratory procedure for determining GR and in developing and executing an effective reclamation program. Gypsum is frequently, although not always, used as part of the reclamation program.

Abbreviations

- **CEC**
  - cation exchange capacity;
- **EC_e**
  - electrical conductivity of the saturation extract;
- **ESP**
  - exchangeable sodium percentage; GR, gypsum requirement;

Sodic and saline soils commonly form in arid or semiarid environments where precipitation and/or drainage are insufficient for salts to be leached from soil profiles. Evaporation of water from the soil surface leaves salts behind where they accumulate. As the soil solution becomes increasingly concentrated, the less soluble salts precipitate. Calcium and magnesium salts, being less soluble than sodium salts, precipitate as lime ($CaCO_3$), gypsum ($CaSO_4$ $2H_2O$), epsomite ($MgSO_4$ $7H_2O$), and other minerals. Sodium, which is more soluble, remains in the soil solution, occupies cation exchange capacity (CEC), and can result in sodic or saline-sodic soils.

By USDA definition, a ***sodic soil*** has 15% or more of its CEC occupied by sodium and an electrical conductivity of the saturation extract (EC_e) less than 4 deciSiemens per meter (dS/m). Sodic, non-saline soil is de-flocculated or dispersed and has poor structure, low porosity, and very slow water infiltration. Dispersed organic matter produces a black color at the soil surface; thus, a common older term for it is *black alkali* soil.

A ***saline soil*** has an EC_e greater than 4 dS/m and less than 15% sodium on its cation exchange sites. Upon drying *in situ*, a white crust may form at the soil surface; thus, these soils have also been called *white alkali* soils. The high salinity and low sodicity of saline soils results in flocculated, well-structured soils.

A ***saline-sodic soil*** is both saline and sodic (EC_e greater than 4 dS/m and more than 15% of exchange capacity occupied by sodium). In contrast to sodic soils, saline-sodic soils contain sufficient salt to flocculate the soil, providing good improving structure and porosity despite the elevated exchangeable sodium. Saline soils can also have a white crust and are also called *white alkali* (the term white alkali does not differentiate between saline-sodic and saline soils). The expressions sodic, saline, and saline-sodic are preferred to the older *white* and *black alkali* terms.

The terms saline and non-saline do not describe the effects of soil salinity on plants. Effects of salinity on plant species are highly variable. Some plants are impacted by salinities less than 4 dS/m, whereas others may be unaffected by EC_e greater than 15 dS/m or more.

Leaching the Soil

Leaching a saline soil to reduce salt levels is sufficient for reclamation. In contrast, leaching a saline-sodic soil without appropriate amendments can produce a sodic soil, making reclamation much more difficult and more expensive, and must be avoided. Instead, exchangeable sodium is first replaced with calcium, often in the form of gypsum ($CaSO_4 \; 2H_2O$), and the displaced sodium can then be leached from the soil. The result is a non-saline, non-sodic soil.

Water availability and quality are critical for leaching exchangeable sodium. Leaching with water high in sodium content (indicated by a high sodium adsorption ratio, SAR) may exacerbate the sodium condition. A saline (high EC) water with a low SAR may contain sufficient salt for reclamation of sodic soils without the addition of any amendment although the resulting soil salinity may limit the crops that can be grown. Further leaching with non-saline (low EC) water can continue reclamation.

Adequate internal drainage is essential for leaching soil, thereby moving salts below crop rooting zones. If a restrictive layer such as dense clay or a cemented hard pan impedes water movement through the soil profile, salts cannot be moved beyond the rooting zone and may return as water evaporates from the soil surface.

Determining Amount of Gypsum to Apply

Close up of saline seep from a Montana field. Source: USDA-

NRCS Montana.

Determining the appropriate amount of gypsum to apply is key for soil reclamation. A method for estimating the GR was described by W. R. Schoonover and published in USDA Handbook 60 (United States Salinity Laboratory Staff, **1954**). The method is simple and straight forward. An aliquot of soil is shaken in a measured amount of saturated gypsum ($CaSO_4$ H_2O) solution (about 29 $cmol_c$/L). The shaken mixture is filtered. Calcium plus magnesium concentrations are measured in the saturated gypsum solution prior to mixing with soil as well as in the filtrate. Where the amount of Ca + Mg in the filtrate is less than in the saturated solution, the difference indicates the amount of soluble calcium required to saturate the soil CEC with calcium. If the amount in the filtrate is more than that in the saturated solution, soil may be able to be reclaimed without the addition of an amendment. These soils may contain native mineral gypsum that can dissolve, providing the soluble calcium needed to displace sodium.

An alternative GR calculation can be made using measurements of CEC and the percentage of CEC occupied by sodium (the exchangeable sodium percentage, ESP). This approach is based on the concept than 1 $cmol_c$/kg of Ca^{2+} can replace 1 $cmol_c$/kg of Na^+ (one charge of Ca^{2+} replaces one charge of Na^+). For gypsum, 1 $cmol_c$ weighs 0.86 g. Therefore, to replace all the sodium in 1 kg of a soil containing 10 $cmol_c$/kg of exchangeable sodium would require the addition of 8.6 g of gypsum. Calculations can be adjusted to determine the amount of gypsum needed to replace less than 100% of the exchangeable sodium.

This “ESP reduction” method of calculating GR can be complicated by the difficulty of accurately determining CEC of calcareous or gypsiferous soils. In calcareous soils, CEC should be measured using an alkaline exchanging solution to prevent dissolution of native calcium carbonate (Normandin et al., 1998). These problems are avoided with the Schoonover method, which is simpler and more rapid.

For either method of estimating GR, the amount of gypsum to apply on a field basis requires an estimate of the mass of soil to be treated. This depends on the depth of soil to be treated as well as the soil bulk density. If bulk density is unknown, the typical weight of an acre plow layer (or acre furrow slice—the soil in 1 acre and to a depth of about 7 inches) of 2,000,000 lb can be used.

Other Considerations

Montana field with saline seep. Source: USDA-NRCS Montana.

When using gypsum as a soil amendment, the particle size of applied gypsum is a factor to be considered. Finer material will dissolve faster than courser material. The degree of crystallinity also affects speed of reaction. Mined gypsum is relatively well crystalized and will react more slowly than gypsum produced during phosphate fertilizer production or from flue gas desulfurization.

In soils containing calcium carbonate, alternatives to gypsum can be effective. Mineral lime (calcium carbonate) in these soils can be converted to gypsum by adding sulfur, sulfuric acid, or other acidic or acid-forming materials (see Table 1 for equivalent quantities of various soil amendments). The acid dissolves the calcium carbonate, and the dissolved calcium forms gypsum. Gypsum can also be used to reclaim calcareous sodic soils.

Table 1. Equivalent quantities of some common amendments for sodic soil reclamation

Note: This is Table 27 from Abrol et al., **1988**. a These quantities are relative to gypsum and based on 100% pure materials. If the material is not 100% pure, necessary correction must be made.

Amendment	**Relative quantity**[a]
Calcium chloride ($CaCl_2 \cdot 2H_2O$)	0.85
Sulfuric acid (H_2SO_4)	0.57
Iron sulfate ($FeSO_4 \cdot 7H_2O$)	1.62
Aluminum sulfate [$Al_2(SO_4)_3 \cdot 18H_2O$]	1.29
Sulphur (S)	0.19
Pyrite (FeS_2)—30% sulfur	0.63
Calcium polysulfide (CaS_5)—24% sulfur	0.77

Saline and sodic soils are notoriously variable. Often some areas will require more gypsum than others, and some will be reclaimed faster than others. One technique for improving efficiency is to apply a “low” rate of gypsum, leach, and reapply to remaining sodic spots identified by additional soil testing or observation of field conditions.

The Schoonover GR is a useful tool for estimating the amount of gypsum needed to provide soluble calcium for reclamation of sodic soils. The ESP reduction method can utilize exchangeable cation measurements routinely provided by many test laboratories but suffers from inaccuracies in these measurements. In either case, GR determinations are estimates that provide an educated starting point for soil reclamation. Keen field observation along with follow-up soil testing can make reclamation of saline, sodic, and saline-sodic soils efficient and cost effective.

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