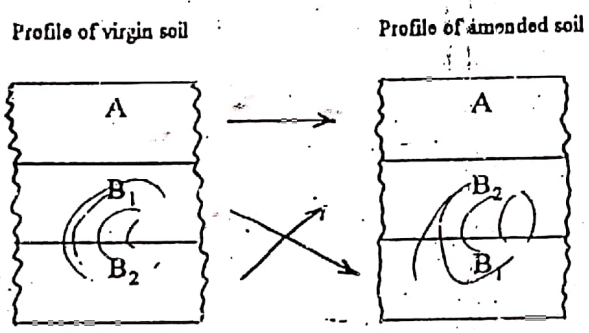
Hauling

This technique involves removal of the salt affected surface soil and replacing it with a good soil up to a desired depth. Hauling is absolutely useful but it might not be applicable every where because this method is considered expensive..

Horizon mixing

This method is used when the surface soil is good but the upper subsoil has undesirable characteristics. This situation occurs in saline-sodic/sodic soils having a favourable soil surface underlain by a slowly permeable, sodium-affected B horizon which is underlain by a more permeable horizon sometimes containing gypsum. The objective of profile mixing is to retain the surface soil while inverting the subsoil and substratum. this is done by removing the surface soil, deep ploughing the subsoil and substratum, then again replacing the surface soil.



The purpose of first three methods is to increase soil permeability directly by fine and coarse textured layers and to obtain a more uniform layer (deep ploughing), by breaking the impermeable layers (subsoiling), and by incorporating sand to a fine textured soil (sanding). Hauling deals with the replacement of the salt-affected surface soil with a good soil while horizon mixing covers an undesirable soil layer with a better material from a lower layer.

Chemical methods

The choice of a chemical amendment at any place depends upon its relative effectiveness as judged from improvement of soil properties and crop growth, its availability, cost, handling and application difficulties, and the time required to react in the soil and to replace the adsorbed Na^+. However, nature of the sodic soil to be reclaimed has an over-riding consideration in this respect. Amendments have shown different levels of effectiveness in reclaiming sodic/saline-sodic soils of varying characteristics. Chemical amendments generally used in saline-sodic/sodic soil reclamation fall into two broad categories:

1. **Inorganic amendments**, these can be further subdivided into three types.
   a) Soluble calcium salts, like $CaCl_2$, gypsum (mined gypsum) and phosphogypsum (a by-product from the manufacture of high-analysis P fertilizers).

b) Slowly soluble calcium salts, like ground limestone ($CaCO_3$).

c) Acidifying materials. These amendments work as Ca^{2+} mobilizers in calcareous soils by enhancing the conversion of $CaCO_3$ to more soluble $CaSO_4$, $Ca(HCO_3)_2$, $Ca(NO_3)_2$ or $CaCl_2$ include H_2SO_4, HCl, HNO_3, sulphur, pyrite (FeS_2), lime sulphur (CaS_5), $FeSO_4$, and $Al_2(SO_4)_3$.

Some chemical fertilizers may supply soluble Ca^{2+} directly [$Ca(NO_3)_2$ and single superphosphate (SSP)] or indirectly by producing physiological acidity within the zones of their application [$(NH_4)_2SO_4$ and urea]. The application of such fertilizers in the usual economical doses can not be expected to reduce the soil sodicity to a large extent.

Because of its comparatively low price, general availability and easy application than other amendments, gypsum is the most commonly used source of Ca^{2+} for the reclamation of both calcareous and non-calcareous sodic/saline-sodic soils. The gypsum required for reclamation, in megagram per hectare (Mg ha^{-1}, 1Mg = 1000kg),of sodic and saline-sodic soils is called gypsum requirement (GR) of the soils. A laboratory method (Schoonover's method) is generally used to determine the GR of the sodic and saline-sodic soils. Other inorganic amendments used for soil reclamation can be applied under suitable conditions. Equivalent quantities of chemically pure amendments relative to one Mg of gypsum are given in the following Table.

Table Amounts of amendments equivalent to one megagram of gypsum

Amendment	Formula	Amount equivalent to 1 Mg of gypsum (1 ton or 1000 Kg)
Gypsum	$CaSO_4 . 2H_2O$	1.00
Calcium chloride	$CaCl_2 . 2H_2O$	0.85
Sulphur	S_8	0.19
Ferrous sulphate	$FeSO_4 . 7H_2O$	1.61
Ferric sulphate	$Fe_2(SO_4)_3 . 9H_2O$	1.09
Aluminum sulphate	$Al_2(SO_4)_3 . 18H_2O$	1.29
Sulphuric acid (36*N*)	H_2SO_4	0.57
Hydrochloric acid (12*N*)	HCl	1.71

2. Organic amendments

Organic matter is needed to maintain and even to improve the physical, chemical and fertility characteristics of normal as well as salt affected soils. The organic amendments include green manures, farm manures, poultry manures, slaughter house waste, etc. The use of some organic polymers (polyvinyl alcohol, *PVA*) has also been suggested for the reclamation of sodic soils. By-products of certain industries, e.g. pressmud and molasses meal from sugar industry may be effective but their extensive use

Sulphate

is limited because of limited availability. These amendments can reclaim saline-sodic/sodic soils but at a very slow rate.

Methods of amendment application

The method of application of amendments to sodic soils is crucial in determining their reclamation efficiency. Highly corrosive amendments, like H_2SO_4 added to water passing through metal or concrete irrigation systems, may cause damage to the water carrying channels/pipes. In the case of gypsum, uniform spreading and depth of mixing are very important. Surface application of gypsum, i.e. directly on the surface or mixed shallowly (upto 10 cm) was found the best for soils having surface crusting and infiltration problems.

Particle-size of amendments

Maintenance of an adequate level of soluble Ca^{2+} is very important during the reclamation of sodic soils. This increases the rate of removal of exchangeable Na^+ and keeps the reaction steady in forward direction. The effects of particle size and source in the case of gypsum are very crucial for the rapidity of dissolution of this amendment to supply adequate soluble Ca^{2+}. The effect of particle-size has been investigated by many workers. Generally, The finer grades improve the sodic/saline-sodic soils earlier than the coarser particles because of greater dissolution. The coarser gypsum gives lower initial electrolyte levels which are maintained or increased with time. It has been found desirable to have a mixture of particles to obtain the dual benefit of an initial rapid dissolution of some fine gypsum followed by longer, sustained release of Ca^{2+} from coarser particles. In Pakistan, gypsum powder of less than 30 mesh size is marketed for application to the saline-sodic/sodic soils..

Chemical reactions of amendments

The following chemical equations illustrate the mauner in which various inorganic chemical amendments react in calcareous saline-sodic/sodic soils and non-calcareous saline-sodic/sodic soils. In these equations, the □ represents the soil exchange complex.

Calcareous saline-sodic/sodic soils

Gypsum

$$2Na\square + CaSO_4 \rightleftharpoons Ca\square + Na_2SO_4$$

Sulphur

$$2S + 3O_2 \rightleftharpoons 2SO_3 \qquad \text{(microbial oxidation)}$$

$$SO_3 + H_2O \rightleftharpoons H_2SO_4$$

$$H_2SO_4 + CaCO_3 \rightleftharpoons CaSO_4 + CO_2 + H_2O$$

$$2Na\square + CaSO_4 \rightleftharpoons Ca\square + Na_2SO_4$$

(6)

Lime-sulphur (calcium polysulphide)

$$CaS_5 + 8O_2 + 4H_2O \rightleftharpoons CaSO_4 + 4H_2SO_4$$

$$H_2SO_4 + CaCO_3 \rightleftharpoons CaSO_4 + CO_2 + H_2O$$

$$2Na\square + CaSO_4 \rightleftharpoons Ca\square + Na_2SO_4$$

Iron sulphate

$$FeSO_4 + H_2O \rightleftharpoons H_2SO_4 + FeO$$

$$H_2SO_4 + CaCO_3 \rightleftharpoons CaSO_4 + CO_2 + H_2O$$

$$2Na\square + CaSO_4 \rightleftharpoons Ca\square + Na_2SO_4$$

Sulphuric acid

$$H_2SO_4 + CaCO_3 \rightleftharpoons CaSO_4 + CO_2 + H_2O$$

$$2Na\square + CaSO_4 \rightleftharpoons Ca\square + Na_2SO_4$$

Hydrochloric acid

$$2HCl + CaCO_3 \rightleftharpoons CaCl_2 + CO_2 + H_2O$$

$$2Na\square + CaCl_2 \rightleftharpoons Ca\square + 2NaCl$$

Nitric acid

$$2HNO_3 + CaCO_3 \rightleftharpoons Ca(NO_3)_2 + CO_2 + H_2O$$

$$2Na\square + Ca(NO_3)_2 \rightleftharpoons Ca\square + 2NaNO_3$$

Non-calcareous saline-sodic/sodic soils

1 Gypsum

Same as in calcareous saline-sodic soils

2 Sulphur

$$2S + 3O_2 \rightleftharpoons 2SO_3 \qquad \text{(microbial oxidation)}$$

$$SO_3 + H_2O \rightleftharpoons H_2SO_4$$

$$2Na\square + H_2SO_4 \rightleftharpoons 2H\square + Na_2SO_4$$

Lime-sulphur (calcium polysulphide)

$$CaS_5 + 8O_2 + 4H_2O \rightleftharpoons CaSO_4 + 4H_2SO_4$$

~~$+ CaCO_3 \rightleftharpoons + CO_2 + H_2O$~~

$$10Na\square + 4H_2SO_4 + CaSO_4 \rightleftharpoons 8H\square + Ca\square + 5Na_2SO_4$$

Iron sulphate

$$FeSO_4 + H_2O \rightleftharpoons H_2SO_4 + FeO$$

$$2Na\square + H_2SO_4 \rightleftharpoons 2H\square + Na_2SO_4$$

Sulphuric acid

$$2Na\square + H_2SO_4 \rightleftharpoons 2H\square + Na_2SO_4$$

Hydrochloric acid

$$Na\square + HCl \rightleftharpoons H\square + NaCl$$

Nitric acid

$$Na\square + HNO_3 \rightleftharpoons H\square + NaNO_3$$

The results reported from time to time on the effectiveness of various chemical amendments for the reclamation of sodic/saline-sodic soils show a variety of response. Generally, H_2SO_4 among the acidulents and gypsum from other amendments were found to be the most effective reclaimants. Because of its comparatively low price and freight, general availability and easy application than other amendments, gypsum is the most commonly used source of Ca^{2+} for the reclamation of both calcareous and non-calcareous sodic/saline-sodic soils.

Biological methods

The term "biological reclamation" is used to describe the reclamation of a salt-affected soil by growing crops on the affected area. Sometimes, addition of organic matter to the salt-affected soils as farm yard/green manure is also included under the same heading. Use of manures/other organic materials for the reclamation of salt-affected soils should preferably be treated separately to avoid confusion between the organic and the biological amendments.

The soil being host for crops is influenced by both the below- and above-ground plant parts. The below-ground parts comprising roots can modify conditions within the root-soil interface (rhizosphere) in many ways. Roots tend to change the soil pH, lower oxygen concentration, release organic compounds and complex energy sources such as exudates, secretions, and mucilages, produce chelating and/or reducing substances, increase CO_2 partial pressure, provide channels for soil solution movement,