

Alkali soil

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Alkali, or alkaline, soils are clay soils with high pH (> 8.5), a poor soil structure and a low infiltration capacity. Often they have a hard calcareous layer at 0.5 to 1 metre depth. Alkali soils owe their unfavorable physico-chemical properties mainly to the dominating presence of sodium carbonate, which causes the soil to swell^[1] and difficult to clarify/settle. They derive their name from the alkali metal group of elements, to which sodium belongs, and which can induce basicity. Sometimes these soils are also referred to as (*alkaline*) *sodic soils*.

Alkaline soils are basic, but not all basic soils are alkaline.

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Rice cultivation / paddyfield in alkali soils

Causes

The causes of soil alkalinity can be natural or man-made:

1. The natural cause is the presence of soil minerals producing sodium carbonate (Na_2CO_3) and sodium bicarbonate (NaHCO_3) upon weathering.
2. Coal-fired boilers / power plants, when using coal or lignite rich in limestone, produce ash containing calcium oxide. CaO readily dissolves in water to form slaked lime— $\text{Ca}(\text{OH})_2$ —and carried by rain water to rivers / irrigation water. Lime softening process precipitates Ca and Mg ions / removes hardness in the water and also converts sodium bicarbonates in river water into sodium carbonate.^[2] Sodium carbonates (washing soda) further reacts with the remaining Ca and Mg in the water to remove / precipitate the total hardness. Also water-soluble sodium salts present in the ash enhance the sodium content in water. The global coal consumption is 7700 million tons in the year 2011. Thus river water is made devoid of Ca and Mg ions and enhanced Na by coal-fired boilers.
3. Many sodium salts are used in industrial and domestic applications such as Sodium carbonate, Sodium bicarbonate (baking soda), Sodium sulphate, Sodium hydroxide (caustic soda), Sodium hypochlorite (bleaching powder), etc. in huge quantities. These salts are mainly produced from Sodium chloride (common salt). All the sodium in these salts enter into the river / ground water during their production process or consumption enhancing water sodicity. The total global consumption of sodium chloride is 270 million tons in the year 2010. This is nearly equal to the salt load in the mighty Amazon River. Man made sodium salts contribution is nearly 7% of total salt load of all the rivers. Sodium salt load problem aggravates in the downstream of intensively cultivated river basins located in China, India, Egypt,

Pakistan, west Asia, Australia, western US, etc. due to accumulation of salts in the remaining water after meeting various transpiration and evaporation losses.^[3]

- Another source of man made sodium salts addition to the agriculture fields / land mass is in the vicinity of the wet cooling towers using sea water to dissipate waste heat generated in various industries located near the sea coast. Huge capacity cooling towers are installed in oil refineries, petrochemical complexes, fertilizer plants, chemical plants, nuclear & thermal power stations, centralized HVAC systems, etc. The drift / fine droplets emitted from the cooling towers contain nearly 6% sodium chloride which would deposit on the vicinity areas. This problem aggravates where the national pollution control norms are not imposed or not implemented to minimize the drift emissions to the best industrial norm for the sea water based wet cooling towers.^[4]
- The man-made cause is the application of softened water in irrigation (surface or ground water) containing relatively high proportion of sodium bicarbonates and less calcium and magnesium.^[1]

Agricultural problems

Alkaline soils are difficult to take into agricultural production. Due to the low infiltration capacity, rain water stagnates on the soil easily and, in dry periods, cultivation is hardly possible without copious irrigated water and good drainage. Agriculture is limited to crops tolerant to surface waterlogging (e.g. rice, grasses) and the productivity is low.

Chemistry

Soil alkalinity is associated with the presence of sodium carbonate (Na_2CO_3) or sodium bicarbonate (NaHCO_3) in the soil,^[5] either as a result of natural weathering of the soil particles or brought in by irrigation and/or flood water.

- $\text{Na}_2\text{CO}_3 + \text{H}_2\text{O} \rightleftharpoons 2\text{NaOH} + \text{CO}_2$
- $\text{NaHCO}_3 \rightleftharpoons \text{NaOH} + \text{CO}_2$

Sodium carbonate in water can produce carbon dioxide (CO_2), escaping as a gas or absorbed by Algae, and sodium hydroxide (Na^+OH^-), which is alkaline (or rather basic) and gives high pH values ($\text{pH} > 8.5$).^[5]

Notes:

- Water (H_2O) is partly dissociated into H_3O^+ (hydronium) and OH^- (hydroxyl) ions. The ion H_3O^+ has a positive electric charge (+) and the hydroxyl group OH^- has a negative charge (−). In pure, neutral water, the concentration of H_3O^+ and OH^- ions equals 10^{-7} eq/l each (respectively 19×10^{-7} g/l and 17×10^{-7} g/l), very small concentrations.
- 1 eq = 1 equivalent weight corresponds to as many grams of the substance as its formula weight divided by its valence. It is also known as *gram-molecule* or mole per unit of valence. For the hydronium ion (H_3O^+) the formula weight equals 19, and for the hydroxyl group (OH^-) it equals 17.
- In neutral water, the pH, being the negative log value of the H_3O^+ concentration in eq/l, is 7. Similarly, the pOH is also 7. Each unit decrease in pH indicates a tenfold increase of the H_3O^+ concentration. Similarly, each unit increase in pH indicates a tenfold increase of the OH^- concentration.

- In water with dissolved salts, the concentrations of the H_3O^+ y OH^- ions may change, but their sum remains constant, namely $7 + 7 = 14$. A pH of 7 therefore corresponds to a pOH of 7, and a pH of 9 with a pOH of 5.
- Formally it is preferred to express the ion concentrations in terms of chemical activity, but this hardly affects the value of the pH.
- Water with excess H_3O^+ ions is called acid ($\text{pH} < 7$), and water with excess OH^- ions is called alkaline or rather basic ($\text{pH} > 7$). Soil moisture with $\text{pH} < 4$ is called very acid and with $\text{pH} > 10$ very alkaline (basic).

The reaction between Na_2CO_3 and H_2O can be represented as follows:



Carbonic acid H_2CO_3 is unstable and produces H_2O (water) and CO_2 (carbon dioxide gas, escaping into the atmosphere). This explains the remaining alkalinity (or rather basicity) in the form of soluble sodium hydroxide and the high pH or low pOH.

Not all the dissolved sodium carbonate undergoes the above chemical reaction. The remaining sodium carbonate, and hence the presence of CO_3^{2-} ions, causes CaCO_3 (which is only slightly soluble) to precipitate as solid calcium carbonate (limestone), because the product of the CO_3^{2-} concentration and the Ca^{2+} concentration exceeds the allowable limit. Hence, the calcium ions Ca^{++} are immobilized.

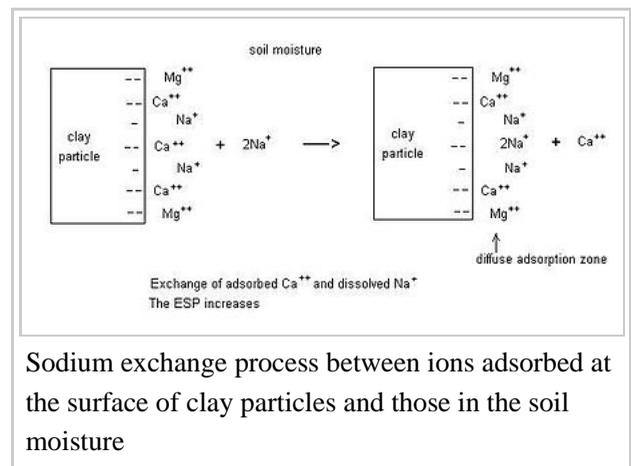
The presence of abundant Na^+ ions in the soil solution and the precipitation of Ca^{++} ions as a solid mineral causes the clay particles, which have negative electric charges along their surfaces, to adsorb more Na^+ in the *diffuse adsorption zone* (**DAZ**, see figure, officially called *diffuse double layer*^[6]) and, in exchange, release previously adsorbed Ca^{++} , by which their *exchangeable sodium percentage* (**ESP**) is increased as illustrated in the figure.

Na^+ is more mobile and has a smaller electric charge than Ca^{++} so that the thickness of the DAZ increases as more sodium is present. The thickness is also influenced by the total concentration of ions in the soil moisture in the sense that higher concentrations cause the DAZ zone to shrink.

Clay particles with considerable ESP (> 16), in contact with non-saline soil moisture have an expanded DAZ zone and the soil swells (dispersion).^[6] The phenomenon results in deterioration of the soil structure, and especially crust formation and compaction of the top layer. Hence the infiltration capacity of the soil and the water availability in the soil is reduced, whereas the surface-water-logging or runoff is increased. Seedling emergence and crop production are badly affected.

Note:

- Under saline conditions, the many ions in the soil solution counteract the swelling of the soil, so that saline soils usually do not have unfavorable physical properties. *Alkaline soils, in principle, are not saline since the alkalinity problem is worse as the salinity is less.*



Alkalinity problems are more pronounced in clay soils than in loamy, silty or sandy soils. The clay soils containing montmorillonite or smectite (swelling clays) are more subject to alkalinity problems than illite or kaolinite clay soils. The reason is that the former types of clay have larger specific surface areas (i.e. the surface area of the soil particles divided by their volume) and higher cation exchange capacity (CEC).

Note:

- Certain clay minerals with almost 100% ESP (i.e. almost fully sodium saturated) are called bentonite, which is used in civil engineering to place impermeable curtains in the soil, e.g. below dams, to prevent seepage of water.

The quality of the irrigation water in relation to the alkalinity hazard is expressed by the following two indexes:

1) The sodium adsorption ratio (SAR,^[5])

The formula for calculating sodium adsorption ratio is:

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{[\text{Ca}^{++}/2 + \text{Mg}^{++}/2]}} = \frac{\{\text{Na}^+/23\}}{\sqrt{\{\text{Ca}^{++}/40 + \text{Mg}^{++}/24\}}}$$

where: [] stands for concentration in milliequivalents/liter (briefly meq/l), and { } stands for concentration in mg/l.

It is seen that Mg (Magnesium) is thought to play a similar role as Ca (Calcium).

The SAR should not be much higher than 20 and preferably less than 10;

When the soil has been exposed to water with a certain SAR value for some time, the ESP value tends to become about equal to the SAR value.

2) The residual sodium carbonate (RSC, meq/l,^[5]):

The formula for calculating residual sodium carbonate is:

$$\begin{aligned} \text{RSC} &= [\text{HCO}_3^- + \text{CO}_3^{=}] - [\text{Ca}^{++} + \text{Mg}^{++}] \\ &= \{\text{HCO}_3^-/61 + \text{CO}_3^{=}/30\} - \{\text{Ca}^{++}/20 + \text{Mg}^{++}/12\} \end{aligned}$$

which must not be much higher than 1 and preferably less than 0.5.

The above expression recognizes the presence of bicarbonates (HCO_3^-), the form in which most carbonates are dissolved.

While calculating SAR and RSC, the water quality present at the root zone of the crop should be considered which would take into account the leaching factor in the field.^[7] The partial pressure of dissolved CO_2 at the plants root zone also decides the Calcium present in dissolved form in the field water. USDA follows the adjusted SAR^[8] for calculating water sodicity.

Soil improvement

Alkaline soils with solid CaCO_3 can be reclaimed with grass cultures, organic compost, waste hair / feathers, organic garbage, waste paper, rejected lemons/oranges, etc. ensuring the incorporation of much acidifying material (inorganic or organic material) into the soil, and enhancing dissolved Ca in the field water by releasing CO_2 gas.^[9] Deep ploughing and incorporating the calcareous subsoil into the top soil also helps.

Many times salts' migration to the top soil takes place from the underground water sources rather than surface sources.^[10] Where the underground water table is high and the land is subjected to high solar radiation, ground water oozes to the land surface due to capillary action and gets evaporated leaving the dissolved salts in the top layer of the soil. Where the underground water contains high salts, it leads to acute salinity problem. This problem can be reduced by applying mulch to the land. Using poly-houses or shade netting during summer for cultivating vegetables/crops is also advised to mitigate soil salinity and conserve water / soil moisture. Poly-houses filter the intense summer solar radiation in tropical countries to save the plants from water stress and leaf burns.

Where the ground water quality is not alkaline / saline and ground water table is high, salts build up in the soil can be averted by using the land throughout the year for growing plantation trees / permanent crops with the help of lift irrigation. When the ground water is used at required leaching factor, the salts in the soil would not build up.

Plowing the field soon after cutting the crop is also advised to prevent salt migration to the top soil and conserve the soil moisture during the intense summer months. This is done to break the capillary pores in the soil to prevent water reaching the surface of the soil.

Clay soils in high annual rain fall (more than 100 cm) areas do not generally suffer from high alkalinity as the rain water runoff is able to reduce/leach the soil salts to comfortable levels if proper rain water harvesting methods are followed. In some agricultural areas, the use of subsurface "tile lines" are used to facilitate drainage and leach salts. Continuous Drip irrigation would lead to alkali soils formation in the absence of leaching / drainage water from the field.

It is also possible to reclaim alkaline soils by adding acidifying minerals like pyrite or cheaper alum or Aluminium sulfate.

Alternatively, gypsum (calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) can also be applied as a source of Ca^{++} ions to replace the sodium at the exchange complex.^[9] Gypsum also reacts with sodium carbonate to convert into sodium sulphate which is a neutral salt and does not contribute to high pH. There must be enough natural drainage to the underground, or else an artificial subsurface drainage system must be present, to permit leaching of the excess sodium by percolation of rain and/or irrigation water through the soil profile.

Calcium Chloride is also used to reclaim alkali soils. CaCl_2 converts Na_2CO_3 into NaCl precipitating CaCO_3 . NaCl is drained off by leaching water. Spent acid (HCl , H_2SO_4 , etc.) can also be used to reduce the excess Na_2CO_3 in the soil/water.

Where urea is made available cheaply to farmers, it is also used to reduce the soil alkalinity / salinity primarily.^[11] The NH_4 (Ammonium) present in urea which is a weak cation releases the strong cation Na from the soil structure into water. Thus alkali soils absorb / consume more urea compared to other soils.

To reclaim the soils completely one needs prohibitively high doses of amendments. Most efforts are therefore directed to improving the top layer only (say the first 10 cm of the soils), as the top layer is most sensitive to deterioration of the soil structure.^[9] The treatments, however, need to be repeated in a few (say 5) years' time.

Trees / plants follow gravitropism. It is difficult to survive in alkali soils for the trees with deeper rooting system which can be more than 60 meters deep in good non-alkali soils.

It will be important to refrain from irrigation (ground water or surface water) with poor quality water.

One way of reducing sodium carbonate is to cultivate glasswort or saltwort or barilla plants.^[12] These plants sequester the sodium carbonate they absorb from alkali soil into their tissues. The ash of these plants contains good quantity of sodium carbonate which can be commercially extracted and used in place of sodium carbonate derived from common salt which is highly energy intensive process. Thus alkali lands deterioration can be checked by cultivating barilla plants which can serve as food source, biomass fuel and raw material for soda ash and potash, etc.

Leaching saline sodic soils

Saline soils are mostly also sodic (the predominant salt is sodium chloride), but they do not have a very high pH nor a poor infiltration rate. Upon leaching they are usually not converted into a (sodic) alkali soil as the Na⁺ ions are easily removed. Therefore, saline (sodic) soils mostly do not need gypsum applications for their reclamation.^[13]

See also

- Environmental impact of irrigation
- Soil pH
- Soil salinity control
- Cation-exchange capacity
- Soil fertility
- Residual Sodium Carbonate Index
- Drip irrigation
- Fertilizer
- Soil salinity
- Ammonia volatilization from urea
- Phosphate rich organic manure
- Red mud
- Phosphogypsum
- Soda lake
- Agreti green vegetable
- Sajji Khar
- Barilla
- Index of soil-related articles

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