

## Origin, Properties and Amelioration of Sodic Soils

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In the American view, dissolved inorganic salts adversely affect the properties of soils as a medium for plant growth in two main ways: 1. by increasing the osmotic pressure of the soil water and 2. by increasing the level of saturation of the soil cation-exchange materials with Na.

Soil material whose water at saturation has an osmotic pressure greater than 1.5 bars (electrical conductivity, EC,  $> 4$  mmho/cm) is considered to be saline, whereas if the sodium-adsorption-ratio, SAR ( $\text{Na}/\sqrt{\text{Ca} + \text{Mg}}$ , concn in mmoles/l) of the water exceeds 10, corresponding to an exchangeable-sodium-percentage (ESP) of about 15 at field-water contents, the material is considered to be sodic. On these bases soil material is classified as saline, sodic, nonsaline sodic, or saline sodic.

**Origin of sodic soils.** Sodic soils usually develop when soil material is subjected to waters having an abnormally high SAR ( $>5$ ) and/or a high proportion of  $\text{HCO}_3$  salts. They may form by surface applications of water or by the upward movement of groundwater, or by both. The tendency of a water to cause sodic soils is called its sodic hazard. The level to which the SAR of the soil water and the ESP of the soil material increases when subjected to waters having a sodic hazard depends upon the complex interaction of several factors: 1. the SAR of the incoming water, 2. the extent to which the volume of the incoming water decreases owing to evapotranspiration, 3. the precipitation of  $\text{CaCO}_3$  and occasionally  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  from the water as the volume decreases, and 4. the dissolution of Ca, Mg, and Na from soil minerals including  $\text{CaCO}_3$ ,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , and primary silicates. As the volume of water in the soil decreases by evapotranspiration, the SAR increases by a factor equal to the square root of the volume decrease factor, initial volume/subsequent volume. Further, if the solubilities of  $\text{Ca}(\text{HCO}_3)_2$  and  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  are exceeded as the volume of soil water decreases, the SAR of the soil water will increase additionally owing to the removal of Ca from solution. On the other hand, the dissolution of Ca and Mg from soil minerals lowers the SAR of the soil water owing to its appreciable solubility. For slightly weathered soil material of arid zones, dissolution of primary silicates (mainly ferromagnesium and plagioclase feldspar minerals) typically yields 3 to 4 me/l of Ca + Mg but  $< 1$  me/l of Na to the soil water; and, if the soil water is undersaturated with  $\text{Ca}(\text{HCO}_3)_2$ , small amounts of Ca will dissolve from soil  $\text{CaCO}_3$ .

For surface applications of water over time the reciprocal of the leaching fraction, LF, (depth of drainage water/depth of applied water) is a measure of the volume decrease factor. Hence, for this case, the effect of decreasing

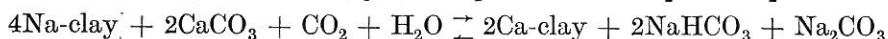
volume of soil water on its SAR is given by the equation

$$\text{SAR}_{\text{dw}} = \sqrt{1/\text{LF}} \text{SAR}_{\text{iw}}$$

where dw and iw refer to drainage and applied water, respectively. The calculated pH that a water would have if in equilibrium with  $\text{CaCO}_3$  ( $\text{pH}_c$ ) is an index of the tendency of the water to precipitate or dissolve  $\text{CaCO}_3$ . Based on experimental data involving 1. soil that yields typical amounts of dissolved Ca and Mg from minerals, 2. applications of waters having a range of SAR and  $\text{pH}_c$  values, and 3. use of various LF's, an empirical procedure has been developed for calculating  $\text{SAR}_{\text{dw}}$  values that take into account the  $\text{pH}_c$  value and the dissolution of minerals. The procedure consists of multiplying the measured Ca + Mg concentration of the applied water by a factor ranging from 0.2 to 5 that depends upon the water's  $\text{pH}_c$  value and the LF. The adjusted Ca + Mg concentration is then used to calculate an adjusted  $\text{SAR}_{\text{iw}}$  value which, in turn, is substituted in the above equation for calculating  $\text{SAR}_{\text{dw}}$ . The development of sodic soils by upward movement of groundwater has not been quantitatively studied but as essentially all of the upward moving water is eventually evapotranspired, the volume decrease and salt precipitation factors are maximized, and the mineral dissolution factor is minimized. Hence, with a water of a given sodic hazard, the SAR of the soil water and the ESP will increase faster and to a higher level if the movement is upward from a watertable.

**Properties of sodic soils.** The distinctive and dominant properties of sodic soils result from the abnormally high SAR of their soil water and the associated ESP. Owing to the presence of adsorbed Na, the clay-organic matter complex of sodic soils upon wetting swells, and both clay and organic matter tend to disperse so as to impair the permeability and tilth of the soil. The extent of swelling and dispersion depends upon the SAR and salt concentration of the soil water, the clay mineralogy, and the free  $\text{Fe}_2\text{O}_3$  and organic matter contents of the complex. The higher the SAR, and the lower the concentrations of salt, free  $\text{Fe}_2\text{O}_3$ , and organic matter, the greater the swelling and dispersion. Kaolinite and chlorite are nonswelling clay minerals, whereas montmorillonite swells markedly, and secondary micas and vermiculite swell slightly.

The physical properties of sodic soils are adverse whether they do or do not contain  $\text{CaCO}_3$ , and some sodic soils having poor physical properties are indeed acid in reaction. At low salt contents,  $\text{CaCO}_3$ -containing sodic soils usually have pH values in excess of 8.5. The alkalinity of such soils is due to the presence of significant concentrations of  $\text{NaHCO}_3$ , and, if the pH is  $> 9.5$ , of  $\text{Na}_2\text{CO}_3$ . The  $\text{NaHCO}_3$  and  $\text{Na}_2\text{CO}_3$  result from the equilibrium reaction of Na-clay with  $\text{CaCO}_3$  in the presence of  $\text{CO}_2$  and  $\text{H}_2\text{O}$ :



However, even at a partial  $\text{CO}_2$  pressure of 0.1 bar, the  $\text{NaHCO}_3 + \text{Na}_2\text{CO}_3$  concentration of the soil water will not exceed 15 or perhaps 20 me/l as long as Ca-clay is present.

The pH of low-salt,  $\text{CaCO}_3$ -containing sodic soils may be sufficiently high to interfere with the mineral nutrition of some crops, e.g., rice, and the Ca concentration of the soil water at high SAR ( $> 30$ ) may be sufficiently low to cause Ca-deficiency in legumes and other high Ca-requiring crops.

Over centuries of time, sodic soils with good drainage and leaching

Table 1  
 Alkalinity ( $\text{HCO}_3^- + \text{CO}_3^{2-} + \text{OH}^-$ ), Ca and Na concentrations of solutions in  
 equilibrium with Na—Ca Panoche soil (4 parts water: 1 part soil) as influenced  
 by ESP,  $\text{pCO}_2$  and  $\text{CaCO}_3^*$

Soil treatments			Equilibrium solution				Soil alkalinity as $\text{Na}_2\text{CO}_3$ %
ESP	$\text{CaCO}_3$	$\text{pCO}_2$ atm.	pH	$\text{HCO}_3^- + \text{CO}_3^{2-} + \text{OH}^-$ me/l	$\text{Ca}^{++}$ me/l	$\text{Na}^+$ me/l	
20	—	0	6.65	1.0	<1	1.6	0.02
20	+	0	7.26	2.4	<1	2.7	0.05
20	—	0.1	6.20	1.9	<1	2.5	0.04
20	+	0.1	6.65	8.5	4.6	2.7	0.18
50	+	0	8.56	4.0	<1	3.1	0.08
50	+	0.1	6.81	11.8	2.1	10.0	0.25
100	—	0	7.31	3.3	<1	2.6	0.07
100	+	0	9.30	10.4	<1	9.0	0.22
100	—	0.1	6.23	5.7	<1	4.6	0.12
100	+	0.1	7.19	26.9	<1	26.0	0.57

\* Data of CRUZ-ROMERO, Ph.D. Thesis, Univ. of California, Riverside

by rain water develop a sequence of morphological properties described briefly as follows: stage 1 (solonetz) — a thin layer of light, friable surface soil underlain by a deeper, dark, compact, columnar layer, and stage 2 (soloth) — a thin brown layer of friable soil over a deeper whitish, platy, leached layer that is, in turn, underlain by the lower part of the stage 1 columnar layer.

**Amelioration of sodic soils.** Sodic soils usually do not develop rapidly and normally they cannot be ameliorated quickly. In general, the sequence of steps in amelioration are 1. deepening the water table, if high, 2. removal of adsorbed Na and salt, and 3. improvement of permeability and tilth. The deepening of water tables by artificial drainage is an extensive subject in itself and will not be discussed.

Contrary to a widely held belief, adsorbed Na is not significantly removed from sodic soils by hydrolysis upon leaching; significant amounts are removed only if  $\text{CaCO}_3$  is present, the reaction being according to the equation given in the previous section. Application of  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  or occasionally sulfur (which forms  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  in  $\text{CaCO}_3$ -containing soils) followed by leaching is perhaps the most common method employed to replace adsorbed Na in the US. However, the efficiency of  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  is limited by its relatively low solubility which is usually insufficient to induce flocculation of the clay-organic matter complex and permit acceptable water intake and transmission rates for amelioration. Leaching with successive dilutions of highly saline water having 30% or more of Ca + Mg salts, if available, is an effective means of removing adsorbed Na while maintaining adequate soil permeability. As the saline water is diluted with low-salt water, its SAR decreases by a factor nearly equal to the square root of the dilution factor, so that with successive dilutions, the water progressively supplies Ca and Mg for adsorbed Na replacement while providing a sufficient concentration of salt to maintain flocculation of the clay-organic matter complex. Successive dilutions of sea water saturated with  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  are highly satisfactory for removing adsorbed Na by this process. Sodic soils treated by the high-salt water dilution method usually have good permeability and tilth after the SAR of the soil

water has been reduced to 10 or less. Where applications of  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  are used to replace adsorbed Na, cropping, involving root action with wetting and drying, and/or additions of organic matter, are usually required before acceptable permeability and tilth are attained.

Much of the adsorbed Na in sodic soils not containing  $\text{CaCO}_3$ , especially if the soil pH is  $< 7$ , is removed upon application of  $\text{CaCO}_3$  and leaching. For solonetz soils having salt and  $\text{CaCO}_3$  present in the C-horizon but not in the A- and B-horizons, plowing to a depth of 60 or more cm, so as to mix the horizons, not only causes replacement of most of the adsorbed Na upon leaching but improves permeability and tilth as well.

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