Chapter 12

Soil Salinity and Sodicity

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> ***"In virtually all societies of the world soil degradation through salts is a process that leads to the loss of a natural resource essential for sustaining agriculture" –***

12.1. Introduction

All soils and natural waters contain soluble salts. The amount of salts in the root zone (or the salt concentration in the soil solution) determines whether the soil is "normal" or "salt-affected" when an "excessive" amount or concentration of soluble salts occurs in the soil and it adversely affects crop growth.

In irrigated areas, the formation of salt-affected soils is the most important process of land degradation. Salt-affected soils exist mostly under arid and semi-arid climates, in more than 100 countries. Annual rainfall in arid and semi-arid regions is not sufficient to leach down salts to the deeper layers of soil. Coupled with it, high evaporation in these areas results in the accumulation of large amount of salts in the root zone. Magnitude of accumulation of salts (soil salinization) has been found to increase with increase in dryness of the area. The salt-affected soils are also encountered in humid regions, in areas subjected to sea water intrusions in deltaic regions and other low-lying areas, which occasionally get inundated by the sea water.

The extent of soil salinization and/or sodification depends on the type and amount of salts, their relative abundance in the soil, degree of solubility and effect on soil pH. For example, in 1 litre of pure water 710 g of Epsom salt ($MgSO_4.7H_2O$), followed by 357 g of table salt ($NaCl$) could be dissolved, whereas only 2.6 g of gypsum ($CaSO_4.2H_2O$) could be dissolved. The solubility of calcite ($CaCO_3$) is very low (0.013 g L^{-1}), which increases with increase in partial pressure of CO_2 and decrease in pH of the soil.

When multiple salts are in solution, their interaction influences solubility. For example, the solubility of gypsum increases in the presence of NaCl; thus, in salt-affected soils, the amount of gypsum in solution could be potentially three times as much as in non-saline soil.

12.2. Distribution of Salt-affected Soils

Globally, more than 800 million hectares (Mha) of land are estimated to be salt-affected (FAO 2008). These soils cover a range of soils defined as saline, saline–sodic and sodic.

According to one estimate (Mandal *et al.* 2010), an area of 6.74 Mha in India suffers from salt accumulation out of which 3.78 Mha are sodic while 2.96 Mha are saline soils (**Figure 12.1**). The extent and distribution of salt-affected soils in different states of India is given in **Table 12.1**. The states of Gujarat (2.20 Mha) and Uttar Pradesh (1.37 Mha) in India have the largest area under salt-affected soils.

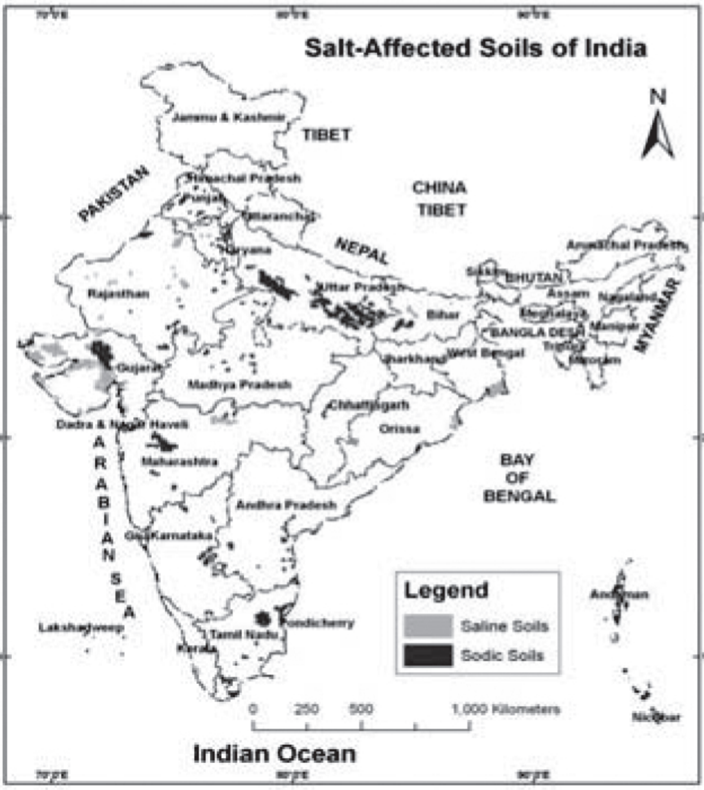

Figure 12.1. Distribution of the salt-affected soils in different states of India

Table 12.1. Extent and distribution of salt-affected soils (ha) in India

State	Saline soils	Alkali soils	Coastal saline soils	Total
Andhra Pradesh	0	1,96,609	77,598	2,74,207
A & N islands	0	0	77,000	77,000
Bihar	47,301	1,05,852	0	1,53,153
Gujarat	12,18,255	5,41,430	4,62,315	22,22,000
Haryana	49,157	1,833,99	0	2,32,556
J & K	0	1,75,00	0	1,7,500
Karnataka	1,307	1,48,136	586	1,50,029
Kerala	0	0	20,000	20,000
Maharashtra	1,77,093	4,22,670	6,996	6,06,759
Madhya Pradesh	0	1,39,720	0	1,39,720
Orissa	0	0	1,47,138	1,47,138
Punjab	0	1,51,717	0	1,51,717
Rajasthan	1,95,571	1,79,371	0	3,74,942
Tamil Nadu	0	3,54,784	13,231	3,68,015
Uttar Pradesh	21,989	13,46,971	0	13,68,960
West Bengal	0	0	4,41,272	4,41,272
Total	**17,10,673**	**37,88,159**	**12,46,136**	**67,44,968**

Generally, salt-affected soils of the arid regions belong to the order Aridisols. However, in some other regions, salt-affected soils have also been classified under the orders Alfisols, Mollisols, Inceptisols and Vertisols. The most common diagnostic horizon is ochric epipedon; sub surface horizon can be argillic, natric, cambic, calcic, gypsic and/or salic. Mica (illite) is the dominant clay mineral followed by kaolinite in the salt-affected soils of the Indo-Gangetic Plains. Other minerals present include chlorite, vermiculite, calcite, K-feldspars, sepiolite and anatase. Salt-affected black soils are rich in swelling and shrinking minerals, *i.e.* smectites. In addition to the dominance of montmorrilonite, these soils also contain varying amounts of chlorite, illite and kaolinite minerals depending upon the type of geological formation and history of soil development.

12.3. Sources of Salinity and Alkalinity

The main sources and causes of salt accumulation include:

- Geo-chemical weathering of rocks and parent materials and the salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials
- Derived directly from sea water by flooding or intrusion into ground water resources
- Salt-laden sand blown by sea winds
- Indiscriminate and injudicious use of irrigation waters of different qualities
- Capillary rise from subsoil salt beds or from shallow brackish ground water
- Lack of natural leaching due to topographic situation and economic activities in arid and semi-arid regions.

The major constituents of dissolved salts in soil are the cations *viz.* sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), and the anions *viz.* chloride (Cl^-), sulphate (SO_4^{2-}), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-). The salinity can be expressed as electrical conductivity (EC) of the irrigation water (ECw), the soil water (ECss) or the saturated soil extract (ECe). Sodicity is measured in the soil by exchangeable sodium percentage (ESP) and in soil solution by sodium adsorption ratio (SAR).

Too much sodium causes problems related to soil structure. As sodium percentage increases, so does the risk of dispersion of soil aggregates (see **Figures 12.2** and **12.3**). Any salt that accumulates in excessive amounts in soil can cause toxicity and plant growth problems.

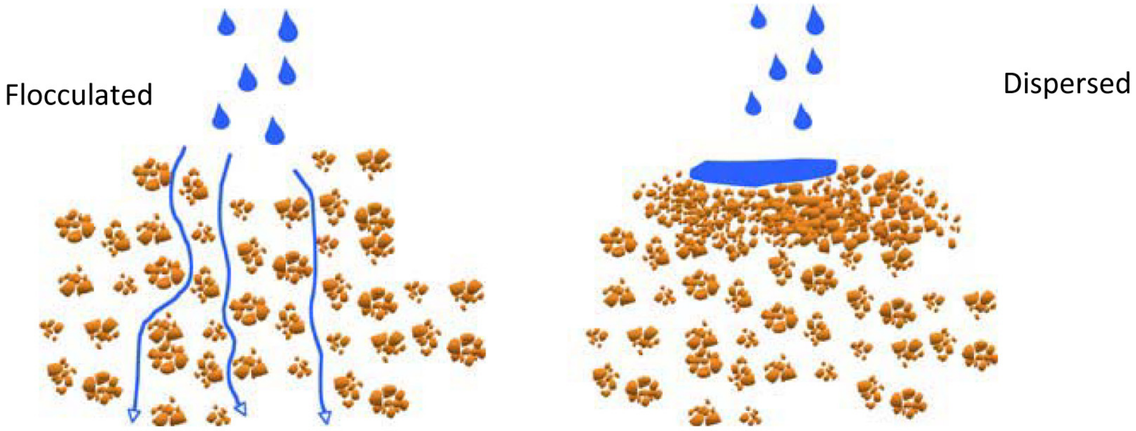

Figure 12.2. The difference between flocculated (aggregated) and dispersed soil structure. Flocculation (left) is important because water moves through large pores and plant roots grow mainly in pore space. Dispersed clays (right) plug soil pores and impede water movement and soil drainage.

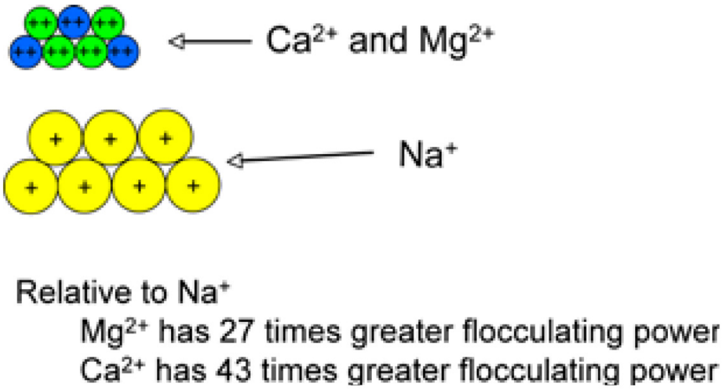

Figure 12.3. Cations as flocculators. Cations bring together negatively charged clay particles to flocculate soil clays (making clumps or "aggregates"). Sodium (Na^+) is a much poorer flocculator than Ca^{2+} and Mg^{2+} because it has less charge and because its ionic size in water is much larger

12.4. Classification of the Salt-affected Soils

The US Salinity Laboratory Staff in 1954 grouped salt-affected soils into three general categories for management purposes (**Table 12.2**).

Table 12.2. Classification of salt-affected soils

Salt-affected soil	Soil pH (pHs)	Electrical conductivity (ECe) (dS m^{-1})	Sodium adsorption ratio (SAR)	Exchangeable sodium percentage (ESP)	Typical soil physical condition (soil structure)
None	< 8.5	< 4	<13	< 15	flocculated
Saline	< 8.5	>4	<13	<15	flocculated
Sodic	< 8.5	<4	>13	>15	dispersed
Saline-sodic	< 8.5	>4	>13	>15	flocculated

12.4.1. Saline Soils

These soils contain sufficient neutral soluble salts which adversely affect the growth of most crop plants. The soluble salts are chiefly sodium chloride and sodium sulphate. But, saline soils also contain appreciable quantities of chlorides and sulphates of Ca^{2+} and Mg^{2+}. These soils are characterized by electrical conductivity of the saturated extract (ECe) more than 4 dS cm^{-1} at 25 °C and exchangeable sodium percentage (ESP) less than 15 and sodium adsorption ratio (SAR) less than 13 (**Table 12.2**). The soil pH is ordinarily less than 8.5. Because of the presence of excess salts and low amounts of Na^+ ion on exchange sites, these soils are usually in a flocculated state and their permeability is considered to be equal to or higher than the normal soils. Most of these soils have salt efflorescence or white encrustation of soluble salts at the surface. In India, these soils are known by different names such as *'Thur'* in Punjab, *'Reh'* in Uttar Pradesh and *'Luni'* in Rajasthan.

12.4.2. Sodic Soils

These soils contain sodium salts capable of causing alkaline hydrolysis, mainly Na_2CO_3. Such soils were termed as the 'alkali' soils in older literature. The sodic soils have ECe less than 4 dS m^{-1} at 25 °C, ESP more than 15 and SAR more than 13 (**Table 12.2**). Most of the sodium is in exchangeable form. Very small amounts of free salts are present in soil solution. The soil pH is more than 8.5. As a result of irrigation, strongly alkaline conditions may develop in these soils and pH values reaching or exceeding 10 are common. When organic matter is dispersed and deposited on the surface, sodic soils appear brown-black and are sometimes known as black alkali soils. These soils are also known as *'Kallar'* in Punjab, *'Usar'* in Uttar Pradesh and *'Kshar'* in Gujarat.

12.4.3. Saline-sodic Soils

These soils have high concentration of neutral salts and appreciable sodium on the exchange complex *i.e.* have problems because of sodium *and* other salts. The saline-sodic soils have ECe more than 4 dS m^{-1} at 25 ^{o}C, ESP more than 15 and SAR more than 13. In these soils, both free salts and exchangeable Na^+ are present. Excess salts present in the soil keep the soil flocculated and the soil pH is normally less than 8.5. Upon leaching, when free salt content decreases, these soils may behave like a sodic soil (pH > 8.5) because of the hydrolysis of exchangeable Na^+.

The selection of the critical value for ECe 4 dS m^{-1} to distinguish a saline soil from non-saline soil is based on the expected salt damage to crops. At this level, the yield of many crops is restricted. At ECe values between 2 and 4 dS m^{-1}, the growth of only sensitive crops is affected. Below ECe value of 2 dS m^{-1}, the effect of salinity is negligibly small. Use of ESP value of 15 is arbitrary since no sharp changes in soil properties have been observed as the proportion of Na^+ ions on the exchange complex is increased. The U.S. Salinity laboratory has used, from history and experience, the ESP value of 15 as a boundary limit to distinguish sodic from the non-sodic soils.

Based on Indian experience, saline and sodic soils are distinguished on the basis of preponderance of chlorides and sulphates over that of sodium. If $Na^+/(Cl^- + SO_4^{2-})$ ratio is less than 1 and pH of the saturated soil paste (pHs) is less than 8.2, the soil is designated as saline and if ratio of $Na^+/(Cl^- + SO_4^{2-})$ is more than 1.0 and pHs is more than 8.2, soil is defined as the sodic.

The two main groups of salt-affected soils i.e. saline soils and sodic soils differ not only in their chemical characteristics but also in their geographical and geochemical distribution, as well as in their physical and biological properties (**Table 12.3**). In nature the various sodium salts do not occur absolutely separately, but in most cases either the neutral salts or the ones capable of alkaline hydrolysis or both these processes exercise a dominant role on the soil-forming processes and therefore in determining whether the soil is saline, sodic or saline-sodic in nature.

12.5. Chemistry of the Salt-affected Soils

Salt accumulation is the first stage on the sequence of processes leading to the formation of salt-affected soils. Saline and sodic soils occur in areas of limited rainfall (annual rainfall < 500 mm) where the amount of water coming from precipitation is not sufficient to drain away surface or ground water. As water is largely lost in the atmosphere through evaporation or transpiration, salts are left behind in the soil gradually resulting in salt accumulation.

12.5.1. Salinization

The process of accumulation of soluble salts in the soil is called salinization. The salts are mostly NaCl, Na_2SO_4, $CaCO_3$ and $MgCO_3$. Sodium salts often dominate the early stages

Table 12.3. Distinguishing features of saline and sodic soils

Characteristics	Saline soils	Sodic soils
1. Chemical	a) Dominated by neutral soluble salts consisting of chlorides and sulphates of sodium, calcium and magnesium. b) pH of saturated soil paste is less than 8.2. c) An electrical conductivity of the saturated soil extract (ECe) of more than 4 dS m^{-1} at 25 °C is the generally accepted limit above which soils are classed as 'saline'. d) No well-defined relationship between pH of the saturated soil paste and ESP of the soil or the sodium adsorption ratio of the saturation extract (SARe). e) Although Na is generally the dominant soluble cation, the soil solution also contains appreciable quantities of divalent cations, e.g. Ca and Mg. f) Soils may contain significant quantities of sparingly soluble calcium compounds, like gypsum.	Appreciable quantities of neutral soluble salts generally absent. Measurable to appreciable quantities of salts capable of alkaline hydrolysis, *e.g.* Na_2CO_3, present. b) pH of the saturated soil paste is more than 8.2. c) An exchangeable sodium percentage (ESP) of 15 or more is the generally accepted limit above which soils are classed as 'sodic'. ECe is generally less than 4 dS m^{-1} at 25 °C but may be more if appreciable quantities of Na_2CO_3 etc. are present. d) A well-defined relationship between pHs and the ESP of the soil or the SARe for an otherwise similar group of soils such that the pH can serve as an approximate index of soil sodicity (alkali) status. e) Sodium is the dominant soluble cation. High pH of the soils results in precipitation of soluble Ca and Mg such that their concentration in the soil solution becomes very low. f) Gypsum is nearly always absent in such soils.
2. Physical	a) In the presence of excess neutral soluble salts, the clay fraction is flocculated and the soils have a stable structure. b) Permeability of soils to water and air and other physical characteristics are generally comparable to normal soils.	a) Excess exchangeable sodium and high pH result in the dispersion of clay and the soils have an unstable structure. b) Permeability of soils to water and air is restricted. Physical properties of the soils become worse with increasing levels of exchangeable sodium and pH.
3. Effect on plant growth	Plant growth is adversely affected through i) effect of excess salts on the osmotic pressure of soil solution resulting in reduced availability of water to plant roots and (ii) toxicity of specific ions, *e.g.* Na, Cl, B, etc.	Plant growth is adversely affected through: i) the dispersive effect of excess exchangeable sodium resulting in poor physical properties, ii) effect of high soil pH on nutritional imbalances including a deficiency of calcium and iii) toxicity of specific ions, *e.g.* Na, CO_3, HCO_3, Mo, etc.
4. Soil improvement	Improvement of saline soils essentially requires removal of soluble salts in the root zone through leaching and drainage. Application of amendments is generally not required.	Improvement of sodic soils essentially requires the replacement of sodium in the soil exchange complex by calcium through use of soil amendments such as gypsum and leaching and drainage of salts resulting from reaction of amendments to reduce exchangeable sodium.
5. Geographic distribution	Saline soils generally occur in arid and semi-arid regions.	Sodic soils generally occur in semi-arid and sub-humid regions.
6. Ground water quality	Ground water in areas dominated by saline soils has generally high electrolyte concentration and pose a potential salinity hazard.	Groundwater in areas dominated by sodic soils has generally low to medium electrolyte concentration and some of it may have high residual alkalinity having a potential sodicity hazard.

of salinization. Calcium and magnesium salts accumulate gradually. The soils developed are called *saline soils* or *white alkali soils*; in the past also known as *solonchaks* (**Figure 12.4**). Salinization can also occur locally in soils reclaimed from the sea bottom, and soil in coastal areas affected by the tides.

Figure 12.4. Saline soils in India

12.5.2. Sodication or Alkalization

Addition of sodium-containing salts particularly its carbonates to the soil may result in saturating the soils exchange complex with Na. As the salt concentration increases, calcium and magnesium may precipitate as their respective carbonates. It causes calcium carbonate to accumulate in the soils and results in a gradual increase in proportion of sodium in solution and thereby the proportion of the sodium adsorbed on soil colloids also increases (**Figure 12.5**).

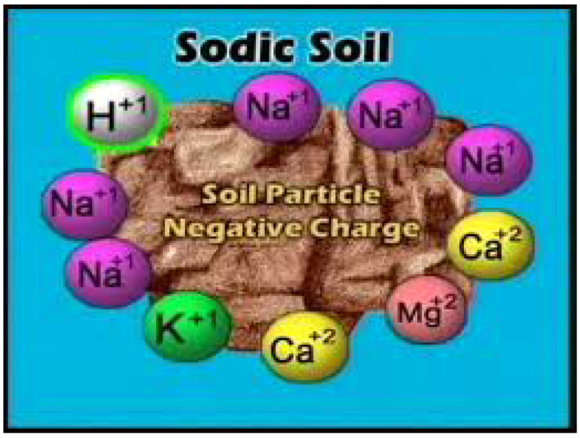

Figure 12.5. Exchange complex of a sodic soil

The process of progressively increasing the Na saturation on the soils exchange complex is called sodication. Sodication induces deterioration in physical properties and the soils so formed are called *sodic soil, solods, solonetz or black alkali soils* (**Figure 12.6**). If these soils occur only in small areas (in small localized spots), are often called *slick spots*.

Figure 12.6. Views of barren sodic soils

If extensive leaching of a saline-sodic soil occurs in the absence of any source of calcium or magnesium, part of the exchangeable sodium is gradually replaced by hydrogen. Such soil may be slightly acidic in nature, yet it may contain enough sodium to give it an unstable structure. Such a soil is designated as a *degraded sodic soil,* earlier known as *degraded alkali soil*.

To distinguish saline and sodic soils from other soils, Richards (1954) proposed a use soluble salt and exchangeable sodium content as the two robust criteria. These parameters are expressed in terms of (1) ECe for soluble salts, and (2) ESP for exchangeable sodium content. In addition, SARe is also used to estimate soil sodicity.

12.5.3. Soil pH

In saline soils, generally no well-defined relationship exists between pH of the saturated soil paste (pHs) and soil ESP or SARe. However, in sodic soils, a well-defined relationship between pHs and the ESP of the soil or the SARe exists such that the pH can serve as an approximate index of soil sodicity (alkali) status. However, soil sodication does not necessarily result in an increase in soil pH. Many sodic soils are neutral in reaction having higher proportion of neutral Na salts such as NaCl. The strong alkaline reaction (pH=10) of most sodic soil is caused by alkalization. The latter is due to hydrolysis of Na^+ ions or Na_2CO_3 compounds:

$$Na_2CO_3 + 2H_2O = 2Na^+ + 2OH^- + H_2CO_3 \qquad \ldots(12.1)$$

$$\text{Clay–Na} + H_2O = \text{Clay-H} + Na^+ + OH^- \qquad \ldots(12.2)$$

The OH^- ions produced increase the soil pH, where the Na^+ saturates the exchange complex. The latter, in turn, may undergo hydrolysis, which also contributes towards increasing the OH^- ion concentration in the soil.

12.5.4. Electrical Conductivity

The electrical conductivity of the saturated extract (ECe) is an indirect expression of the total salt concentration in the soil, without reference to the nature and composition of the salts. A large range of units is used to describe salinity (**Table 12.4**) but deci Siemens per meter, (dS m^{-1}) instead of mmhos cm^{-1} in older literature is adopted as the standard measure of electrical conductivity and hence salinity. It is customary to measure EC at a standard temperature of 25 °C to take out the influence of temperature.

The preparation of a saturated extract is laborious and, therefore, soil water extracts are prepared at fixed ratios, e.g. 1:1 (100 g air dry soil mixed in 100 g water), 1:2 or 1:5.

Table 12.4. Factors for converting various salinity units to deci Siemens per meter (dS m^{-1}) (TSS=Total soluble salts)

Unit conversion			Factor
mS cm^{-1}	to	dS m^{-1}	×1
mmho cm^{-1}	to	dS m^{-1}	×1
mS m^{-1}	to	dS m^{-1}	×0.01
μS cm^{-1} (EC units)	to	dS m^{-1}	×0.001
μmho cm^{-1} (EC units)	to	dS m^{-1}	×0.001
meq L^{-1} (Salts)	to	dS m^{-1}	×0.10
Osmotic potential (bars)	to	dS m^{-1}	x -1/0.36

The EC value is then inversely proportional to the water content as indicated in the following conversion:

$$EC_{1:1} = 2EC_{1:2} = 5EC_{1:5} \qquad \text{....(12.3)}$$

It should, however, be recalled that this proportionality between salt concentration and soil moisture content only holds true for highly soluble salts like NaCl and Na_2SO_4. For slightly soluble salts like $CaCO_3$ (lime) and to a lesser extent $CaSO_4$ (gypsum), smaller values of the concentration ratio apply since precipitation of these salts occurs upon concentration.

12.5.5. Exchangeable Sodium Percentage

The exchangeable sodium percentage (ESP) corresponds to the amount of adsorbed sodium, compared to the CEC and is expressed as:

$$ESP = \frac{E_{Na}X}{CEC} \times 100 \qquad \text{....(12.4)}$$

Cation exchange capacity of the salt-affected soils composed mainly of Na^{2+}, Ca^{2+} and Mg^{2+} as the dominant exchangeable cations, can be expressed as:

$$CEC = E_{Na} + E_{Ca} + E_{Mg} \qquad \text{....(12.5)}$$

where CEC is the cation exchange capacity of a soil in cmol$(p^+)kg^{-1}$ of dry soil; and $E_{Na,}$ E_{Ca} andE_{Mg} and correspond to the amount of the adsorbed sodium, calcium and magnesium, respectively. The ESP is an expression of the sodicity and dispersion tendency of a soil. The soil solution has a major influence on the chemical properties of the soil adsorption complex as given by Gapon's equation

$$\frac{E_{Na}}{E_{Ca} + E_{Mg}} = K_G \frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}/2}} \qquad \text{...(12.6)}$$

where K_G, termed as the Gapon Constant, is the exchange coefficient which has a value ranging between 0.010 to 0.015 (meq $L^{-1})^{-1/2}$. The concentrations of Na^+, Ca^{2+} and Mg^{2+} in the soil solution are expressed in me L^{-1}. The Gapon equation demonstrates that a more concentrated soil solution results in higher amount of E_{Na} at the expense of E_{Ca} and E_{Mg} causing an increase in ESP. In the case of dilution, E_{Ca} and E_{Mg} will replace E_{Na} and ESP will decrease.

The determination of ESP can be made following appropriate procedures in the laboratory. However, for routine analysis of large soil samples, this determination is too time-consuming. Also it requires expert handling and unless carefully determined, it might lead to erroneous results. Although the relationship between pH and ESP is complex when applied to a wide range of soils yet pH may be used as a satisfactory indication of exchangeable sodium for similar types of soils. From land reclamation point of view, pH and ESP of the soils of the Indo-Gangetic plains are well correlated (**Table 12.5**). Since pH can be

Table 12.5. Relationship between pH and ESP of the soils of Indo-Gangetic plains

pHs	pH_2	ESP
8.0 - 8.2	8.5 - 9.2	20
8.2 - 8.4	9.2 - 9.4	20-35
8.4 - 8.6	9.4 - 9.7	35-50
8.6 - 8.8	9.7 - 9.8	50-65
8.8 - 9.0	9.8 - 9.9	65-75
9.0 - 9.2	9.9 - 10.6	85-100

pH_s & pH_2 are the pH of the saturated soil paste and 1:2 soil:water suspension, respectively.

easily and rapidly determined in the laboratory, this parameter has widely been used to assess the degree of sodicity of the Indo-Gangetic plains. In some areas, if the relationship between pH and ESP is not satisfactory, the more tedious determination of CEC and exchangeable sodium may be required to evaluate sodicity and related reclamation problems.

12.5.6. Sodium Adsorption Ratio

Because of the equilibrium existing between the soil and soil solution it is possible to measure the sodicity from SAR derived from the concentrations of sodium, calcium and magnesium in the soil solution.

$$\text{SARe} = \frac{\text{Na}^{+}}{\sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2}} \qquad \ldots(12.7)$$

where SARe is the SAR of the saturation extract of the soil. The SARe can be determined in the laboratory more easily than ESP and helps estimate the ESP form combination of equations (6)and (7) as given below:

$$\text{ESP} = \left(\frac{\text{K}_\text{G}.\text{SARe}}{1+\text{K}_\text{G}.\text{SARe}}\right)\times 100 \qquad \ldots(12.8)$$

For a wide range of soils, the following relationship has been observed between SARe and ESP:

$$\text{ESP} = \frac{100(\text{-}0.0126 + 0.01475\text{SARe})}{1+(\text{-}0.0126+0.01475\text{SARe})} \qquad \ldots(12.9)$$

12.6. Reclamation and Management of Salt-affected Soils

The primary objective of reclamation and management of salt-affected soils is to reduce soluble salts and exchangeable sodium to levels that permit ideal or near ideal plant growth so that the productivity of these soils is restored. For that, replacement of excess Na ions from the exchange complex and leaching out the salts below the root zone are to be accomplished and provision of adequate drainage (*See inbox*) is a pre-requisite to achieve these objectives.

Without adequate drainage, proper reclamation of any salt-affected soil cannot be achieved on a long-term basis. Salt-affected soil problems do not develop overnight, it takes years for salts to accumulate enough to reduce crop growth and/or water infiltration. Reclamation can take just as long. For systematic planning for carrying out a reclamation programme,

Drainage

There must be drainage to reclaim a sodic, saline, or saline-sodic soil. Make sure you have adequate drainage.

What is drainage? How do I make sure I have it? What can I do to improve it?

Drainage is the unimpeded downward movement of water beyond the crop root zone. It is the ability to move water through and out of the root zone. Hardpans, bedrock, and shallow water tables impede drainage.

Signs of poor drainage include surface ponding, slow infiltration, or a soil that remains wet for prolonged periods of time. Digging within and below the root zone can also indicate where a drainage problem exists.

In most of the cases, poor drainage can be improved by breaking up a hardpan with deep tillage. If drainage is impeded by a shallow water table or bedrock, artificial drainage must be installed or another use for the land might need to be considered.

proper characterization and cause of the problem required *i.e.* extent and kind of salinity and sodicity problem have to be thoroughly understood. Understanding the implications and costs of a reclamation plan is important. For reclamation of salt-affected soils, physical, chemical and biological methods have been developed. These are discussed as below:

12.6.1. Physical Reclamation

This type of reclamation involves physical and mechanical means to remove the salts and/or to improve permeability and thereby internal drainage within the soil profile. These methods include deep-ploughing, sub-soiling, profile inversion, sanding, flushing and scrapping.

Deep ploughing and sub-soiling methods mechanically break the impermeable layer, cemented sub-soil layer or hardpan in the soil profile at some depth to enhance the infiltration and transportation of salts dissolved in water to deeper soil layers. Deep ploughing has been shown to benefit water penetration, aeration and plant growth in the poorly-structured soils. However, the benefits of deep ploughing are short-lived, especially on sodic soils. Profile inversion can be employed in situations where surface soil is relatively free of salts and Na but soil below is sodic, saline or saline-sodic. In this method, good surface soil is retained while the salty sub-soil is inverted down the profile. It is, however a cumbersome procedure. Hence it is not followed by the farmers.

Sometimes sand is mixed in the salt-affected soil to improve permeability and air-water relations in the root zone. However, in clayey sodic soils, inadequate quantities of sand will rather create problems due to sand's cementing effect. In such cases, large quantities of sand have to be applied to check the cementing effect that at times seems impractical for a large area.

Flushing involves washing away the surface accumulated salts by flushing water over the surface. It is sometimes used to desalinize soils having surface salt crusts. Because the amount of salts that can be flushed from the soil is rather small, this method does not have much practical significance. Scrapping the salts that have accumulated on the soil surface by mechanical means has had only a limited success although many farmers have resorted to this procedure. It might temporarily improve crop growth, but the ultimate disposal of salts still poses a major problem. Also this method fails to give a permanent solution under shallow water table conditions where salts can again rise and accumulate at the surface due to evapotranspiration.

12.6.2. Chemical Reclamation

Reclamation of sodic soil requires removal of part or most of the exchangeable sodium, improvement of the soil physical structure and lowering of the soil pH. The exchangeable sodium is replaced by the more favourable calcium ions according to the exchange reaction given in equation and the sodium thus exchanged is leached out of the root zone.

$$2\text{ Na-X} + \text{Ca}^{2+}\text{(solution)} = \text{Ca-X} + 2\text{Na}^{+}\text{(solution)}\downarrow \qquad \ldots(12.10)$$

Where, 'X' is the exchange complex of the soil.

Calcium needed for this reaction can be furnished by either calcium-based amendment or calcium carbonate present in the soil whose solubility may be enhanced by application of organic amendments or acid formers. Amendments are the materials which provide Ca^{2+} or mobilize Ca^{2+} in the soil for replacing exchangeable sodium to reduce alkalinity (pH) and sodicity (ESP) of the soil. For reasonably quick results cropping must precede the application of soil amendments followed by leaching for removal of soluble salts from the soil profile

The amount and type of chemical amendments required to reclaim a sodic soil depend upon physico-chemical properties of soil mainly pH, EC and ESP. Crop tolerance to sodicity and economic condition of the farmers determine the desired level of replacement of exchangeable sodium. Generally, there are two types of chemical amendments:

a) *Soluble sources of calcium:* Gypsum ($CaSO_4.2H_2O$), calcium chloride ($CaCl_2$) and phospho-gypsum (an industrial bye-product)

b) *Acids or acid-formers:* Elemental sulphur, sulphuric acid, sulphates of iron and aluminium, pyrites and lime sulphur

The choice and effectiveness of these two types of amendments mainly depend upon presence or absence of $CaCO_3$ in the soil. In absence of $CaCO_3$ as is the case in non-calcareous soils, only soluble sources of calcium should be used and application of acids or acid-formers is not recommended. But, when soil contains calcium, both the sources may be used. Although sparingly soluble $CaCO_3$ is a potential source of calcium and is recommended for acid soil reclamation, it is not recommended for the reclamation of sodic soils because of its low solubility which decreases further with rise in soil pH.

12.6.2.1. Chemical Reactions of the Commonly used Amendments

Chemical reactions of the different amendments in the salt-affected soils are as follows:

Reactions:

a) Gypsum

$$CaSO_4 + \underset{\text{Sodic soil}}{2NaX} = CaX + Na_2SO_4\,(\text{Leachable}) \downarrow \qquad \ldots(12.11)$$

b) Calcium chloride

$$CaCl_2 + \underset{\text{Sodic soil}}{2NaX} = CaX + 2\,NaCl\,(\text{Leachable}) \downarrow \qquad \ldots(12.12)$$

c) Sulphur

The first step is a biological oxidation of elemental sulphur facilitated by autotrophic bacteria, *Thiobacillus*

$$2S + 2H_2O + 3O_2 = 2H_2SO_4 \qquad \ldots(12.13)$$

d) *Suplhuric acid in a calcareous sodic soil*

$$H_2SO_4 + CaCO_3 = CaSO_4 + H_2O + CO_2 \qquad \ldots(12.14)$$

Sulphuric acid can also react with two molecules of $CaCO_3$ yielding equivalent of two soluble calcium for each equivalent of acid such as:

$$H_2SO_4 + 2CaCO_3 = CaSO_4 + Ca(HCO_3)_2 \qquad \ldots(12.15)$$

In practice, therefore, only 1.5 equivalents of calcium can be expected from one equivalent of acid.

e) *Pyrites*

Pyrite (FeS_2), like elemental sulphur first oxidizes into an acid, which in turn reacts with soil lime to yield soluble calcium:

$$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + H_2SO_4 \qquad \ldots(12.16)$$

$$CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2 \qquad \ldots(12.17)$$

$$2Na\text{-}X + CaSO_4 = Ca\text{-}X + \underset{\text{(Leachable)}}{Na_2SO_4} \downarrow \qquad \ldots.(12.18)$$

The rate of oxidation of pyrites is slow; however, its maximum oxidation can be ensured by storing the freshly mined pyrites for a period of 15-20 days in a well aerated but covered place under moist conditions (preferably 10 % moisture). The efficiency of pyrites increases when it is applied on the basis of its water soluble sulphur content. Best reclamation results are obtained when pyrites contain 4-6% water soluble sulphur and its pH is less than 3.0.

In some areas, cheap acidic industrial wastes are available which can be profitably used for improvement of the sodic soil. Pressmud, a waste product from sugar factories, is one such material commonly used for soil improvement. It contains either lime or gypsum depending on whether the sugar factory is adopting carbonation or a sulphitation process for the clarification of juice. It also contains variable quantities of organic matter.

Because of its high solubility in water, calcium chloride is the most readily available source of soluble calcium but it has rarely been used for reclamation because of its high cost. Similarly iron and aluminum sulphates are usually too costly and are seldom used for any large-scale improvement of sodic soils. Large-scale use of sulphuric acid for improving sodic soils is generally not recommended because of handling and application difficulties associated with the large volumes of these acids at the field level.

12.6.2.2 Gypsum for Reclamation of the Sodic Soils

Figure 12.7. Effect of gypsum on plant growth

Mined gypsum is the most commonly used chemical amendment for sodic soil reclamation because of its abundant availability and low cost. Chemically gypsum is $CaSO_4.2H_2O$ and occurs extensively as the natural deposits. In India, gypsum deposits have been estimated to be more than 1000 Mt. It must be ground before it is applied to the soil. Gypsum has been used successfully to reclaim the sodic soils and enhance crop productivity of these once barren lands (**Figure 12.7**). It reacts with both Na_2CO_3, and the adsorbed sodium as follows:

$$Na_2CO_3 + CaSO_4 = CaCO_3 + Na_2SO_4 \text{ (leachable)}\downarrow \qquad \ldots(12.19)$$

$$2\text{Na-clay micelle} + CaSO_4 = \text{Ca –clay micelle} + Na_2SO_4 \text{ (leachable)}\downarrow \qquad \ldots(12.20)$$

12.6.2.2.1. Application Method

Gypsum is normally applied-broadcast and then incorporated into the soil by disking or ploughing as it is more effective in the removal of exchangeable sodium than when applied on the soil surface. Also mixing limited quantities of gypsum in shallower depths is more beneficial than mixing it with deeper depths. Deeper-mixing exposes gypsum to react with Na_2CO_3 of the soil resulting in lesser reduction in ESP throughout the depth. This can decrease the seed germination rate and consequently the crop yield. In shallow mixing, soluble carbonates move down with the wetting front without reacting with applied gypsum.

For improving sodic soils with hardpans or dense clay subsoil layers, deep ploughing (up to 100 cm) has been found to be a useful practice. Improvement in crop yields as a result of deep ploughing occurs because of enhanced water intake rates and depth of penetration. This practice results in the doubling of the effective available water holding capacity of the subsoil layers.

12.6.2.2.2. Gypsum fineness and solubility

Since gypsum is excavated as lumps from deposit sites, it requires grinding before it can be used for sodic soil reclamation. The fineness to which gypsum must be ground is a matter of economic consideration. It is often said that the finer the gypsum particles, the more effective it would be for the reclamation of sodic soils. But very fine grinding involves higher cost. Application of very finely ground gypsum results in a high initial hydraulic conductivity of a sodic soil with free soluble carbonates but it decreases sharply with time. On the other hand, treatment with gypsum passed through 2 mm mesh and having a range of particle size distribution helps in maintaining the soil permeability at higher level and for a longer period.

12.6.3. Biological Reclamation

Sodic soils are generally low in organic matter. Addition of organic materials and crop residues in the soil helps in improving and maintaining soil structure, preventing erosion, and supplying essential plant nutrients besides reclaiming the sodic soils. Organic materials and the plant roots help in enhancing the biological activity in soil. Organic amendments on decomposition increase the partial pressure of CO_2 and produce organic acids. These processes help in increasing electrolyte concentration, mobilizing calcium through enhancing the solubility of soil calcite, lowering pH and ESP of the soil. Most commonly used organic amendments are crop residues, FYM, green manure, poultry manure etc.

The effectiveness of any organic amendment depends upon the amount of CO_2 produced and extent of reduction. To achieve maximum benefits from application of organic amendments, submerged conditions should be maintained to help maintain lower redox potential (*i.e.* the reduced conditions) during the course of their decomposition. Due to their coarse texture and slow decomposition, these organic materials do not allow the pores to be clogged and make the soil porous by maintaining channels and voids which improve water penetration and facilitate leaching of the salts out of the root zone.

Generally application of organic materials together with inorganic amendments is cost-effective, hastens the reclamation process and increases the crop yields; thus, their combined use should be encouraged. Application of 20 t FYM ha^{-1} combined with gypsum gives higher crop yields than the gypsum applied alone. Also application of FYM is economical only when it is locally available with the farmer. But when it is to be purchased then it is not economical compared to gypsum alone. For biological amelioration to be effective, relatively large quantities of organic amendment *i.e.* FYM (30-40 t ha^{-1}) have to be applied. Further, if the C:N ratio of organic materials is very wide as is the case with saw dust, rice husk and rice straw, these materials decompose slowly and may be less effective than *Sesbania* which has a narrow C:N ratio. Under such circumstances, deficiency of N may be encountered and should be taken care of. Nevertheless, beneficial effects of straw incorporated in a sodic soil under submerged conditions can be attributed to: (i) the decomposition of organic matter, evolution of CO_2 and certain organic acids, (ii) lowering of pH and the release of cations by solubilization of $CaCO_3$ and other soil minerals thereby increasing the EC, and (iii) replacement of exchangeable Na by Ca and Mg, causing lowering of the ESP.

Organic materials when applied in conjunction with inorganic amendments or when applied alone in soils of mild sodicity, have proved beneficial. Thus their use in the reclamation of sodic soils occupies an important place.

12.6.4. Gypsum Requirement – Concept and Methods for Determination

The quantity of gypsum or any amendment necessary to reclaim sodic soil depends on the total quantity of sodium that must be replaced. This, in turn, depends on the soil texture and mineralogical make-up of the clay, extent of soil deterioration as measured by exchangeable sodium percentage (ESP) and the crops to be grown. The relative tolerance of a crop to exchangeable sodium and its normal rooting depth will largely determine the soil depth up to which excess adsorbed sodium must be replaced for achieving satisfactory crop growth. Replacement of each mole of adsorbed sodium per 100 g soil will require half a mole of soluble calcium. The quantity of pure gypsum required to supply half a centimol of calcium per kg soil for the upper 15 cm soil depth can be compared as

$$\frac{\text{molecular weight of gypsum}}{200} = \frac{172}{200} = 0.86 \text{ g kg}^{-1} \text{ soil}$$

$$= 86 \times 10^{-5} \text{ kg kg}^{-1} \text{ soil} = 86 \times 10^{-5} \times 2.24 \times 10^{6} \text{ kg ha}^{-1} = 1926 \text{ kg or } 1.93 \text{ t ha}^{-1}$$

If it is desired to replace larger quantities of adsorbed sodium, the quantity of gypsum can be accordingly increased. Quantities of other amendments relative to gypsum are produced in **Table 12.6**.

In many laboratories the quantity of gypsum required for reclaiming sodic soil is determined by the gypsum requirement (GR) method suggested by Schoonover (1952). The test is performed by mixing a small soil sample (5 g) with a relatively large volume of saturated gypsum solution and measuring the calcium lost from the solution after reaction with soil. Sodium salts in a sodic soil are so diluted by this treatment that nearly complete displacement of exchangeable sodium by calcium from the gypsum solution

Table 12.6. Equivalent quantities of some common amendments for sodic soil reclamation

Amendment	Relative quantity
Gypsum ($CaSO_4$ $2H_2O$)	1.00
Calcium chloride ($CaCl_2.2\ H_2O$)	0.85
Sulphuric acid (H_2SO_4)	0.57
Iron sulphate ($FeSO_4.7H_2O$)	1.62
Aluminium sulphate ($Al_2(SO_4)_3.18H_2O$)	1.29
Sulphur (S*)	0.19
Pyrite (FeS_2*) - 30% Sulphur	0.63
Pressmud (Lime sulphur, 9% Ca, 24% S)	0.77

* Hundred per cent oxidation is assumed of materials like sulphur or pyrite in order to be as effective as soluble calcium compounds. In practice, however, this does not happen; thus their effectiveness is much lower.

occurs. The decrease in calcium from the gypsum solution when expressed on the basis of tonnes of $CaSO_4.2H_2O$ per 30 cm of soil is taken as the gypsum requirement of the soil.

Many sodic soils contain, in addition to excessive quantities of exchangeable sodium, appreciable amounts of soluble sodium carbonate. In such cases, the gypsum requirement test evaluates the amount of calcium required to replace the exchangeable sodium plus that required to neutralize all the soluble sodium carbonate in the soil. Therefore, sufficient amount of gypsum must be added to react with both soluble sodium carbonate and exchangeable sodium to achieve complete reclamation. However when gypsum is surface-applied after leaching the soil, only a small fraction of the soluble carbonates reacts with applied calcium and a major fraction of the soluble carbonates leaches without reacting with applied gypsum. Thus, under field conditions, one irrigation prior to application of gypsum would further ensure leaching of soluble carbonates, eliminating the need of additional quantities of gypsum for neutralizing the free and soluble sodium carbonate. Therefore in the modified procedure for estimating GR, the soil is washed free of soluble carbonates with alcohol before proceeding with the determination of gypsum requirement. It gives a more realistic estimate of the gypsum needs of sodic soils containing varying amounts of soluble carbonates.

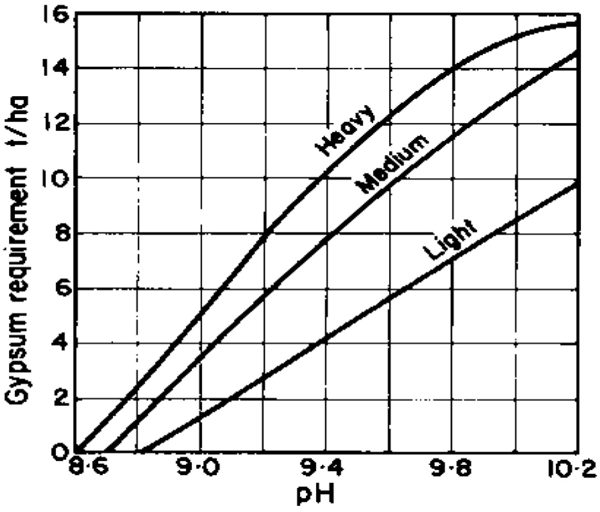

Figure 12.8. Relationship between pH of 1:2 soil-water suspension and the gypsum requirements of sodic soils of the Indo-Gangetic plains. Light, medium and heavy refer to soils with a clay content of approximately 10, 15 and 20%, respectively

It has been earlier pointed out that a relationship exists between soil pH and the exchangeable sodium percentage. Such a relationship has been established for sodic soils of the Indo-Gangetic plains and a graphical relationship between pH of 1:2 soil-water suspension and the gypsum requirement of the surface 15 cm depth is given in **Figure 12.8**. Since pH can be determined easily and it is measured on 1:2 soil-water suspension in most of the Indian laboratories, it can be very useful in field work. During reclamation, the aim is to obtain reasonable good first crop of rice. Several field experiments on sodic soils of Indo-Gangetic Plains have suggested that application of gypsum @ 25-50% of GR is sufficient for this purpose. Generally 25% GR has been found to be optimum for rice and 50% GR for the wheat following rice (Gupta and Abrol 1990). The reason is that the normal crop of rice can be obtained even in soils having ESP of over 50-55 compared to ESP of about 35-40 in case of wheat. Moreover, in the Schoonover's method GR is worked on the basis of 30 cm soil depth. For first crop of rice and following second crop of wheat, there is no need to reclaim this much soil depth because self-reclamation through mobilization of Ca^{2+} also begins simultaneously.

12.6.5. Gypsum-application based Agro-technology for reclamation of sodic soils under Rice-Wheat System

Practical and feasible reclamation technology for rice-wheat cropping system was developed to reclaim the sodic soils of the North West India in early 1980s, thanks to the pioneering work done at CSSRI, Karnal is given in box:

a) As a first step ensure proper land levelling.
b) Leach out of the excess salts from the sodic soil by ponding with irrigation or rain water for a period of 10 days prior to gypsum application after proper land levelling. This can be accomplished most efficiently during summer. This step will ensure leaching of soluble salts and soluble carbonates, if any.
c) Apply gypsum dose (calculated on the basis of soil test), evenly-broadcast and mix thoroughly with the top 10 cm of soil.
d) Again apply heavy irrigation and keep the water ponded for about 15 days to promote leaching out the salts and other reaction products out of the root zone.
e) After complete drainage of water and attaining field capacity (*Wattar*) conditions, grow green manure particularly *Dhaincha* after conventional tillage. After about 45-50 days, incorporate *Dhaincha* into the soil 2-3 days before the rice transplanting.
f) Prefer rice as the first crop in the reclamation because of following reasons:
    i) Rice can tolerate high level of soil sodicity and can withstand an ESP of 50 without any significant yield loss.
    ii) Submergence and biological activities of rice roots enhance the partial pressure of CO_2 that increases solubility of native $CaCO_3$through its conversion to soluble $Ca(HCO_3)_2$ which, in turn, lowers ESP by replacing Na from the soil exchange complex and that hastens reclamation process.
    iii) Ponding of water required for optimum rice growth is a distinct advantage in sodic soils because poor air-water relationship of these soils adversely affects other crops, which cannot tolerate submerged conditions. Standing water is also simultaneously used for dissolving gypsum and then leaching of the salts.
    iv) Dispersion of organic matter decreases in the presence of rice roots. So, leaching of sodic soils may help conserve the soil organic matter, losses of which otherwise will be quite substantial in the absence of rice crop.
    v) Cultivation of rice in poorly drained sodic soils helps in storing 10 to 20 cm of rain water in the fields. It helps in reducing the drainage needs of the area compared to the other crops and helps in the recharging of ground water.
g) In the next *rabi* season, wheat can be grown as the second crop to get the economic returns.

Based on relative tolerance of crops, their reclaiming effect on soil and economic returns, it has been observed that *Sesbania*-rice-wheat is the best cropping pattern in a highly sodic soil and this cropping pattern should be followed in first 4 to 5 years of reclamation. When pH of the surface soil comes down in the range of 8.5 to 9, other moderate and less tolerant crops can be included in the cropping sequence *viz.* mustard, sugarcane, barley and cotton. Then the other crops which are sensitive to sodicity, can be grown profitably after that period.

12.7. Swell-shrink Salt-affected Soils

Black soils commonly known as swell-shrink or cracking clay soils (Vertisols and their intergrades) occur in many parts of the world. In India these soils occupy an area of 72.9 Mha. Majority of these soils occur in the lower piedmont plains or valleys and in micro-depressions that have developed in the alluvium of weathered Deccan basalt.

Salt-affected swell-shrink soils have peculiar characteristics. Degradation of the swell-shrink soils due to salinity or sodicity causes profound influence and harmful effects on soil properties as well as on crop production. Due to their uniqueness in comparison to other salt-affected soils, their management strategies also vary.

12.7.1. Uniqueness of Swell-shrink Salt-affected Soils

When dry, Vertisols have a very hard consistence, whereas when wet they are very plastic and very sticky. The swell-shrink salt-affected soils (Vertisols and associated intergrades) of dry climates of peninsular India are unique in their characteristics as compared to the soils in the Indo-Gangetic plains or other soils elsewhere in the country. Accordingly their reclamation practices are also different. The reclamation is quite difficult owing to their high clay contents and intrinsic slow permeability coupled with sodium saturated clay due to degradation. These soils have poor drainage, but these soils generally show no salt-efflorescence on the soil surface due to high soil salinity/sodicity.

These soils do not qualify to be termed as the salt-affected soils as per the United States Salinity Laboratory criteria; however, the saturated hydraulic conductivity of sub-soils of Vertisol is adversely affected by clay dispersion caused by exchangeable sodium/magnesium. Despite low ESP, these have severe drainage problems. In the context of deterioration of soil physical condition and its harmful effect on plant growth, ESP 15 is considered too high to differentiate sodic soils from non-sodic soils in case of swell-shrink heavy clay soils. A value of SHC less than 10 mm hr^{-1} instead of ESP or SAR has been advocated as a diagnostic criteria for the sodic Vertisols of central peninsular India. As regards their management therefore, improving drainage porosity is most crucial. Sodic swell-shrink soils exhibit unique structural problems due to physical processes like slaking, crusting and hard setting. These problems can affect water and air movement, plant available water holding capacity, root penetration, seedling emergence, runoff and erosion as well as tillage and sowing operations (**Figure 12.9**). The smectitic clay in combination with high exchangeable sodium in these soils results in high degree of shrink-swell potential which causes the problems of internal drainage, thereby adversely affecting the crop production. The soils exhibit deep wide cracks during summers. The sowing time is most crucial in these soils due to narrow range of workable soil moisture. The soils need more draft power and hence are difficult for tillage. The bulk density of soils increases due to compaction caused due to swelling in the subsoil.


Figure 12.9. Poor growth of wheat crop in saline sodic Vertisols

Sodic subsoil clays are highly dispersive at electrolyte concentrations below a particular threshold concentration. On drying, the swollen or dispersed clay particles block the pathways for air and water transport. The resulting product is a dense, slowly permeable layer. In these soils, calcium carbonate accumulates during pedogenesis, sodium accumulation generates sodium bicarbonate and carbonate elevating the soil pH to above 9. In addition to the toxicity of carbonate and bicarbonate ions, high pH also leads to the occurrence of Fe, Mn, Cu, Zn and P deficiencies.

12.7.2. General Characteristics

1. Swell-shrink saline soils have pH between 7.0 and 8.5 and sodic soils have pH between 8 and 9.5.
2. Soils are generally heavy textured (clayey) and smectite is the dominant clay mineral.
3. The electrical conductivity of saturation paste extract is >4 dS m^{-1} in case of saline soils and variable in case of sodic soils but is generally less than 4 dS m^{-1}.
4. The sodic soils can have variable ESP which can go up to 30 which increases down the depth in soil profile.
5. These soils are mostly calcareous throughout the profile and the $CaCO_3$ accumulation increases down the depth.
6. These soils often do not show surface efflorescence.
7. Sodic soils are dispersed and hence have poor physical properties resulting in restricted water and air movement.
8. These soils are poor in microbial population and deficient in N and Zn.
9. Ground water quality in these areas is generally not good and these waters are not suitable for irrigation.

a) Formation due to primary salinity/sodicity: Black soils are mainly confined to river valleys. These soils are degraded due to historical and natural reasons of primary salinity. One of such valleys is Purna valley which is unique tract of Vertisols and associated soils in Vidarbha region of Maharashtra having combination of three-fold problems *viz.* the native salinity/sodicity, poor drainability and poor quality ground water. Such soils also occur in the basins of semi-arid eco-regions of the country. These have severe limitations for their sustainable use owing to the development of adverse physical condition especially poor internal drainage even at ESP value of 5. The unique feature of these soils is that though salinity is widely developed, presence of salts on surface is hardly seen. However, use of well water which is generally of poor quality makes the situation more problematic. The initiation of alkalization is operative in these soils in subsurface layers as a consequence of salt accumulation and it progresses in upward direction along with capillary rise of soil solution during dry periods. The major problems of these soils apart from native salinity/sodicity and poor hydraulic conductivity are their high degree of swell-shrink potential, compact and dense subsoil. These have resulted in complete leaching of salts from soil due to severe drainage impairments.

b) Irrigation-induced secondary salinization: Many areas of Vertisols and associated soils of irrigation projects in canal commands are affected due to waterlogging and secondary salinization. Main causes of salt problems in these soils are due to unscientific irrigation, topographic situation, aridity in climate, ground water rise due to canal seepage and poor drainability of soils. These soils can have saline, saline sodic and sodic characteristics.

Extension of irrigation to the arid and semi-arid regions, largely has led to an increase in the area under shallow water tables and has intensified the hazards of salinity and sodicity. This is because irrigation water brings in additional salts and releases immobilized salts in the soil through evapotranspiration and concentrating dissolved salts in the soil solution. The relative significance of each source in contributing soluble salts depends on the natural drainage condition, soil properties, ground water quality, irrigation water quality, and management practices.

Faulty management of irrigation water has resulted in widespread occurrence of the twin problems of waterlogging and soil salinity in several irrigation projects. The problem is further aggravated in swell-shrink soils due to very high clay content of soils with slow permeability and restricted drainage causing fast deterioration in soil quality and serious reduction in the crop yields. For instance, the soils of Mula canal command in Ahmednagar district of Maharashtra which were normal before introduction of canal irrigation have become degraded due to salinity and sodicity. The crop productivity of these soils has also been seriously impacted.

12.7.3. Soil Management Practices

Management practices for sustainable use of the swell-shrink soils are as follows:

12.7.3.1. Use of Amendments

Green manures and crop residues are the potential organic amendments in addition to gypsum for bringing on gradual soil improvement in physical and biological properties of the calcareous black sodic soils. Many sodic soils contain inherent or precipitated calcite ($CaCO_3$), at varying depths in the soil profile. Dissolution of this calcite by natural means is almost negligible. Amelioration of these soils has been predominantly achieved through the application of chemical amendments. However, cost of amendment has increased over the past two decades due to competing demands and limited sources of availability and high cost of transportation. Conjunctive use of FYM along with gypsum is a sustainable practices; FYM helps in reducing the dose of gypsum.

12.7.3.2. Drainage

Drainage of sodic swell-shrink soils presents special problems. Lowering of the ground water table by tile drains is ineffective because of extremely poor hydraulic characteristics of the soil. Vertical drainage from any bore hole or well from which underlying water is extracted either under pressure or through pumping is a promising practice for lowering the water table in these areas. Reclamation of saline-sodic deep Vertisols by installation of sub-surface drainage at 75 m spacing with 80 mm diameter PVC corrugated pipe along with incorporation of sugarcane trash @ 5 t ha^{-1} or green manuring with ***dhaincha*** provides effective drainage and significantly increases the productivity of crops. Apart from controlling ground water table, management of *monsoon* rains poses tricky problems in sodic soil areas. During rainy days, crops face excess water conditions and have near drought during dry spells. To overcome this and to conserve excellent quality water of the rain, a three tier system of water management involving rain water storage in crop land, shallow dug-out ponds and provision of surface drains has been recommended.

12.7.3.3. Land Configurations/Modifications

Improved land management with special care on efficient drainage of excess water is imperative to obtain higher yields in Vertisols. Broad bed-and-furrow system is an effective technology to attain high yield and reduce soil erosion in black soils. Raised broad beds act as the *in situ* bunds and contribute to moisture conservation in the dry period with simultaneous check on soil erosion, while the furrows help in safe disposal of excess water and prevent the vagaries associated with waterlogging.

12.7.3.4. Tillage and Crop Establishment

In swell-shrink sodic soils tilth is very poor because of high pH and ESP. The soils are very hard and compact when dry and very sticky when wet and there-fore, need to be tilled very carefully at the optimum moisture content. The effective root zone in alkali soils in the initial stage of reclamation is restricted to 10-15 cm depth because deep ploughings in an alkali soil devoid of $CaCO_3$ or $CaSO_4$ deposits in sub-soil may further deteriorate soil structure leading to reduced permeability of soil to water.

12.8. Leaching Requirement, Leaching Methods and Drainage Systems

The first step for ensuring crop production in salt-affected soils is to leach the salts to below the root zone. For sodic soils, application of appropriate chemical/organic amendments is required to displace sodium ions from the exchange complex before initiating any leaching and drainage programme. Thus, it is important to ensure adequate drainage in the soil for allowing sufficient leaching for the success of any reclamation process. It requires that sufficient water should pass through the soil to lower the salt concentration to permissible limits and help maintain salt and water balance in the root zone soil. When salts come from a shallow water table, the water table must be lowered by providing drainage before reclamation can be accomplished.

Leaching the salt-affected soil will generate a lot of highly salty drainage water and suitable measures for its disposal should be considered before initiating any leaching programme. It becomes critical and calls for more attention in areas with shallow water table. Reclamation rate depends on the amount of water travelling through the profile and out of the root zone (the leaching fraction).

In nutshell, the extent and magnitude of leaching varies with soil properties such as soil texture, soil structure, pore geometry of the soil, cracking phenomenon and clay mineralogy, initial salt content and its chemical composition, quality of water (amount and type of salts) used for leaching, leaching technique/method, nature of crops (Salt tolerance/sensitivity) and, water table depth.

Since saline soils mostly occur in areas deficient in good quality water; we must aim at improving efficiency of salt removal, which is defined as the quantity of soluble salts removed per unit volume of water applied. The amount of water required for leaching of salts to pre-determined level can be computed from $(C_f - C_i)/(Co - Ci)$ with D_w/D_s. Here, Co is the initial salt concentration; C_f is the final salt concentration, C_i is salinity of irrigation water while D_w is the depth of water displaced from a given depth of soil (D_s).

12.8.1. Leaching Requirement

The success of any leaching programme in the long run requires that the output of salts leaving the root zone should be more than, or equal to the inputs *i.e.* quantity of salts entering the root zone.

For an upland well drained soil, salt and water balance can be expressed as:

$$D_{iw}.C_{iw} + D_{rw}.C_{rw} = D_{dw}.C_{dw} + D_{ew}.C_{ew} \qquad \ldots(12.21)$$

And for shallow water soils (Water table < 2 m) as:

$$D_{iw}.C_{iw} + D_{rw}.C_{rw} + D_{cw}.C_{cw} = D_{dw}.C_{dw} + D_{ew}.C_{ew} \qquad \ldots(12.22)$$

where D_{iw}, D_{rw}, D_{dw}, D_{ew} and D_{cw} denote depth of irrigation water, rain water, drainage water, evapo-transpired water and capillary water, respectively and C_{iw}, C_{rw}, C_{dw}, C_{ew} and C_{cw} represent respective salinities of irrigation water, rain water, drainage water, evapo-transpired water and capillary water, respectively. Considering the concentration of salts of rain water (rw) and evapo-transpired water (ew) as negligible, the salt content at any given time for a given soil layer 'S' for well drained soils is given by equation (12.23):

$$S = D_{iw}.C_{iw} - D_{dw}.C_{dw} \quad \text{…(12.23)}$$

And for soils with shallow water table it is given by

$$S = D_{iw}.C_{iw} - D_{dw}.C_{dw} + D_{cw}.C_{cw} \quad \text{…(12.24)}$$

Under steady state condition, as 'S' becomes zero equation 12.23 for well drained soils reduces to:

$$D_{iw}.C_{iw} = D_{dw}.C_{dw} \text{ or } D_{dw}/D_{iw} = C_{iw}/C_{dw} \quad \text{…(12.25)}$$

C_{iw}/C_{dw} is defined as the leaching fraction

Equation 12.25 is rearranged to give equation 12.26

$$D_{dw} = D_{iw}.C_{iw}/C_{dw} = \text{Leaching requirement (LR)} \quad \text{...(12.26)}$$

D_{dw} the depth of drainage water under these conditions is called leaching requirement and is a product of the depth of irrigation water and leaching fraction.

And leaching requirement (LR) for shallow water table soils can be deduced from equation 12.24 as:

$$LR = D_{dw} = (D_{iw}.C_{iw} + D_{cw}.C_{cw})/C_{dw} \quad \text{….(12.27)}$$

Equations 12.26 and 12.27 imply that with increase in salinity of irrigation water, larger quantities of water (D_{iw}) have to be applied to control salt build-up to the desired level. The quantity of irrigation will still be more for shallow water table conditions particularly when salinity of the ground water is high and it can add to build-up of salts in the root zone through the process of capillary rise. However, sub-surface drainage may be needed under such conditions to ensure drainage to maintain desired salt and water balance. These calculations for LR are fairly accurate for most of the soils. In applying equations for LR, the value for salinity of the drainage water (C_{dw}) leaving bottom of the root zone is usually assumed to be the maximum permissible soil salinity (ECe).

Leaching fraction (LF) can be defined as the proportion of the depth of irrigation water that must pass through the root zone to maintain desired salt and water balance and to prevent yield reductions beyond acceptable level. Efficiency of leaching through irrigation water is seldom 100% and so the above equations can be further refined by the including the leaching efficiency factor, the value of which is generally less than 1%.

12.8.2. Leaching Methods

Continuous or intermittent ponding with sufficient quantity of water is the most common method used for leaching the salts out of the root zone. The efficiency of this method also varies with the texture of the soil; it will be more in coarse textured soils compared to fine textured soils. Lower water holding capacity of coarse textured soils leads to higher pore volumes of displacing water while low intake rate of fine textured soils leads to larger fraction of water to be wasted as runoff or as evaporation from stagnant water at the soil surface.

The basin furrow method of leaching is considered to be more efficient than ponding methods. Water in this method, is allowed to meander back and forth across the field through adjacent sets of furrows. The quantity of water required is much less than that needed for ponding method of leaching.

The efficiency of leaching method mainly depends upon how uniformly the water is applied in the field. Therefore, proper land levelling is a very important step before initiation of the leaching process. Variations in micro-relief within the field lead to the differential salinity build up; enhanced salinity in raised areas and relatively lower salinity in depressions presumably due to more leaching. In general, depth of water to be used for leaching should be equivalent to the depth of the soil to be reclaimed. As a thumb rule, passing of 1 m leaching water per meter soil depth under continuous ponding removes 80% of the soluble salts from the soil.

12.8.3. Monsoon-induced Leaching

The concept of LR is mainly of practical significance for areas having no or very low rains where nearly a steady state can be achieved. Under continental monsoon climate as in India, concentration of rains in a short span of 2-3 months is the most uncontrolled factor causing non-steady state reduction in salinity. Water penetrating into soils during this period usually exceeds the evapo-transpiration demands of crops and this induces leaching of salts. This water gets stored in the soil profile to be consumed by winter crops. In addition to the role of monsoons in salt leaching, largely inefficient irrigation systems in India (farm irrigation efficiency of 60-70%) also inadvertently contribute towards leaching requirements.

12.8.4. Drainage Systems

Reclamation of salt-affected soils basically needs drainage for evacuating excess water and salts from the crop root zone. Provision of drainage, as already stated, is of utmost importance for saline soils. Drainage system should be designed to regulate the salt and water balance for both the surface and sub-surface soil. For dense and impervious sodic soils, sub-surface drainage is not very effective but for soils with shallow water table for most part of the year and having poor quality ground water, the sub-surface drainage will be useful.

12.9. Differential Tolerance of Crops to Salinity/ Alkalinity

Crops differ considerably in their ability to tolerate salinity and sodicity. These crop-specific differences can be exploited by selecting crops that can produce satisfactory yield under given level of root zone salinity and sodicity. Apart from variations among different crops to tolerate salinity/sodicity, crop cultivars also vary widely in their relative salt tolerance. The relative salt tolerance depends upon the genetic make-up of the plant, its rooting behaviour, growth stage, nature, amount and distribution of salts in the soil profile and climatic conditions of the area. The harmful effects of salts on plants can be ascribed to soil reaction, osmotic effects, changes in proportion of exchangeable cations, ionic (nutritional) imbalance) and related specific ion toxicity effects and, physical properties of the soil.

Crop yields generally do not significantly decrease until the salt concentration exceeds a specific level *i.e.* the threshold level. The threshold level varies for different crops and their varieties. With increase in salinity beyond threshold level, yield of most crop starts declining linearly (food and fibre crops) and asymptotically (beans, onions, gram, lentil etc.). The relative growths are estimated using response functions consisting of the following two linear lines: (i) one with zero slope representing yield stability under increasing level of salinity, and other (ii) where yield decreases as a function of increasing salinity of the soil as per equation 26

$$Yr = 100b(ECe - a) \quad \text{....(12.28)}$$

where, Yr is the relative yield at a given ECe, ‘a’ is the threshold salinity expressed in dS m^{-1}, and ‘b’ is the slope expressed in per cent decrease per dS m^{-1}. General guidelines can be drawn for selection of different crops based on their relative tolerance to salinity (**Table 12.7**) and sodicity (**Table 12.8**) under Indian conditions (Gupta and Abrol 1990).

Besides the sodicity-tolerant crops listed in **Table 12.8**, Karnal grass and para grass also have family high degree of tolerance to sodic environment. The information on relative salinity and sodicity tolerance has a great significance as it helps us to choose economically viable crops to be grown at different stages of reclamation.

Table 12.7. Relative salt tolerance of important field crops

Plant species	Threshold salinity (dS m^{-1})	Slope (% per dS m^{-1})	EC$_e$(dS m^{-1}) for relative yield of		
			90%	75%	50%
Rye	11.4	10.8	12.3	13.7	16.0
Guar	8.8	17.0	9.4	10.3	11.7
Barley	8.0	5.0	10.0	13.0	18.0
Cotton	7.7	5.2	9.6	12.5	17.3
Sugarbeet	7.0	5.9	8.7	11.2	15.4
Sorghum	6.8	16.0	7.4	8.4	9.9
Wheat	6.0	7.1	7.4	9.5	13.0
Rye grass	5.6	7.6	6.9	8.2	10.8
Soybean	5.0	20.0	5.5	6.2	7.5
Cowpea	4.9	12.0	5.7	7.0	9.1
Groundnut	3.2	29.0	3.6	4.1	4.9
Rice	3.0	12.0	3.8	5.1	7.2
Maize	1.7	12.0	2.5	4.0	5.9
Sugarcane	1.7	5.9	3.4	5.9	10.1
Flax	1.7	12.0	2.5	4.0	5.9
Berseem	1.5	5.7	3.2	5.9	10.2

Table 12.8. Relative tolerance of crops to soil sodicity

ESP (range*)	Crop
2 – 10	Deciduous fruits, nuts, citrus, avocado
10 – 15	Safflower, black gram, peas, lentil, pigeon pea
16 – 20	Chickpea, soybean
20 – 25	Clover, groundnut, cowpea, onion, pearlmillet
25 – 30	Linseed, garlic, cluster beans
30 – 50	Oats, mustard, cotton, wheat, tomatoes
50 – 60	Beets, barley, *Sesbania*
60 – 70	Rice

*Relative yields are 50% of the potential of the given crops in the respective sodicity ranges

12.10. Quality of Irrigation Water and Conjunctive Use of Mutli-quality Waters

All the irrigation waters contain some salts, but the amount and nature of salts vary. The concentration and composition of dissolved constituents in water determines its quality. The quality of irrigation water depends mainly on its salt content (salinity), proportion of Na^+ to divalent cations and nature of anions (alkalinity or sodicity) and toxicity of some ions. Many other important criteria in assessing water quality for other uses, such as taste, colour, odour, turbidity, hardness, pH, biological oxygen demand (BOD), chemical oxygen demand (COD), elements like B, F, S, Li, N and P etc. and other pathogenic organisms are usually not so important for irrigation water.

The most important criterion for evaluating water quality is its total salt concentration. The quantities of salts dissolved in irrigation water are usually expressed in terms of EC, mg L^{-1} (ppm) or meq L^{-1}, the former being more popular because of ease and precision in its measurement. In irrigated agriculture, salinity of irrigation waters is commonly expressed in terms of EC (dS m^{-1}). The EC values range from 0.6 dS m^{-1} for fresh water to 1.5-3.0 dS m^{-1} for brackish water to about 45 dS m^{-1} for sea water (Choudhary *et al.* 2011).

12.10.1. Criteria for Evaluation of Irrigation Water

a) Total concentration of soluble salts that determine salinity

b) Relative proportion of sodium to other cations that determine sodicity

c) Anion composition of water especially the concentration of CO_3^{2-} and HCO_3^- with respect to the concentration of basic cations such as Ca^{2+} and Mg^{2+}

d) Concentration of boron, fluoride, selenium or any other ions that may be toxic to plant growth, even when present in small quantities. In addition, there can be specific ion toxicities of Na^+, Cl^- and HCO_3^- in some cases.

12.10.2. USSL Classification

Based on EC and SAR different classifications have been proposed for assessing water quality but no classification has uniform applicability that may work at all locations under all conditions. However, the most common classification at the global level has been given by United States Salinity Laboratory (USSL) in 1954 (Richards 1954). It is based on electrical conductivity and sodium adsorption level (SAR). In this classification, four salinity and four sodium hazard classes have been proposed (**Figure 12.10**).

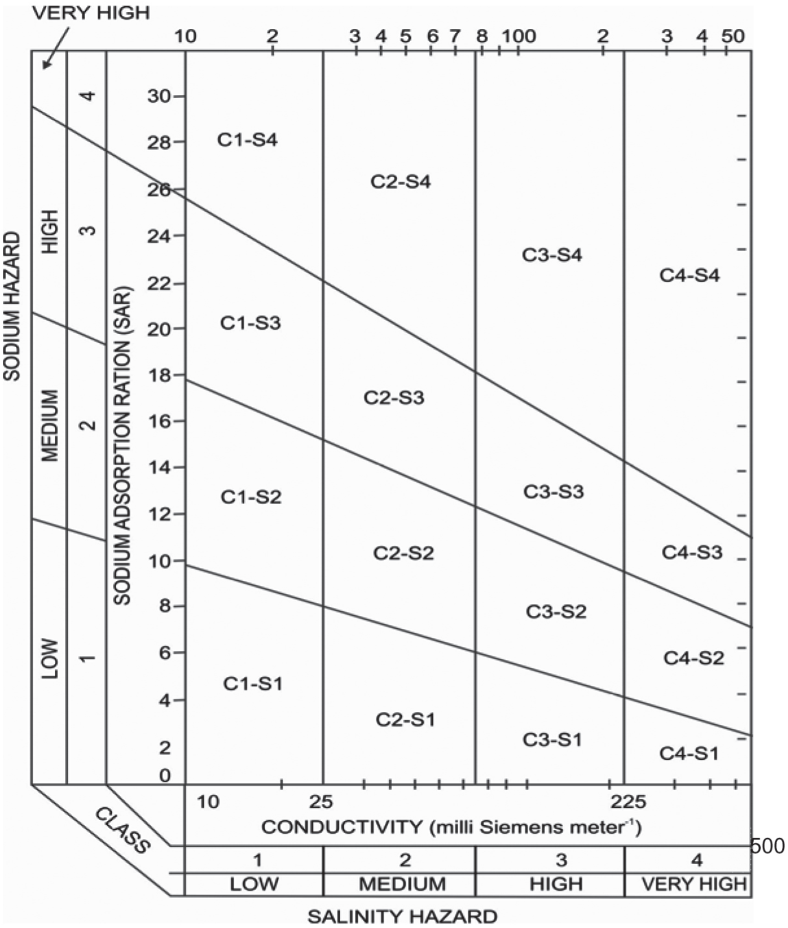

Figure 12.10. Classifications of irrigation water according to United State Soil Salinity Laboratory (Richards 1954)

Salinity hazard: According to USSL classification, four salinity classes *i.e.* C1, C2, C3 and C4 have been proposed based on EC values expressed as mS m^{-1} (formally expressed as μmhos cm^{-1}; 1 mS m^{-1} = 10 μmhos cm^{-1}) . Classes C1 (0-25 mS m^{-1}) and C2 (25-75 mS m^{-1}) are considered suitable for irrigation (no or negligible problem) while C3 (75-225 mS m^{-1}) and C4 (225-500 mS m^{-1}) are not suitable for irrigation purpose as these waters can cause severe salinity problem in the soil when used for irrigation.

Sodium hazard: High concentrations of sodium are undesirable in irrigation water because sodium adsorbs onto the soil exchange complex at the expense of other cations namely calcium and magnesium. It is estimated as the ratio of the sodium concentration to the concentration of calcium and magnesium; this ratio is known as sodium adsorption ratio (SAR) given by equation 12.29:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \qquad \ldots(12.29)$$

In this equation concentrations are cations are expressed in meq L^{-1}.

Low sodium hazard (S1, 0 - 10 SAR) in **Figure 12.10** presents negligible sodicity hazard in soil while medium sodium hazard water (S2, 10 - 18 SAR) can present appreciable hazard but can be used for irrigation with appropriate management. High (S3, 18-26 SAR) and very high sodium hazard (S4, SAR > 26) are harmful as these can cause appreciable build-up of ESP in the soil and hence are unsuitable for irrigation purpose.

12.10.3. Electrical Conductivity × Sodium Adsorption Ratio Interaction

The EC-SAR interaction is based on the fact that higher concentrations of Ca^{2+} and Mg^{2+} are able to counteract the dispersive nature of Na^{+}, thereby reducing dispersion effects on soil structure (**Figure 12.11**). Infiltration rates are severely reduced when EC is very low (less than 1 dS m^{-1}), even though SAR may not be excessively high. On the other hand, there may be less of a reduction in infiltration rates when sodicity is coupled with high salinity. This interaction between EC and SAR is important in determining management techniques. For instance, if rain-diluted/ non-saline irrigation is applied to soil previously irrigated with saline-sodic water, soil EC could drop more quickly than the SAR, and infiltration and soil structure could get worsened.

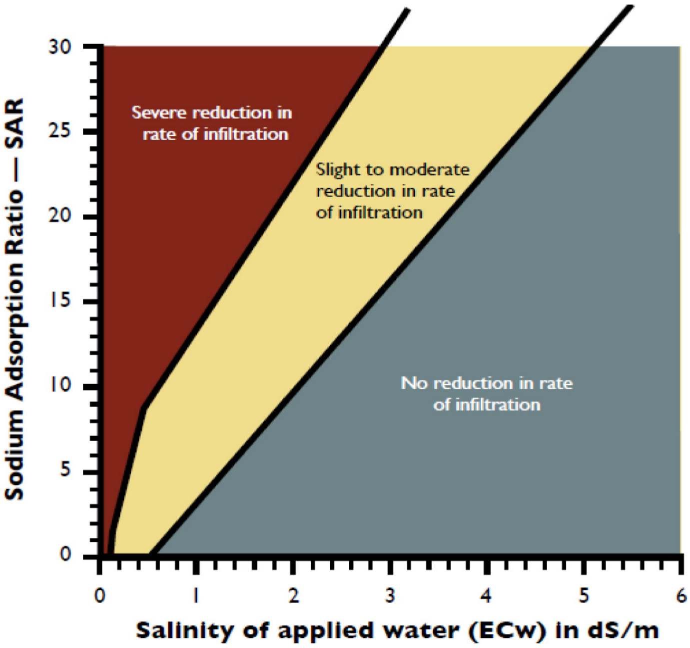

Figure 12.11. Interaction between EC and SAR on infiltration rates of irrigation water. Relationship is independent of soil texture

Caution: The EC-SAR interaction is negative impact of high EC on plant health. Regardless of improved infiltration, plant establishment and growth will be poor if EC levels are too high. Thus, when determining the effect of Na^{+} on infiltration and other soil properties, EC and all of its associated effects should also be taken into consideration.

12.10.4. Residual Sodium Carbonate

The sodicity of the water is also described by residual sodium carbonate (RSC, Eaton 1950). It predicts a potential infiltration problem and is given by equation 12.30.

$$\text{RSC} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \qquad \ldots(12.30)$$

where concentrations of cations and anions are given in meq L^{-1}. As a result the unit of RSC is also meq L^{-1}.

The concept of RSC is being used in soil testing laboratories in India and other south Asian countries to predict sodicity hazard of irrigation waters and is being accordingly used to make recommendations to the affected farmers.

12.10.5. Adjusted Sodium Adsorption Ratio (Adj. SAR)

The SAR is now being reported as the new adj. SAR proposed by Suarez (1981), commonly known as "Adj. R_{Na}". The Adj. R_{Na} procedure adjusts the calcium concentration of irrigation water (Cax) to the expected equilibrium value based on $p\text{CO}_2$, salinity (ECiw) and HCO_3: Ca ratio.

The Adj. R_{Na} is given by equation 29:

$$\text{Adj. } R_{Na} = \frac{Na^+}{\sqrt{(Cax^{2+} + Mg^{2+})/2}} \qquad \ldots. (12.31)$$

Results from several experiments in northwest India indicate that Adj. R_{Na} can serve as a useful index to predict the ESP increase from irrigation with alkali waters in millet/maize-wheat rotation, because it does not require the use of any empirical constant compared to SAR. But for the rice-based cropping sequences, development of empirical constant is needed for all the indices or a value of 2.6 Adj. R_{Na} seems to be reliable.

In India, poor-quality saline and/or sodic (containing high carbonates of Na) ground waters constitute a major portion (32-84%) of the total irrigation potential of ground waters in different states. Most of the ground waters in north-western semi-arid parts of India receiving 500-700 mm rainfall annually test high in residual alkalinity than those in the dry arid regions receiving less than 350 mm annual rainfall where the ground waters are generally saline in nature.

Generally, saline water is defined as water having EC > 2 dS m^{-1} or 2000 µmhos cm^{-1}. However, different states of India follow different limits of salinity for ground water for irrigation purpose *e.g.* the upper limit of salinity for irrigation water in Haryana, Punjab, Delhi, Western Rajasthan, Eastern Rajasthan, Gujarat and Uttar Pradesh are 6, 4, 3, 8, 6, 3.46 and 2.25 dS m^{-1}, respectively. The Bureau of Indian Standards has also classified irrigation water vide: 11624 of 1986 on the basis of electrical conductivity. Irrigation waters with EC < 1.5, 1.5-3.0, 3.0-6.0 and > 6.0 dS m^{-1} are designated as low, medium, high and very high saline, respectively.

Some of the irrigation waters have a tendency to produce alkalinity/sodicity hazards depending upon the absolute and relative concentrations of specific cations and anions contained in them. Sodic irrigation water has SAR higher than 10 and RSC higher than 2.5 meq L^{-1}. However these values are only guidelines since specific values will depend upon the crop, chemical and physical characteristics of the soil, and climate.

12.10.6. Criteria based on Researches in India

Water that is generally classified as unsuitable for irrigation might be used safely depending upon the salinity and composition of the water, soil characteristics and management strategies adopted. This has led to replacement of conservative water quality standards with site-specific guidelines, where factors like soil texture, rainfall, subsurface drainage, and crop tolerance have been given the due consideration. Based on these considerations, All India Coordinated Project – Saline Water, CSSRI, Karnal, HAU, Hisar and PAU, Ludhiana in 1990 jointly developed following water quality guidelines (**Table 12.9**).

Table 12.9. Guidelines for using poor quality irrigation waters

A. Saline water (RSC < 2.5 meq L^{-1}*)*

Soil texture (% Clay)	Crop tolerance	Upper limits of ECw (dS m^{-1}) in rainfall regions (mm)		
		< 350	350-550	550-750
Fine	S	1.0	1.0	1.5
(> 30)	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Moderately	S	1.5	2.0	2.5
fine	ST	2.0	3.0	4.5
(20-30)	T	4.0	6.0	8.0
Moderately	S	2.0	2.5	3.0
coarse	ST	4.0	6.0	8.0
(10-20)	T	6.0	8.0	10.0
Coarse	S	-	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

S, ST and T denote sensitive, semi-tolerant and tolerant crops to salinity in irrigation waters

B. Sodic waters containing RSC > 2.5 meq L^{-1} *and ECw < 4.0 dS* m^{-1}*)*

Soil texture (% Clay)	Limits of		Remarks
	SAR (meq L^{-1})$^{1/2}$	RSC (meq L^{-1})	
Fine	10	2.5-3.5	(1) When the waters have Na < 75% (> 30) (Ca+Mg> 25%) or rainfall is > 550 mm, the upper limits of the RSC range
Moderately fine (20-30)	10	3.5-5.0	
Moderately coarse (10-20)	15	5.0-7.5	
Coarse (< 10)	20	7.5-10.0	

(i) Textural criteria should be applicable for all soil layers down to at least 1.5 m depth.

(ii) In areas where ground water table reaches within 1.5 m, at any time of the year or a hard subsoil layer is present in the root zone, the limits of next finer textural class should be used.

Adapted from Minhas and Gupta (1992)

12.11. Conclusions

Salt-affected soils cover vast areas in arid and semi-arid regions. High evaporation in these areas results in the accumulation of large amount of salts in the root zone that adversely affect the plant growth. Nevertheless, many of these are potentially fertile soils and, can be very productive if properly managed. According to USSL classification, the salt-affected soils are grouped in three classes based on the total salt concentration (EC) and proportion of sodium among the cations (SAR and ESP). The physical conditions of saline and saline-sodic soil are satisfactory for plant growth but the sodic soils are largely dispersed and poorly aerated with low water permeability. Based on Indian experience, salt-affected soils are classified in two categories i.e. saline and sodic soils; which are distinguished on the basis of preponderance of chlorides and sulphates over that of sodium. If sodium is more than chlorides and sulphates with pH of the saturated soil paste (pHs) less than 8.2, the soil is saline and if the sodium is less than chlorides and sulphates and pHs > 8.2 then soil is sodic in nature.

The first step for ensuring crop production in salt-affected soils is to lower the salinity within acceptable limits by leaching out the salts and maintain salt and water balance in the root zone. It is important to ensure adequate drainage in the soil. For reclamation of sodic soil, application of appropriate amendment such as gypsum ($CaSO_4.2H_2O$) is required to displace sodium ions from the exchange complex before initiating leaching. Calcium supplied through gypsum or any other amendment will stimulate flocculation and increase permeability of the soil to facilitate leaching of the replaced sodium and other salts out of the root zone.

Injudicious use of poor quality ground waters in many arid and semi-arid regions for irrigation leads to the build-up of salinity and/or sodicity in soil and deterioration of soil health because of which sustainability of crop production is adversely affected. Despite these harmful effects, the poor quality waters can also become a valuable resource for irrigation and sustaining crop production, when used and managed correctly.

Study Questions

Q.1. Why do saline and sodic soils occur in dry regions?

Ans. 1. Rainfall in arid and semi-arid regions is not sufficient to leach down salts to the deeper layers of soil. Coupled with it, high evaporation in these areas results in the accumulation of large amount of salts in the root zone. Accumulation of salts has been found to increase with increase in dryness of the area.

Q.2. Explain classification of salt-affected soils based on Indian experience

Ans. 2. Based on Indian experience, saline and sodic soils are distinguished on the basis of preponderance of chlorides and sulphates over that of sodium. If $Na^+/(Cl^- + SO_4^{2-})$ ratio is less than 1 and pH of the saturated soil paste (pHs) is less than 8.2, the soil is saline in nature. If ratio of $Na^+/(Cl^- + SO_4^{2-})$ is more than 1.0 and pHs is more than 8.2, soil is defined to be sodic. The experiences about Indian sodic soils show that ECe is limitless if originating from high concentrations of carbonates and bicarbonates from sodium.

Q.3. Why the plants grown in saline soils appear water-stressed?

Ans. 3. The main effect of high concentration of soluble salts on plants in a saline soil is osmotic stress. The semi-permeable membrane of plant roots permits water to pass but rejects most of the salts. Osmotically it becomes difficult for the roots to extract water from saline solutions and thus, plants growing in saline soils appear water stressed. At times, these soil conditions are known as 'wet drought' conditions because of physiological unavailability of water to plants.

Q.4. Describe uniqueness of swell-shrink salt-affected soils

Ans. 4. The swell-shrink salt-affected soils (Vertisols and associated intergrades) of dry climates of peninsular India are unique in their characteristics as compared with the soils in the Indo-Gangetic plains or other soils elsewhere in the country because of following reasons.

- When dry, Vertisols have a very hard consistence, whereas when wet they are very plastic and very sticky.
- The optimum soil moisture range for tillage (moist soil with a friable consistence) is narrow. The reclamation of these soils is quite difficult owing to their high clay contents and intrinsic slow permeability coupled with sodium saturated clay due to degradation.
- These soils have poor drainage, however, they generally show no salt-efflorescence on the soil surface due to high soil salinity/sodicity.
- These soils do not qualify as salt-affected soils as per the United States Salinity Laboratory criteria; however, the saturated hydraulic conductivity of their sub-soils is adversely affected by clay dispersion caused by exchangeable sodium/magnesium.
- In the context of deterioration of soil physical condition and its harmful effect on plant growth, ESP 15 is considered too high to differentiate sodic soils from non-sodic soils in case of swell-shrink heavy clay soils.
- A value of SHC less than 10 mm hr^{-1} instead of ESP or SAR has been advocated for the sodic Vertisols of central peninsular India.

Q.5. Why do high sodium relative to calcium causes dispersion of soil colloids?

Ans. 5. High amounts of sodium compared with calcium increase the zeta potential of the soil exchange complex which causes repulsion of clay particles from each other, thereby causing dispersion of soil colloids. This is a typical property of alkali/sodic soils.

Q.6. Calculate the leaching requirement to prevent the buildup of salts in the upper 30 cm if the ECiw is 1.5 dS m^{-1} and ECdw is 7.5 dS m^{-1}.

Ans. 6. Leaching requirement (LR) =ECiw/ECdw

So LR in this case = 1.5/7.5 = 0.20

That means 20% of applied irrigation water with EC 1.5 dS m^{-1} should pass beyond 30 cm to control the buildup of salts beyond 7.5 dS m^{-1}.

Q.7. Why gypsum is most commonly used in reclamation of sodic soils? Give its chemical reactions

Ans. 7. Mined gypsum is the most commonly used chemical amendment for sodic soil reclamation because of its abundant availability and low cost. Gypsum is chemically $CaSO_4.2H_2O$ that occurs extensively in natural deposits. In India, gypsum deposits are estimated to be more than 1000 Mt. It must be ground before it is applied to the soil.

Gypsum reclaims the sodic soils to improve crop productivity. It reacts with both the Na_2CO_3, and the adsorbed sodium as follows:

$Na_2CO_3 + CaSO_4 = CaCO_3 + Na_2SO_4$ (leachable)↓

2Na-clay micelle + $CaSO_4$ =Ca –clay micelle + Na_2SO_4 (leachable)↓

Q.8. Calculate the gypsum requirement to reclaim a sodic soil with an ESP of 40 and a CEC of 20 cmol(p^+)kg^{-1} to reduce the ESP of the upper 30 cm soil to about 10%. Assume purity of the gypsum to be applied is 70%.

Ans. 8. The soil has a CEC of 20 cmol(p^+)kg^{-1} and ESP of 40, and we desire an ESP of approximately 10 following treatment.

ESP of 40 – desired ESP of 10 = ESP of 30, or 30% exchangeable Na must be replaced with calcium (Ca) to achieve the desirable ESP.

0.30 (30%) x 20cmol(p^+)CEC/kg = 6cmol Na/kg soil that must be replaced.

The quantity of pure gypsum required to supply half a cmol of calcium per kg soil for the upper 15 cm soil depth is equal to:

Molecular weight of gypsum/200 = 172/200 = 0.86 g kg^{-1} soil= 86 x 10^{-5} kg kg^{-1} soil

= 86 x 10^{-5} x 2.24 x 10^6 kg ha^{-1} =1926 kg or 1.93 t ha^{-1}

For 30 cm soil depth it is equal to 1.93 x 2 = 3.86 t ha^{-1}

So to neutralize 6cmol/kg of Na quantity of pure gypsum = 3.86 x 6 = 23.16 t ha^{-1}

If purity of gypsum is 70%, then quantity of gypsum required will be 23.16 x 100/70 = 33.08 t ha^{-1}

Thus, about 33 tonnes of 70% pure gypsum per hectare would be required to reclaim the top 30 cm of this soil to reduce ESP from 40 to 10.

Q.9. What are the characteristics that determine irrigation water quality?

Ans. 9. Following are the characteristics that determine irrigation water quality

a) Total concentration of soluble salts that determine salinity
b) Relative proportion of sodium to other cations that determine sodicity
c) Anion composition of water especially the concentration of CO_3^{2-} and HCO_3^- with respect to the concentration of basic cations such as Ca^{2+} and Mg^{2+}.
d) Concentration of boron, fluoride, selenium or any other ions that may be toxic to plant growth, even when present in small quantities. In addition, there can be specific ion toxicities of Na^+, Cl^- and HCO_3^- in some cases.

Q.10. An irrigation water contains 500, 150 and 30 mg L^{-1} of Na^+, Ca^{2+} and Mg^{2+}, respectively. Calculate (a) SAR of the irrigation water, (b) approximate EC in dS m^{-1} and (c) osmotic pressure of the irrigation water.

Ans. 10. Amount of Na^+ in me L^{-1} = 500/23 = 21.7

Amount of Ca^{2+} in me L^{-1} = 150/20 = 7.5

Amount of Mg^{2+} in me L^{-1} = 30/12 = 2.5

Total cations = 21.7 + 7.5 + 2.5 = 31.7 me L^{-1}

(a) SAR of irrigation water = Na/[(Ca + Mg)/2] = 21.7/(7.5 + 2.5)/2 = 21.7/5 = 21.7/2.24 = 9.68 say 9.70
(b) Approximate EC of irrigation water = Total cations (me L^{-1})/10 = 31.7/10 = 3.17 dS m^{-1}
(c) Osmotic pressure of irrigation water = EC (ds m^{-1}) x (-0.36) = -3.17/0.36 = -8.80 bars

Q.11. An irrigation water contains 1.0, 7.0, 2.0 and 1.0 me L^{-1} of CO_3^{2-}, HCO_3^-, Ca^{2+} and Mg^{2+} respectively. Calculate the RSC of the irrigation water and comment on its suitability

Ans. 11. Residual sodium carbonate (RSC) = (CO_3^{2-}+ HCO_3^-) - (Ca^{2+} and Mg^{2+})

Putting all values, we get RSC = (1.0 + 7.0) – (2.0 + 1.0) = 8.0 – 3.0 = 5.0 me L^{-1}

Water having RSC of 5.0 me L^{-1} can be used in moderately coarse textured soils with 10 to 20 % clay and with caution in moderately fine textured soils having 20 to 30% clay.

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