Salt-affected Soils and their Managements

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Abstract

Accumulation of excessive salt in irrigated soils can reduce crop yields, reduce the effectiveness of irrigation, ruin soil structure, and affect other soil properties. This publication is designed to evaluate the kind and amount of salts present in soils and to select management alternatives.

1. Introduction

Generally, in addition to soil-related factors such as too low or too high moisture content, low fertility, and poor physical conditions, excess soil salinity may also inhibit normal crop growth and development (Kelley, 1951). Actually, in most arid and semi-arid regions where precipitation is insufficient to leach the salt from the root zone, accumulation of excessive amounts of soluble salts in the root zone is a major limiting factor in production and/or management of quality. Wherever salinization of soils occurs, it is a continuous process resulting from various combinations of insufficient precipitation, inadequate irrigation, poor drainage, irrigation with poor quality water, and/or the upward movement of salts from saline underground water (Abrol and Dahiya, 1974). As a general rule, if the amount of water applied to the soil (irrigation plus natural precipitation) exceeds evapotranspiration, salt movement is downward (Szabolcs, 1974). Conversely, salt movement is upward if evapotranspiration exceeds the amount of water applied.

2. Origin and Distribution of Salts

Salt-affected soils often occur on irrigated lands, especially in arid and semi-arid regions, where annual precipitation is insufficient to meet the evaporation needs of plants (FAO, 1976a). As a result, salts are not leached from the soil, but accumulated.

2 .1. Mineral weathering without leaching

During the physical and chemical weathering process, salts are released from rocks and minerals of the earth's crust. In humid areas, soluble salts are carried down through the soil profile percolating rainwater and ultimately transported to the sea. In arid regions, leaching is very limited. Therefore, salts tend to accumulate (Abrol and Dahiya, 1974).

2.2. Dissolution of fossil salts

Groundwater or drainage water from irrigation system can dissolve appreciable amount of saline deposit, and the resultant water can be very high in salt content (Beek and Van Breemen, 1973).

2.3. Atmospheric deposition

Rainfall may contain as high as 50 to 200 mg liter^{-1} of salts near the seacoast. This amount decreases rapidly as rain moves towards island. Rain water is high in Na, Cl and Mg near the seacoast, whereas island precipitation is dominated by calcium and magnesium sulphate (Szabolcs, 1979). Over several thousand years, this atmospheric deposition becomes significant.

2.4. Salt movement with water

If downward movement of water is not a limiting factor , then salt will move downward to the wetting front (Bazilevick, 1965). However, if plants take up most of water, then salt will accumulate near the surface and becomes detrimental to plants.

2.5. Upward movement with capillary water

Water from groundwater table within a few meters from the soil surface can move up by capillary action, where it evaporates and leaves behind its salts. The amount of salt accumulations can be very large in the top 15 cm of soil.

3. Classification of Salt-affected Soils

Salt-affected soils may contain excess soluble salts, excess exchangeable sodium, or both. Salt- affected soils can be categorized into three groups depending on the total soluble salts and the amount of sodium salts (FAO, 1976b). Table 1 and 2 summarizes different salt-affected soils as saline, sodic, and saline-sodic. Electrical conductivity (EC)-the ability of a soil solution to carry an electrical current-is used to measure soluble salts. The higher the EC value, the higher will be the soluble salt content of soil (Szabolcs, 1980). Sodium adsorption ratio (SAR) is a measure of the amount of sodium present in the soil in comparison to calcium and magnesium. Such soils are generally divided into three groups as follows:

3.1. Saline soils

The saturation extract of these soils has an EC greater than 4 decisiemens meter^{-1} (dS.m^{-1}) and exchangeable sodium percentage (ESP) below 15. Soil pH is generally below 8.5. Saline soils are often referred to as *white alkali*, and are easily recognized by the white salt crust formed on the surface as the soil dries. Given adequate water and drainage, these soils can be desalinized by leaching.

3.2. Sodic (alkali) soils

This category applies to soils wherein EC of the saturation extract is less than 4 dS.m^{-1}, the ESP exceeds 15, and soil pH is generally above 8.5. These soils, often referred to as *black alkali*, are recognized by the absence of the white surface crust when the soil dries. High levels of sodium in these soils, combined with relatively low levels of calcium and magnesium, cause dispersion of clay particles resulting in structure-less soil with low water and air permeability.

3. 3. Saline-sodic (alkali) soils

The saturation extract of these soils has an EC greater than 4 dSm^{-1}, and ESP greater than 15. Soil pH is seldom above 8.5 (Kovda, 1965). If existing soluble salts are leached downward while exchangeable sodium in the soil profile remains constant, soil properties are likely to resemble closely to those of sodic (alkali) soils. However, as long as soluble salts are present, these soils are more similar to saline soils in both appearance and physical properties. Levels of salinity/sodicity in a given soil can vary greatly over relatively short distances.

4. Salt-affected Soils in India

Salt-affected soils (Figure 1) generally occur in regions that receive salts from other areas, and water act as the primary carrier. Although the weathering of rocks and minerals is the source of all salts, rarely are the salt-affected soils formed from the accumulation of salts *in situ*. About 6.73 million hectares of India's land area (Table 1) is afflicted with the twin problems of alkalinity and salinity coupled with water-logging, which seriously reduce agricultural productivity (Abrol, 1982) and have grave implications for our food security system (Abrol et al., 1980). Distribution of salt-affected soils in different agro-climatic regions has also been mentioned in Table 3.

5. Diagnosing Saline and Sodic Soil Problems

5.1. Laboratory diagnosis

Soil testing laboratories typically evaluate pH and EC as a part of routine analysis (FAO, 1971b). If pH is high (>8.5), SAR should also be calculated. See Table 4 to evaluate the laboratory test results.

Symptoms and causes of salinity, high pH, specific ion toxicity, and sodicity are frequently confused (Abrol et al., 1980.). Each of these conditions can have adverse affects on plant growth, but they differ significantly in their cause and relative impact. Effective management of these problems varies and requires proper diagnosis (Abrol, 1982). Proper diagnosis is critical to successful problem correction.

5.2. In-field diagnosis

Visual symptoms (Table 5) can be used to identify these problems, but ultimately soil test is the best way for an accurate diagnosis (ILACO, 1981). When salinity is suspected from a high water table, one may be able to measure groundwater depth by boring holes with an auger. If free water collects in holes is <4-5 feet deep, a drainage problem is indicated. Normally, high pH or basic soil does not look different than soil with neutral pH, although sometimes the soil may have a powdery substance on its surface. Plants growing in these soils sometimes give clues about the problem. High pH reduces the availability of some nutrients (zinc, iron, phosphorus) to the plants.

Therefore, signs of high soil pH include yellow stripes on middle to upper leaves (signs of zinc and iron deficiency), or dark green or purple coloring of the lower leaves and stems (signs of phosphorus deficiency). Looking for symptoms is useful when growing high pH sensitive plants such as dry beans, sorghum, or silver maples. Corn and wheat are moderately susceptible to high pH and may also suffer from nutrient deficiencies on these soils.

Plants growing in saline soils may appear water stressed. This is because the high salt content of the soil hampers the ability of plants to take up water from the soil. Water naturally moves from areas of low salt content to high salt content. Sometimes a white crust is visible on a saline soil surface. Plants that are sprinkler irrigated with saline water often show symptoms of leaf burn, particularly on young foliage.

If a soil is sodic, a brownish-black crust is sometimes formed on the surface due to dispersion of soil organic matter (Richards, 1954). Dispersion of soil particles also results in crusting and impaired drainage. Often one will first notice reduced seedling emergence and viability. By the time darkened crusts are visible on the soil surface, the problem becomes severe where plant growth and soil quality are significantly affected. Laboratory analysis of soil is the best way to diagnose these problems before plant growth is severely damaged.

5.3. What can be done after diagnosis?

There are several management options available once the extent of the problem and its source are properly identified.

6. Management of Salt-affected Soils

6.1. Leaching

Saline soils irrigated with large quantity of water having low to moderate levels of salts are reclaimed as the salts leach below the root zone. Initially, reclamation rate depends on the amount of water traveling through the profile and out of the root zone (the leaching fraction). Thus, it is important to ensure that there is adequate drainage in the soil to accommodate an adequate leaching fraction. When salts come from a shallow water table, the water table must be lowered by providing drainage before reclamation can be accomplished.

In some situations, lowering the water table might not be economical, and an alternate crop or land use might be a better choice (Biggar and Nielsen, 1962). Many saline soils are the result of irrigation with water containing moderate to high levels of salts. Although leaching will minimize salt accumulation, no amount of leaching will entirely correct the problem until an alternate irrigation source is secured to mix with or replace the poor-quality water. On soils where the best management strategies are used, salts will be lowered to no more than 1.5 times the EC of the irrigation water.

The higher the EC of the water used for leaching, the larger the leaching fraction needed to lower soil EC (FAO, 1976b). As a general rule, soil salinity (EC) is reduced by one-half for every 6 inches of good quality water (an EC lower than the target for the soil) that moves through the soil. Thus, if the target zone is 30 inches deep and the EC is 1.5 dSm^{-1}, 6 inches of water should flow deeper than 30 inches to reduce the soil EC to 0.75 dSm^{-1}. Monitor soil EC following each water application and adjust leaching practices accordingly.

Coarser-textured (sandy) soils require less management to leach salts because infiltration rates are high and more water can be applied over a shorter period of time (Abrol et al., 1988). Fine-textured soils (clays) require more management to move salts out of the soil because the infiltration rate is lower and less water can be added at one time, thereby potentially creating problems with ponding and run off.

6.2. Other management practices

When good-quality water and/or adequate drainage are not available, the only option short of abandoning the field may be to select crops tolerant to saline soil conditions (Maas and Hoffman, 1977). Table 6 shows the expected yield reduction for some crops at various ECs. Plants are most susceptible to salinity at germination, becoming more salt-tolerant as they mature. Where germination is the primary concern, leaching all salts out of the root zone is usually not feasible or required. Moving salts away from the germinating seed is all that may be needed. Soils can remain productive even where complete reclamation is not possible. These situations require careful management and continuous monitoring to ensure that productivity remains acceptable.

For example, highly saline waste water generated from a coal-fired power plant can be used for irrigation with a combination of adequate acreage, water applied in slight excess of evapotranspiration, and use of tolerant crops (such as alfalfa and barley). Crop growth and harvest will aid in salt removal, improving water penetration, and supplying organic matter. Thus, vegetation management is an important part of reclamation. Since salts increase the osmotic potential of soil water, plants have greater difficulty absorbing water under saline conditions. Therefore, saline soil must be maintained at a higher moisture level than non-saline soil for a crop to obtain adequate water. This often requires more frequent, but lower volume, irrigations. Drip irrigation can be effective in maintaining high soil moisture in saline soils.

Soil amendments such as elemental sulfur, gypsum, other calcium materials and other soil amendments do not help reclaim saline soils, despite claims to the contrary. Instead, these materials add salts and compound the problem. Manures, composts, and other soil amendments should be analyzed to determine the kind and quantity of salts present. Further, anything soluble in water will add to the salt load and increase soil EC.

In conclusion, the only way to remediate saline soils is to remove salts from the root zone, which can be accomplished only with good drainage and the application of high-quality irrigation water. Sodic soils usually are the most expensive to reclaim, and in many situations reclamation is not economical. The reclamation procedures discussed here can improve sodic soils, but many years or decades of good soil and crop management are required to fully remediate a sodic soil.

7. Crop Tolerance to Soil Salinity

Excessive soil salinity reduces the yield of many crops (Pearson, 1960). This ranges from a slight crop loss to complete crop failure depending on the type of crop (Table 7) and the severity of the salinity problem. The salt tolerance of a plant can be defined as the plant’s capacity to endure the effects of excess salt in the medium of root growth (FAO, 1985). The mode of tolerance can vary (Table 7), i.e. some avoid salinity, some evade or resist salinity, and a few others actually tolerate it. Salt avoidance is usually accomplished by limiting germination, growth and reproduction to specific seasons during the year; growing roots into non-saline soil layers; or by limiting salt uptake.

Salt evasion can be achieved by accumulating salts in specific cells or by secretion of excess salts. Salt tolerance is attained only in plants in which the protoplasm functions normally and endures a high salt content without apparent damage. Salt tolerance of plants varies greatly during different phases of growth and development. Sugar beets, a species with a relatively high salt tolerance during vegetative growth, is more sensitive to salinity during germination than corn, which is salt-sensitive during growth. The salt tolerance of barley during grain production is half as compared to earlier growth stages. Although several treatments and management practices can reduce salt levels in the soil, there are some situations where it is either impossible or too costly to attain desirably low soil salinity levels. In some cases, the only viable management option is to plant salt-tolerant crops. Sensitive crops, such as pinto beans, cannot be managed profitably in saline soils. Table 7 shows the relative salt tolerance of field, forage, and vegetable crops. Table 8 shows the approximate soil salt content where 0, 10, 25, and 50% yield decreases may be expected. Actual yield reductions will vary depending upon the crop variety and the climatic conditions during the growing season.

It has been understood that fruit crops may show greater yield variation because of availability of a large number of rootstocks and varieties. Also, stage of plant growth has a bearing on salt tolerance. Plants are usually most sensitive to salt during the emergence and early seedling stages. Tolerance usually increases as the crop grows. The salt tolerance values apply only from the late seedling stage through maturity during the period of most rapid plant growth. Crops in each class are generally ranked in order of decreasing salt tolerance.

From the above discussion it is pertinent that selection of crop cultivars tolerant to salinity and alkalinity is a feasible strategy to maintain sustainable crop production in salt affected areas. Researches have been directed to develop techniques for evaluating and selecting salt tolerant crop cultivars with high yielding background. A novel approach has been adopted to screen pipe line hybrids/parents for selection of salt tolerant cultivars. Reasonable success has been achieved to meet the goal (Maiti et al., 2006; Maiti et al., 2009) so far.

7.1. Drainage

Soils with a sodicity problem must have drainage to facilitate sodium removal from the root zone (Shalhevet and Kamburov, 1976). When a high water table is part of the problem, it must be lowered before reclamation can proceed. Drainage can also be improved by altering the topography or by installing tile drains (FAO, 1971a). Drainage can be improved in some cases by planting deep-rooted perennials such as alfalfa, but it is crucial to maintain permeability. When irrigation canal seepage is the cause of high water, the canal water must be intercepted before it enters the field, or the canal must be sealed to reduce seepage.

7.2. Tillage and amendments

Tillage often is necessary to physically break up sodium-rich layers and mix amendments into the soil. Coarse organic materials that decompose slowly, e.g. straw, corn stalks, sawdust, or wood shavings used for animal bedding, can help improve soil structure (Agarwal and Yadav, 1956) and infiltration when used with other reclamation practices.

7.3. Supplying calcium to improve water infiltration

Improving water infiltration rates in sodic soils requires increasing soil EC to more than 4 dSm^{-1} or reducing the ESP (Cairns and Bowser, 1977). The ESP required for improved water infiltration depends on soil texture and irrigation method. Soils with high amounts of sand usually can tolerate higher ESP (up to 12) still retaining water infiltration and percolation properties. Soils that are sprinkler irrigated typically require a lower ESP for good water infiltration compared to soils irrigated with surface irrigation systems. Calcium is required for sodic soil reclamation, as it will displace sodium and reduce the ESP and SAR. If possible, use irrigation water that is high in calcium and salinity during the initial phase of reclamation.

Injecting gypsum (calcium sulfate) into irrigation water increases salinity and calcium (Narayana, 1980). As sodium is replaced, water lower in calcium and salinity can be used. Heavy applications of manure or old alfalfa hay worked into the soil will dissolve existing lime and release calcium as decomposition progresses. Gypsum is the most common material used to supply calcium for sodic soil reclamation. The *gypsum requirement* is the amount of gypsum needed to reclaim the soil to a specified depth.

Gypsum is used because it is calcium-rich, dissolves at high pH, and does not contain elements or compounds that might interfere with reclamation (Overstreet et al., 1980). The sulfate in gypsum is not likely to be a problem for crops, even though it is applied in quantities greatly in excess of plant need (Abrol and Bhumbla, 1979). Calcium nitrate or calcium chloride minerals can be used to reclaim sodic soils, but they generally are more costly and are likely to produce other negative effects on plant growth or the environment. Nitrate is considered a groundwater contaminant and is not a good choice.

Limestone (calcium carbonate) is another commonly available mineral that contains calcium. However, it is not used for reclaiming sodic soils because it is not soluble at high pH levels common in these soils (Oster and Frenkel, 1980). Theoretically, limestone can be used if acidifying agents are also added to the soil. This solution is both impractical and expensive. Elemental sulfur (S) can be used for sodic soil reclamation (Oster and Frenkel, 1980). Use S only if free lime already exists in the soil. The addition of sulfur does not directly add calcium to the soil. However, elemental sulfur oxidizes to form sulfuric acid which dissolves lime which often exists in arid and semi-arid zone soils.

The dissolution of indigenous lime provides calcium necessary to reclaim a sodic soil. When adequate moisture and temperatures are present, oxidation of elemental sulfur will be completed within one or two growing seasons. Soil amendments, such as S, should be incorporated to increase the rate of reaction and to speed reclamation (El-Gabaly, 1971). When S is left on the soil surface, or when the soil is dry or cold, microbial conversion of S to sulfuric acid is delayed (Starkey, 1966.). Where available and economical, addition of acids directly to the soil accomplishes the same effect as S, but specialized equipment is required for safety concerns. Before using S or acids, it is important to verify that the soil contains sufficient lime to dissolve.

7.4. Irrigation water management

Some irrigation waters, typically those pumped from deep wells contain high concentrations of bicarbonate and have a high SAR (high concentration of sodium relative to calcium + magnesium). Application of these waters can create sodic soils over time. Both the EC and the SAR of the irrigation water determine the effect of water application on soil structure and the potential for water infiltration problems (Bazilevick, 1965). Irrigation water that is high in bicarbonate or carbonate can react with calcium in the soil solution to form calcium carbonate. This process removes calcium from the soil solution. As calcium in the soil solution is reduced, soil SAR and sodium hazard increase. Precipitation of calcium carbonate in pore spaces also reduces water infiltration and percolation in soils that are not tilled. The most effective means of avoiding this problem is to acidify the irrigation water prior to application (Bhumbla and Abrol, 1972). When an acid such as sulfuric acid is added to irrigation water, it reacts with bicarbonates to form water and carbon dioxide.

Prior to treatment of salt affected soil, it is important that the site is carefully characterized. Factors such as volume and frequency of salt spillage, soil characteristics, topography of the land and the stratographic layout or horizontal band, commonly known as *horizons of the sub-soil*, have an influence on the remediation design. Also, the quantity of amendments required to improve a sodic condition depends on the soil texture and its sodium ion concentration.

8. References

Abrol, I.P., 1982. Reclamation of wastelands and world food prospects. Trans. 12th International Congress. Soil Science. (Panel Discussions Papers). 5, 317-337.

Abrol, I.P., Bhumbla, D.R., 1979. Crop response to differential gypsum application in a highly sodic soil and the tolerance of several crops to exchangeable sodium under field conditions. Soil Science 127, 79-85.

Abrol, I.P., Chhabra, R., Gupta, R.K., 1980. A fresh look at the diagnostic criteria for sodic soils. In: International Symposium on Salt Affected Soils. Central Soil Salinity Research Institute, Karnal. February 18-21, 142-147.

Abrol, I.P., Dahiya, I.S., 1974. Flow-associated precipitation reactions in saline-sodic soils and their significance. Geoderma 11, 305-312.

Abrol, I.P., Yadav J.S.P., Massoud, F.I., 1988. Salt-affected soils and their management, Soil Resources, Management and Conservation Service, FAO Land and Water Development Division, FAO of United Nation 5, 9, 14.

Agarwal, R.R. and Yadav, J.S.P., 1956. Diagnostic techniques for the saline and alkali soils of the Indo-Gangetic alluvium in Uttar Pradesh. Journal of Soil Science 7, 109-121.

Bazilevick, N.I., 1965. Geochemistry of sodic soils (In Russian). Nauka Publishers, Moscow.

Beek, C.G.E.M., Van Breemen, N., 1973. The alkalinity of alkali soils. Journal of Soil Science 24, 129-136.

Bhumbla, D.R., Abrol, I.P., 1972. Is your water suitable for irrigation? Indian Farming 22(4), 15-17.

Biggar, J.W., Nielsen, D.R., 1962. Miscible displacement in soils: Experimental information. Soil Science Society of America Journal 25, 1-5.

Cairns, R.R., Bowser, W.E., 1977. Solonetzic soils and their managements. Canada Department of Agriculture, Ottawa, Canada, 37.

El-Gabaly, M.M., 1971. Reclamation and management of salt affected soils. In: Salinity Seminar, Baghdad. Irrigation and Drainage Paper, 7. FAO, Rome.

FAO, 1971a. Drainage of heavy soils. Irrigation and Drainage Paper, 6. FAO, Rome, 109.

FAO, 1971b. Reclamation and management of salt affected soils. In: Salinity Seminar, Baghdad. Irrigation and Drainage Paper, 7: 50-79. FAO, Rome.

FAO, 1976a. Water quality for agriculture. Irrigation and Drainage Paper 29. FAO, Rome, 97

FAO, 1976b. Soil management and agronomic practices. In: Prognosis of Salinity and Alkalinity. Soils Bulletin 31: 111-118. FAO, Rome.

FAO, 1985. Water quality for agriculture. Irrigation and Drainage Paper 29. Rev. 1. FAO, Rome, 174.

ILACO., 1981. Agricultural compendium for rural development in the tropics and subtropics. Elsevier Scientific Publishing Company, Amsterdam, 739.

Kelley, W.P. ,1951. Alkali soils. Reinhold Publication Corporation, New York.

Kovda, V.A., 1965. Alkaline soda-saline soils. Agrokemia es Talajtan. Suppl. 14, 15-48.

Maas, E.V., and Hoffman, G.J., 1977. Crop salt tolerance-current assessment. Journal of Irrigation and Drainage 103, 115-134.

Maiti, R.K., Sarkar, N.C., Gupta, A., Vidyasagar, P., 2009. Evaluation and selection of sunflower hybrids and parents for tolerance to different levels of salinity at the seedling stage. International Journal of Agriculture, Environment & Biotechnology 2, 57-63.

Maiti, R.K., Vidyasagar, P., Singh, V.P., 2006. Comparative study on the levels of tolerance to NaCl-salinity of some crop cultivars (sorghum, pearl millet, rice, maize, cotton and sunflower at early emergence and germination stage. Crop Research 31, 434-439.

Narayana, V.V.D., 1980. Reclamation of alkali soil - engineering aspects. CSSRI Bulletin 6, 6.

Oster, J.D., Frenkel, H., 1980. The chemistry of reclamation of sodic soils with gypsum and lime. Soil Science Society of America Journal 44, 41-45.

Overstreet, R., Martin, J.C.,King, H.M. ,1980. Gypsum, sulfur and sulfuric acid for reclaiming an alkali soil of the Fressio series. Hilgardia 21, 113-127.

Pearson, G.A., 1960. Tolerance of crops to exchangeable sodium. USDA Information Bulletin 216, 4.

Richards, L.A., (ed.) 1954. Diagnosis and improvements of saline and alkali soils. USDA. Agriculture Handbook 60, 160.

Shalhevet, J., Kamburov, J., 1976. Irrigation and Salinity. A World Wide Survey. International Commission on Irrigation and Drainage. New Delhi, India, 106.

Starkey, R.L., 1966. Oxidation and reduction of sulfur compounds in soils. Soil Science 101, 297-306.

Szabolcs, I., 1974. Salt affected soils in Europe. Martinus Nijhoff, The Hague, 63.

Szabolcs, I., 1979. Review of research on salt affected soils. Natural Resources Research XV, UNESCO, Paris.

Szabolcs, I., 1980. Saline and alkali soils - commonalities and differences. In: International Symposium on Salt Affected Soils. 18-21 Feb. Central Soil Salinity Research Institute, Karnal, India, 1-6.

Table 1: Salt affected soils in India

Sl. No.	State	Saline soil (ha)	Sodic soil (ha)	Total (ha)	Total (Lakh ha)
1	Andhra Pradesh	77,598	196,609	274,207	2.74
2	A and N island	77,000	0	77,000	0.77
3	Bihar	47,301	105,852	153,153	1.53
4	Gujarat	1,680,570	541,430	2,222,000	22.22
5	Haryana	49,157	183,399	232,556	2.32
6	Karnataka	1,893	148,136	150,029	1.50
7	Kerala	20,000	0	20,000	0.20
8	Maharashtra	184,089	422,670	606,759	6.07
9	Madhya Pradesh	0	139,720	139,720	1.40
10	Orissa	147,138	0	147,238	1.47
11	Punjab	0	151,717	151,717	1.52
12	Rajasthan	195,571	179,371	374,942	3.75
13	Tamil Nadu	13,231	354,784	368,015	3.68
14	Utter Pradesh	21,989	1,346,971	1,368,960	13.69
15	West Bengal	441,272	0	441,272	4.41
	Total	2,956,809	3,770,659	6,727,468	67.27

Table 2: Type of salt-affected soils in India

Sl. No.	Types	Rainfall (mm)	Distribution
1	Inland saline soils of arid and semi- arid region	< 500	Haryana, Punjab, Rajasthan, Uttar Pradesh, and Jammu & Kashmir
2	Inland saline soils of sub-humid region	1000-1400	Mainly in Bihar
3	Inland salt-affected medium to deep black soil	700-1000	Madhya Pradesh, Maharashtra, Andhra Pradesh, Rajasthan, Gujarat, Karnataka
4	Medium to deep black soils of deltaic and costal semi-arid region	700-900	Saurashtra coast in Gujarat and Deltas of Goddavari and Krishna river in Andhra Pradesh
5	Saline micaceous deltaic alluvium of humid region	1400-1600	Sunderban delta in West Bengal and parts of Mahanadi delta in Orissa
6	Saline-humid and acid-sulphate soils of humid tropical region	2000-3000	Malabar coast of Kerala
7	Saline marsh of Rann of Kutch	< 300	Rann of Kutch of Gujarat
8	Saline and alkali soils of Indo- Gangetic alluvium	550	Parts of Indo-Gangetic alluvial region

Table 3: Distribution of salt-affected soils across agro-climatic zones in India

Zone No.	Name	Salt-affected area (000 ha)
3	Lower Gangetic plain	628.40
4	Middle Gangetic plain	476.01
5	Upper Gangetic plain	848.34
6	Trans-Gangetic plain	765.47
7	Eastern plateau and hills	17.28
8	Central plateau and hills	719.37
9	Western plateau and hills	441.55
10	Southern plateau and hills	535.09
11	East-coast plain and hills	925.31
12	West-coat plain and hills	53.08
13	Gujarat plain and hills	953.91
14	Western dry region	282.00
15	Island region	77.00
	Total	6727.46

Table 4: Classification of salt-affected soils

Classification	EC (dS m^{-1})	Soil pH	SAR	Soil physical condition
Saline	>4	<8.5	<13	Normal
Sodic	<4	>8.5	≥13	Poor
Saline-sodic	>4	<8.5	≥13	Normal
High pH	<4	>7.8	<13	Varies

Table 5: Diagnosing high pH, salinity or sodicity problems

Problem	Potential symptoms
High pH	Nutrient deficiencies manifested as stunted, yellow, and dark green to purplish plants
Saline soil	White crust on soil surface, water stressed plants, leaf tip burn
Saline irrigation water	Leaf burn, poor growth, moisture stress
Sodic soil	Poor drainage, black powdery residue on soil surface
Saline-sodic soil	Generally, same symptoms as saline soil

Table 6: Crop tolerance to soil salinity

Site	Soil type	Crop	Threshold EC (dSm^{-1})	Slope (%)
Sampla	Sandy loam	Wheat Mustard	5 6	29 75
Karnal	Sandy loam	Mustard Mug bean Sorghum	3.8 1.8 2.2	6.9 20.7 10.6
Agra	Sandy loam	Wheat Mustard Berseem	8.2 6.1 3.5	19.8 20.7 12.5
Dharwad	Black clay	Wheat Sorghum Safflower	2.3 2.1 2.8	20.5 3.9 20.7
Indore	Black clay	Safflower Berseem	2.8 20	5 11.2

Table 7: Relative tolerance of crop to salinity and sodicity

Saline soil			Sodic soil		
Tolerant	Semi-tolerant	Sensitive	Tolerant	Semi-tolerant	Sensitive
Barley	Wheat	Gram	Rice	Wheat	Groundnut
Sugar beet	Rice	Pea	Sugar beet	Barley	Cowpea
Cotton	Sorghum	Ground nut	Sugarcane	Oats	Lentil
	Maize		Peas		

Table 8: Potential yield reduction from saline soils for selected crops

Crops	Relative yield decrease (%)			
	0	10	25	50
Field crops	(ECe)			
Barley	8	10	13	18
Sugar beets	7	8.7	11	15
Wheat	6	7.4	9.5	13
Sorghum	4	5.1	7.2	11
Soybean	5	5.5	6.2	7.5
Corn	1.7	2.5	3.8	5.9
Bean	1	1.5	2.3	3.3

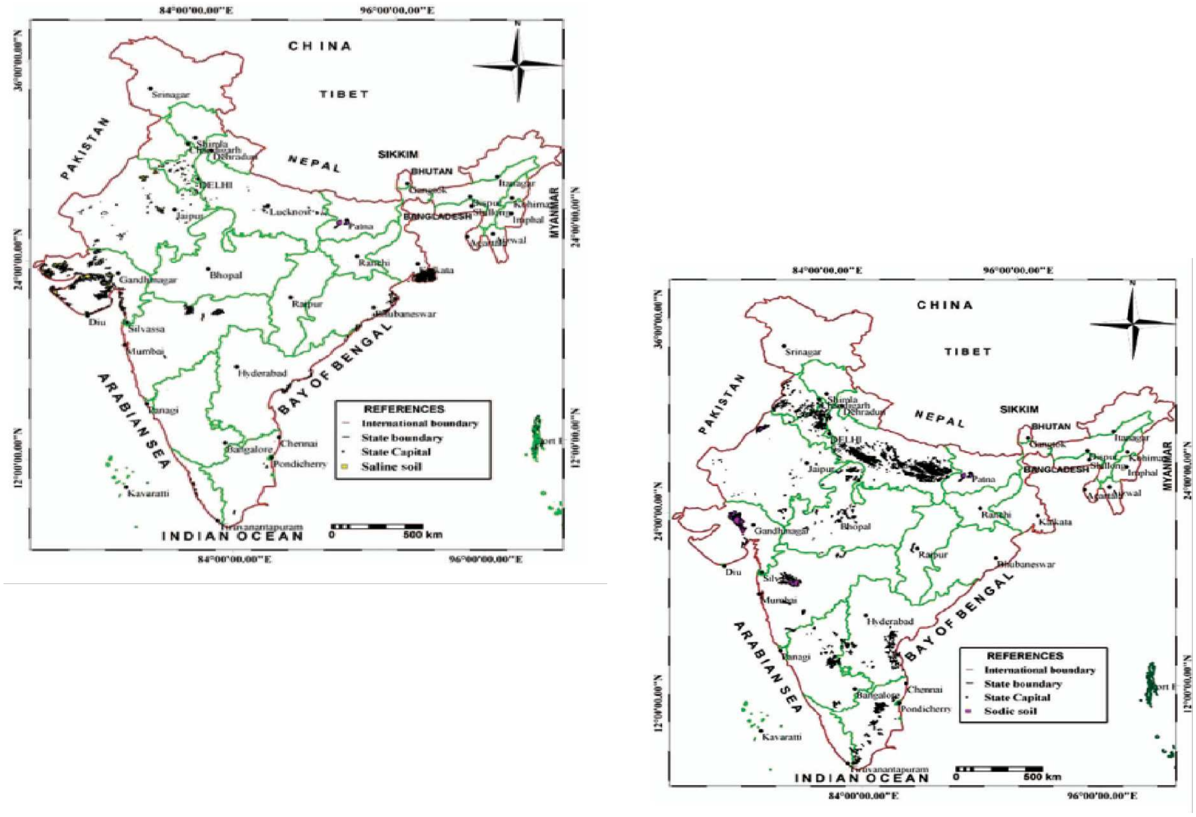

Figure 1: Distribution of saline and sodic soils in India