Chapter 9

Salt-affected Soils: Sources, Genesis and Management

Muhammad Zia-ur-Rehman, Ghulam Murtaza, Muhammad Farooq Qayyum, Saifullah, Muhammad Saqib and Javed Akhtar[†]

Abstract

The extent of salt-affected soils is proliferating because of different natural and anthropogenic factors like high temperature, low rainfall, poor quality of irrigation water etc. Different nature salts are being accumulated at the surface of soils and make environment difficult for plants to grow on such soils due to the reduced hydraulic conductivity and the low permeability. This leads to alter physical and chemical properties of soils making them non-productive for general cropping. Different management and remedial technologies are available to combat with the problem but the most striving concern is to opt the most economical and environment friendly technology. Different halophytic species can be used for the productive use of saline soils. Sodic and saline-sodic soils can be reclaimed using different amendments, which can provide soluble calcium to replace exchangeable sodium adsorbed on clay surfaces. There are two main types of amendments: those that add calcium directly to the soil and those that dissolve calcium from calcium carbonate already present in the soil. Studies demonstrated that under adverse conditions tree plantations may provide positive returns to investment and significant economic and social benefits to land users. These findings suggest that there is an opportunity for capital investment in afforesting abandoned salt-affected lands with multipurpose

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[†]Muhammad Zia-ur-Rehman[*], Ghulam Murtaza, Saifullah, Muhammad Saqib and Javed Akhtar
Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan.
[*]Corresponding author's e-mail: ziasindhu1399@gmail.com

Muhammad Farooq Qayyum
Department of Soil Science, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University Multan, Pakistan.

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University of Agriculture, Faisalabad, Pakistan.

tree species. This chapter covers the introduction of salt-affected soils, associated aspects, management, and their reclamation.

Keywords: Salinity, Brackish Water, Root Zone Salinity, Reclamation, Management.

9.1. Introduction

Salt-affected is a general term used for soils which contain soluble salts or exchangeable sodium and/or both, in such amounts that can retard growth and development of plants. Such soils cause reduction in crop yield and are required to be managed and remediated for sustainable agriculture. Mostly salt-affected soils exist in arid and semi-arid regions but also found in some humid to sub-humid climatic areas, where conditions are favorable for their development. In Pakistan 6.67×10^6 ha area is under salt contamination (Khan, 1998) mainly due to unavailability of good quality water for irrigation. Ground water may supplement irrigation needs because of increased cropping intensity and competition from non–agricultural sectors for fresh water. At present, in Pakistan, more than 1.07×10^6 tube wells are pumping out 9.05×10^6 ha–m ground water (Anonymous, 2011) and 70-80 % of this water is unfit (Latif and Beg, 2004; Ghafoor et al. 2004) for agricultural crops having high electrical conductivity (EC), sodium adsorption ratio (SAR) and/or residual sodium carbonate (RSC) that have negative impacts for crop growth and development. In arid and semi-arid climatic zones use of low quality irrigation water has become a common practice to fulfill the needs of ever increasing population demands for food crops. (Qadir et al. 2007). Pakistan is situated in an arid to semi-arid region. As the fresh water supplies are getting short, farmers are pumping low quality (high EC, SAR and RSC) ground water for irrigation which is further aggravating the soil and ground water salinity and related hazards. These soils are adversely affecting the economic yields of crops and consequently leading to uneconomical crop production and rural poverty. In the suburbs of Indus Basin in Pakistan various research studies have been conducted and results reveal that almost 20-43% yield loss occur in salt affected fields as compared to normal ones. Qadir et al. (2014) reported that 36-69% yield loss with the average of 48% for rice crop occur due to salinity hazards. In this chapter, different aspects of salt-affected soils along with their management and remedial measures have been discussed.

9.2. Sources of Salts

Salts may originate from various sources acting either alone or in combination. However, the primary and major source of salts in soils and oceans is rocks and minerals present in the Earth crust which are weathering with the passage of time. Although the salts currently occurring in the ocean arise mainly from the weathering process of the rocks and minerals in Earth crust, now the ocean is functioning as an important "source" for the redistribution of salts.

9.2.1. Parent material and weathering process

As a result of in-situ weathering process, salts are released into soils and are accumulated or removed depending on the prevailing environmental conditions. Under humid conditions, salts leach through soils and are transported to the nearby streams and rivers resulting in formation of inland salt-affected areas. However, under arid to semi-arid climatic conditions, the weathering products accumulate in-situ and result in the development of salinity and/or sodicity. This process of formation of salt-affected soils as result of accumulation of salts released during weathering is called primary salination/sodication. In Pakistan salt-affected soils have been formed by: (i) deposition of physically transported salts along with parent material (PM) such as NaCl and $CaSO_4$ in the salt range belt of Pakistan; and (ii) mineral weathering in-situ, i.e., transformation of soil mineral and dissolution of sparingly soluble salts deposited along with PM as well as those formed later e.g. gypsum, lime etc.

9.2.2. Irrigation water

All the natural waters contain dissolved salts. The expected effect (adverse or favorable) is highly dependent upon type and amount of salts and volume of irrigation water used. Canals of Pakistan contain best quality irrigation water as it contains salts varying from 120 to 200 mg L^{-1}. As an estimate, 10-cm deep irrigation with canal water in one hectare may add 120-180 kg salts. Other common source of irrigation and salts is ground water, which are mostly brackish in arid regions like Pakistan but the levels of EC, SAR and RSC in ground waters are quite variable. On an average, the ground waters in Pakistan contain up to 1250 mg salts L^{-1} (Ghafoor et al. 2004). A 10-cm deep irrigation using groundwater may add 1.2 Mg salts ha^{-1}. Such additions of salts in the soils highly depend upon depth of ground water table, volume of water used for irrigation, and type of salts as well as upon the evaporative demand of the atmosphere.

9.2.3. Flood waters and waste effluent

Flood water mostly redistributes the already present salts but may become important in some parts of the world such as during monsoon in Pakistan. Similar is the case with untreated sewage water as a source of salts, particularly in the Third World countries where it is used to irrigate crops, mainly vegetables, around cities or is disposed-off into the existing irrigation channels. Such irrigation waters are of particular concern with respect to heavy metals entry in the food chain of human beings and because of many pathogens as well as toxic organic materials.

9.2.4. Sea water

Sea water (EC > 4 dSm^{-1}, SAR > 50-55) intrusion as well as sea water sprays could contribute large quantities of salts but the action is a bit localized along coastal areas. Almost similar is the mode of inland saline seeps to contribute salts. However, importance of playas (Lakes having input but no output of effluent) need special consideration in some areas of the world. The soils in coastal areas are enriched with salts coming from sea through various ways, such as:

a) Striking of sea water high-tides with nearby surface soil;
b) Entry of sea water through rivers, estuaries, etc.;
c) Ground-water inflow; and
d) Salt-enriched sprays transported up to many kilometers inland from the sea coast and deposited as dry "fall-out" or "wash-out" by showers. Inland deposition of NaCl at a rate of 20-100 kg ha^{-1} $year^{-1}$ is quite common and values of 100-200 kg ha^{-1} $year^{-1}$ for nearby coastal areas have been reported. Although these amounts may appear small, but their regular deposition over long periods of time may lead to salinization of the soils.

9.2.5. Lacustrine and marine deposits

According to geological information, once whole of the Indian sub-continent was under sea. Gradually, sediments from Himalayas produced up-lands which were later developed for agriculture. Hence, some of the salts could be considered as fossil salts. Irrigation with low quality water reveals that salts already present in the soil profile are transported to the soil surfaces with irrigation which are left behind after evaporation. Thus, after a longer period of time salts that were previously evenly distributed in the whole profile may selectively accumulate on the soil surface and give rise to saline soils. Accumulation of salt-laden runoff water and its subsequent evaporation in the un-drained basin is also a cause of salinity in many low-laying areas.

9.2.6. Fossil salts

Salts accumulation in the arid regions often involves "fossil-salts" which are a consequence of earlier deposits or entrapped solutions in former marine or lacustrine deposits. Salt release may occur through natural as well as anthropogenic activities. An example of the former situation is the rise of salt bearing ground water through an originally impervious cap (which became permeable as a result of weathering process) overlaying saline strata. Examples of latter scenario are assembly of canals along with water works within the saline strata and use of ground water for irrigational purposes. In Rajasthan, India, a canal built on an underlying gypsum layer has resulted in development of salinity in the area within only a few years of its construction. This has been due to perched water table and contribution of salts from the underground gypsum layer.

9.2.7. Chemical fertilizers and waste materials

Utility of inorganic fertilizers is increasing and that of organic manures is decreasing in agricultural fields but their contribution to overall salt build-up in soils is insignificant. However, certain situations, such as dumping of cow's dung slurry, sewage sludge or industrial by products such as press mud or pyrites, can contribute to excessive accumulation of certain ions those could limit soil productivity.

9.3. Genesis of Salt-affected Soils

The mode of soils-origin and/or the processes and factors involving in soil formation from un-consolidated parent material is defined as soil genesis, i.e., it is a process of developing soils from parent material. Genesis is a continuous but slow process that includes decreasing the particle size of the parent material, reordering of mineral particles, addition of certain materials such as organic matter and salts, changing the kinds of minerals, creating horizons, and producing clays.

9.3.1. Genesis of primary salt-affected soils

The following factors mostly contributed towards the genesis of salt-affected soils in Pakistan.

9.3.1.1. Salty parent material

Presence of primary minerals as the special constituent of parent material is the most important factor for genesis of salt-affected soils. Arid to semi-arid climatic zones of the world including Pakistan have more common soil salinity concerns due to low precipitation which is inadequate for leaching of salts below root zones. Under these circumstances soluble salts coupled with exchangeable Na^+ have accumulated over thousands of years during the process of soil formation. This is the case of primary/old/ancient salt-affected soils. These soils existed before the advent of the canal irrigation system in the Indus Plains of Pakistan.

9.3.1.2. Aridity and uneven distribution of rainfall

Most of the soils of Pakistan exist in arid to semi-arid climatic regions. Most of the rainfall occurs during monsoon (July-August) while during major part of the year the salts present in the soil tend to move upward with water through capillary action. The rainfall that is received (mostly < 500 mm annually) is not sufficient to leach down the salts away from the root zone. Moreover, the net upward movement of water in the soil along with evaporation at the surface provokes the accumulation of mineral salts in the surface soil.

9.3.1.3. Physiographic unevenness

Micro unevenness of the soil surface is generally not observable. This situation can be visualized from different depths of the standing water after a heavy rainfall. The rainwater flows from the convex parts over the sloping parts and is accumulated on concave parts. In parts where there is low effective leaching (convex and sloping parts), accumulation of salts takes place. Hence, patches of salts develop in an uneven soil. In Pakistan, the natural drainage is poor due to lower slope of 30 cm per 1609 m which promotes the salinization and sodication processes.

9.3.2. Genesis of secondary salt-affected soils

Introduction of canal water irrigation system in Pakistan is the major cause of evolution of secondary or man-made salt-affected soils. However, the extent of secondary salt-affected areas is very small than the primary salt-affected areas.

Several factors act alone or in combination to form secondary salt-affected soils. Insufficient or unequal application of irrigation water, imperfect soil drainage, waterlogging, brackish ground water, improper soil and water management, seepage from canals and water courses or combination of these factors are the principal causes for the formation of secondary salt-affected lands.

9.3.2.1. Sodication

Sodication can be defined as process of accumulation of exchangeable Na^+ content in the soil that results in the formation of poor soil structure along with unavailability of essential nutrients (Qadir et al. 2004). The salts of Na^+ Ca^{2+} and Mg^{2+} as well as Cl^- and SO_4^{2-} are present in excess under salt-affected soils while those present in smaller amounts are cations like K^+ and NH_4^+ and anions like CO_3^{2-}, HCO_3^- and NO_3^-. When salt concentration in soil is very high, a part of Ca^{2+} and Mg^{2+} precipitates as $CaCO_3$, $MgCO_3$, $CaSO_4$ and $MgSiO_3$. The precipitation of these salts results in the increased proportion of Na^+ in soil solution as well as on the exchange complex. In this way, saline soils can be regarded as responsible for genesis of sodic soils. For this reason, most of the moderately to strongly saline soils in Pakistan are generally saline-sodic/sodic as well. Sodication generally leads to deflocculation (dispersion), poor drainage and poor aeration in soil (Shainberg and Letey, 1984). In addition, severe nutrient imbalance results in these soils which may be in the form of deficiency as well as toxicity of certain vital elements. Such physical and chemical impairments lead towards low yield and production due to negative impacts on root growth activity coupled with soil micro-organisms. The color of sodic soils is most often dark that is due to deposition of discrete and suspended organic matter prevailing in soil solution at the soil surface. In such soils, after evaporation, darkening of the soil color is increased which may extend up to blackish in.

9.4. Classification of Salt-affected Soils

Salt-affected soils are usually characterized into three main groups 1) saline, 2) sodic and 3) saline-sodic.

9.4.1. Saline soil

Saline soil is referred as a soil that contains plenty of soluble salts that have adverse effects on plant growth but does not contain excessive exchangeable Na^+. Most of the soluble salts in saline soils are composed of cations Na^+, Ca^{2+}, and Mg^{2+} and of anions Cl^-, SO_4^{2-}, and HCO_3^-While in minute concentrations other cations such as K^+ and NH_4^+ along with anions including NO_3^-, CO_3^{2-} and BO_4^{2-} also occur in these soils. Saline soils have $EC_e \geq 4$ dS m^{-1}, SAR < 13 $(mmol\ L^{-1})^{1/2}$, ESP < 15and $pH_s < 8.5$.

9.4.2. Sodic Soil

Sodic soil can be defined as a soil that restrains adequate concentrations of exchangeable Na^+ that have serious impacts on plant growth and development but not having excessive concentration of soluble salts. Soil structure, aeration, and hydraulic conductivity are deteriorated by the excessive amount of exchangeable

Na^+. Sodic soils have $EC_e < 4$ dS m^{-1}, SAR > 13 (mmol $L^{-1})^{1/2}$, ESP > 15 and $pH_s >$ 8.5.

9.4.3. Saline-sodic soil

Saline-sodic soil refers to a soil having both soluble salts as well as exchangeable Na^+ in sufficient amounts that cause harmful impacts on all type of crop plants Saline-sodic soils are characterized as the soils that have: $EC_e > 4$ dS m^{-1}, $pH_s > 8.5$, SAR > 13 (mmol $L^{-1})^{1/2}$ and ESP > 15.

In some literature, the term "alkali" is used in place of "sodic", i.e., for soils having excess exchangeable Na^+. Hence, the terms "saline-alkali" in place of "saline-sodic" and "alkali" in place of "sodic" are used. However, the use of the term "alkali" is being discouraged because of its ambiguity with the term "alkaline" which refers to the soils having pH > 7.0. According to an estimate (Khan 1998), the salt-affected soils of Pakistan cover on area of about 6.67×10^6 ha.

On global basis, the salt-affected soils exist mostly under arid and semi-arid climates in more than 100 countries covering about 9.55×10^6. These soils cover about 25% and 60 % of the world's irrigated and cultivated land, respectively. Overall, about 62% of the salt-affected soils of the world are saline-sodic/sodic while 38% are saline (Tanji 1990).

Table 9.1 Extent of soil salinity/sodicity problem in Pakistan

Province	Area (Million ha)
Punjab	1.234
Sindh	3.04
Balochistan	0.12
KPK	0.11
Pakistan	4.50

Source: WAPDA (2003)

Table 9.2 Salt-Affected Area (m ha) of Punjab, Pakistan

Year	Area Survyed	Salt Affected			
		Uncultivted	Cultivated	Total	%age
1945-46	4.84	0.42	0.49	0.91	18.80
1955-56	5.96	0.05	0.69	1.20	20.64
1965-66	6.88	0.44	0.68	1.12	16.28
1975-76	7.34	0.37	0.61	0.98	13.35
1985-86	7.57	0.30	0.58	0.88	11.62
2000-01	7.92	1.16	1.51	2.67	33.71

Source: Ahmad and Chaudhry (1997)

9.5. Chemistry of Soil Solution in Salt-affected Soils

9.5.1. Soil solution

The soil system is composed of three phases of matter; 1) solid, 2) liquid and 3) gas. The solid part is comprised of a mixture of mineral and organic material and provides the skeletal frame work of the soil. In this frame work, a system of pores exists which is shared jointly by the liquid and gaseous phases. The gaseous phase, or soil air, is a mixture of gases. The liquid portion of soil matrix also known as soil solution, is comprising of water, small quantities of dissolved gases and dissolved solutes. Soil solution is the medium in which most soil chemical reactions occur. It bathes the plant roots and forms the source from which the roots of plants and other organisms obtain their required, nutrients and water.

Table 9.3 Saline area (in 000' ha) in different districts of southern Punjab

Sr. No	District	Area surveyed	Salt affected area	
1	Bahawalnagar	623.7	130.4	20.9
2	Bahawalpur	468.5	23.3	5.0
3	RahimYar Khan	720.8	119.8	16.6
4	Dera Ghazi Khan	150.7	24.6	16.3
5	Muzafar Garh	474.8	92.9	19.6
6	Layah	246.4	0.9	0.4
7	Rajan Pur	237.2	25.9	10.9
8	Vehari	431.4	28.4	6.6
9	Khanewal	377.5	61.2	16.2
10	Multan	361.0	59.8	16.6
11	Lodhran	173.2	25.3	14.6
12	Sahiwal	258.7	28.7	11.1
13	Okara	439.4	44.1	10.0
14	Pak Pattan	235.3	14.4	6.1
15	Faisalabad	544.3	90.3	16.6
16	Toba Tek Singh	308.5	38.1	12.4
17	Jhang	482.9	109.0	22.5
18	Kasur	280.9	46.0	16.4
19	Shiekhupura	523.6	70.6	13.5
20	Gujranwala	416.5	52.1	12.5
21	Hafiza Abad	60.7	20.4	33.6
22	Mandi Bahudin	182.2	4.0	2.1
23	Sargodha	497.1	59.5	12.0
24	Khushab	181.1	0.8	0.4
25	Bakhar	314.8	1.5	0.5

Source: Punjab Development Statistics (2006)

9.6. Soil Salinity Evaluation

9.6.1. Root zone

The area of the soil matrix from which plant roots uptake water and other essential nutrients is known as root zone or rhizosphere. Plants absorb water from the soil by applying immense absorptive force more than that with which it is held with soil. When plants fail to apply enough absorptive force for the uptake of sufficient water from the soil, they face water stress. This situation prevails when soil becomes too dry or the osmotic potential of the soil solution decreases significantly. Mainly salts decrease the free energy of the water molecules which ultimately decrease the water potential of soil solution consequently plant suffers with water deficiency. If we take two soils having similar physicochemical properties except that one is normal and the other is salt affected soil, plants have to exert more force for the absorption of water from salt affected soils compared to that with the normal soil. Salts have more affinity for water due to its polarity and plants require higher absorptive force to take in water from the salt affected soil as compared to the normal land having same amount of water.

9.6.2. Evaluation of average root zone salinity

The average of five points in the root depth can be helpful in the evaluation of average root zone salinity in the soils. These points can be assumed as:

1) The soil surface (EC_{sw0})
2) Bottom of the upper quarter of the root zone (EC_{sw1})
3) Bottom of the second quarter depth (EC_{sw2})
4) Bottom of the third quarter depth (EC_{sw3})
5) Bottom of the fourth quarter or the soil water draining from the root zone (EC_{sw4})

The following assumptions are used to estimate the average root zone salinity to which crop responds.

1) Salinity of the applied irrigation water = 1 dS m^{-1}
2) Crop water demand (ET) = 1000 mm per season
3) The crop water use pattern is 40-30-20-10. This means that the crop will get 40 % of its ET demand from the upper quarter of the root zone, 30 % from the next quarter, 20 % from the next, and 10 % from the lowest quarter.
4) Crop water use will increase the concentration of the soil-water which drains into the next quarter, i.e., $EC_{sw0} < EC_{sw1} < EC_{sw2} < EC_{sw3} < EC_{sw4}$
5) Desired leaching fraction (LF) = 0.15. The leaching fraction of 0.15 means that 15 % of the applied irrigation water entering the surface percolates below the root zone and 85 % is used by the crop to meet its ET demand and water lost by surface evaporation.

9.6.3. Salinity control in the root zone

In the root zone the salinity control depends on adequate leaching of excess salts that is directly proportional to the heavy irrigation and rain fall which reduces the soil infiltration capacity. High rainfall receiving areas also known as humid regions have sufficient water to flush out the salts from the rhizosphere or root zone. Controversial to this phenomenon in arid to semi arid climatic zones where rain fall is very low while temperature is very high soil salinity problem prevails. Water balance of the crop root zone provides the calculations for the amount of irrigation water required for the proper growth and development of the plants. Water flows through the root zone of crops in the following forms:

1) Irrigation water (D_i)
2) Rainfall (D_r)
3) Upward movement of the ground water (D_g)

Water flows out of the root zone due to:

1) Evaporation (D_e)
2) Transpiration (D_t)
3) Drainage (D_d)

Variation between water flowing into the root zone and out of the root zone is equal to The change in water storage can be calculated by subtracting the water flowing out of the root zone from the water flowing into the root zone. Therefore, water balance equation for change in storage (D_s) may be written as:

$$D_s = (D_i + D_r + D_g) - (D_e + D_t + D_d) \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

While change in salt storage (root zone salinity), i.e. S_s can be explained by the following equation:

$$S_s = (D_iC_i + D_rC_r + D_gC_g + S_m + S_f) - (D_dD_d + S_p + S_c) \ \ldots \quad (2)$$

Where

C = Salt concentration

S_m = Salt dissolved from minerals in soils

S_f = Salt concentration contributed as the fertilizers or a constitute of amendment

S_p = Salt in the form of precipitations

S_c = Salt removed due to crop harvesting

If $D_i + D_r + D_g$ in equation (1) are less than $D_e + D_t$, the water deficit in soil is compensated by the absorption of water from the soil storage along with lowering the drainage process. With the passage of time the deficiency is completely fulfilled and thus become zero. When D_s become less, soil becomes dry that leads to reduction in D_e and crops face water stress that causes the D_t reduction. In the beginning due to these processes water loss occur in the root zone that remains equal to the water supplied at the zero drainage. Nevertheless, in the absence of drainage water higher salt concentration in the root zone results in the saline stored water. As salinity increases, the osmotic stress of the plant increases, which further reduces transpiration and thus plant dies when salts increase continuously.

In the presence of shallow water tables, deficiencies in $D_i + D_r$ may be offset by D_g. If movement of ground water is upward drainage becomes zero. This situation cannot continue forever. Under the dynamic field conditions, upward water movement coupled with drainage remain continue alternately throughout the year especially in the cultivated areas. If upward flow continues while leaching remains insufficient, soil salinity will retard the plant growth and development and ultimately plants die. That is why if salinity problem prevails there is the need of net downward water movement for the sustainability of the crop production. The conditions that control the inward water flow as well as outward from the root zone are not true for the steady-state conditions permanently. Due to these processes salt concentration in the soil solution varies over time. The primary objective of water management is the maintenance of this variation that controls the excess drainage as well as reduction of plant growth and development.

9.6.4. Salt precipitation

The equation (2) shows that the salt balance of a root zone is influenced by the precipitation of soluble salts. As a result, concentration of salts that leach down may be less than the applied quantity. At low leaching fractions (LF=0.1), almost $\geq$ 20% salts become precipitated from the irrigational water and thus not present into the drainage water. Therefore, salt precipitation component is an important factor for the calculation of salt balance especially under less leaching fraction.

9.7. Reclamation of Salt-affected Soils

Several techniques are adapted to reclaim salt-affected soils. The fitness of each technique depends upon a number of factors, e.g., 1) Physical, chemical and mineralogical characteristics of the soil; 2) Internal soil drainage; 3) Presence of pans in the subsoil; 4) Climatic conditions; 5) Content and types of salts present; 6) Quality and quantity of water available for leaching; 7) Quality and depth of ground water; 8) Desired rate of replacement of excessive exchangeable Na^+, if present; 9) Presence of lime or gypsum in the soil; 10) Availability and cost of the amendments; 11) Availability of the equipment for soil tillage, if needed; 12) Crops grown in the region; 13) Topographic features of the land; and 14) Time available for reclamation.

Good internal soil drainage, land leveling, and deep ground water (preferably below 3 m) are considered essential prerequisites for successful reclamation. From reclamation point of view, the salt-affected soils may be divided into two categories; 1) saline and 2) sodic/saline-sodic.

9.7.1. Reclamation of saline, sodic/saline-sodic soils

Saline soils restrain only higher concentration of soluble salts and their reclamation is done by leaching with excess of good quality irrigation water that carries salts into the deeper soil layers. Amount of water to be applied is important and it depends on several factors such as initial soil salinity and moisture levels, techniques of water application, and soil type etc. Good quality irrigation water is normally required for soil reclamation.

For reclamation of sodic/saline-sodic soils, a soluble source of Ca^{2+} such as gypsum is added in the soil followed by flooding with good quality irrigation water. The Na^{+} ions on exchange complex are replaced by Ca^{2+}, and removed from root zone along with dissolved salts in leaching water. Thus reclamation of both soils (saline and sodic/saline-sodic) requires flow of water through the profile.

Overall, the methods of reclamation of saline-sodic/sodic soils may be grouped into: 1) Physical methods; 2) Chemical methods; 3) Biological methods; 4) Hydro-technical method; 5) Electro-reclamation method; and 6) Synergistic approach. Apart from decrease in salinity/sodicity hazard, the method used at a particular site must be able to perk up the physical soil conditions by minimizing exchangeable Na^{+} that deteriorates the physical properties of sodic soils. Soil aggregates in sodic soils slake and disperse and hence reduce porosity (Qadir and Schubert 2004). An effective amendment/method improves porosity, hydraulic conductivity and infiltration rate and decreases bulk density (Murtaza et al. 2009). physical properties of sodic soils maybe refined by the reclamation processes due to the incorporation of high amount of Ca^{2+} as compared to Na^{+} in soil solution as well as on exchange sites. This flocculates the dispersed soil thereby improving water conducting soil properties.

9.7.1.1. Physical methods

Several methods, viz. deep ploughing, subsoiling, hauling, sanding, and horizon mixing are used to improve salt-affected soils by physical/mechanical treatments:

i. Deep ploughing

Deep ploughing involves ploughing to a depth from about 40 cm to 150 cm. This is a beneficial method on stratified soils having impermeable layers. After a series of experiments, it was found that a single deep ploughing having 40 to 75 cm depth economically improved the calcareous sodic soils both physically and chemically. Under conditions where the subsoil is more sodic than the surface soil, then deep ploughing should be avoided. However, this method is very helpful to speed up soil reclamation if the subsoil is gypsiferous, i.e. the subsoil contains a good quantity of gypsum.

ii. Subsoiling

Sub-soiler is comprised of erect steel/iron strips also known as knives/tines that are almost 60 to 90 cm apart and are pulled by the use of high power tractor through the soil. In this way soil channels are opened and permeability is increased. Significance of sub-soiling lies in the fact that the favorable impacts of sub-soiling remain continue till many years due to break down of lime layer. Even if breakdown of lime layer does not occur it is beneficial for one season.

iii. Sanding

In this practice, sand is mixed with a fine-texture soil that does not contain high clay content to make it more porous for accelerating the permeability process. By sanding the soil texture of the surface soil is changed permanently. Moreover, it improves root penetration, water and air permeability that facilitate the leach down of salts from root zone. For better results, sand should be mixed with at least 10 cm of surface soil.

iv. Hauling

In this technique, surface of the salt affected soil is removed and a layer of good quality soil is applied there. Hauling is absolutely useful but it might not be applicable everywhere because this method is considered expensive.

v. Horizon mixing

This method is used when the soil profile has good surface horizon but lower horizon has undesirable characteristics. Such characteristics are found in saline-sodic/sodic soils which have a favorable surface soil underlain by a slowly permeable, sodium-affected B horizon which is underlain by a more permeable gypsum-horizon. Benefit of the profile mixing is that it preserves the surface soil but upturn the subsoil along with substratum. This process is done by removal of upper surface, deep mixing of underlining subsoil coupled with substratum and at last again substituting the upper soil surface.

Profile of a virgin soil		Profile of an amended soil
A	______	A
B_1		B_2
B_2		B_1

9.7.1.2. Chemical methods

Chemical methods employ use of chemical amendments to improve soil properties and crop growth. Chemical amendment at any place is chosen depending upon various factors such as its availability, cost, handling and application difficulties, and the time required to react within the soil profile and to reinstate the adsorbed Na^+. Various amendments reveal different levels of effectiveness for the reclamation of sodic as well as saline-sodic soils of varying characteristics. Chemical amendments generally used for renovation of saline-sodic/sodic soils can be categorized into two basic groups:

i. Inorganic amendments

These can be further subdivided into three types.

a) Soluble calcium salts, such as $CaCl_2$, gypsum (mined gypsum) and phosphor-gypsum that results from the assemblage of high analysis phosphatic fertilizers.

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

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

Inorganic fertilizers may furnish soluble Ca^{2+} directly like calcium nitrate $Ca(NO_3)_2$ and single superphosphate (SSP) and/or indirectly by the addition of ammonium sulphate $[(NH_4)_2SO_4]$ and urea that enhance the physiological acidity (pH < 7) in the vicinity of their application. However large scale application of such fertilizers to reclaim the soil sodicity problem is not an economical approach.

Among various inorganic amendments gypsum has declared as the most efficient, cheap, environment friendly and easily available amendment that is the rich source of Ca^{+2} (Ghafoor et al. 2004). It is a proximal approach to reclaim the calcareous as well as non-calcareous sodic and/or saline-sodic soils. The gypsum required for reclamation, in Mega-gram per hectare (Mg ha^{-1}, 1Mg = 1000 kg = 1 ton), of sodic and saline-sodic soils is called gypsum requirement (GR) of the soils. A laboratory method (Schoonover's method) is generally used to determine the GR of the sodic and saline-sodic soils. Other inorganic amendments used for soil reclamation can be applied under suitable conditions. Equivalent quantities of chemically pure amendments relative to one Mg of gypsum are given in the following Table.

Table 9.4 Amount of amendments is equivalent to one mega gram of gypsum

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

Source: Qadir et al. (2001)

The solubility and relative effectiveness of gypsum depends upon its mesh size. The suitable particle size of gypsum used is between the 8-30 mesh, such that the particles should pass through a 2 mm sieve while 50% among them must also pass through 0.5 mm (30 mesh) sieve (Talib and Akram 2001).

ii. Organic amendments

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

Table 9.5 Properties of loam soil as affected by ECe:SAR_{ss} receiving gypsum @ 50 % soil GR.

Treatment	Gyp. mesh size	pHs	ECe (dS m^{-1})	SAR
ECe:SARss :: 8:8	Passed through 5 mesh	7.76	1.25	1.12
ECe:SARss :: 8:8	Passed through 16 mesh	7.56	1.21	1.18
ECe:SARss :: 8:8	Passed through 30 mesh	7.75	1.37	1.50
ECe:SARss :: 8:48	Passed through 5 mesh	7.84	2.04	1.97
ECe:SARss :: 8:48	Passed through 16 mesh	8.05	2.13	2.26

Source: Farid (2000)

9.7.1.3. Biological methods

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

Plant parts either above or below ground have great influence on soil. Plant parts that are present below the ground through root-soil interaction have great impact on soil conditions. For example, roots tend to change the soil pH, lower oxygen concentration, release organic compounds and complex energy sources such as exudates, secretions, and mucilages, produce chelating and/or reducing substances, increase CO_2 partial pressure, endow it the channels that support soil solution flow, improve various microbial processes and reveal impact on the soil physical as well as chemical properties. The above-ground plant parts change the microclimate by providing soil cover, reducing the temperature of the soil, improve the soil mulching, slow down the evaporation process and therefore resist the upward flow of salts by reducing capillary rise. Even after the harvesting of the crops, below ground residual plant parts incorporate the soil organic matter through root parts coupled with rhizomes and other constituents. The possible mechanisms of biological reclamation may be associated with long chain of various reactions. These involve: 1) release of CO_2 in the rhizosphere as a result of root and microbial respiration; 2) formation of carbonic acid (H_2CO_3) via CO_2 dissolution in water; 3) reaction of H_2CO_3 with the native $CaCO_3$ to form relatively more soluble $Ca(HCO_3)_2$; 4) release of Ca^{2+} ions from $Ca(HCO_3)_2$; and 5) replacement of exchangeable Na^+ by the Ca^{2+}.

Plants growing in saline/sodic soils have limited biomass production. In saline soils, crop yields are reduced by disturbing the water along with nutrient balance for plants while in sodic soils, plant growth is affected due to deteriorated physical conditions of soils. Moreover, in sodic soils, the excess Na^+ in the root medium disturbs the nutrition of plants. The selection of plant species to reclaim the salt affected soils should be very careful. Plant species vary in their tolerance to soil salinity/sodicity and irrigation requirements resulting in variable efficiency of growth. Generally, salt dilution supports the water loving plants due to heavy irrigation whereas the salt tolerant plants get benefits through both natural as well as adaptive modifications when cultivated in saline water environment.

Stage of vegetative growth and kind of vegetation play a vital role in modifying the environment of the host soil. At early stages of growth, crop roots occupy some of the soil macropores that would otherwise be available for infiltration. The amount of root mass, its rate of decay as well as ability to form root channels can markedly be different among crops. Regarding kind of vegetation, plant species that are stress tolerant especially under salt affected conditions are important for reclamation. Plant species that are stress tolerant and grow efficiently in wide range of stresses conditions could render them in an expanded range of adaptability and utility compared to others. Some research workers favored the inclusion of *kallar* grass, sesbania or sudan grass as the first crop to start and speed up the reclamation process of salt affected soils. The salt tolerant plant species generally perform more efficiently in calcareous salt affected soils than the non-calcareous soils. In calcareous soils, their roots act as Ca^{2+} mobilizers via dissolution of the native $CaCO_3$. In some experimental studies, amount of soluble Ca^{2+} in calcareous sodic soils cultivated with salt tolerant plants were observed sufficient for the marked reduction in the salinity and sodicity levels.

Although growing of certain salt tolerant plant species for improvement of salt-affected soils is an age old practice, yet little work has been reported to evaluate the role of these species in terms of soil amelioration over a certain period of time and at different growth stages. Many workers have simply correlated a good stand and harvest of certain salt tolerant forage plants from the salt-affected areas with the decrease in salinity/sodicity hazard without analyzing the soil characteristics. Very few studies give the requisite information on actual changes in EC_e and SAR/ESP of saline-sodic/sodic soils during reclamation through biological means. Generally, reclamation of saline-sodic/sodic soils through biological means is considered a slower than the application of inorganic amendments. However, biological reclamation can be started at a relatively low initial cost.

9.7.1.4. Hydro-technical technique

Using this technique saline water that has high concentration of electrolyte is applied that affect the soil permeability and thus continuous addition of water for dilution purposes leads towards the "valence dilution" effect. Eaton and Sokoloff (1935) described the "valence dilution" effect for the very first time when they were conducting an experiment regarding reclamation of sodic soils. In soil water system where monovalent and divalent cations in solution as well as in absorbed form is equal, application of further water leads the equilibrium towards the preferable adsorption of divalent cations such as Ca^{2+} as compared to the monovalent cations, such as Na^{+}. Reverse to this phenomenon takes place when evapotranspiration makes the soil solution too much concentrated.

The ratio of divalent cations to the total cations (with concentrations expressed in $mmol_c\ L^{-1}$) of the irrigation water must be ≥ 0.3 that leads towards the less use of water for proficient reclamation process. Rarely a few natural water sources sustain this ratio while for all other situations use of extra Ca^{2+} source is required that can be incorporated by various processes including; 1) application of gypsum into the soil after subsequent irrigation and/or 2) placement of gypsum stones into the water channels for the sufficient addition of Ca^{2+} into saline water. The basic problem for the conduction of this technique is the unavailability of primary facilities including collection, transport and reclamation of saline water

9.7.1.5. Electro-reclamation approach

Electro-reclamation approach can be defined as the amelioration process of salt affected soils using the principle electrodialysis technique. Numerous research studies including laboratory as well as field experiments reveal that use of electric current for the reclamation process speed up the reclamation mechanism manifolds although it is not the complete substitute for the traditional reclamation processes. This method of soil reclamation has shown some encouraging results which indicate increased solubility of $CaCO_3$ to supply more Ca^{2+} to replace the exchangeable Na^{+}. Moreover, this method created an environment which was effective for leaching of soluble salts and exchangeable Na^{+}.

It is too early to recommend this method for practical use in agriculture of Pakistan and elsewhere in the world.

9.7.1.6. Synergistic approach (combination of reclamation methods)

Under certain conditions, reclamation can be speeded up by combining the various reclamation methods, e.g. a saline-sodic soil having an impermeable layer of 15 cm width at a soil depth. In this case, use of physical and chemical approaches collectively may be much better than the use of either chemical or physical method alone. In most of the cases, this approach is practiced for the reclamation of salt affected soils at farmers' level.

Combined use of gypsum along with various organic amendments decreased the salinity/sodicity problem to great extent. Gypsum application with various organic amendments is reported like gypsum in combination with FYM (Murtaza et al. 1999); gypsum in combination with sesbania green manure (Baig and Zia, 2006); gypsum in combination with rice husk (Chang and Sipio 2001) shown remarkable effects in reducing salinity/sodicity problem.

As already discussed, use of gypsum for the reclamation of salt affected soils is a wide spread approach. However, in a developing country like Pakistan, although gypsum is available in abundance yet its prospective use is restricted because of the bitter reality that an amount of more than Rs.28000 per hectare (considering an average gypsum requirement of sodic soils = 14 Mg ha^{-1}) is needed to purchase the amendment only. This high price is not acceptable by the small farmers occupying the greater part of the affected soils. Thus high cost of reclamation process makes it out of reach approach for common person and there is very low progress regarding sodic reclamation in county. It is highly recommended that Government should provide gypsum at subsidized rates on credit to poor farmers.

9.8. Management of Salt-affected Soils

Management of salt-affected soils can be done by following certain measures. These measures can be divided into two categories, i.e. measures for the management of reclaimed salt-affected soils, i.e. normal soils, and measures for the management of salt-affected soils.

9.8.1. Management of reclaimed soils

General measures for prevention of salinization in reclaimed salt-affected soils aim to protect the soils from the development/reoccurrence of salt build up. These measures include:

1) Maintenance of a downward balance of movement of salts and water
2) Reduction in the replenishment of the ground waters and ingress of salts into irrigated areas
3) Reduction in ground water evaporation

9.8.1.1. Measures for maintaining a downward balance of salt and water movement in the soils

Wherever natural drainage is available or artificial drainage has been provided, prevention of salination can be done if the balance of moisture movement (water) is maintained downward in the soil profile, i.e. more water is applied than the amount of water moving upward in the soil profile under evapo-transpiration forces. This can be achieved by the use of irrigation depth greater than the consumptive use of crops or by including such crops in the rotations which require excess irrigation depth (high delta water crops).

9.8.1.2. Measures for reducing the replenishment of ground waters and ingress of salts into irrigated areas

i. Planned, rationed water utilization

Planned water utilization can be practiced in accordance with the nature of the soil, the depth of ground waters, type of agricultural crops grown and the type of economy in each irrigation system. This effort makes it possible to reduce the ingress of water and easily soluble salts into the irrigated territory by as much as 20-30 % of the head water intake. However, this requires the equipment for water measurement and control.

ii. Water usage according to weather conditions

A study of the autumn, winter, spring and summer weather forecasts should be done so that in the wet period of time no watering is done.

iii. Control of surplus irrigation

Surplus irrigation water must never be spread in any part of the irrigated area and flood water has to be controlled.

iv. Control of seepage

Seepage must be kept to a minimum. The losses in areas where the canals and water courses are not lined may be as high as 45 %. It is necessary to line the canals and water courses to control the conveyance losses as much as possible. Good results may be obtained in the initial stages by coating with clay materials.

v. Remodeling of ancient irrigation systems

Many of the ancient irrigation systems have not been rebuilt. Some canals lack the requisite hydrotechnical equipment, are meandering and too long. Measures are needed to reconstruct these systems according to the requirements of modern agriculture.

vi. Provision of water for domestic purposes

The use of irrigation canals for the delivery of water for domestic purpose during the period without irrigation must be avoided to control water seepage. For this purpose, special canals, storage ponds or wells have to be constructed.

vii. Field leveling

The fields must be carefully leveled under conditions where surface irrigation methods are used. This practice improves water-use efficiency.

viii. Correct planning for rice growing

Rice requires huge amount of irrigation water. If a greater part of an area is under rice cultivation, a sharp rise in the ground water may occur. Rice growing areas must be specially selected. They must lie at some distance from the main areas of irrigated land, and have good artificial drainage. Some areas, like the Indus Plains of Pakistan, are suitable only for rice growing because of the large volume of irrigation water available only during the summer.

9.8.1.3. Measures for reducing ground water evaporation

Ground water can move from the lower depths to the surface soil where water evaporates and leaves behind salts. The following measures can help reduce the ground water evaporation.

i. Plant cover over the field

To reduce ground water evaporation, it is necessary to keep a plant cover over the field. This is especially important in irrigated farming. Plant cover provides shade to the field, act as mulch and thus reduce surface evaporation.

ii. Improvement of soil structure

A granular water-resistant soil structure weakens the capillary rise and thus reduces the evaporation. Soil structure can be improved by the addition of organic matter (green manure), stubble incorporation in soil instead of burning, deep ploughing, cultivation in relation to irrigation schedule, and avoid overflowing of water after which the soil forms a crust upon drying.

iii. Tree plantation along roads and canals

Strip afforestation slows down the speed of winds and increases the air humidity thereby reducing the evaporation. On the other hand, the water consumption of trees is very high, thus the water table is maintained/lowered.

iv. Use of ground water for irrigation

Some ground waters having salt concentrations under permissible limits can be used for irrigation. This practice lowers the water table and decreases direct evaporation.

9.9. Management Strategies for Salt-affected Soils

Management of salt-affected soils can be divided into different aspects including leaching requirement (LR), selection of salt tolerant crops, irrigation practices, balanced fertilization, and planting techniques.

9.9.1. Leaching requirement

Part of the irrigational water that has to pass through root zone for the control of soil salinity problem at a specific level is referred as leaching requirement. It can also be described as the ratio between equivalent depth of drainage water (D_{dw}) to the equivalent depth of irrigation water (D_{iw}). Similarly, LR can be calculated from the knowledge of the amount of salts present into the irrigation water (EC_{iw}) and the permissible level of salt concentration in the drainage water (EC_{dw}). Importance of LR can be depicted by the following simple equation as:

$$LR = D_{dw} \ni D_{iw} = EC_{iw} \ni EC_{dw} \quad .... \quad (1)$$

Leaching requirement may be demonstrated in fraction form as well as percentage. The calculations for LR are made by assuming that there is always a steady-state water flow along with uniform application of irrigation water, no removal of salts in the harvested crop, no rainfall and no precipitation of soluble salts in the soil. By considering such assumptions drainage conditions of soil, depth of root zone, moisture and salt storage in soil, and cation exchange reactions remain neglected. On the other hand, it is assumed that the soil drainage will permit the specified leaching. Regarding field crops if $EC_{dw} = 8$ dS m^{-1} it can be tolerated and thus formula for the calculation of LR would be as:

$$LR = D_{dw} \ni D_{iw} = EC_{iw} \ni EC_{dw} = EC_{iw} \ni 8$$

For irrigation waters with EC values of 1, 2, 3, and 4 dS m^{-1}, respectively, the LR will be 13, 25, 38, and 50%. These are the maximum values because rainfall, removal of salts by crops, and precipitation of salts in soils are seldom zero. The predicted value of LR may reduce if these factors are properly taken into consideration.

Equation 1 must be used with great care as the provision of steady-state and/or longtime average in this case is assumed. In equation 1 average EC of the irrigation water must be used over averaged longtime for the conductivities of the rain water (EC_{rw}) and irrigation water (EC_{iw}) as described in the given equation:

$$EC_{(rw+iw)} = (D_{rw}\, EC_{rw} + D_{iw}\, EC_{iw}) \ni (D_{rw} + D_{iw}) \quad \text{. . . . .} \quad (2)$$

Where D_{rw} and D_{iw} are indicating the depths of rain water along with the irrigational water that enters into the soil respectively. In order to restrain the soil salinity to cross a specified value, knowledge related to the consumptive use of water is an important factor if the LR concept has to be under consideration while determining either the depth of irrigation water that must be applied or the minimum depth of water that must be drained. The depth of irrigation water (D_{iw}) is related to consumptive use (D_{cw}) and the depth of drainage water (D_{dw}) by the equation:

$$D_{iw} = D_{cw} + D_{dw} \quad \text{. . . . .} \quad (3)$$

Using equation 1 to remove D_{dw} from equation 3 gives:

$$D_{iw} = D_{cw} / (1 - LR) \quad \text{. . . . .} \quad (4)$$

Expressing the LR in equation 4 in terms of conductivity ratio in equation 1 gives:

$$D_{iw} = [EC_{dw} / (EC_{dw} - EC_{iw})]\, D_{cw} \quad \text{. . . . .} \quad (5)$$

Thus, the depth of irrigation water (D_{iw}) can explained using the EC of irrigation water, consumptive use and salt tolerance of a crop. The crop salt tolerance is taken into account by the selection of the permissible values of EC of the drainage water or EC of the soil saturation extract.

9.9.2. Crop selection for salt-affected soils

In salt-affected soils, the wise selection of crops that can provide suitable yields (50% lower) under saline conditions may clearly differentiate between success and failure of any management option, particularly during early phase of colonization of such soils. Plant’s ability to endure the hazards of soil salinity within the root zone and provision of proficient growth is declared as the salt tolerance of the plants. salt tolerance potential of various plants can be evaluate using the following criteria as:

1) The ability of the crop to survive on salt-affected soils.
2) The acceptable yield of the crop on salt-affected soils, mostly 50 % reduced yield
3) The relative yield of the crop on a salt-affected soil as compared with its yield on a normal soil under the similar growing conditions.

The salt tolerance of a plant is not an exact value. It depends on many factors, viz. environmental and edaphic factors (soil fertility, physical condition of soil, salt distribution in soil profile, irrigation practices, climate) and biological factors (stage of growth, varieties and rootstocks). The salt tolerance of some plants is given in Table 9.6.

Table 9.6 Tolerance of some crops to saline conditions. Salinity expressed as electrical conductivity

Sensitive (0-4 dS m^{-1})	**Moderately tolerant (4-6 dS m^{-1})**	**Tolerant (6-8 dS m^{-1})**	**Highly tolerant (8-12 dSm^{-1})**
Almond	Corn	Figs	Barley
Bean	Grain Sorghum	Oats	Cotton
Clover	Lettuce	Pomegranate	Olive
Onion	Soybean	Sunflower	Rye
Potato	Tomato	Wheat	Wheatgrass

Source: Brady and Weil (2016)

9.9.3. Balanced fertilization

Salinity, sodicity and their combination induce unfavorable nutrient ratios in soils. Excess of Na^+ and deficiency of many macro- and micro-nutrients are common in sodic and saline-sodic soils. The predominant factors responsible for low nutrient availability and mobility in sodic soils are high soil pH and poor soil physical conditions due to dispersed soil matrix because of Na^+ dominance. For this reason, special fertilizer management practices are needed for optimum crop production.

Low organic matter coupled with deficiency of nitrogen is the basic feature of the salt affected soils. Nitrogen deficiency can be met by adopting the green manuring technique using sesbania species that also decrease the harms and hazards of salinity/sodicity. During the reclamation of the sodic soils part of the N may also leach down along with the other soluble salts and Na^+. Some studies that were conducting in Pakistan (Murtaza 2011) as well as in India (Yaduvanshi and Dey 2009) reveal that application of higher dose of nitrogen than the requirement for the crops growing under saline/sodic conditions endow with more yield and production may be due to stimulation of dilution effect coupled with enhanced salt tolerance potential of plants (Woyema et al. 2012). Yaduvanshi and Dey (2009) and Murtaza et al. (2014) reviewed a series of experiments and recommended that rice and wheat crops grown in sodic soils should receive 25-30% N over and above the recommended rates for non-saline/sodic soils.

Sodic and saline-sodic soils usually have higher available phosphorus than the normal soils because higher concentrations of Na_2CO_3 results in the formation of soluble Na_3PO_4. On the basis of some studies, it has been proposed that the sodic soils after reclamation require less additional P fertilizer for some years. Similarly, it has been suggested that a 50% reduction in the recommended dose of P may be practiced for a rice-wheat rotation grown up to three years during reclamation without yield loss. Increasing sodicity nearly always results in a deficiency of Ca^{2+} concentration in the soil. Fertilizers containing Ca^{2+} (calcium nitrate, single superphosphate) or those producing physiological acidity (ammonium sulphate, urea) perform better than the equivalent rates of Ca-free or physiologically less acidic materials like NH_4NO_3 etc. Generally, it is recommended that application of fertilizers, except P containing fertilizers, to the marginal salt-affected soils should be done at higher rates (15-30%) compared to their counterpart normal soils in any agro-ecological zone.

9.9.4. Planting techniques

Under field conditions, it is possible through the modification of planting practices to minimize the tendency of salts to accumulate around the seed and to improve the stand of crops those are sensitive to salts during germination. Seeds of a crop sprout only when they are placed so as to avoid excessive salt around them. The pattern of salt concentration changes with the shape of beds on which seeds are sown.

9.9.5. Saline agriculture

Saline agriculture is defined as the profitable and integrated use of genetic resources (plants, animals, fish, insects and microorganisms) and improved agricultural practices to obtain better use from saline land and saline irrigation water on a sustained basis. Saline agriculture presents a systematic approach for the utilization of salt-affected lands involving a combination of salt tolerant crops, crop genotypes and salt tolerant grasses, trees and shrubs. The components of this system are site-specific and are changed according to the farmer needs, land capability, locality, market availability and climatic conditions of the area. Salt-affected lands are mostly potentially productive although with a lot of spatial variability. Therefore, the potential of salt-affected land is evaluated and considered to select plants and other genetic resources for its utilization. Slightly salt-affected lands are used for salt tolerant varieties of different crops. Moderately salt-affected lands are used for salt-tolerant trees and grasses and the highly salt-affected lands are used for salt-tolerant shrubs and bushes.

In the world there are more than 1500 salt-tolerant plants species but in Pakistan less than 1% of these species are present. The major crops including rice, wheat, cotton and maize have different tolerance to salinity and associated problems. It has been observed that these major crops have little or no growth at EC_e 15 dS m^{-1}. However, there is genetic difference among the genotypes of each crop. Rice cultivars KS-282 and NIAB-6 are moderately salt-tolerant which produce about 30-35% more paddy than ordinary varieties. But rice is only crop that gives best results in water logged and sodic soil conditions. Salt-tolerant wheat varieties selected by Saline Agriculture Research Center at the University of Agriculture Faisalabad include SARC-I, SARC-II, SARC-III, SARC-IV, SARC-V and SARC-VI. Cotton crop is a salt tolerant crop but problems occur with the emergence in sodic or saline-sodic soils condition. NIAB-78 and MNH-93 are best salt tolerant cotton varieties.

Salt tolerant trees and grasses include date palm (*Phoenix dactylifera*), sugarbeet (*Beta vulgaris*), wheat and semidwarf (*Triticum aestivum*), bermuda grass (*Cynodon dactylon*), kallar grass (*Diplachne fusca*), mesquite (*Prosopis juliflora*) and river salt bush (*Atriplex amnicola*). Many of the salt tolerant plants have the potential to rapidly grow at electrical conductivity $EC_e \geq 30$ dS m^{-1}. These other salt-tolerant plants which can be used in saline agriculture include sugar beet (*Beta vulgaris*), fig (*Ficus *carica*), guar (*Cyamopsis tetragonoloba*), oats (*Avena sativa*), papaya (*Carica papaya*), rape (*Brassica napus*), sorghum (*Sorghum bicolar*), soybean (*Glycine max*), Rhodes grass (*Chloris gayana*) and *cynodon dactylon* species (dela khabbal grass).

9.10. Economics of Soil Reclamation

Crop cultivation on stress soil is usually dejected because of the expensive soil reclamation process. While the success of any technology is dependent upon its cost: benefit ratio, economics is always considered a key factor for adoption by farmers. In most of the studies, economic evaluation of treatments is overlooked. If it is computed, then only on the basis of variable costs and produce only. The long term benefits, like appreciation in land value, improved environment, farm-level employment opportunities etc are not included in economic analysis. Multi-location research studies that were conducted on salt affected soils of Indus Basin in Pakistan comparing different amendments for the reclamation of saline sodic soils declare that gypsum has proved highly cost-effective than acids or acidulents for native soils. Acids and acid formers for the treatment of native salt-affected soils are not suitable because of clay mineralogy concerns since considerable chlorite is present in clay fraction. However, organic matter has no substitute regarding health of normal and salt-affected soils. The biological reclamation approach, although is cost-effective than the chemical amendments, but time and amount of irrigation water required to achieve soil reclamation make it impractical for most of the farmers except landlords. Small land holding (70% farmers own land <5 ha) is another issue to be considered while recommending reclamation technologies.

9.11. Conclusion

Soil and water salinity/sodicity are potential threat to irrigated agriculture. Salination and sodication of millions of hectares of land continues to severely reduce crop production in Pakistan and rest of the world. Salt-affected soils are classified into three major categories namely saline, saline-sodic, and sodic. Saline soils can easily be reclaimed through simple leaching with good quality water without any amendment even high EC water can serve the purpose during initial phase. For the reclamation of saline-sodic/sodic soils, there is a need of some Ca-amendment and gypsum is the most promising. Lower solubility of mined gypsum compared to other industrial sources is an additional advantage to sustain electrolyte concentration in these soils. Acids or acid formers can reclaim such soils relatively at a faster rate but at a much higher cost. Another way to combat the salinity/sodicity of soils is saline agriculture approach, i.e. cultivation of salt tolerant plants. Along with reclamation measures, various aspects related to agronomic management like mulching, tillage, green manuring and seed bed preparation do merit.

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