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:

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

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

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

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 ≥ 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.