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:

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

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:

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

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:

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

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

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

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

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

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.

References

Ahmad, N.C. and M.R. Chaudhry (1997). Review of research on reclamation of salt-affected soils in Pakistan, Publication No. 175, IWASRI, WAPDA, Lahore

Anonymous (2011). Statistics of Pakistan. Ministry of Food, Agriculture and Livestock, Government of Pakistan, Islamabad, Pakistan.

Baig, M.B. and M.S. Zia (2006). Rehabilitation of problem soils through environmental friendly technologies - ii: role of sesbania (sesbania aculeata) and gypsum. Agric. Trop. Subtrop. 39: 26–33.

Chang, M.H. and Q.A. Sipio (2001). Reclamation of saline-sodic soils by rice husk. J. Drain. Water Manage. 5: 29–33.

Eaton, F.M. and V.P. Sokoloff (1935). Adsorbed sodium in soil as affected by the soil to water ratio. Soil Sci. 1:528–534.

Farid, M. (2000). Effectiveness of various gypsum particle sizes to reclaim a saline-sodic soil having different ECe : SAR ratios. *M.Sc. Thesis,* Dept. Soil Sci., Univ. Agri., Faisalabad, Pakistan

Ghafoor, A., M. Qadir and G. Murtaza (2004). Salt affected soils: principles of management. Allied Book Center, Urdu Bazar, Lahore, Pakistan.

Khan, G.S. (1998). Soil Salinity/Sodicity Status in Pakistan. Soil Survey of Pakistan, Lahore, Pakistan.

Latif, M. and A. Beg (2004). Hydrostaticaly issues, challenges and options in OIC member states.pp.1–14. In: Latif, S. Mahmood and M. M. Saeed (Eds), Training Workshop on Hydrostatically Abatement and Advance Techniques for Sustainable Irrigated Agriculture. September 20-25, 2004, Islamabad, Pakistan.

Murtaza, B., G. Murtaza M. Saqib and A. Khaliq (2014). Efficiency of nitrogen use in rice wheat cropping system in salt-affected soils with contrasting texture. Pak. J. Agric. Sci. 51: 431–441.

Murtaza, G. (2011). Technology transfer for using tube well water on salt affected soils for crop production. Final technology report for FDTTPC funded project (Jully, 2008 – June, 2011). Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan

Murtaza, G., A. Ghafoor, G. Owens, M. Qadir and U.Z. Kahloon (2009). Environmental and economic benefits of saline sodic soil reclamation using low quality water and soil amendments in conjugation with a rice wheat cropping system. J. Agron. Crop Sci. 1995: 124–136.

Murtaza, G., M.N. Tahir, A. Ghafoor and M. Qadir (1999). Calcium losses from gypsum and farm yard manure treated saline-sodic soilduring recalimation. Int. J. Agri. Biol. 1: 19–22.

Qadir M. and J.D. Oster (2004). Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. Sci. Total Environ. 323:1–19.

Qadir, M., B.R. Sharma, A. Bruggeman, R. Choukar-Allah and F. Karjah (2007). Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. Agric. Water Manage. 87: 2–22.

Qadir, M., E. Quillérou, V. Nangia, G. Murtaza, M. Singh, R.J. Thomas, P. Drechsel and A.D. Noble (2014). Economics of salt-induced land degradation and restoration. Natural Resources Forum, A United Nations Sustainable Development Journal DOI: 10.1111/1477-8947.12054

Qadir, M., S. Schubert, A. Ghafoor and G. Murtaza (2001). Amelioration strategies for sodic soils: a review. Land Degrade. Dev. 12: 357–386.

Schoonover, W.R. (1952). Examination of soils for alkali. Extension Service, University of California, Berkley, California, Memeograph. USA.

Shainberg, I. and J. Letey (1984) Response of soils to sodic and saline conditions. Hilgardia 25: 1–57

Sharif, A. (2011). Technical adaptations for mechanized SRI production to achieve water saving and increased profitability in Punjab, Pakistan, Paddy Water Environ. 9: 111–119.

Tanji, K. K. (1990). The nature and extent of agricultural salinity problems. In: TANJI K.K. (ed.), Agricultural salinity assessment and management. ASCE Man. Rep. Engin. Prac. 71: 1–41.

WAPDA (Water and Power Development Authority) (2003). Salinity and reclamation department, SCARP Monitoring Organiztion, Lahore, Pakistan

Weil, R.R. and N.C. Brady (2016). The Nature and Properties of Soils, New Jersey, USA, Prentice Hall.

Woyema, A., G. Bultosa and A. Taa (2012) Effect of different nitrogen fertilizer rates on yield and yield related traits for seven Durum Wheat (*Triticum turgidum* L. var Durum) cultivars grown at Sinana, South Eastern Ethiopia. Afr. J. Food Agric. Nutr. Dev. 12: 6079-6094.

Yaduvanshi, N. and P. Dey (2009). Nutrient management in sodic soils. In: G. Singh, A. Qadar, N.P.S. Yaduvanshiand and P. Dey (eds.). Enhancing nutrient use efficiency in problem soils. Central Soil Salinity Res. Inst. Karnal, New Delhi, India. pp. 84–108.

Zinc-enriched farm yard manure improves grain yield and grain zinc concentration in rice grown on a saline-sodic soil. Int. J. Agric. Biol. 14: 787–792.