Soil salinity development, classification, assessment, and management in irrigated agriculture

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2.1 INTRODUCTION

Arid zones receive inadequate and irregular precipitation to accomplish leaching of salts originally present in the soil profile. Normally when the precipitation is more than 1000 mm per annum, salinity should not develop. This is not the case in arid zones; therefore, salts accumulate in soils. Salt buildup in concentrations detrimental to plant growth is a constant threat in irrigated crop production.

In arid and semiarid regions, evapotranspiration is higher than the total annual rainfall. Therefore, rainfall contributes insignificantly to groundwater recharge, and hence there is a general shortage of fresh quality water to offset the total agriculture water demand in these countries. The shortage of fresh water necessitates the use of marginal quality ground water, such as brackish and saline, for irrigated agriculture. This is highly demanded in water-scarce regions. The improper use of saline/brackish water in irrigated agriculture often introduces salinity and sodicity problems and the soil if not properly managed can reach a condition where it cannot be exploited to its full production capacity. Under such conditions, irrigated agriculture has faced the challenge of sustaining its productivity for centuries, particularly soil and water salinity, poor irrigation, and drainage management continue to plague agriculture especially in arid and semiarid regions (Tanji, 1996).

If soil becomes saline and sodic, it creates plant- and soil-related problems that restrict plant growth through undermining soil quality, and hence many plants either fail to grow in saline soils or their growth is retarded significantly; however, few plants grow well on saline soils (Maas, 1990). Therefore, soil salinity often restricts options for cropping in a given area. Because of this reason, understanding salinity in irrigated agriculture fields is essential for their precise management. Salinity management is highly site specific and depends on factors such as site characteristics, nature of soils, and local hydrological conditions. Soil salinity and sodicity are global issues and not restricted to one country or region.

Once the soil salinity and sodicity are diagnosed and site characteristics are established, integrated management and reclamation strategies specific to the site can be formulated for better results and long-time sustainability of irrigated agriculture.

2.1.1 Salinity and Sodicity: A Global Scale Problem

Planet Earth consists of land surface of about 13.2×10^9 ha, out of which only 7×10^9 ha are arable and only 1.5×10^9 ha are cultivated (Massoud, 1981). Of the cultivated lands, about 0.34×10^9 ha (23%) are saline and another 0.56×10^9 (37%) are sodic. Older estimates (Szabolcs, 1989) suggest 10% of the total arable land to be affected by salinity and sodicity, and extends over more than 100 countries and almost all continents.

2.1.2 Salinity and Sodicity

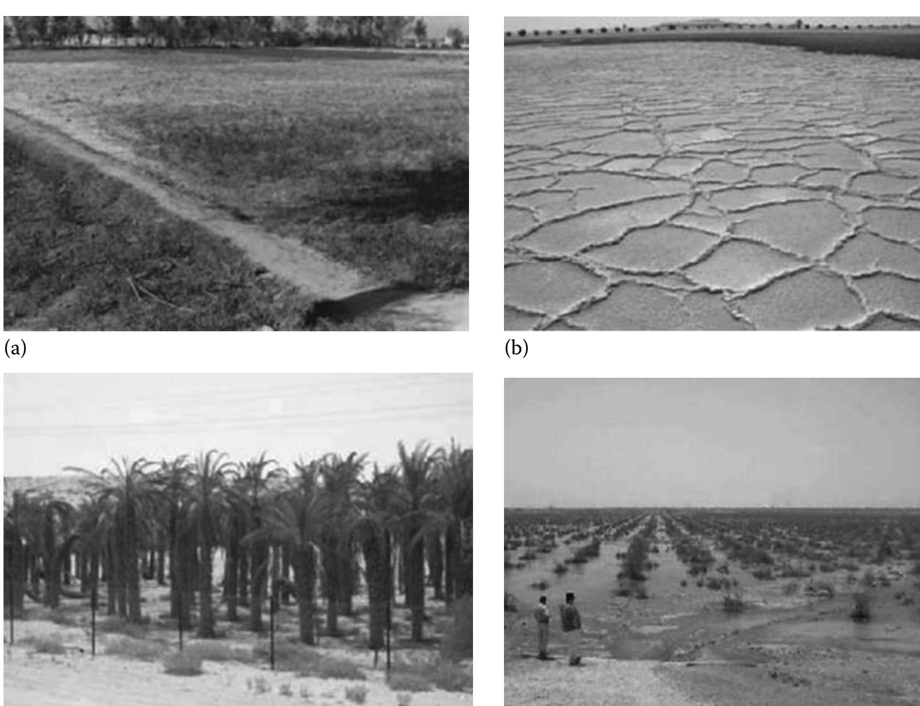
Some people get confused between salinity and sodicity. *Salinity* is a measure of the concentration of all the soluble salts in soil or water. It is expressed as decisiemens per meter (dS m^{-1}) or millisiemens per centimeter (mS cm^{-1}). If we want to keep our soils productive, we need to identify potential salinity problems and be ready with remedies or actions to help reduce the effects or avoid them in the first place. *Sodicity* is a measure of sodium ions in soil or water relative to calcium and magnesium ions (Richards, 1954). It is expressed either as the sodium adsorption ratio (SAR) or as the exchangeable sodium percentage (ESP). If the SAR of the soil equals or is greater than 13 or ESP equals or is greater than 15, the soil is termed sodic (Richards, 1954).

2.1.3 Causes of Salinity Development

There may be a number of causes (Plate 2.1) of soil salinity development: (1) inherent soil salinity (parent material); (2) seawater intrusion to coastal areas; (3) uses of brackish/saline water in farming and urban landscapes area; (4) restricted drainage developed into a high water table; (5) low rainfall; and (6) high rate of evapotranspiration. The rainfall contributes 10–200 kg salts per year per ha, depending on the vicinity of the area to the sea or inland.

In farming areas, the continuous pumping of ground water and subsequent use for irrigation purposes (recycling) usually lowers the water table; however, this practice resulted in an increase in water salinity and covert normal soils to become saline with low productivity. These soils need attention for their management and reclamation.

Pumping groundwater to alleviate surface salinity and to lower water table is an effective way, with the condition that ground brackish water is not used directly for irrigation, but with some management, e.g., conjunctive or cyclic use. In areas where water table is high and persistent, the imbalance in the natural water, the clearing of vegetation and the general absence of deep rooted trees, and the absence of adequate drainage cause soil salinity. As the groundwater rises, it brings salt to the surface through capillary rise and subsequent evaporation, which can be harmful to plants by reducing yields. The quality of the groundwater used for irrigation and its rates of recharge are critical too. These considerations make land-water management in irrigated arid lands a delicate task. Subject to these limitations, irrigation helps reduce risks linked to soil moisture stress and enhances yield.



(a) (b) (c) (d)

PLATE 2.1 Soil salinization, waterlogging, and plant growth. (a) Patchy salinity in wheat field. (b) Salt accumulation through sea water intrusion—salt flat. (c) Affect of salinity on date palm trees. (d) Waterlogging in forestry field.

The groundwater usually rises 0.6–1.5 m or more in the soil above the water table by capillarity, depending upon texture, structure, and other factors. The water reaching the surface evaporates, leaving a salt-deposit typical of saline soils. Generally, water table below 2 m is considered safe for irrigated agriculture.

2.1.3.1 Salinity Development: Hypothetical Cycle

Recently, Shahid et al. (2010) have published a hypothetical salinization development cycle in irrigated agriculture fields (secondary salinization). Figure 2.1 depicts poor irrigation and drainage management and high temperature as the main causes of secondary salinization.

2.1.3.2 Dryland Salinity Development

In Australia, dryland salinity is very common and is developed due to clearing of trees to convert the area to arable agriculture. In the former, the rainfall is compensated through high evapotranspotration with no or insignificant leaching; in the latter case, low evapotranspiration relative to former lead the extra rain to leach down and with poor drainage condition, water table developed and subsequent evaporation caused dryland soil salinization.

2.1.4 Damage due to Salinity

An exact estimate of losses caused due to salinity in an area is difficult to know; however, it is clear that losses may be quite considerable, and high cost of work to be done to control salinity must also be added. Different types of salinity damage are; saline water tables can cause productive land to become barren; soil salinity also enhances "erosion" and loss of farm income; salinity can deteriorate the quality of drinking water; in salt-affected areas, roads and building foundations are weakened by high salty water tables and high water table also affects biological activity in the soil.

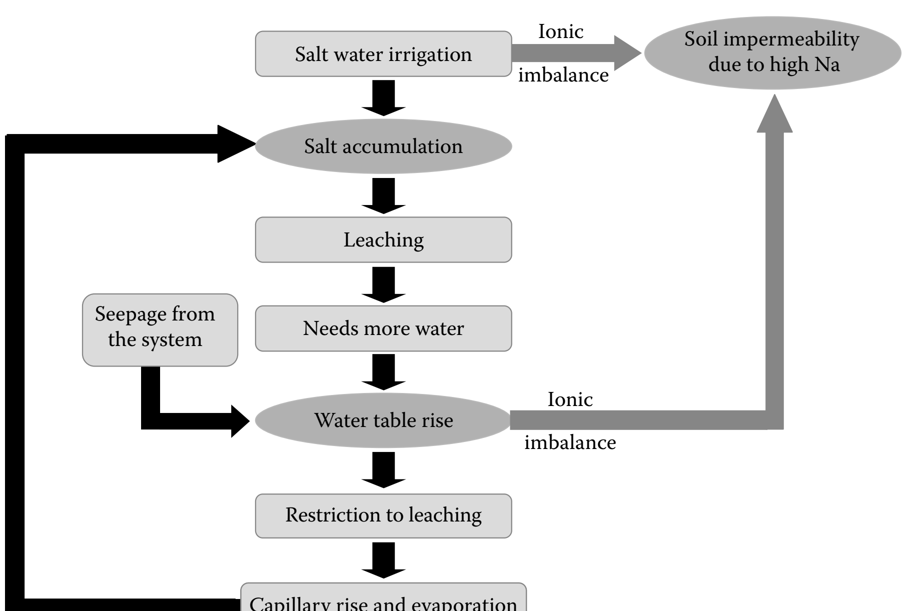


FIGURE 2.1 Hypothetical salinization cycle. (From Shahid, S.A. et al., Mapping and monitoring of soil salinization, remote sensing, GIS, modeling, electromagnetic induction and conventional methods—case studies, in *Proceedings of International Conference on Management of Soil and Groundwater Salinization in Arid Regions*, Sultan Qaboos University, Sultanate of Oman, January 11–14, 2010. Volume 1: Keynote papers and Abstracts, pp. 59–97.)

2.1.5 Quick Facts about Salinity and Plant Growth

Proper plant selection is one way to moderate yield reductions caused by excessive soil salinity. The stage of plant growth has a direct bearing on salt tolerance. Generally, the more mature the plant, the more tolerant it is to salt. Most fruit trees are more sensitive to salt than are vegetable, field, and forage crops and generally, vegetable crops are more sensitive to salt than are field and forage crops.

2.1.6 Indicators of Soil Salinization

Once soil salinity is developed in irrigated agriculture fields, it starts showing its effects on soil properties and plant growth. The white salt crust, reduced plant vigor, salt stain on dry soil surface, affected area worsen after rainfall, marked changes in leaf color and shape, and presence of naturally growing halophytes and trees are either dead or dying are the indicators of soil salinity, which can be observed in the field without laboratory analyses.

2.1.7 Classes of Soil Salinity and Plant Growth

Electrical conductivity of the soil saturation extract (ECe) is the standard measure of salinity. Richards (1954) has described general relationship of ECe and plant growth.

Class	ECe (dS m^{-1})	Plant Growth
0 Nonsaline	0–2	Salinity effects mostly negligible
1 Very slightly saline	2–4	Yields of very sensitive crops may be restricted
2 Slightly saline	4–8	Yields of many crops restricted
3 Moderately saline	8–16	Only tolerant crops yield satisfactory
4 Strongly saline	>16	Only a few very salt-tolerant crops yield satisfactory

2.2 CLASSIFICATION OF SALT-AFFECTED SOILS

A soil, which contains sufficient soluble salts in the root-zone to impair the growth of crop plants, is defined as "saline." However, because salt injury depends on species, variety, growth stage, environmental factors, and nature of the salts, it is very difficult to define a saline soil precisely. The definitions are based on salt content either alone or in conjunction with texture, morphology, or hydrology (Richards, 1954; Northcote and Skene, 1972; FAO-UNESCO, 1974; Soil Science Society of America, 1978). The most widely accepted definition of a saline soil is one that gives an electrical conductivity of extract from saturated soil paste (ECe exceeding 4 dS m^{-1} at 25°C), while FAO-UNESCO (1974) mapped soils with ECe exceeding 15 dS m^{-1} as strongly saline soils or solonchaks.

2.2.1 U.S. Salinity Laboratory Staff (Richards, 1954) Classification

The term "salt-affected" soil is being used more commonly to include saline, saline-sodic, and sodic soils, which are clearly differentiated by Richards (1954). The term "alkali" to describe soils with excess exchangeable sodium (ES) is being discouraged due to its ambiguity (Overstreet et al., 1951).

Saline soils are those which have pHs usually less than 8.5, ECe > 4 dS m^{-1} and ESP < 15. The high ECe with low ESP tends to flocculate soil particles into aggregates. The soils are usually recognized by the presence of white salt-crust during some part of the year. Permeability is either greater or equal to those of similar normal soils.

Saline-sodic soils contain sufficient soluble salts (ECe > 4 dS m^{-1}) to interfere with the growth of most crop plants and sufficient ESP (>15) to affect the soil properties and plant growth adversely by the degradation of soil structure. The pHs may be less or more than 8.5.

Sodic soils contain ESP >15 and ECe < 4 dS m^{-1} and pHs generally range between 8.5 and 10 and may even be as high as 11. The low ECe and high ESP tends to deflocculate soil aggregates and hence lower their permeability.

2.2.2 FAO-UNESCO Classification (1974)

Salt-affected soils (halomorphic soils) are also indicated on the soil map of the world (1:5,000,000) by FAO-UNESCO (1974) as solonchaks and solonetz. The origin of both solonchak and solonetz are Russian. Solonchaks are soils with high salinity (ECe > 15 dS m^{-1}) within 125 cm of the soil surface. The FAO-UNESCO (1974) divided solonchaks into four mapping units: (1) *orthic solonchaks*—the most common solonchaks; (2) *gleyic solonchaks*—with groundwater influencing the upper 50 cm; (3) *takyric solonchaks*—solonchaks in cracking clay soils and; (4) *mollic solonchaks*—solonchaks with dark colored surface layer, often high in organic matter. Soils with a lower salinity than solonchaks, but higher than 4 dS m^{-1} are mapped as "saline phase" of other soil units.

A "solonetz" is a sodium-rich soil that has an ESP > 15. The solonetz are subdivided into three mapping units: (1) *orthic solonetz*—the most common solonetz; (2) *gleyic solonetz*—those soils with groundwater influence in the upper 50 cm, and (3) *mollic solonetz*—the soils with a dark colored surface layer, often high in organic matter. Soils with a lower ESP than a solonetz, but higher than 6, are mapped as a "sodic phase" of other soil units.

2.2.3 USDA: Soil Survey Division Staff Classification (1993)

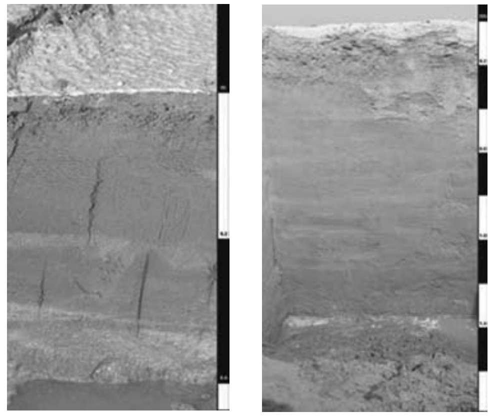
The following classes of salinity are used if the EC has not been measured, but salinity is inferred (Soil Survey Division Staff, 1993). These are: class 0 (nonsaline, 0–2 dS m^{-1}); class 1 (very slightly saline, 2–4 dS m^{-1}), class 2 (slightly saline, 4–8 dS m^{-1}), class 3 (moderately saline, 8–16 dS m^{-1}), and class 4 (strongly saline ≥ 16 dS m^{-1}). The class 0 shows no visible salts on the soil surface and plant growth is not affected by salinity/sodicity. In classes 1 and 2, the plant growth may be uneven or patchy. Salts are generally present in small-sized patches (Plate 2.1a), which do not cover more than 25% area collectively. In class 3, the plant growth on these soils is very patchy and the salts are fairly visible on the soil surface. The area in class 4 lies unused and may support some salt-tolerant plants.

2.2.4 USDA-NRCS (Keys to Soil Taxonomy, 2010) Classification

The Keys to Soil Taxonomy (USDA-NRCS, 2010) system of classification has hierarchies of groups of soils (taxa). In this system, the true salt-affected soils belong to the order "Aridisols" and suborder salids. At the third level of classification, there are great groups named Natrargids, which are argids with a high ESP and are equivalent to solonetz on the soil map of the world (FAO-UNESCO, 1974). At this third level (great group) of classification, there are also the aquisalids (Plate 2.2a—salids with water table within 1 m from soil surface) and haplosalids (Plate 2.2b—where water table is below 1 m or even deeper) in the suborder of salids, which are equivalent to solonchaks on the soil map of the world.

2.2.5 Russian System of Salinity Classification

In the Russian classification, the solonchaks may be "external solonchaks" with the soluble salts throughout the whole soil or internal solonchaks with soluble salts in the subsoil or substratum only. The solonchaks are subdivided according to the composition of salts. The following types have been recognized: nitrate, nitrate-chloride, chloride, chloride-sulfate, sulfate-chloride, sulfate-soda, soda, and borate solonchaks. The external solonchaks are of different types (flooded, puffed, sabkha),



(a) (b)

PLATE 2.2 Soil salinity classes (USDA-NRCS): (a) aquisalids—water table at 40 cm and (b) haplosalids—water table at 140 cm.

sometimes the subdivision is made according to the origin of the salt, e.g., closed basin, marine, allochthonous air blown, and anthropic.

2.3 SALINITY ASSESSMENT

Accurate measurement is essential to understand soil salinity problem for better management, to improve crop yield and to maintain root zone soil health. If the salinity could be measured, it could be managed. A reliable salinity assessment method is required. The choice of the method, however, depends on purpose, size of the area, depth of soil to be assessed, number and frequency of measurement, accuracy required, and available resources.

There are a number of soil salinity assessment tools, such as salinity monitor maps prepared over a period of time to assess present salinity problem and to predict future salinity risk to the area, salinity indicators on soil surface, vegetative indicators, conventional salinity tests (EC 1:1 or 1:5; ECe) and modern methods (Geophysical—EM38; salinity sensors).

2.3.1 Remote Sensing and Soil Salinity

Remote sensing acquires information about the Earth's surface without actually being in contact with it. The fundamentals of remote sensing in soil salinity assessment and examples of such studies from the Middle East, Kuwait, Abu Dhabi Emirate, and Australia have been described recently by Shahid et al. (2010). The remote sensing imagery picks surface reflection and provides general salinity information of the area; however, it lacks information about root zone salinity, which requires other conventional (EC meters) and modern methods (EMI and salinity probes) to be used. The combination of salinity maps taken over period of time and digital elevation model (DEM) help predict salinity risk in the area (Furby et al., 1995, 1998).

2.3.2 Conventional Methods

Soil salinity measurement is made on georeferenced (using GPS) field sampling, and laboratory analysis of extract from saturated soil paste (Plate 2.3a) by EC meter is accepted as the standard way of soil salinity assessment, expressed as desisiemens per meter (dS m^{-1}) or millisiemens per centimeter (mS cm^{-1}). This is due to the amount of water that a soil holds at saturation, is related to soil texture, surface area, clay content, and cation-exchange capacity. The lower soil:water ratios (1:1, 1:2, 1:5) are also used in many laboratories; however, the results require calibration with ECe to select salt-tolerant crops.

PLATE 2.3 Salinity assessment methods: (a) saturation extract collection, (b) salinity surveys by EM38, (c) activity meter and probe, (d) placing sensor in the root zone, (e) buried sensor and smart interface and (f) instant viewing of EC on smart datalogger.

2.3.3 Modern Methods

The salinity assessment and management at farm level help farmers improve crop productivity. The conventional field sampling and laboratory analysis is a tedious, expensive, and time-consuming process. Other quicker and modern methods can be used in the field salinity mapping, such as electromagnetic induction (EMI-EM38) and activity meter with salinity probe. The EM38 (Plate 2.3b) is most commonly used in agricultural surveys and for rapid assessment of the soil's apparent electrical conductivity (ECa) in millisiemens per meter (mS m^{-1}). The EM38 has transmitter and receiving coils. The transmitter coil induces an electrical current into the soil and the receiving coil records the resulting electromagnetic field. The EM38 provides a maximum of 1.5 and 0.75 m depth of exploration in vertical and horizontal dipole modes, respectively. EC mapping is one of the simplest, least expensive salinity measurement tools. Integration of GIS with salinity data results in salinity maps and help farmers interpret yield variations and in understanding subtle salinity differences across agricultural fields, allowing them to develop more precise management zones and, ultimately, potentially higher yields.

Activity meter with salinity probe (Plate 2.3c) is handy equipment and gives instant apparent electrical conductivity (ECa) information in mS cm^{-1} and g L^{-1}. The German-made PNT3000 COMBI + model is commonly used in agriculture, horticulture, and landscape sites for rapid salinity assessment and monitoring. It provides an extended EC-measuring range from 0 to 20 mS cm^{-1} and from 20 to 200 mS cm^{-1}. The unit includes stainless steel measuring electrode 250 mm long for direct soil salinity measurements; EC-plastic probe with platinum-plated ring sensors and high-quality aluminum-carrying case. The operation is convenient and simple; only one button makes the full operation possible. It is essential to validate ECa values with ECe from same fields. In both cases, the ECa must be correlated to ECe for crop salt tolerance.

The most modern salinity logging system (Plate 2.3d through f) is real-time dynamic automated salinity logging system (RTASLS). In this system, ceramic sensors are buried in the rootzone where salinity monitoring is required. Each salinity sensor is fitted with an external smart interface that consists of an integrated microprocessor containing all the required information to allow autonomous operation of the sensor, including power requirements and logging interval. The smart interface resolution is 16 bit, offering highly precise and accurate recording of the salinity sensor. The smart interface is connected to DataBus, which leads to Smart Datalogger. The Smart Datalogger searches the DataBus and automatically identifies the number of salinity sensors connected and begin logging them at the predetermined intervals. Instantaneous readings from sensors can be viewed on the logger's display directly in the field without the need for a laptop. Data can also be accessed in the field by memory stick or remotely using a mobile phone modem. This data is then available for graphing and interpretation in Excel (Shahid et al., 2009a).

2.4 SOIL SALINITY IN IRRIGATED FIELDS AND RELATIVE YIELD PREDICTION

Crops can tolerate salinity up to certain levels without a measurable loss in yield (this is called threshold level). As a general rule, the more the salt tolerant the crop, the higher the threshold level. At salinity levels greater than the threshold, crop yield reduces linearly as salinity increases. Using the salinity values in a salinity/yield model developed by Maas and Hoffman (1977), predictions of expected yield loss can be made. Maas and Hoffman expressed salt tolerance of crops by the following relationship:

$$\mathrm{Yr} = 100 - s(\mathrm{ECe} - t)$$

where

Yr is the percentage of the yield of crop grown in saline conditions relative to that obtained on nonsaline conditions
t is the threshold salinity level where yield decrease begins
s is the percent yield loss per increase of 1 ECe (dS m^{-1}) in excess of t

Salinity mapping at the farm level and Table 2.1 may be used as a guide to predict yield losses.

2.5 SALINITY MANAGEMENT AND RECLAMATION

It is essential to keep the plant root zone salinity below crop threshold level to get higher production and to maintain soil health. This requires careful management and reclamation of irrigated agricultural fields. The main objectives of management and reclamation should be to bring more soils under cultivation, to increase the yield per unit area, and to increase the water and fertilizer use efficiency, and to improve livelihood of the farmers. Efficient, effective, and long-term reclamation of saline soils require the lands to be well leveled before leaching is initiated, additional supply of good quality water is required and good subsurface drainage is essential. The physical, hydraulic, chemical, and biological techniques are the methods of soil reclamation.

2.5.1 Physical Method

Physical method includes land leveling, salts scraping, deep ploughing and tillage, subsoiling and sanding. In order to remove salts through leaching or flushing, *leveling* (preferable laser leveling) is a prerequisite to allow uniform distribution of water. The objective is to leach the salts or flush from the surface if a near surface restrictive layer is present. The leveling process may compact the soil due to heavy machinery used, subsoiling or chiseling should follow this practice. In certain cases, salt crusts formed at surface can be removed by mechanical means. In small agricultural farms, salt *scraping* is the simplest and most economic way of reclaiming saline soils. Scraping can minimize

TABLE 2.1
General Threshold (*t*) and Slope (*s*) Values to Calculate Crop Yield as a Function of Soil Salinity for Various Crops

Crops	Threshold (*t*) ECe (dS m^{-1})	Slope (*s*) % Yield Loss per 1 ECe (dS m^{-1}) above (*t*)
Alfalfa (*Medicago sativa*)	2.0	7.3
Barley for grain (*Hordeum vulgare*)	8.0	5.0
Bean (*Phaseolus vulgaris*)	1.0	18.9
Bean, dry edible (*Phaseolud vulgaris*)	1.0	19.0
Cabbage (*Brassica oleracea*)	1.8	9.7
Carrot (*Daucus carota*)	1.0	14.1
Clover (*Trifolium* spp.)	1.5	12.0
Corn for grain (*Zea mays*)	1.7	12.0
Corn for silage (*Zea mays*)	1.8	7.4
Cucumber (*Cucumis sativus*)	2.5	13.0
Date (*Phoenix dactylifera*)	4.0	3.6
Lettuce (*Latuca sativa*)	1.3	13.0
Onion (*Allium cepa*)	1.2	16.1
Pepper (*Capsicum annum*)	1.5	14.1
Potato (*Salanum tuberosum*)	1.7	12.0
Radish (*Raphanus sativus*)	1.2	13.0
Sorghum for grain (*Sorghum bicolor*)	6.8	16.0
Soybean (*Glycine max*)	5.0	20.0
Spinach (*Spinacia oleracea*)	2.0	7.6
Sugar beet (*Beta vulgaris*)	7.0	5.9
Tomato (*Lycopersicum esculentum*)	2.5	9.9
Wheat for grain (*Triticum aestivum*)	6.0	7.1

Source: Hoffman, G.J., Water quality criteria for irrigation. Biological System Engineering University of Nebraska, Institute of Agricultural and Natural Resources. Publication No. EC 97–782, 2001.

Notes: *s*, % yield loss per 1 ECe (dS m^{-1}) increase above *t* (ECe) value; *t*, salinity threshold ECe (dS m^{-1}), where yield is optimum.

the salts temporarily; however, they can reappear with a continuous feed of ground water to the surface. Low salinity in the rootzone can be achieved through *tillage* practices by manipulating the soil surface condition, i.e., bed shape and irrigation management (Plate 2.4a). It is very well recognized that salts tend to accumulate on the ridges top away from the wet ridge shoulder (Plate 2.4b) when furrow irrigation is adopted. Placing the seeds on off-center slope of the single row will put the seed (Plate 2.4a) in minimum salinity and optimum moisture condition. Under high salinity, the alternate row should be left unirrigated; this will ensure maximum accumulation of salts in the unirrigated area and leave the irrigated furrows free of salts and fit for planting seeds (Plate 2.4b and c). *Subsoiling* is particularly important for disrupting the dense layers (Plate 2.4d) at depth to enhance permeability (Shahid et al., 2009b). In the absence of subsoiling, flushing should be preferred over leaching; the latter compounds the salinity problem in the root zone due to the dense layer. Subsoiling is important while reclaiming sodic soils after the addition of a suitable amendment such as gypsum and watering the field.

If the soil surface to be reclaimed is very heavy textured, mixing of sand, "sanding," to the surface can change the texture permanently, and the soils become more permeable and easy to reclaim. This practice also provides a favorable environment for plant growth compared to the original soil without sanding.

(a) (b) (c) (d)

PLATE 2.4 Seed bed, salinity development, and plant growth: (a) Seed placement on furrow shoulder, (b) salt accumulation on ridge tops, (c) barley plants growing on ridge shoulder, and (d) dense layer need subsoiling.

2.5.2 Hydrological Method

Hydrological method is concerned with water use and drainage. In irrigated agriculture, the objective is to free the root zone from salts through leaching to lower depths and the subsequent drainage and surface flushing of dissolved salts. The rootzone salinity may increase if the net downward movement of salts is less than the salt input from irrigation, and salt water flux to surface. Therefore, salt balance must be kept under control, and this is a function of irrigation water salinity and to the success of drainage system.

Traditionally, saline soils have been reclaimed by flooding or by ponding water. In general, the depth of soil leached is roughly equal to the depth of water infiltrated during leaching. In order to leach the salts, the leaching requirement (LR) is very important. The LR is the calculated fraction (depth) or quantity of water that must pass through the rootzone to maintain the EC of the drainage water at or below some specified level. The recent trend is to minimize this LR in order to prevent raising the groundwater and minimize the load to drainage system (Mashali, 1995). Methods of LR calculation and to predict the losses in yield due to salinity are described by Rhoades (1992).

Timely leaching is important to assure root zone salinity is not exceeded above crop salinity tolerance limit for extended periods of time or critical stage of plant growth. In normal conditions, leaching can be accomplished at each irrigation; however, in soils with low infiltration rate and for crops sensitive to excess moisture in the rootzone, leaching at each irrigation may not be appropriate. Leaching can be done when soil moisture is low and water table is deep; it should precede the critical growing stage; at low evapotranspiration demand; at night, during high humidity, in cooler weather and; at the end of cropping season, as appropriate to area.

The drainage lowers water table, provides adequate leaching, minimizes upward water flux, and thus controls salinity buildup. Provided the subsurface is permeable and relief is adequate, natural drainage may work; however, experience shows that such ideal conditions do not prevail in saline areas, and therefore, a drainage system is always required. Based on site condition, nature of the problem, and available resources, a suitable drainage system (surface or subsurface) can be selected. Surface drainage allows runoff excess water before entering to soil and subsurface drainage is used to control water table at safer depth, consisting of open ditches or tile drains or perforated plastic pipes, mole drainage, and vertical drainage (pumping water) when the deep horizons have an adequate hydraulic conductivity.

2.5.2.1 Modern Irrigation Methods

In arid and semiarid zones, the major constraints are limited quantities of good quality water and to increase its efficiency; and exploitation of unsuitable brackish/saline water for irrigation. Therefore, a suitable irrigation method is to be selected without invoking soil salinity hazards. Each irrigation system develops salinity at a specific soil zone that is to be carefully monitored.

Surface irrigation includes flood, basin, border, and furrow methods. At the end of each irrigation cycle, soil dries out concentrating the salts, which adversely affects the crop yield. Frequent irrigation may lower the salinity, but increase the wastage of water; the alternatives to improve the efficiency of water are the drip, subsurface, or sprinkler irrigation. This shift from conventional surface irrigation to modern irrigation is costly and requires assurance on better crop adaptability.

A good *sprinkler* irrigation must meet the requirements of the crop for water (ET). It often allows efficient and economic use of water and reduces deep percolation losses. If water application through sprinkler is in close agreement with crop needs (ET and leaching), drainage and high water table problem can be greatly reduced, which in turn should improve salinity control. The use of high salinity water may lead to leaf burn and, therefore, the quality of water must match with the leaf burn tolerance of plants. Under sprinkler irrigation, the net salinity built up is at subsurface.

The *drip* (trickle) irrigation supplies the required quantity of water to the crop almost on a daily basis. The poor quality water used in drip irrigation may yield better due to continuous high moisture contents and daily replenishment of water loss by ET. Drip has priority over sprinkler as the latter may cause leaf burn, defoliation of sensitive species, which is not the case with drip irrigation. Maximum salt accumulation is outside the edges of the area wetted by emitters (Plate 2.5).

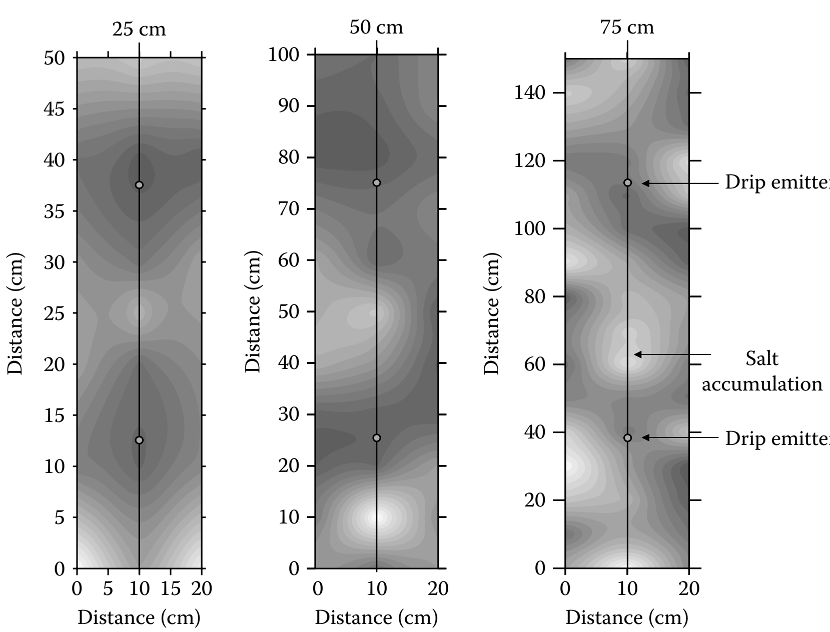


PLATE 2.5 Drip irrigation and salt accumulation (salinity map).

The daily irrigation continuously moves the moisture down to keep the salts under control. Plants may get shock due to high salinity when rainfall, as the rain water pushes the salts from edges to central rootzone; it is advisable to not shut the drip irrigation during rainfall to push the salts continuously toward the edges of the area wetted by emitters.

Subsurface drip irrigation (SDI) compared with other irrigation systems SDI reduce water losses to evaporation, deep percolation, and completely eliminate surface runoff (Phene, 1990), increase crop marketable yield and quality (Ayers et al., 1999), and can result in high nutrient use efficiency (Thompson et al., 2002). Saline irrigation water can be used with SDI, while maintaining yields and improving water use efficiency compared to surface irrigation (Tingwu et al., 2003; Cahn and Ajwa, 2005) because SDI can result in suitable root-zone salinity. The limitation of SDI is that salts continuously build up at surface through capillary action above the buried drip lines during growing season (Oron et al., 1999) and therefore the concept of LR does not work under SDI; however, salts above buried drip (surface salinity) can be managed by supplementing with sprinkler irrigation (Thompson, 2010). This approach may be costly, but a compromise.

2.5.3 Chemical Method

Chemical methods are used to reclaim sodic soils. To have successful crops on sodic soils, ESP of the soil must be below threshold (<15). The main aim is to increase the concentration of calcium in the soil. The long-term objective is to replace ES with calcium, and use organic matter to bind the soil and improve its structure. Gypsum ($CaSO_4 \cdot 2H_2O$) is commonly used amendment (to supply Ca) to rectify sodicity problem in irrigated fields. Calcium causes particles to form clusters (flocculates), forming a very clear puddle of water. Gypsum addition changes the soil chemistry in two ways: (1) by increasing salt solution clay do not swell and disperse. This is a short-term effect, which occurs as the gypsum dissolves; (2) the calcium from gypsum replace the ES attached to the clays (exchange complex). The process changes a sodic clay to a calcium clay, making it less prone to swelling and clay dispersion. The displaced sodium cations are leached below the plant root zone. Mined gypsum (10 mesh) is commonly used.

The addition of HCl and H_2SO_4 is only recommended where soils are sodic and calcareous. The acid induces Ca from $CaCO_3$ and Ca released work in similar manner as from gypsum. Acids are highly corrosive and dangerous to handle; special equipments are available to apply acid in the field and usually it is applied with irrigation water.

Addition of elemental sulfur may also be useful in reclaiming sodic soils, with the condition that it is properly oxidized. The sulfur (S) may be oxidized through biological oxidation by *Thiobacillus thiooxidans*, in sodic soils it is very slow process. The final product is H_2SO_4.

2.5.4 Biological Method

2.5.4.1 Serial Biological Concentration of Salts

The concept of serial biological concentration of salts (SBCS) (Heuperman, 1995) may provide an alternative salt management option, especially where groundwater pumping and safe disposal is an issue. The objective of SBCS is therefore to lower water table and reduce water volume. The SBCS system involves reuse of drainage water on progressively increasing salt-tolerant crops (salt-sensitive crops, salt-tolerant crops, halophytes, trees, etc.). In SBCS cropping system, each crop is underlain by tile drain for the collection of water to be used to irrigate the next stage. Along the crop sequence, the volume of drainage water collected is reduced due to plant water use, and the salinity of the drainage water increases since there is little or no salt uptake by plants. The highly saline water can be either transferred to treatment plants where through reverse osmosis or other techniques, it can be treated and salts can be removed, or the final effluent is contained in relatively small evaporation ponds making it feasible to consider the use of floor lining to eliminate leakage. These ponds could be used for fish farming. The highly saline water may be collected in a series of ponds where through evaporation salts may be harvested, and may have commercial value such NaCl (halite) for caustic soda factories and other uses.

2.5.4.2 Biosaline Agriculture (Practicing Salt-Tolerant Crops)

Biosaline agriculture means economic utilization of salt-affected soils, saline/brackish waters for agricultural purposes. It involves cultivation of salt-tolerant species of agricultural significance and adoption of special agronomic practices to improve their productivity under such conditions. Some scientists use saline agriculture concept, but "biosaline" is much broader in scope and includes manipulation of desert and sea resources for food and fuel (energy) production. Tables for salt tolerance of different crops are reported elsewhere (Maas, 1990).

For practical biosaline agriculture, the very first step is to identify the nature of the problem and then to visualize appropriate measures for maximum economic returns under the specific situation. Biosaline agriculture has many dimensions such as selection/breeding of salt-tolerant genotypes and plant species; domestication of salt-tolerant wild plant species for economic exploitation of salt-affected lands; introduction into the cultivated crops/other plant species genes of salt tolerance from their wild relatives through genetic engineering; agronomic practices including methods of land preparation, planting, irrigation and fertilizers application; and physiological studies with the following objectives. Other aspects in biosaline agriculture are; (1) to determine critical plant factors controlling yield under saline conditions, (2) to study physiological differences between salt-tolerant and salt-sensitive genotypes with a view to develop selection criteria for salt tolerance, (3) to improve yield through special treatments at critical stages during plant growth, and (4) the use of salty water for agricultural purposes. The Dubai based International Center for Biosaline Agriculture is specialized in such studies and have developed various production systems and introduced in many countries (Pakistan, UAE, Oman, Tunisia, Syria, Jordan, Palestine, Uzbekistan, etc.) for saline soils.

2.5.5 Alternatives for Using Marginal Saline Lands

There are persuasive reasons to extend the range of agricultural production into more saline environment. Some of these areas are uneconomical to reclaim by conventional soil reclamation procedures, e.g., leaching of salts and their drainage and use of chemical amendments. On such areas, the management and improvement of wild stands of *Atriplex* (salt-bush) for grazing have been pursued for many years in Australia. Now, there is increasing interest in cultivating, breeding, and managing selected *Atriplex* species for intensive forage production with highly saline water (Plate 2.6a).

Halophytes are one choice for such soils; they can grow under very saline conditions, for example, *Juncus vigidus* and *J. acutus* can grow in saline marshes or under irrigation with brackish water

(a)

(b)

PLATE 2.6 Alternative use of saline lands: (a) Atriplex growing in inland salt flat (sabkha) and (b) coastal mangroves in Abu Dhabi Emirate.

or even seawater. The culms provide fibers for high-quality paper production and the seeds have the medicinal value. The *Leptochloa fusca* (kallargrass) as forage, green manuring, compost, crop, pulp for paper production is found to be salt-tolerant in almost any salt-affected soils in most areas even irrigated with highly sodic water. Mangroves grown in coastal areas (Plate 2.6b) are other options; they provide fuel and fodder and deserve more attention for planting along shorelines. The sites may also be used for recreation purposes.

2.6 ECONOMIC, ENVIRONMENTAL, AND SOCIAL LOSSES DUE TO SOIL SALINITY

Economic losses are faced through loss of agricultural production and costs are incurred for land rehabilitation for public utilities.

Environmental losses are introduced through land degradation by physical, chemical, and biological changes in the soils and waterways, loss of vegetation and change to the landscape.

Social losses include an increased production costs on farms and reduced value of land as a result of soil salinization. The person from the salinized area move away and the social set up is disturbed.

2.7 RESEARCH–EXTENSION–FARMER LINK

There should be strong link of research–extension–farmers to benefit the end chain member (farmers, the stakeholders). Therefore, education to farming community is vital in increasing awareness and understanding of salinity. Advisory program should be developed to help farmer's plan and use salinity control practices on their farms. Salinity mapping on whole farm scale is the best practice for crop selection. Farmers should realize the significance of salinity mapping for the sustainable use of their farms. Salinity exhibitions for community education should be arranged in government institutes; demonstration days at the farmer's field are also useful. Preparation of introductory brochures for salinity control and management at the farm level and their distribution to the farming community can enhance their understanding to tackle salinity in a sustainable way. The awareness of the problem to teachers gives students hands-on experience and helps them discuss options with their students. After all, today's students will be tomorrow's soil resource users and managers.

2.8 SUMMARY

Salt-affected soils are a major global issue owing to their adverse impact on agricultural productivity and sustainability. Soil salinity/sodicity undermines the resource base by decreasing soil quality. This could be natural or a symptom of misuse and mismanagement that jeopardizes the integrity of soil's self-regulatory capacity. Recent estimates show that salt-affected soils occur throughout the world. The countries affected by salinization are predominantly located in arid and semiarid regions where continued irrigation with low-quality groundwater has contributed the expansion of salt-affected soils. In order to exploit these soils to their full potential, there is a need for a sound basis to optimize their use, determine their potential, productivity, and suitability for growing different crops, characterize these soils, and identify appropriate integrated reclamation and management practices. Management and reclamation can only be achieved if causes rather than the symptoms are identified and controlled. In this chapter, technologies for the characterization, reclamation, and management of salt-affected soils are described. In addition, different classification systems of salt-affected soils adopted in the world as well as soil reclamation technologies including hydraulic, physical, chemical, and biological approaches are described. Moreover, some possible alternatives to utilize the salt-affected soils are also discussed. Finally, link between research–extension–farmers has been proposed. The chapter demonstrates an easy format and language that is designed to be user-friendly.

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