Chapter 1
Introduction to Soil Salinity, Sodicity and Diagnostics Techniques

Shabbir A. Shahid, Mohammad Zaman, and Lee Heng

Abstract It is widely recognized that soil salinity has increased over time. It is also triggered with the impact of climate change. For sustainable management of soil salinity, it is essential to diagnose it properly prior to take proper intervention measures. In this chapter soil salinity (dryland and secondary) and sodicity concepts have been introduced to make it easier for readers. A hypothetical soil salinity development cycle has been presented. Causes of soil salinization and its damages, socio-economic and environmental impacts, and visual indicators of soil salinization and sodicity have been reported. A new relationship between ECe (mS/cm) and total soluble salts (meq/l) established on UAE soils has been reported which is different to that established by US Salinity Laboratory Staff in the year 1954, suggesting the latter is specific to US soils, therefore, other countries should establish similar relationships based on their local conditions. Procedures for field assessment of soil salinity and sodicity are described and factors to convert EC of different soil: water (1:1, 1:2.5 & 1:5) suspensions to ECe from different regions are tabulated and hence providing useful information to those adopting such procedures. Diversified salinity assessment, mapping and monitoring methods, such as conventional (field and laboratory) and modern (electromagnetic-EM38, optical-thin section and electron microscopy, geostatistics-kriging, remote sensing and GIS, automatic dynamics salinity logging system) have been used and results are reported providing comprehensive information for selection of suitable methods by potential users. Globally accepted soil salinity classification systems such as US Salinity Lab Staff and FAO-UNESCO have been included.

Keywords Salinity · Sodicity · Diagnostics · Electromagnetic · Geostatistics · GIS · Kriging · Electron microscopy

1 Introduction

Soil is a non-renewable resource; once lost, can’t be recovered in a human lifespan. Soil salinity, the second major cause of land degradation after soil erosion, has been a cause of decline in agricultural societies for 10,000 years. Globally about 2000 ha

M. Zaman et al., *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*, https://doi.org/10.1007/978-3-319-96190-3_1

of arable land is lost to production every day due to salinization. Salinization can cause yield decreases of 10–25% for many crops and may prevent cropping altogether when it is severe and lead to desertification. Addressing soil salinization through improved soil, water and crop management practices is important for achieving food security and to avoid desertification.

1.1 What Is Soil Salinity?

Soil salinity is a measure of the concentration of all the soluble salts in soil water, and is usually expressed as electrical conductivity (EC). The major soluble mineral salts are the cations: sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and the anions: chloride (Cl^-), sulfate (SO_4^{2-}), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and nitrate (NO_3^-). Hyper-saline soil water may also contain boron (B), selenium (Se), strontium (Sr), lithium (Li), silica (Si), rubidium (Rb), fluorine (F), molybdenum (Mo), manganese (Mn), barium (Ba), and aluminum (Al), some of which can be toxic to plants and animals (Tanji 1990).

From the point of view of defining saline soils, when the electrical conductivity of a soil extract from a saturated paste (ECe) equals, or exceeds 4 deci Siemens per meter (dS m^{-1}) at 25 °C, the soil is said to be saline (USSL Staff 1954), and this definition remains in the latest glossary of soil science in the USA.

1.1.1 Units of Soil Salinity

Salinity is generally expressed as total dissolved solutes (TDS) in milli gram per liter (mg l^{-1}) or parts per million (ppm). It can also be expressed as total soluble salts (TSS) in milli equivalents per liter (meq l^{-1}).

The salinity (EC) was originally measured as milli mhos per cm (mmho cm^{-1}), an old unit which is now obsolete. Soil Science has now adopted the Systeme International d'Unites (known as SI units) in which mho has been replaced by Siemens (S). Currently used SI units for EC are:

- milli Siemens per centimeter (mS cm^{-1}) or
- deci Siemens per meter (dS m^{-1})

The units can be presented as:

1 mmho cm^{-1} = 1 dS m^{-1} = 1 mS cm^{-1} = 1000 micro Siemens per cm (1000 μS cm^{-1})

- EC readings are usually taken and reported at a standard temperature of 25 °C.
- For accurate results, EC meter should be checked with 0.01 N solution of KCl, which should give a reading of 1.413 dS m^{-1} at 25 °C.

No fixed relationship exists between TDS and EC, although a factor of 640 is commonly used to convert EC (dS m^{-1}) to approximate TDS. For highly concentrated solutions, a factor of 800 is used to account for the suppressed ionization effect on EC.

Similarly, no one relationship exists between ECe and total soluble salts (TSS), although a factor of 10 is used to convert ECe (dS m^{-1}) to TSS (expressed in meq l^{-1}) in the EC range of 0.1–5 dS m^{-1} (USSL Staff 1954). One relationship between ECe and TSS is presented in the Agriculture Handbook 60 (USSL Staff 1954). This relationship was developed using USA soils and has been widely used (worldwide) for over six decades. No efforts have been made to validate this relationship in other soils, though recently Shahid et al. (2013) have published a similar relationship for sandy desert soils ranging from low salinity (desert sand) to hyper-saline soils (coastal lands) in the Abu Dhabi Emirate. This latter work established a relationship between ECe and TSS which differs significantly from that of USSL Staff (1954), thus, opening the way for other countries to develop country-specific relationships which will allow better prediction and management of their saline and saline-sodic soils.

1.1.2 Why Total Soluble Salts *Versus* ECe Relationship Is Required?

Laboratories in some developing countries do not generally have modern equipment, i.e. flame emission spectrophotometer (FES), atomic absorption spectrophotometer (AAS), or inductively coupled plasma (ICP) in order to analyze soil saturation extracts or water samples for soluble Na^+ to determine sodicity (sodium adsorption ratio – SAR). In contrast, Ca^{2+} and Mg^{2+} are easy to measure using a titration method, one which does not require modern instruments. Currently, these laboratories in many developing countries determine soluble Na^+ by calculating the difference between the total soluble salts (TSS) and the quantities of Ca^{2+} + Mg^{2+} in order to make the analyses affordable, as below:

$$\mathbf{Na^+ = \left[\left(\text{Total soulble salts}\right) \text{minus} \left(Ca^{2+} + Mg^{2+}\right)\right]}$$

The TSS are recorded from a graph [see Fig. 4, page 12 of the Agriculture Handbook 60 (USSL Staff 1954)] by using the ECe value (Fig. 1.1). The Na^+ amount is then used to determine SAR so that exchangeable sodium percentage (ESP) can be calculated as:

$$\mathrm{SAR} = \frac{\mathrm{Na^+}}{\sqrt{\frac{1}{2}\left(\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}\right)}}$$

$$\mathrm{ESP} = \frac{[100\,(-0.0126 + 0.01475 \times \mathrm{SAR})]}{[1 + (-0.0126 + 0.01475 \times \mathrm{SAR})]}$$

Where, each of Na^+, Ca^{2+} + Mg^{2+} concentrations are expressed in milli equivalents per liter (meq l^{-1}) and SAR is expressed as (milli moles per liter)$^{0.5}$ (mmoles l^{-1})$^{0.5}$.

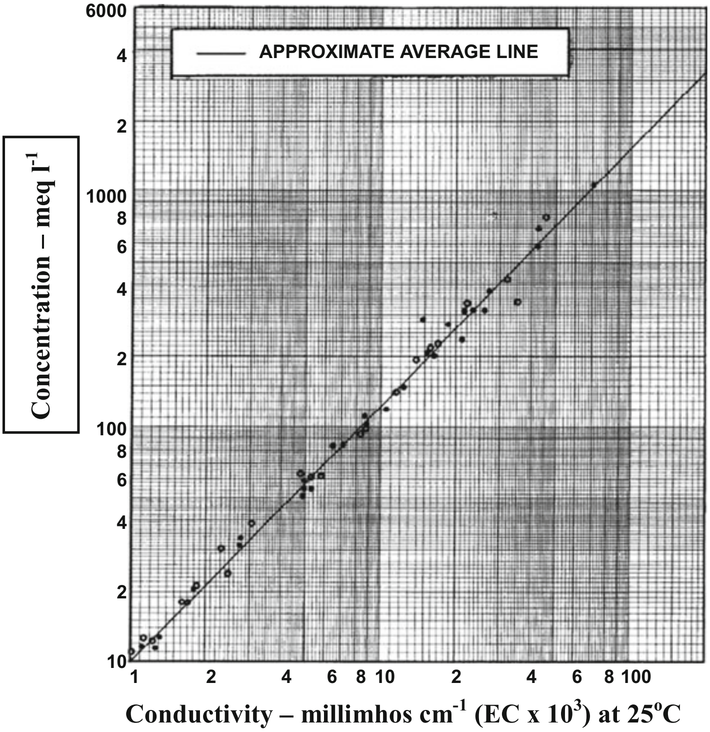

Fig. 1.1 Relationship between total soluble salts (TSS) on y-axis and ECe on x-axis. (Source: Fig. 4, page 12, Agriculture Handbook 60 (USSL Staff 1954))

In the above method of determining Na^+ by calculating the difference between TSS and Ca^{2+} + Mg^{2+}, any K^+ amounts present are added to the Na^+ (which is thus overestimated). It should be noted that the TSS versus ECe curve developed by USSL Staff (1954) was developed for the Western North American soils and, thus, may or may not be representative of soils of other countries. Hence, using such a practice may lead one to overestimate the sodicity hazard in irrigation waters or in saturation extracts of soils. This could lead to incorrect predictions and the use of inappropriate management options.

The finding of Shahid et al. (2013) has revealed an appreciable difference between the straight line (TSS versus ECe) determined from USSL Staff (1954) relative to protocols established by Shahid et al. (2013), shown in Figs. 1.1 and 1.2.

The TSS/ECe ratio, thus, ranges between 10 (at ECe 1 dS m^{-1}) and 16 (at ECe 200 dS m^{-1}) based on USSL Staff (1954) relationship (Fig. 1.1). In contrast, use of the relationship obtained from the methods developed by Shahid et al. (2013), the TSS/ECe ratio ranged between 10 (at 1 dS m^{-1}), 11.38 (at ECe 200 dS m^{-1}) and 12 (at ECe 500 dS m^{-1}). A comparative representation is shown in Figs. 1.3 and 1.4.

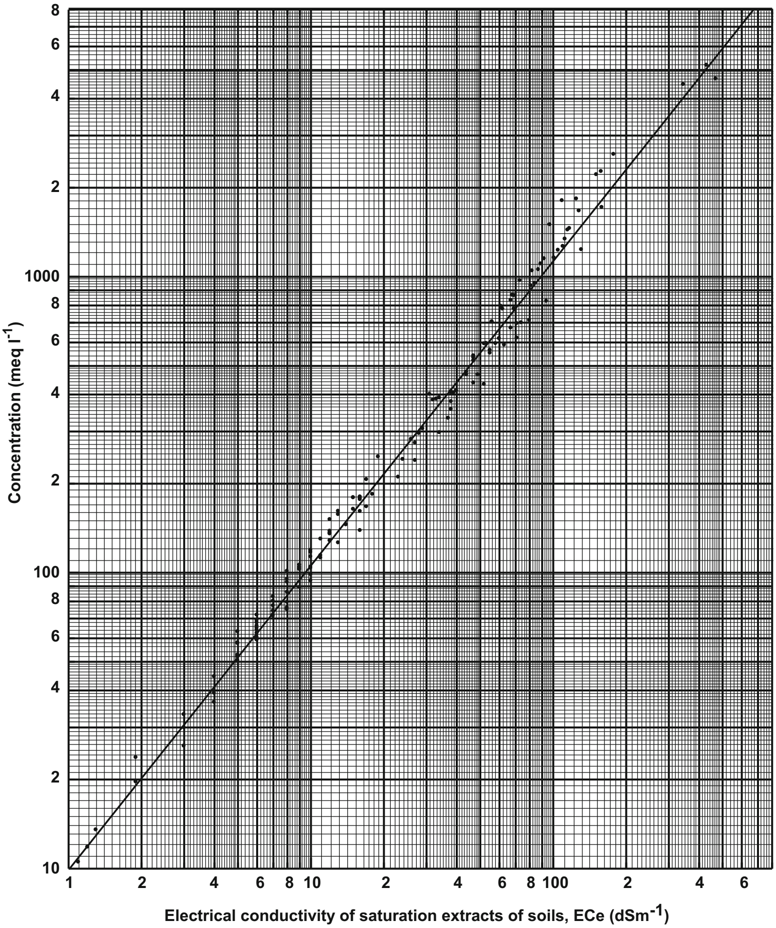

Fig. 1.2 Relationship between TSS and ECe (from Shahid et al. 2013)

In order to test the above lines to determine soil sodicity, Shahid et al. (2013) gave three examples using one soil type, as below.

Example 1

Determination of sodium adsorption ratio (SAR) accomplished by analyzing soil saturation extract for ECe (using an EC meter), and soluble Na^+, Ca^{2+}, Mg^{2+} determined by using an atomic absorption spectrophotometer.

ECe $= 51$ dS m^{-1}
Soluble Na^+ $= 480$ meq l^{-1}
Ca^{2+} $= 50$ meq l^{-1}
Mg^{2+} $= 38$ meq l^{-1}
SAR $= 72.4$ (mmoles l^{-1})$^{0.5}$

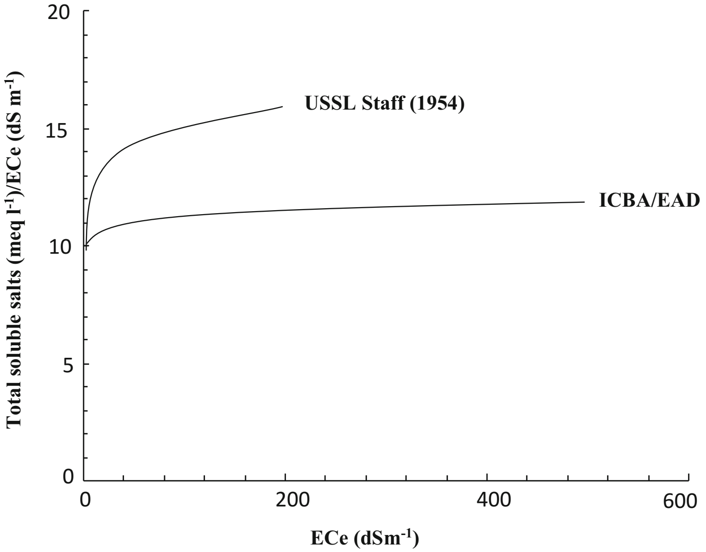

Fig. 1.3 A comparison of the relationship between total soluble salts (TSS)/ECe established using the Agriculture Handbook 60 curve (USSL Staff 1954) for the soils of Abu Dhabi Emirate and the relationship established for the same soils by the ICBA/EAD curve (Shahid et al. 2013)

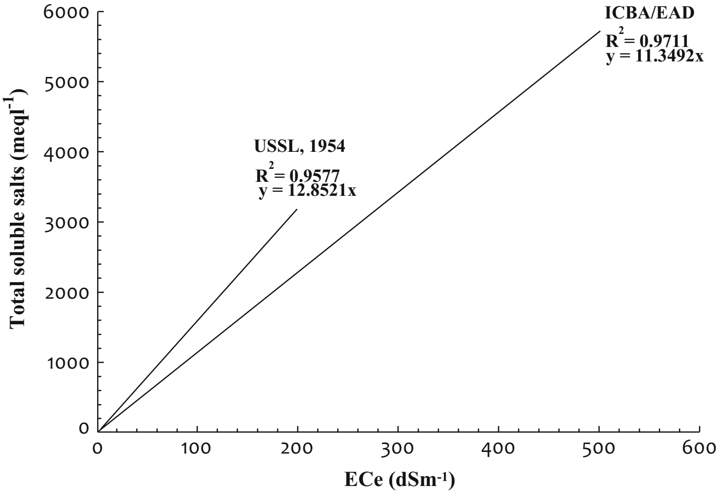

Fig. 1.4 Average lines showing the relationship between ECe and total soluble salts (TSS) from the USSL method (line from Fig. 1.1, above) for the soils of Abu Dhabi Emirate using the method developed by Shahid et al. (2013) using the average line adapted from Fig. 1.2, above

Example 2
Determination of sodium adsorption ratio (SAR) accomplished by analyzing soil saturation extract for ECe (using an EC meter), soluble Ca^{2+} and Mg^{2+} (by titration procedure) and soluble Na^{+} estimated by calculating the difference between TSS and $Ca^{2+} + Mg^{2+}$ using USSL Staff (1954) relationship (Fig. 1.1).

ECe = 51 dS m^{-1}
TSS = 720 meq l^{-1} (from Fig. 1.1)
Soluble Na^{+} = 632 meq l^{-1} (by difference, i.e. 720–88 = 632)
Ca^{2+} = 50 meq l^{-1}
Mg^{2+} = 38 meq l^{-1}
SAR = 95.32 (mmoles $l^{-1})^{0.5}$

Example 3
Determination of sodium adsorption ratio (SAR) accomplished by analyzing soil saturation extract for ECe (using an EC meter), soluble Ca^{2+} and Mg^{2+} (by titration procedure) and soluble Na^{+} by calculating the difference using the relationship developed by Shahid et al. (2013) (Fig. 1.2).

ECe = 51 dS m^{-1}
TSS = 560 meq l^{-1} (from Fig. 1.2)
Soluble Na^{+} = 472 meq l^{-1} (by difference, i.e. 560–88 = 472)
Ca^{2+} = 50 meq l^{-1}
Mg^{2+} = 38 meq l^{-1}
SAR = 71.2 (mmoles $l^{-1})^{0.5}$

The above three examples clearly show that the SAR (71.2) when determined by using the Shahid et al. (2013) relationship (Fig. 1.2) is very close to the SAR determined by analyzing the saturation extract by modern laboratory equipment (71.2 versus 72.4). However, when SAR was determined by using the USSL Staff (1954) relationship, it was appreciably higher (95.32) than the SAR values determined by other procedures.

This indicates that the Na^{+} value obtained by using the USSL Staff (1954) relationship can lead to higher SAR and can, thus, mislead the sodicity prediction. The above examples have confirmed that the relationship established for the soils of Abu Dhabi Emirate by Shahid et al. (2013) can be used reliably to determine soil sodicity (SAR and ESP). Thus, the analyses become rapid and affordable for the use in developing countries. Also of importance is the need for developing countries, e.g. the Gulf Cooperation Council (GCC) and ARASIA countries, who are relying on the USSL Staff (1954) curve to determine soluble sodium by calculating the difference between TSS and $Ca^{2+} + Mg^{2+}$, to validate this relationship for local soils.

2 Causes of Soil Salinity

There can be many causes of salts in soils; the most common sources (Plate 1.1) are listed below:

- Inherent soil salinity (weathering of rocks, parent material)
- Brackish and saline irrigation water (Box 1.1)
- Sea water intrusion into coastal lands as well as into the aquifer due to over extraction and overuse of fresh water
- Restricted drainage and a rising water-table
- Surface evaporation and plant transpiration
- Sea water sprays, condensed vapors which fall onto the soil as rainfall
- Wind borne salts yielding saline fields
- Overuse of fertilizers (chemical and farm manures)
- Use of soil amendments (lime and gypsum)
- Use of sewage sludge and/or treated sewage effluent
- Dumping of industrial brine onto the soil

Plate 1.1 Soil salinity development in agriculture and coastal fields. (**a**) Salinity in a furrow irrigated barley field, (**b**) Salinity in a sprinkler irrigated grass field, (**c**) Salinity due to sea water intrusion in coastal land

Box 1.1: Salt Loads in Soil Due to Irrigation

It is generally believed that irrigation with fresh water is safe for optimum crop production; this may be true for short duration. However, if this water is used over a long period without managing for salinity, a significant quantity of salts will be added into soil. A simple example is given below.

Assume that fresh water (EC 0.2 dS m^{-1}) is used for irrigating the crop and 8500 cubic meters per hectare (850 mm) of this water is used over the entire crop season. The water of EC 0.2 dS m^{-1} contains approximately 128 mg l^{-1} salts (0.2×640) which are equivalent to 0.128 kg per cubic meter of irrigation

(continued)

Box 1.1 (continued)

water. Over the crop season, 1088 kg of salts will, thus, be added to each hectare with the irrigation water. If we assume that the dry matter harvested from each hectare is about 15 metric tons, and there is 3.5% by weight of total salts in the harvested crop biomass, then the portion of salt harvested with the crop is 525 kg. This leaves 563 kg of salts in the soil directly or in the plant parts (belowground, stubbles, debris) which will be returned to the soil by cultivation and subsequent decay of the plant biomass left in the field. This example is a very conservative one. It is more likely that water of a higher salinity will be used for irrigation. Thus, a salinity management program needs to be implemented for virtually all irrigated agricultural crops, especially those growing in low natural rainfall areas.

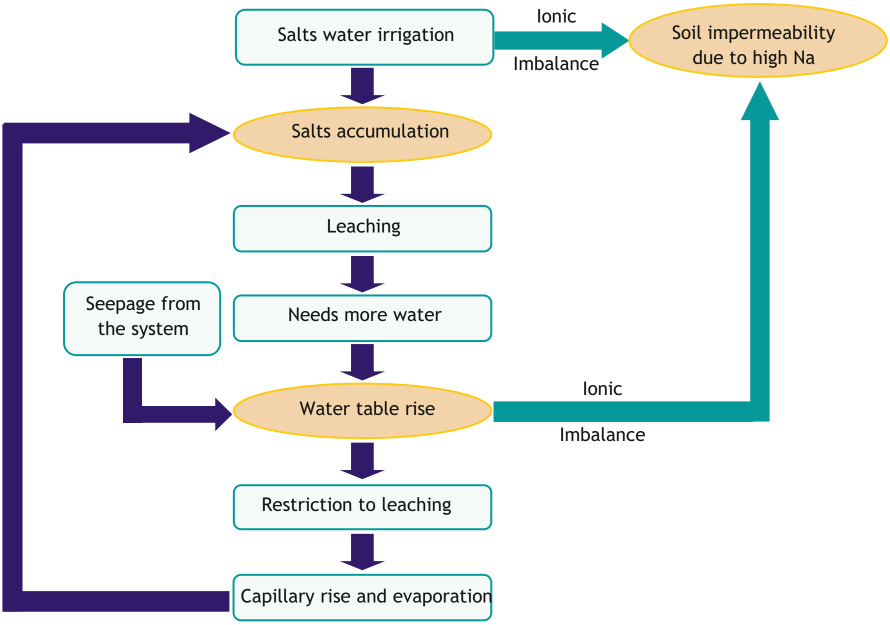

Fig. 1.5 A hypothetical soil salinization cycle. (Adapted from Shahid et al. 2010)

3 Salinity Development in Soils – A Hypothetical Cycle

Recently Shahid et al. (2010) have hypothesized a soil salinity cycle in order to present various facets in the development of soil salinity (Fig. 1.5).

4 Types of Soil Salinity

4.1 Dryland Soil Salinity

Salinity in dryland soils develops through a rising water table and the subsequent evaporation of the soil water. There are many causes of the rising water table, e.g. restricted drainage due to an impermeable layer, and when deep-rooted trees are replaced with shallow-rooted annual crops. Under such conditions, the groundwater dissolves salts embedded in rocks in the soil, with the salty water eventually reaching the soil surface, and evaporating to cause salinity. Dryland salinity can also occur in un-irrigated landscapes. There are no quick fixes to dryland salinity, though modern technologies in assessment and monitoring can allow one to follow and better understand how salinity develops. The most important of these new technologies utilizes the interpretation of remote sensing imaging over a period of time.

The potential technologies to mitigate dryland salinity include the pumping of saline groundwater and its safe disposal or use, as well as the development of alternate crop plant production systems to maximize saline groundwater use, such as deep-rooted trees. Such a deep-rooted trees system utilizes groundwater and lowers water table, the process called ***biodrainage*** (or biological drainage). In Australia dryland salinity is a major problem, one which costs Australia over $250 million a year from impacts on agriculture, water quality and the natural environment. Dryland salinity is an important problem which must be approached strategically using scientific diagnostics.

4.2 Secondary Soil Salinity

In contrast to dryland salinity, secondary salinity refers to the salinization of soil due to human activities such as irrigated agriculture.

Water scarcity in arid and desert environments necessitates the use of saline and brackish water to meet a part of the water requirement of crops. The improper use of such poor quality waters, especially with soils having a restricted drainage, results in the capillary rise and subsequent evaporation of the soil water. This causes the development of surface and subsurface salinity, thereby reducing the value of soil resource. Common ways of managing secondary salinity in irrigated agriculture are:

- Laser land leveling which facilitates uniform water distribution
- Leaching excess salts from surface soil into the subsoil
- Lowering shallow water tables with safe use or disposal of pumped saline water
- Tillage practices, seed bed preparation and seeding
- Adaption of salt tolerant plants

- Cycling the use of fresh and saline water
- Blending of fresh water with saline water
- Minimize evaporation and buildup of salts on surface soil through conservation agriculture practices such as mulching (see Chap. 6 on how nuclear techniques of oxygen-18 and hydrogen-2 help to partition between evaporation and transpiration to enhance water use efficiency on farm), addition of animal manure and crop residues, etc.

The management of secondary salinization in irrigated agriculture is discussed in more detail in Chap. 5.

5 Damage Caused by Soil Salinity

Some of the damages caused by increasing the soil salinity (Shahid 2013) are listed below:

- Loss of biodiversity and ecosystem disruption
- Declines in crop yields
- Abandonment or desertification of previously productive farm land
- Increasing numbers of dead and dying plants
- Increased risk of soil erosion due to loss of vegetation
- Contamination of drinking water
- Roads and building foundations are weakened by an accumulation of salts within the natural soil structure
- Lower soil biological activity due to rising saline water table

6 Facts About Salinity and How It Affects Plant Growth

Franklin and Follett (1985) have described the effects of salinity on plant growth as listed below:

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

7 Visual Indicators of Soil Salinity

Once soil salinity develops in irrigated agriculture fields, it is easy to see the effects on soil properties and plant growth (Plate 1.2). Visual indicators of soil salinization (Shahid and Rahman 2011) include:

- A white salt crust
- Soil surface exhibits fluffy
- Salt stains on the dry soil surface
- Reduced or no seed germination
- Patchy crop establishment
- Reduced plant vigor
- Foliage damage – leaf burn
- Marked changes in leaf color and shape occur
- The occurrence of naturally growing halophytes – indicator plants, increases
- Trees are either dead or dying
- Affected area worsens after a rainfall
- Waterlogging

8 Field Assessment of Soil Salinity

Visual assessment of salinity only provides a qualitative indication; it does not give a quantitative measure of the level of soil salinity. That is only possible through EC measurement of the soil. In the field, collection of soil saturation extract from soil paste is not possible. Therefore, an alternate procedure is used, e.g. a soil:water suspension (1:1, 1:2.5, 1:5) for field salinity assessments.

- EC can be measured on several soil:water (w/v) ratios
- EC measurement at field capacity (fc) is the most relevant representing field soil salinity. The constraint in such measurement is difficulty to extract sufficient soil water
- Compromise is EC measurement from extract collected from saturated soil paste

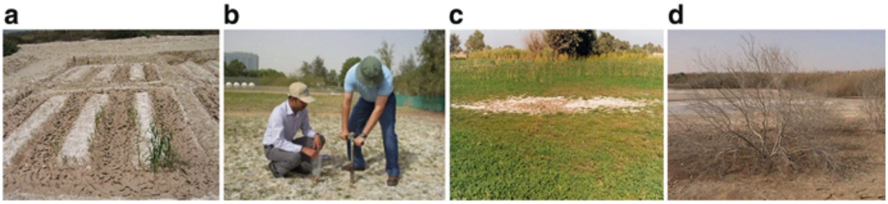

Plate 1.2 Field diagnostics of soil salinity – visual indicators for quick guide. (**a**) Salt stains and poor growth, (**b**) Leaf burn grassy plot, (**c**) Patchy crop establishment, (**d**) Dead trees due to salt stress

- The relationship between ECfc to ECe is generally (ECfc = 2ECe) for most of the soils, except for the sand and loamy sand textures
- Laboratory measurement of soil extract salinity (ECe) is laborious. Thus, EC of extracts using different soil:water ratios can be measured in the field and correlated to ECe, because ECe is the appropriate parameter used in salinity management and crop selection.
- Commonly used soil:water ratios in field assessment of salinity are:
  - 10 g soil +10 ml distilled water (1:1)
  - 10 g soil +25 ml distilled water (1:2.5)
  - 10 g soil +50 ml distilled water (1:5)

The EC values obtained for different soil:water ratio extracts can then be correlated to the EC of soil saturation extract (ECe) as explained below (Shahid 2013; Sonmez et al. 2008). It should be noted that EC values of 1:1, 1:2.5, 1:5 soil:water extracts are site- specific and, thus, can be used as a general guideline only. However, once correlations are established with ECe (EC of soil saturation extract) from the same soil samples, the derived ECe can be used reliably in salinity management and crop selection. Suitable conversion factors can be used based on soil type (Table 1.1).

Table 1.1 Conversion factor for deriving the ECe from the EC of extracts from different soil:water ratio suspensions

Relationship	References
ECe versus $EC_{1:1}$	
ECe = $EC_{1:1} \times 3.03$	Al-Moustafa and Al-Omran (1990) – Saudi Arabia
ECe = $EC_{1:1} \times 3.35$	Shahid (2013) – UAE (sandy soil)
ECe = $EC_{1:1} \times 3.00$	EAD (2009) – Abu Dhabi Emirate (sandy soil)
ECe = $EC_{1:1} \times 1.80$	EAD (2012) – Northern Emirates (UAE)
ECe = $EC_{1:1} \times 2.06$	Akramkhanov et al. (2008) – Uzbekistan
ECe = $EC_{1:1} \times 2.20$	Landon (1984) – Australia
ECe = $EC_{1:1} \times 1.79$	Zheng et al. (2005) – Oklahoma (USA)
ECe = $EC_{1:1} \times 1.56$	Hogg and Henry (1984) – Saskatchewan, Canada
ECe = $EC_{1:1} \times 2.7$	USSL Staff (1954) – USA
ECe = $EC_{1:1} \times 2.42$	Sonmez et al. (2008) – Turkey (sandy soil)
ECe = $EC_{1:1} \times 2.06$	Sonmez et al. (2008) – Turkey (loamy soil)
ECe = $EC_{1:1} \times 1.96$	Sonmez et al. (2008) – Turkey (clay soil)
ECe versus $EC_{1:2.5}$	
ECe = $EC_{1:2.5} \times 4.77$	Shahid (2013) – UAE (sandy soil)
ECe = $EC_{1:2.5} \times 4.41$	Sonmez et al. (2008) – Turkey (sandy soil)
ECe = $EC_{1:2.5} \times 3.96$	Sonmez et al. (2008) – Turkey (loamy soil)
ECe = $EC_{1:2.5} \times 3.75$	Sonmez et al. (2008) – Turkey (clay soil)
ECe versus $EC_{1:5}$	
ECe = $EC_{1:5} \times 7.31$	Shahid (2013) – UAE (sandy soil)

(continued)

Table 1.1 (continued)

Relationship	References
$ECe = EC_{1:5} \times 7.98$	Sonmez et al. (2008) – Turkey (sandy soil)
$ECe = EC_{1:5} \times 7.62$	Sonmez et al. (2008) – Turkey (loamy soil)
$ECe = EC_{1:5} \times 7.19$	Sonmez et al. (2008) – Turkey (clay soil)
$ECe = EC_{1:5} \times 6.92$	Alavipanah and Zehtabian (2002) – Iran (top soil)
$ECe = EC_{1:5} \times 8.79$	Alavipanah and Zehtabian (2002) – Iran (whole profile)
$ECe = EC_{1:5} \times 9.57$	Al-Moustafa and Al-Omran (1990) – Saudi Arabia
$ECe = EC_{1:5} \times 6.40$	Landon (1984) – Australia
$ECe = EC_{1:5} \times 6.30$	Triantafilis et al. (2000) – Australia
$ECe = EC_{1:5} \times 5.6$	Shirokova et al. (2000) – Uzbekistan

9 Soil Sodicity and Its Diagnostics

Sodicity is a measure of sodium ions in soil water, relative to calcium and magnesium ions. It is expressed either as sodium adsorption ratio (SAR) or as the exchangeable sodium percentage (ESP). If the SAR of the soil equals or is greater than 13 (mmoles $l^{-1})^{0.5}$, or the ESP equals or is greater than 15, the soil is termed sodic (USSL Staff 1954).

9.1 Visual Indicators of Soil Sodicity

Soil sodicity can be predicted visually in the field in the following ways

- Poorer vegetative growth than normal, with only a few plants surviving, or with many stunted plants or trees
- Variable heights of the plants
- Poor penetration of rain water – surface ponding
- Raindrop splash action – surface sealing and crusting (hard setting)
- Cloudy or turbid water in puddles
- Plants exhibit a shallow rooting depth
- Soil is often black in color due to the formation of a Na-humic substances complex
- High force required for tillage (especially in fine textured soils)
- Difficult to get soil saturation extracts in laboratory due to a filter blockage with dispersed clay

9.2 Field Testing of Soil Sodicity

Field assessment of relative level of soil sodicity can be determined through the use of a turbidity test on soil:water (1:5) suspensions, with ratings:

- Clear suspension – non sodic
- Partly turbid or cloudy – medium sodicity
- Very turbid cloudy – high sodicity

The relative sodicity can be further assessed by placing a white plastic spoon in these suspensions, as below.

- The spoon is clearly visible means non-sodic
- The spoon is partly visible means medium sodicity
- The spoon is not visible means high sodicity

9.3 Laboratory Assessment of Soil Sodicity

Accurate soil sodicity diagnostics can be made by analyzing soil samples in the laboratory. The standard presentation of soil sodicity is the exchangeable sodium percentage (ESP) derived through using sodium adsorption ratio (SAR). Alternately, ESP can be determined through measurement of exchangeable sodium (ES) and cation exchange capacity (CEC), as below.

$$\mathrm{ESP} = \left(\frac{\mathrm{ES}}{\mathrm{CEC}}\right) \times 100$$

Where, ES and CEC are represented as meq100 g^{-1}soil. An ESP of 15 is the threshold for designating soil as being sodic (USSL Staff 1954). At this ESP level, the soil structure starts degrading and negative effects on plant growth appear.

10 Sodicity and Soil Structure

A lack of sufficient volumes of fresh water for irrigation use in arid and semi-arid regions often results in the need to use water with a relatively high salinity and high sodium ion levels. It has, generally, been recognized that the sodicity affects soil permeability appreciably. The swelling and dispersion of soil clays ultimately destroys the original soil structure – likely the most important physical property affecting plant growth. The soil bulk density (the weight of soil in a given volume) and porosity (open spaces between sand, silt and clay particles in a soil) are mainly used as parameters for the soil structure. The hydraulic conductivity (the ease with which water can move through the soil pore spaces) is the net result of the effect of physical properties in the soil and is markedly affected by soil structure development. The effect of the sodicity of soil water on irrigated soils can be both a surface phenomenon, i.e. showing ***surface sealing***, as well as a subsurface phenomenon (Box 1.2), one where ***subsurface sealing*** also occurs (Shahid et al. 1992). In surface sealing, the soil water sodicity causes a breakdown and slaking of soil aggregates due to wetting. When the soil surface dries, a surface crust is formed. In subsurface sealing, the clay particles in the soil are dispersed and translocate to subsurface layers, where they are then deposited on the surface of the voids, thereby reducing void volume and blocking the pores, thus restricting further water movement, e.g. yielding non-conducting pores.

The surface sealing and crusting due to either water sodicity, or through combined effects of sodicity and raindrop splash action, have both positive and negative effects.

Box 1.2: Effect of Saline-Sodic Waters on Soil Hydraulic Conductivity and Structure in a Simulated System

In a simulated system developed and used by Shahid and Jenkins (1992a,c) for quick screening of soils with regard to their salinity and sodicity, a laboratory experiment was conducted to investigate the effect of saline-sodic water on soil structure and hydraulic conductivity (Shahid 1993). In this system, glass columns were filled with non-saline and non-sodic soil (*Typic camborthid*) which contained both swelling (smectite and vermiculite) and non-swelling (mica, chlorite and kaolinite) minerals, and silty clay loam texture. Five irrigation waters having EC 0 (deionized water), 0.5, 1.0, 1.0 and 2.4 dS m^{-1}, and SAR 0 (deionized water), 20, 25, 40 and 36 $(\text{mmoles } l^{-1})^{0.5}$, respectively, were used in wetting and drying cycles. After 14 wetting and drying cycles, the soil columns were subjected to hydraulic conductivity measurement with the respective waters treatments (above), followed by simulated rain, application of a gypsum saturated solution, and a simulated subsoil application with a gypsum saturated solution.

- The columns remained blocked with the introduction of the gypsum saturated solution. Upon examination, they revealed that a dispersion, translocation and deposition of clay platelets in conducting pores was occurring, and that this was the dominant mechanism of the much reduced hydraulic conductivity (Shahid and Jenkins 1992b; Shahid 1993).
- The columns where hydraulic conductivity was improved with gypsum saturated solution revealed, upon examination, that a swelling of clay minerals had been the main cause of hydraulic conductivity reduction.

(continued)

Box 1.2 (continued)

- The columns where hydraulic conductivity was significantly improved with gypsum saturated solution and subsoiling (disturbing soil in the column) confirmed that the dispersion, translocation and deposition of clay minerals in conducting pores was the dominant mechanism of hydraulic conductivity reduction, with swelling being a minor mechanism.
- Finally, micro-morphological observations (thin section study) of the developed soil fabric in the simulated columns revealed that the dispersion, translocation and deposition of clay platelets in the conducting pores (argillan formation) was the dominant mechanism in restricting hydraulic conductivity (Shahid 1988; Shahid and Jenkins 1991a,b).

10.1 Negative Effects of Surface Sealing

- Increased runoff particularly on slopes leading to sheet and rill erosions
- Mechanical impedance of plant seedling emergence
- Lack of aeration just below the sealed structure
- Retardation of root development
- Increased mechanical force needed for tillage (cultivation) operations

10.2 Positive Effects of Surface Sealing

- Protection against wind erosion
- More economic distribution of irrigation water since longer furrows are possible
- Protection against excessive water losses from the subsoil

11 Classification of Salt-Affected Soils

A soil which contains soluble salts in amounts in the root-zone which are sufficiently high enough to impair the growth of crop plants is defined as ***saline***. However, because salt injury depends on species, variety, plant growth stage, environmental factors, and the nature of the salts, it is very difficult to define a saline soil precisely. That said, the most widely accepted definition of a saline soil is one that has ECe more than 4 dS m^{-1} at 25 °C.

Table 1.2 Classification of salt-affected soils (USSL Staff 1954)

Soil class	ECe, dS m^{-1}	ESP	pH
Saline	≥ 4	< 15	< 8.5
Saline-sodic	≥ 4	≥ 15	≥ 8.5
Sodic	< 4	≥ 15	> 8.5

11.1 US Salinity Laboratory Staff Classification

The term ***salt-affected*** soil is being used more commonly to include saline, saline-sodic and sodic soils (USSL Staff, 1954), as summarized in Table 1.2.

11.1.1 Saline Soils

Saline soils are defined as the soils which have pHs usually less than 8.5, ECe ≥ 4 dS m^{-1} and exchangeable sodium percentage (ESP) < 15.

A high ECe with a 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.

11.1.2 Saline-Sodic 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, primarily by the degradation of soil structure. The pHs may be less or more than 8.5.

11.1.3 Sodic Soils

Sodic soils exhibit an ESP ≥ 15 and show an ECe < 4 dS m^{-1}. The pHs generally ranges between 8.5 and 10 and may be even as high as 11. The low ECe and high ESP tend to de-flocculate soil aggregates and, hence, lower their permeability to water.

11.1.4 Classes of Soil Salinity and Plant Growth

Electrical conductivity of the soil saturation extract (ECe) is the standard measure of salinity. USSL Staff (1954) has described general relationship of ECe and plant growth, as below.

- Non-saline (ECe ≤ 2 dS m^{-1}): salinity effects mostly negligible
- Very slightly saline (ECe 2–4 dS m^{-1}): yields of very sensitive crops may be restricted
- Slightly saline (ECe 4–8 dS m^{-1}): yields of many crops are restricted
- Moderately saline (ECe 8–16 dS m^{-1}): only salt tolerant crops exhibit satisfactory yields
- Strongly saline (ECe >16 dS m^{-1}): only a few very salt tolerant crops show satisfactory yields

11.2 FAO/UNESCO Classification

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 (saline) and solonetz (sodic). The origin of both terms, solonchaks and solonetz, is Russian.

11.2.1 Solonchaks (Saline)

Solonchaks (saline) are soils with high salinity (ECe >15 dSm^{-1}) within the top 125 cm of the soil.

The FAO-UNESCO (1974) divided solonchaks into four mapping units:

- ***Orthic Solonchaks***: the most common solonchaks
- ***Gleyic Solonchaks***: soils with groundwater influencing the upper 50 cm
- ***Takyric Solonchaks***: solonchaks in cracking clay soils
- ***Mollic Solonchaks***: solonchaks with a dark colored surface layer, often high in organic matter
- Soils with a lower salinity than solonchaks, but having an ECe higher than 4 dS m^{-1}, are mapped as a ‘saline phase’ of other soil units.

11.2.2 Solonetz (Sodic)

Solonetz (sodic) is a sodium-rich soil that has an ESP > 15. The solonetz soils are subdivided into three mapping units:

- ***Orthic Solonetz***: the most common solonetz
- ***Gleyic Solonetz***: soils with a groundwater influence in the upper 50 cm
- ***Mollic Solonetz***: soils with a dark colored surface layer, often high in organic matter