Chapter

Soil Salinity and Its Management

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Abstract

Soil salinity is a growing threat all over the world due to its toxic effect to reduce soil fertility and water uptake in the crops. An average of 418 million ha soil is saline in nature. Various climatic, geomorphic and rainfall pattern causes which involved in saline soil formation. To reduce the toxic effect proper management of saline soil is required. Irrigation water also a major concern regarding soil salinity management. Saline irrigation water enhances and maintains the severity soil salinity. Crop production aspects root zone salinity provides a strong negative impact on soil fertility. Salinity causes the reduction in nutrient ion, and water uptake has a significant negative effect on crop yields. Soil and water salinity interactions and their influence on crop growth and management of salinity are deliberated in this chapter.

Keywords: salinity, management, soil fertility, crop growth

1. Introduction

All over the world more than hundred countries approximately 418 million hectare of saline soils are present. Asia alone contribute 46% of soils are salt affected the world. Arid and semi-arid regions of the word highly affected by salinisation 6.27 percentage of soil in Asia affected by salinity. In India 10 mha salt affected soil or 5.5 mha saline and 3.8 mha are sodic soils [1, 2]. Saline soil mainly consist soluble salts like chloride and sulphates of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) and nitrate (NO_3^-) also present. The EC (electrical conductivity) of saline soil is less than 4 dS m^{-1} (deci Siemens/meter), ESP (exchangeable sodium percentage) is less than 15% and pH is less than 8. Less soluble salts like calcium carbonate and calcium sulphate also present. Saline soil having more ionic salt species like Ca^{2+} which flocculates the soil when its dominated by Na which disperse the soil. Saline soils are mostly Ca^{2+} dominated flocculated and well aerated in nature. Dispersion and flocculation also based on clay content of the soil.

2. Process of soil salinisation

There are two forms of salinisation process are present. They are primary or natural salinisation and secondary or anthropogenic salinisation. Due to various hydropedological, geomorphic and climatic factors involved in primary salinisation. Hydeopedological factors like weathering of basic rocks like basalt, gabbro and dolerite, etc. Hydrological factors like high annual moisture flux, climatic factors like low precipitation and high temperature cause more evapotranspiration and geomorphic factor like low relief are the cause of primary salinisation [3–5]. Secondary salinisation due to shallow water level, poor quality irrigation water, over irrigation with improper drainage make increase in water table and discharge of salt near soil surface, over use of ground water in coastal regions sea water intrusion takes place. Finally untreated industrial effluents and waste water having high dissolved salts are the reasons for secondary salinisation [6–9].

3. Measure of analysing soil salinity

Electrical conductivity (EC) is a measure of soil salinity and it's measured by EC meter. EC is reciprocal to the resistance of the conductor. Resistance is directly proportional to the distance between the electrode and inversely proportional to the cross sectional area of the conductor. Resistance expressed as ohms cm^{-1} conductivity expressed m mhos cm^{-1}. Conductivity depends on concentration of the ions in the solution, temperature, valence and length between two electrodes. The conductivity is directly proportional to the, concentration of the solution, solution temperature and valance and inversely proportional to length between two electrodes [10].

Resistance is calculated by ohms law.

$$R = V / I.$$

$$G = 1 / R.$$

where V is the voltage; I, current (ampere); R, resistance of the solution; G, conductance.

Conductance – Reciprocal of electrical resistance of a solution between two electrodes [11].

3.1 Saturation extract (ECe)

In this method involves saturation and subsequent extraction of soil water under partial pressure in order to quantify the salts in the extracted liquid phase. Crop growth response mainly depends on ECe (saturation paste) conversion of EC to ECe on different structural soil important in plant growth point of view. Sand particles can able to hold or adsorb more ions which leads to concentration of salinity will be more in the sandy than clay soil when the amount of salt ion will be the same [12].

3.2 Ranges of soil salinity

Non saline	Slightly saline	Moderately saline	Strongly saline	Extremely saline
0–2	2–4	4–8	8–16	>16

Electrical conductivity (EC) in dS m^{-1} [13].

4. Irrigation water salinity

Irrigation water salinity also a major concern regarding secondary salinisation and crop production (**Table 1**). Saline water highly affects germination,

EC ($dS\,m^{-1}$)	Status	TDS ($mg\,l^{-1}$)
<0.7	Fresh water – drinking and irrigation	<500
0.7–3.0	Slightly saline – irrigation	500–2000
3.0–6.0	Medium saline – suitable for high salt tolerant crops with proper management	2000–4000
>6.0	Highly saline – not suitable for irrigation	4000
>14	Very saline – secondary drainage water	>9000
>45	Brine – sea and industrial water	>30,000

Table 1.
Irrigation water-salinity based classification.

chlorophyll content, growth yield characters of the crop. Due to high salinity of water osmotic and ion imbalance reduction in activation of enzyme responsible for the seed germination and also affects the total chlorophyll due to reduction in leaf pigments and membrane stability. Usually saline water highly influence root zone salinity [14].

5. Salinity effects

5.1 Effect on plant growth

The deficiency of ions, osmatic stress and oxidative stress to the plants. Under high saline condition for plants are not able to maintain osmotic balance leads to loss of turgidity, dehydration of cell due to higher saline environment movement of water from plant sap to soil in order to reduce the concentration gradient [15]. Due to ion toxicity and osmatic stress nutrient absorbed by mass flow greatly reduced. Due to high ion concentration affects soil osmatic potential which reduces the plant available water [16].

5.2 Effect on soil fertility

Soil nutrient availability and uptake affected by higher saline condition. Phosphorus can be affected by fixation of calcium phosphate (Ca-P) due to higher saline condition Ca ion activity is high [17]. N bioavailability and accumulation affected by soil salinity. The 25% of N requirement is fulfilled by N fixation. Soil salinity greatly reduces the N fixing rhizobacterial growth and spread due to lesser photosynthesis cause reduction in photoaccumulates [18]. Also, nitrification reduced by salinity cause increase in NH_4 content which facilitates the loss of NH_4 by volatilisation. Potassium uptake and assimilation affected by Na/Ca ratio cause reduction in K/Na ratio of the plant [19]. Salinity did not have much negative influence on micronutrient bio availability but solubility of micronutrients is little decreased in some conditions.

5.2.1 Nutrient ratios

More than concentration of the ions ratio of nutrient ions which greatly influence the bio availability and uptake of nutrient ions ratios like Na/Ca, Na/K, Ca/Mg and Cl/NO_3 [19].

6. Saline soil management

6.1 Periodical monitoring and assessment by salinity mapping

Various natural and anthropogenic factors which increase the deterioration, and severity of saline soil in order to reduce adverse effect, continuous monitoring and prediction is needed. Various quantitative and qualitative mapping done through multi-temporal and multi-spectral information from remote sensing is needed. Hyper spectral remote sensing: it is having number of narrow and continuous band provide a precise information about difference in halophytes and non halophytes and used to distinguish various salinity classes [20–22].

Number of indices used for measure salinity.

$$NDVI\left(normalised\ difference\ salinity\ index\right)=\frac{\left(R-NIR\right)}{\left(R+NIR\right)} \quad (1)$$

$$Brightness\ index=\sqrt{\mathrm{R2}+NIR.}$$

$$Salinity\ index=\sqrt{B\times R} \quad (2)$$

where NIR, near infrared reflectance; R, red band; B, blue band.

6.2 Physical management of saline soil

i. **Scrapping:** Scrapping is followed in minimal land area where removal of salt accumulated topsoil in order to minimise the root zone salinity and temporary toxic effect of salinity.

ii. **Subsoiling**: soil in deep layers having less salt content compared to above layers subsoiling breaks the top custard soil and make more permeable.

iii. **Deep ploughing**: chisel plough is needed for deep ploughing in order to increases the permeability for better leaching.

iv. **Levelling**: Levelling is to get uniform leaching entire land should be levelled avoiding unnecessary wastage of water.

v. **Sand mixing:** In heavy clay soil permeability was very less. Application and mixing of sand in soil having clay content 30–40% increases the permeability and get higher leaching efficiency.

vi. **Leaching:** Dissolve and translocate the soluble salts in downwards below 45–60 cm. Based on the water availability and soil types the leaching method differentiated into two types continuous leaching and intermittent leaching. Intermittent leaching is done by after drain of previous leaching water another application takes place which is followed in were the scarcity of good quality water.

$$Leaching\ requirement\left(LR\right)=\frac{EC_{iw}}{EC_{dW}}\times 100 \quad (3)$$

where EC_{iw} = electrical conductivity of irrigated water, EC_{dw} = electrical conductivity of drainage water.

vii. **Mulching:** Mulching with crop residues or live crops reduces the evaporation of moisture from the soil surface compared to barren soil. Its reduces the upward pull of salts from ground water table [23–25].

6.3 Chemical method

i. **Gypsum application**: Gypsum application required only the Na content of the soil increased ESP more than 15 or pH more than 8 (saline sodic soil) for replaces the Na^+ by Ca^{2+} and subsequent leaching of Na^+.

ii. **Nutrient addition**: Application of nutrient like NPK, magnesium and hormones like salicylic acid which reduces the toxicity effects of saline soil and raise optimum crop growth and yield. Nitrate which reduces the uptake of chloride, potassium reduces the uptake of Na [26]. Salicylic acid application increases Mg uptake which influences the activity of ATP leads to increase in H^+ATP-ase hydrolytic activity and imports H^+ ion in vacuole leads to increase in sodium sequestration by vacuole. K^+ foliar and soil application significantly reduces the toxic effect of saline soil by maintains the water balance and ion ratio [27].

6.4 Bio remediation of saline soil

Bioremediation is a sustainable approach in order to reduce and alleviate the toxic effect of salinity. Two different types in bio remediation are:

- Phytoremediation
- Microbial remediation

6.4.1 Phytoremediation

Phytoremediation involves using plant species to diminish the concentration of the salts or contaminants in the soil. Plant species like halophytes, hyper accumulating plants, salt tolerant and transgenic salt tolerant plants used for phyto remediation of saline soil. ex., *Tamix chinensis, Lycium chinense, Gossypium hirsutum*. There are three types of halophytes: (a) salt excluding – filters the salt by specially adoptive root system, ex. *Rhizophora muaneta*; (b) salt excreting – regulate the plant internal cell physiology, ex. *Avicennia officinalis*; salt accumulating – accumulating salts in cells and tissues of halophytes, ex. *Sonneratia apetala* [28].

6.4.2 Microbial remediation

Various salt tolerant rhizosphere microbial community (Halophills) which remediate the saline soils. Mechanism of microbial tolerant involves (i) maintains cytoplasmic ionic content equal to the medium, (ii) concentrating solutes for create osmotic balance, (iii) after cell physiology restrict or control movement of water both inside and outside of the cytoplasm [29]. *Halobacillus* sp., like *Bacillus gibsonii*, *Halobacterium salinarum, Staphylococcus succinus*, *Zhihengliuella halotolerans, Oceanobacillus oncorhynchi* are the examples of halotolerent bacteria (**Table 2**) [30].

Halophiles	Tolerate up to (M-molar salt content)
Non-halophiles	<0.2 M
Slightly halophiles	0.2–0.5 M
Moderately halophiles	0.5–2.5 M
Strongly halophiles	1.5–4.0 M
Extremely halophiles	2.5–5.2 M

Table 2.
Classification of microorganisms based on salinity tolerance [31].

6.4.3 Plant microbe interaction

Arbuscular mycorrhizal fungi (AMF) which involves in alleviate the detrimental effect of saline soil by facilitate to satisfy the plants nutrient and water requirement (**Table 3**). AMF increases the nutrient uptake of P, N, Ca, Mg and Zn, maintains the K:Na ratio, accumulate osmolytes like proline, polyamine and antioxidents, physiological changes like increase cell permeability and increase in photosynthetic efficiency finally molecular changes like maintains the activity of transporters like Pht.1 (Phosphorus transpolar) and antiportors of Na^+/H^+ (**Figure 1**) [27, 32–34].

Sensitive (0-4 d Sm–1)	Moderately sensitive (4-6 d Sm–1)	Moderately tolerant (6-8 d Sm–1)	Tolerant (8-12 d Sm–1)
Carrot	Onion	Oats	Asparagus
Cucumber	Lettuce	Cabbage	Beet root
Water melon	Potato	Safflower	Barley
Beans	Rice	Wheat	Rye
Radish	Grape	Spinach	
Pear	Soy Bean	Cotton	
Celery	Tomato		
Citrus			

Table 3.
Classification of crops based on salinity tolerance.

Figure 1.
Physical management practices of salinity management: (a) deep ploughing and (b) mulching.

7. Conclusion

Salinity is a growing threat mainly by anthropogenic activities like improper utilisation of resources. Secondary salinisation cause major factor which decline the soil fertility and leads to reduction productivity of cultivable lands. Among the various management process leaching considered more economical and efficient method. Mulching which greatly reduces further build-up of soil salinity due to reduction in evapotranspiration. Irrigation water management like monitoring salinity of irrigation water, controlled irrigation and blend with good quality water give an acceptable result on salinity management. Salinity of soil is not static, so proper monitoring and management of saline soil is required to get towards a step of global food security. A sustainable way to remediate a saline soil is still to be achievable. The knowledge regards the saline soil is needed for better work on it.

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