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Integrated Methodologies for the Management and Reclamation of Saline Soils

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INTRODUCTION

The problem of salinity is enormous as it occurs are more than 100 countries covering approximately 1 billion hectares (FAO Report, 2015). Globally, more than 900 million hectare of land, accounting for nearly 6 % of the world total land area and approximately 20 % of the total agricultural land is affected by salinity (Chinchmalatpure, 2017). Presently, the total degraded land due to salinity and sodicity is estimated to be 6.74 M ha in India of which 2.2 m ha present in Gujarat state (Sharma *et al*., 2019). In India 6.74 m ha of area has been characterized as salt affected (Sharma *et al.*, 2015), out of which 3.77 m ha is alkali and remaining 2.96 m ha is saline, state wise distribution of saline soil in India reveals that soil salinity is a serious problem across 13 state of the country with Gujarat having largest area of 1.68 m ha (*viz.*, 56.84 % of total saline soil) fallowed by west Bengal (14.92%), Rajasthan (6.61%) and Maharashtra (6.23%). Soil salinity is one of the main environmental problems affecting extensive area of land in both developed and developing country (Rao *et al.*, 2013). Salinity is common in the region of arid and semi arid region where rainfall is too low to maintain a regular percolation of rain water through the soil irrigation is practiced within a natural or artificial drainage system (Qadir *et al*., 2014). Such irrigation practices without drainage management trigger the accumulation of salt in there root zone affecting several soil properties and crop productivity negatively. Saline soil defined as a soil having a conductivity of the saturation extract greater than (4 dS m^{-1} or 4 mmhos cm^{-1}) and an exchangeable sodium percentage (ESP) less than 15. The pH is usually less than 8.5. Formerly these soils were called white alkali soils because of surface crust of white salts (Srinivasan *et al*., 2022). The distinguishing characteristics of saline soils contain sufficient neutral soluble salts to adversely affect the growth of most of the crop plant.

High nitrogen concentration in the soil solution can cause flocculation of soil colloids resulting in decreased stability. As a result, saline soil suffers from poor aeration and subsequent diminished hydraulic conductivity and increased condensation (Shankar & Evelin, 2019). These conditions are hostile for the establishment and growth of plant by subjecting them to osmotic stress, ionic imbalance and oxidative stress. (Evelin *et al.*, 2009).

2. CHARACTERISTICS OF SALINE SOIL

Saline soils are those possessing excessive amounts of soluble salts in their profile (Shankar & Evelin, 2019). The primary constituents of dissolved salts include highly soluble Cl, NO3, and SO42 as well as low soluble salts, CaCO3 and CaSO4 (Hanay *et al.*, 2014). The salinity of soil is expressed in terms of electrical conductivity (ECe) of saturated soil paste, pH, and exchangeable sodium percentage (ESP). Saline soils are characterized by an ECe > 4 dS m^{-1} at 25 C, pH < 8.2, and ESP < 15. However, many fruit and ornamental plants are susceptible to salt effects even in soil ECe range of 2–4 dS m^{-1}. Therefore, it has been recommended to lower the ECe limit for saline soils from 4 to 2 dS m^{-1}. High salt concentration in soils causes instability in soil structure, low infiltration rate, and reduced water-holding capacity (Gehring, 2017). These soils have poor biodiversity, low organic matter, and stressed microbial community. Plants growing in saline areas are subjected to osmotic stress, nutrient deficiencies, as well as toxicities causing ionic imbalances. These phenomena result in the development of oxidative stress. These effects hamper growth, development, and reproduction in plants subsequently leading to decrease in crop yield (Shankar & Evelin, 2019).

Sources and causes of accumulation of salts in soil (Haplogypsids *et al.*, 2006)

1. Capillary rise from subsoil salt beds or from shallow brackish ground water.
2. Indiscriminate use of irrigation waters of different qualities.
3. Weathering of rocks and the salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials.
4. Ingress of sea water along the coast
5. Salt-laden sand blown by sea winds
6. Lack of natural leaching due to topographical situation, especially in arid and semi-arid condition.

3. Integrated Approaches for Reclamation of Saline Soils

Salt-induced crop loss amounts to about $27 billion per year (Shankar & Evelin, 2019). If salinity problem is not managed, the saline areas will become non-cultivable. Therefore, providing solutions to this problem is the need of the hour. To overcome this problem and enhance crop yield, saline soils may be reclaimed to favor plant growth, or the plant is modified to adjust and survive in the saline environment (Shankar & Evelin, 2019). Saline soils can be reclaimed by minimizing salt concentration, decreasing pH value and improving soil structure (Zhao *et al.*, 2020). Soil desalinization can be brought about by harvesting aboveground parts of salt-tolerant plants or allowing leaching of salts from the upper layers of the soil below the root zone (Shankar & Evelin, 2019). A reclaimed soil should be able to control salt concentration, maintain porosity, and provide a conducive environment for water transport in the soil and promote growth and development of plant roots. Reclamation of soil can be accomplished by using various strategies. For successful implementation of each method, a major point of consideration is to provide adequate soil drainage system (Shankar & Evelin, 2019). However, the suitability of each method depends on many factors (Hasanuzzaman *et al.*, 2014):

- Kinds and concentrations of salts present.
- Availability of good-quality water (low electrolyte concentration) for leaching.
- Texture of subsoil

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- The level of groundwater and its quality
- Volume of soil that should be reclaimed
- The landscape of the salt-affected areas
- The type of plant(s) to be cultivated after reclamation
- The climatic conditions
- Availability of time for reclamation
- Cost-effectiveness.

These methods may be implemented individually or in conjunction with other methods for a successful reclamation program.

3.1 PHYSICAL METHOD

3.1,1 Scraping: The salts accumulated on the surface can be removed by mechanical means. This is the simplest & most economical way to reclaim saline soils if the area is very small e.g. small garden lawn or a patch in a field. This improves plant growth only temporarily as the salts accumulate again & again.

3.1,2 Flushing: Washing of surface salts by flushing water. This is especially practicable for soils having a crust & low permeability. However this is not sound method of practice.

3.1.3 Leaching: Leaching with good quality water, irrigation or rain is the only practical way to remove excess salts from the soil. It is effective if drainage facilities are available, as this will lower the water table & remove the salts by draining the salt rich effluent.

3.1.4 Leaching requirement: The amount of water needed to remove the excess soluble salts from the saline soils is called leaching requirement or the fraction of the irrigation water that must be leached through the root zone or soil profile to control soil salinity at any specific level (Salt balance).

3.2 Agronomic and Cultural Methods

In areas where only saline irrigation water is available or when shallow saline water table prevails and soil permeability is low, the following cultural practices are adopted.

3.2.1 Selection of Crops and Crop Rotations: On the basis of crop tolerance to quality of irrigation water or soil salinity the crops can be classified in four groups (Choudhary *et al.*, 2018);

- Highly tolerant crops: Barley, Sugar beet, Datepalm.
- Tolerant: Tapioca, Mustard, Coconut, Spinach, Amaranthus, Pomegranate, Guava, Ber.
- Semi-tolerant: Ash guard, Bitter guard, Brinjal, Cabbage, Cluster bean, Pea, Lady’s finger, Muskmelon, Onion, Potato, Dolichos, Sweet potato, Tomato, Turnip, Water melon.
- Sensitive: Radish, Carrot, Coriander, Cumin, Mint, Grape, sweet orange.

3.2.2 Method of Raising Plants: Crop should be raised by transplanting seedlings (especially vegetables, flowers, fruit trees) than germinating the seeds. Wild root stocks grafted with a good quality but salinity sensitive scion (Mango, citrus, Guava and ornamental plants like rose).

Irrigation Practices: Method of water application- follow furrow or drip irrigation, sub surface irrigation systems and sprinkler irrigation. Frequency of irrigation- irrigation more often (frequent) can maintain better water availability & decrease the salinity should not too much irrigations.

3.2.3 Use of mulching materials to prevent evaporation losses: like straws, plastic sheets etc.

3.2.4 Surface drainage: It is a process by which excess salts from the root zone are removed through leaching the salts into a collection system (Shankar & Evelin, 2019). The salty water can be collected in deep open drains. Else, percolated pipe drains can be buried in the soil to collect leached salty water and conveyed to a collector drain. This technique not only has the ability to lower salinity by as much as 50%; it can also bring down the water table (Shankar & Evelin, 2019). Changes in cropping pattern and intensity can enhance the benefits of subsurface drainage system and improve crop yield and income of farmers (Datta *et al.*, 2000). The prerequisites of subsurface drainage technology are availability of technically skilled manpower and development of infrastructure. However, for its successful implementation, active participation by the government as well as farmers is essential (Shankar & Evelin, 2019). This method has been proven to be technically viable, economically feasible, and socially acceptable by farmers (Shankar & Evelin, 2019).

3.3 BIOLOGICAL METHOD

It is well known that the decomposition of cattle manures and plant residues, in the soil, liberates carbon dioxide and organic acids which help to dissolve any insoluble calcium salts in the soil solution and also neutralize the alkali present. Decomposing organic matter improves soil permeability and increases water-stable aggregates. Organic Amendments for Improvement of Saline Soil Soil amendments namely, farmyard manure, molasses, sugar factory press-mud, green manures, crop residues and different weeds etc., may be incorporated in the salinity affected soil to make improvement and reclamation process over a period of time and the amendment practices (Mary *et al.*, 2020) are as follows.

3.3.1 Green Manuring: The common crops used for green manuring are dhaicha or Jantar (*Sesbania aculeata*), Sunnhemps (*Crotalaria juncea*), barseem (*Trifolium alexandrieum*), sengi (*Melioletus parviflora*) and cowpea (*Vigna sinensis*) etc. They serve on decomposition as sources of readily available nutrients besides acting as solubilizing agent for calcium and neutralizing high pH of alkali soils. Consequent improvement in soil permeability and also increased biological activity help in slowly regenerating the soil. Of all the plants used as green manure, *Sesbania aculeata* has been found most successful on saline soils (Baig & Zia, 2006). The important characteristics of green manuring crops are:

- Legume crops can neutralize alkalinity.
- Highest calcium content on ash basis.
- Thrive well under moderately saline conditions.
- The application of 5.0 tonnes per hectare of Sesbania green manure has been quite effective in gelling higher yields of paddy on saline soils of the mm coast in Andhra Pradesh.

3.3.2 Afforestation: The plant species like *Acacia arabica*, *Melia azadirachta*, *Prosopis juliflora*, *Butea monosperma* , *Tamarix articulate* and *Albizzia lebbeck* can grow within certain limits on the salt affected soils. Some species like *Capparis aphylla*, *Capparis horrida*, *Salvadora oleoides* and *Zizyphus* can be grown or even occur naturally on certain types of salty lands.The forest growth exerts ameliorative effect on the soil by loosening the subsoil and improving permeability through the action of the root system. Organic matter is added by the leaf litter and root residues. Carbonic acid produced through root activity and decay of organic material, mobilizes calcium for replacement of exchangeable sodium (Mary *et al.*, 2020). Besides, there is a general soil and ecological improvement through microbial activity and moderation of the micro-climate.

3.3.3 Bulky Organic Manures: Farm manures have been successfully tried in the treatment of saline-alkaline soils in Haryana and Punjab. The application of 10 tons of farmyard manure with 15 tons of Sesbania green leaves proved almost as beneficial as 30 tons per hectare of Sesbania green manuring, in increasing the yield of paddy

3.4 Chemical Method:

Chemical amendments (Mary *et al.*, 2020) for the purpose of reclamation are either soluble calcium salts like calcium chloride and gypsum or relatively less soluble ground limestone and pressmud from sugar factories and slag from iron factories or acid and acid formers which work as calcium mobilizers like sulphuric acid, sulphur, iron sulphate, aluminium sulphate, lime sulphur etc. Gypsum is the most important amendment for reclamation of salt affected soil. The 0.59 mm fineness of gypsum was more effective in reclamation of saline and alkaline soils (Abdel-Fattah *et al.*, 2015). It is safe, less costly and the supply of calcium for decreasing exchangeable sodium percentage of

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soils results in increased permeability of water to soil. It also helps in reducing the salts from root zone depth by the smooth flow of water in the soil profile.

4. Water Quality Guidelines for Management of Saline Groundwater

Management practices has been established that the success with poor quality water irrigation can only be achieved if factors such as rainfall, climate, depth to water table and water quality, soils and crops are integrated with appropriate crop and irrigation management practices (Minhas, 1996). The available management options mainly include the irrigation, crop, chemical and other cultural practices but there seems to be no single management measure to control salinity and sodicity of the irrigated soil. Several practices interact and should be considered in an integrated manner.

Management Technologies for Use of Saline Ground waters (Sharma, 2008)

1. Selection of semi-tolerant to tolerant crops and crops with low water requirements.
2. Use of crop cultivars having tolerance to salinity.
3. Proper selection of crop sequence.
4. Avoiding saline water use during initial growth stages.
5. Micro-irrigation (drip and sprinkler): Drip experiments at Bikaner, Hisar and Gangavathi centres of AICRP have shown that saline water can be used effectively for vegetable and field.
6. Crops; it helps in reducing the effect of salinity (i.e. Osmotic stress) as well as reducing the fertilizer requirement (Anonymous, 2018b; Singh et al., 2018).
7. Analysis of saline water to evaluate its use potential.
8. Selection of crops/crop varieties that can produce satisfactory yields with saline water irrigation.
9. Selection of tree species, medicinal plants under extreme adverse condition.
10. Pre-sowing irrigation by good quality water so that germination and seedling emergence is not affected. Adequate leaching of accumulated salts.
11. Alternating the area switching i.e. irrigate the selected area with saline water for 3-4 years and then switch on to the next area.

CONCLUTION

The more than a hundred countries are impacted by the issue of salinity, which impacts around a billion hectares of land. The exponentially growing human population and increasing salinity make food security a big challenge. The best strategies for reclaiming salty soils combine physical, cultural, biological, and chemical approaches all into integrated management strategy. Micro-irrigation, crop and cultivar tolerance to salinity, tree species, and medicinal plants are all safe ways to use saline groundwater.

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