Training Manual on
Reclamation and Management of Problem Soils

07-12 April 2025

ICAR-Central Soil Salinity Research Institute
Karnal, Haryana- 132001

Training Manual
for
Watershed Development Officers
on

Reclamation and Management of Problem Soils

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FOREWORD

Soil salinity is a growing challenge that significantly hampers agricultural productivity and environmental sustainability, especially in arid and semi-arid regions. India, with over 6.74 million hectares of salt-affected land, bears a heavy burden due to reduced crop yields and significant economic losses estimated at over Rs. 230 billion in unrealized food grain production.

Reclaiming and managing salt-affected soils is vital not only for restoring agricultural productivity but also for securing the livelihoods of millions who depend on these lands. Solutions such as salt leaching, sustainable use of low-quality water, groundwater recharge, efficient irrigation techniques, nutrient management, and the adoption of salt-tolerant crops are essential to combat this widespread issue.

ICAR-Central Soil Salinity Research Institute (CSSRI) has been at the forefront of research and development in this domain. However, the scale and diversity of the problem require broader participation and enhanced capacity at the grassroots level. Recognizing this need, a six-day training programme on "Reclamation and Management of Problem Soils" has been organized for Watershed Development Officers, with financial support from the Watershed Development Department, Government of Karnataka.

This training manual has been meticulously compiled to serve as a practical and informative resource for field officers. It draws upon the latest research, proven techniques, and real-world experiences to empower participants with the knowledge and skills needed to effectively address salinity and related soil problems in their respective regions.

We are confident that this manual will not only enhance the technical competence of watershed professionals but also contribute meaningfully to sustainable land use practices, improved farmer incomes, and long-term agricultural resilience. We wish all participants a productive and enlightening training experience.

(RK Yadav)

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CHAPTER 1

Technologies of CSSRI for Management of Salt-affected Soils and Poor Quality-Waters

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Salt-affected soils (SAS) is an umbrella term to designate the soils having either excess soluble salts and/or exchangeable sodium. Based on the values of soil saturation paste extract electrical conductivity (ECe), pH (pHs) and exchangeable sodium percentage (ESP), soils are classified into normal, saline, sodic and saline-sodic. However, there are no universally accepted threshold values of these parameters resulting in different classification schemes for SAS in different countries. For example, in Australia, soils with ESP between 6 and 14 are designated as sodic while those having ESP >15 are classified as „strongly sodic‟ (Rengasamy, 2006). This is in contrast to both India and the United States where soils with ESP >15 are considered sodic. Similarly, soils having pHs values >8.5 and >8.2 are considered sodic in the United States and India, respectively. In India, pHs value of 8.2 has been found to be more realistic than 8.5 due to a strong correlation (r= 0.87-0.97) between soil pHs 8.2 and ESP 15 in the sodic soils of IGP. Classification of SAS in India is also different from USA. In India, only two categories (saline: ECe ≥4 dS/m, pHs <8.2, ESP <15; and sodic: ECe <4 dS/m, pHs >8.2, ESP >15) are adopted, while SAS are classified into three categories (saline, sodic and saline-sodic) in USA (Minhas, 2010).

About 20% of the global crop lands have become less productive or, in extreme cases, uncultivable wastelands due to waterlogging and salinization. Presence of salty water in root zone virtually transforms the affected lands into wetland deserts. Soils in many rainfed areas are also reeling under the combined impacts of erosion, salinization and fresh water scarcity. A recent estimate suggests that over 1100 Million hectare (M ha) of global land area is affected by salinity and related problems to varying extents. Certain regions/countries such as Middle East (189 M ha), Australia (169 M ha) and North Africa (144 M ha) suffer from a very high degree of salinization. In South Asia (including India), about 52 M ha area is salt-affected. Despite relentless salinity onslaught (irrigation-induced salinization affects 0.25-0.5 M ha area annually), the fact remains that a large chunk (~85%) of global SAS have only mild to moderate limitations that can easily be overcome by suitable technological interventions (Wicke *et al*., 2011).

In India, ~120 M ha land suffers from one or another kind of degradation: soil erosion (94.9 M ha), salinity and sodicity (6.74 M ha), soil acidity (17.94 M ha) and other stresses (1.07 M ha) (Sharma *et al*., 2015). In saline soils, excess soluble salts consisting mainly of chlorides and sulphates of Na^+, Ca^{2+} and Mg^{2+}, raise soil ECe (≥ 4 dS/m) resulting in reduced water availability (*i.e*., physiological drought) and specific ion toxicities responsible for growth and yield reduction in crop plants. High ESP (>15) deteriorates the structure, impedes the water and air flows, reduces water intake capacity and hampers the root penetration in sodic soils. Current estimated area under SAS (6.74 M ha; comprising of 3.79 M ha sodic and 2.95 M ha saline area) is projected to increase to 16.2 M ha by 2050. Although salt-induced crop losses are common throughout the country, only five states including Gujarat (2.23 M ha), Uttar Pradesh (1.37 ha), Maharashtra (0.61 M ha), West Bengal (0.44 M ha) and Rajasthan (0.38 M ha) together make up ~75% of the total SAS in India (ICAR-CSSRI, 2015).

Salinity problem has become more intricate in the past few decades as evidenced by co-existence of complex problems such as soil erosion, excess salts, nutrient toxicities and waterlogging in many situations. For example, out of 1.72 M ha irrigated area adversely affected by waterlogging (water table lying within 2 m of the land surface) ~1 M ha also suffers from salinity (NAAS, 2015). ICAR-CSSRI has estimated huge salt-induced losses in annual food grain, oilseed and cash crop production. While salinity diminishes ~5.66 Million tonnes of produce valued at Rs. 8,000 Crores (Sharma *et al.* 2016a), sodicity causes annual loss of ~11 Million tonnes (Rs. 15,000 Crores; Sharma *et al*. 2016b). Although such monetary estimates provide a reasonable approximation of the harmful impacts of salinity, basically in relation to farmers‟ sustenance and drain on national exchequer, it is important to understand the spillover effects that debilitate the capacity of SAS to provide a range of vital ecosystem services.

Technologies for Salinity Management

ICAR-Central Soil Salinity Research Institute (ICAR-CSSRI), Karnal was established in 1969 to develop appropriate remedial measures for enhancing agricultural production in salt-affected areas of the country. Taking a cue from the fact that ad-hoc projects in the past did not deliver expected results, policy makers felt the need for a dedicated mission to usher in yield revolution through technology-driven improvements in the productivity of barren saline and sodic lands. In fact, establishment of ICAR-CSSRI marked a two-pronged strategy by the Government of India to safeguard country's food security: i) sustained policy support to augment food availability by large scale dissemination of "*Green Revolution Technologies"* in productive areas; and ii) additional food grain production by reviving the productivity of salt-affected wastelands.

Different technologies developed by ICAR-CSSRI can broadly be categorized into four groups: "*blockbuster technologies"* like gypsum-based package, "*high impact technologies*" like salt tolerant cultivars, "*least adopted technologies*" like sub-surface drainage and "*incubating technologies*" that are still being developed and refined for dissemination on the farmers‟ fields (ICAR-CSSRI, 2017b). Considering the strengths and weaknesses of different technologies have been discussed in the succeeding paragraphs.

Reclamation and Management of Sodic Soils

Gypsum technology

A wide variety of chemicals, *viz*., soluble calcium salts (*e.g*., gypsum and calcium chloride), acids or acid forming substances (*e.g*. sulphuric acid, iron sulphate, sulphur and pyrite) and calcium salts of low solubility (*e.g*. ground limestone) can be used to reduce soil ESP below 15%. Gypsum application improves the availability of exchangeable Ca^{2+} to remove surplus Na^{+} from the soil exchange complex. Gypsum has been used on agricultural lands for a long time (~250 years); as an ameliorant and as a fertilizer source of Ca and S. Gypsum also acts as a soil conditioner to minimize run-off induced soil erosion and nutrient depletion (Chen and Dick, 2011). Despite a large body of evidence from other countries showing the ameliorative effects of gypsum in sodic soils, basic studies were absolutely essential to determine the exact dose, timing and depth of application, and other management issues for desired outcomes under Indian conditions. Concerted efforts in this direction led to the development of gypsum-based package for sodic soil reclamation. Gypsum application @ 50% gypsum requirement (GR) was suggested for the traditional varieties of rice and wheat. In reclaimed lands, reduction in soil ESP was quicker and extended to the deeper depths when rice was grown as the first crop. After few years of release, this technology received an overwhelming response from the farmers and Land Development Agencies of Punjab, Haryana and Uttar Pradesh states. A number of demonstrations organized at farmers‟ fields further enhanced the acceptability of this practice. Gypsum reclaimed sodic lands in many parts of Haryana are still fondly designated as "*Sarkari Killa*‟ (an acre of sodic land reclaimed by government agencies using gypsum technology) to remember the research and policy efforts made in this direction.

Gypsum-bed technology

In areas irrigated with RSC water, gypsum use becomes necessary to alleviate the sodicity risk. Gypsum can either be incorporated into soil or put into irrigation channel (in gunny bags) such that falling tube well water will slowly dissolve the gypsum. However, use of specifically constructed gypsum dissolving beds for this purpose gives far better results (Tyagi, 2003). In gypsum-bed method, irrigation water is passed through a brick-cement chamber containing gypsum clods. Size of the chamber depends on the rate of tube well discharge and RSC of irrigation water. This chamber is connected to a water fall box on one side and to water channel on the other. A net of iron bars covered with wire net (2 mm x 2 mm) is fitted at 10 cm height from the bottom of chamber. With suitable modifications, farmers can also convert their tube well chamber into gypsum chamber. Sodic water flowing from below dissolves the gypsum placed in the chamber and reclaims it (Sharma, 2004). Regardless of the method of application, the basis for calculating the gypsum requirement remains the same. However, time of application varies with the method adopted. In case of soil application, the full amount of gypsum is applied as single basal dose. In the case of water- applied gypsum, neutralization takes place before its application and there is, therefore, no build- up of sodicity in the soil (Tyagi, 2003). Water flowing through gypsum-beds picks Ca^{2+} (3-5 meq L^{-1}) and thus becomes far less harmful than original Na+ saturated water. In fact, soil texture, crop sequence and amount of annual rainfall are the critical factors determining soils‟ susceptibility to RSC level in irrigation water. In areas having relatively higher annual rainfall (500-600 mm), the upper safe limit of RSC can be as low as 2.5 meq L-1 in heavy (fine) textured soils, between 5-7.5 meq L^{-1} in moderately textured and as high as 10 meq L^{-1} in coarse soils; especially when low water requiring crops are grown (Minhas and Tyagi, 1998).

Alternative amendments

Because gypsum is only sparingly soluble in water (2.5 g L^{-1}), large volumes of water are required to hasten gypsum dissolution. Given poor permeability of sodic soils, leaching of displaced Na^+ also takes considerable time. Owing to its high solubility in water, $CaCl_2$ can be a good (direct) source of soluble calcium. After application, $CaCl_2$ works in a manner similar to gypsum but shortens the time required for reclamation. Moreover, in contrast to gypsum and sulphur applied on soil, $CaCl_2$ may be added directly into irrigation water for quick results. In order to give best results, sulphur and similar products should undergo complete oxidation after application. However, high pH of sodic soils limits their oxidation resulting in reduced reclamation efficiency. Complete oxidation of sulphur produces sulphuric acid to replace the exchangeable Na^+. It is due to this reason that sulphur fails to give results comparable to gypsum or sulphuric acid even when used in chemically equivalent quantities (Abrol *et al*. 1988). Recently, an experiment has been started to improve the efficacy of "Reliance Formulate Sulphur" by circumventing the problems of slow oxidation, dustiness and fire hazard that limit the potential use of elemental sulphur. Efforts are also underway to assess the feasibility of marine gypsum as a substitute for mined gypsum. Marine gypsum, a by-product from the manufacturing process of common salt (NaCl), contains NaCl, $MgCl_2$ and $MgSO_4$ as impurities that may increase the ionic strength of aqueous solution by decreasing its activity coefficient resulting in increased solubility of gypsum and higher reclamation efficiency compared to the mineral gypsum. Laboratory experiments revealed very high calcium content (30.5 meq L^{-1}) in marine gypsum based formulation that is in fact comparable to the pure analytical grade gypsum (ICAR-CSSRI, 2017a).

Industrial by-products

Several industrial by-products have also been found effective in overcoming structural and nutritional constraints in sodic soils. Phosphogypsum (hydrated $CaSO_4$), an acidic by-product of wet-acid production of phosphoric acid, is rich in S and Ca. Studies have shown that it can be used as a substitute to mined gypsum and lime for alleviate acidity, Al toxicity, low nutrient availability and sodicity problems. Post methanation effluent (PME) generated through biomethanation of distillery effluent, that is often inadvertently discharged into rivers and other surface bodies, can also be a potential amendment. Fly ash is a by-product of thermal power plants. In India, ~50% of the produce is utilized by cement and concrete industries. Problems being encountered in the safe disposal of this environmental waste can partly be resolved by utilizing it in sodic soil reclamation. Although fly ash treated soils exhibit marked improvements in soil texture, fertility and water-holding capacity, it can sometimes raise the soil pH, salinity and heavy metal contents. Press mud is a by-product of sugar mills. It contains appreciable quantities of many plant nutrients.

Organic materials

Organic amendments like mulches and composts also improve the cation exchange capacity, water retention and plant nutrient availability in saline and sodic soils. Use of crop residues as mulch increases soil organic carbon, formation of water-stable aggregates and water retention. Mulching also reduces rain drop impact insulating the soil against run-off induced erosion. Mulched soils are less affected by scorching heat resulting in reduced evaporative loss of water and low salt movements to the surface. Straw mulching prevented salt accumulation in brackish water irrigated wheat-summer maize rotation (Pang *et al*., 2010). Saline-sodic soils having permanent cover of tephra mulch became normal after 20 years of experimentation as evidenced by decrease in soil ECe from 43 to 1.5 dS/m and ESP from 44 to 9 (Tejedor *et al*., 2003).

Incorporation of municipal solid waste compost (MSWC) accelerates the dissolution of precipitated $CaCO_3$ resulting in increased availability of soluble $Ca2^+$ and eventual replacement of Na^+ ions from exchange sites. It is seen that combined applications of gypsum and MSWC can be more effective than their sole applications. MSWC application enhanced the activities of dehydrogenase, alkaline phosphatise and urease enzymes, improved microbial biomass carbon and nutrient availability in a saline-sodic soil (EC_e: 7.2 dS/m and pH: 8.4) under mustard-pearl millet rotation (Meena *et al*. 2016). Application of MSWC (10 t ha^{-1}) along with gypsum GR^{25} reduced soil pH resulting in enhanced supply of N and P in a saline-sodic soil (pH_2: 10.16; EC2: 3.09 dS/m; ESP: 77.5) compared to sole gypsum application (GR50) (Sundha *et al*., 2017).

Microbial bioformulations

Different microorganisms display higher salt tolerance and can efficiently alleviate salt stress when applied in appropriate form and at right time. Such microbial strains lessen salinity and sodicity risks by reducing the soil pH, EC_e and ESP coupled with improvements in water permeability, soil aggregation, soil microbial biomass carbon and nutrient availability; especially in moderately salt-affected soils. Despite proven efficacy in improving root zone conditions in saline/sodic soils, commercial applications of such microbial inoculants is hampered by relatively higher costs and lack of technical know-how. Concerted efforts to overcome these problems have led to the development of different low-cost microbial bio-formulations capable of improving crop production in salt-affected soils. For example, "CSR-BIO"- a bioformulations based on consortia of *Bacillus pumilus*, *Bacillus thuringenesis* and *Trichoderma harzianum* on dynamic media, acts as a soil conditioner and nutrient mobilize and increases the productivity of rice, banana, vegetables and gladiolus in sodic soils. Similarly, liquid bioformulations based on halophilic plant growth promoting (HPGP) strains, *viz*., Halo- Azo, Halo-PSB and Halo-Azsp have been commercialized for improving crop yields as well as to improve the fertility of sodic soils. Other formulations like Halo-Rhizo and Halo-Mix are in testing and carrier standardization phase (ICAR-CSSRI, 2017a).

Reclamation and Management of Waterlogged Saline Lands

Sub-surface Drainage Technology

Sub-surface drainage (SSD) is an efficient technique for tiding over the twin problems of waterlogging and salinity. SSD network, consisting of concrete/PVC pipes and filters installed at a specified distance and depth manually or mechanically below the land surface, drains out excess salty water. Gradual improvements in design and drain spacing have enhanced the acceptability of SSD at farmers' fields in several waterlogged saline areas of the country (Gupta, 2015). Initial success of SSD projects in Haryana proved catalytic to its spread in other affected states like Rajasthan, Gujarat, Punjab and Maharashtra where ~110,000 ha of waterlogged saline area has been ameliorated until now. Reclaimed lands exhibit marked improvements in crop yields (45% in paddy, 111% in wheat and 215% in cotton) and cropping intensity (> 40%) leading to 2-3-fold increase in farmers, income. Depending on factors such as depth and spacing, soil type and topography, SSD cost varies from location to location. The estimated cost at 2015 price level is INR 65,000 ha^{-1} under government funded schemes for alluvial soils of Haryana and INR 1,25,000 ha^{-1} for heavy textured soils (Vertisols) of peninsular India (Sharma *et al*., 2016a).

Impact evaluation studies reveal that active participation of the farmers is critical to the success of SSD technology. At three SSD sites of Jagsi (Sonipat; 430 ha), Siwana Mal (Jind; 295 ha) and Mokhra Kheri (Rohtak; 520 ha) in Haryana, large patches of salinity gradually disappeared due to timely pumping of sump well during the monsoon season. Rice and wheat yields at Jagsi were at par with the yields obtained in normal soils of Haryana. Similarly, rice and wheat yields improved by 35-110 % and 25-120%, respectively, in the selected SSD blocks of Siwana Mal and Mokhra Kheri sites. Saline drainage water was also reused for irrigating rice and wheat crops in some blocks. In Dudhgaon village of Sangali district of Maharashtra, SSD has been installed over ~1000 ha area benefitting ~1300 farmers. After SSD implementation, over twofold increase was noted in the average yields of sugarcane, wheat and soybean; apparently due to lowering of watertable and salt leaching.

Despite considerable improvements in soil quality, crop yields and farmers' incomes, SSD technology has not spread at the desired pace. Some factors hindering the widespread adoption of SSD include relatively higher initial costs, difficulties in operation and maintenance, lack of active community participation and the problems in safe disposal of drainage water. Small and marginal landholders, though fully aware of the benefits of SSD, can hardly afford the higher establishment costs and recurring expenses. In most of the saline areas of India, water users associations for drainage and irrigation projects are almost non-existent. Since the success of SSD projects rests on collective responsibility, appropriate institutional arrangements for farmers' participation are needed. Problems in the safe disposal of saline effluents can largely be overcome by adopting saline aquaculture and reuse of saline drainage water in irrigation and soil reclamation.

Land shaping models

Large patches of waterlogged sodic lands occur in canal irrigated areas of IGP where post-monsoon water inundation often adversely affects wheat crop. Waterlogging and secondary sodicity problems have considerably increased in the Sarda Sahayak Canal command area of Uttar Pradesh in the past two decades. The situation is particularly grim in poorly drained sodic water irrigated areas. Notwithstanding the astonishing success of gypsum- based technology in Uttar Pradesh, it has become clear that gypsum application is of little avail in waterlogged sodic lands (water table < 2.0 m) that constitute ~15% of the total sodicity- affected area of the state. Water table rise due to excessive canal seepage increases the translocation of basic salts in the root zone.

Considering such constraints, a need has long been felt to develop a sustainable technology for the management of waterlogged sodic soils. Inversion of low pH deeper soil profiles upside down in a pre-specified soil column by elevating field bed can make soil surface favourable for crop production by lowering the water table below a critical level to improve the internal drainage. Land modification (fish ponds and raised and sunken beds) based integrated farming models have been tested and validated as a sustainable solution to enhance the economic value of waterlogged sodic soils (pH ~10.0) for decades (ICAR-CSSRI, 2017a). In sunken beds, water table lies at ~1 m depth resulting in reduced upward salt translocation. Cultivation of rice and water chestnut, and integrated rice-fish culture are the economically viable land use options for the sunken beds. Vegetable crops should preferably be grown on raised beds for higher returns (Verma *et al*., 2015). South-western part of Punjab is also severely affected by these problems. Besides biodrainage and conjunctive use of canal and low quality groundwater, a new technology called multiple well points system is now being recommended to ensure skimming of freshwater floating over brackish groundwater. About 41,000 such wells installed in Muktsar, Faridkot and Ferozepur districts have lowered the water table by 1-7 m leading to 10-20% increase in crop yields. The cost of installation of a 4-well point system is ~INR 45000 per unit (Gupta and Singh, 2014).

Farm ponds are created by excavating ~20% of the soil from a depth of ~3 m. Rainwater stored in these ponds can be used for round-the-year irrigation of crops grown on embankments. Besides fish rearing in the pond and crop cultivation on dykes, poultry and duckery can also be taken up for enhancing profits while recycling the resources among different components. In paddy-cum-fish model, trenches (3 m top width × 1.5 m bottom width × 1.5 m depth) are made around the farmland. Excavated soil is used for making dykes (1.5 m top width × 1.5 m height × 3 m bottom width) to prevent free flow of water from the field and harvesting more rainwater in the field and trench. While dykes are used to grow vegetables throughout the year, rest of the farm area including trenches is used for integrated rice-fish culture (Mandal *et al*. 2013). These interventions can increase the cropping intensity from 114% to 186%. These techniques have been demonstrated at farmers‟ fields for increasing the farm incomes. Subsequent to the adoption of land shaping interventions, farmers‟ net income could increase from mere INR 470 per month (*kharif* rice) to as high as INR 11999 per month (rice-fish-vegetable cropping system). Betel vine cultivation has also emerged as an attractive option to further increase the farm incomes (Mandal *et al*., 2017).

Agro-forestry Models for Sodic Soils

Several trees species slowly improve the physical, chemical and biological properties of sodic soils. Singh *et al*. (1989a) observed that mesquite (*Prosopis juliflora*) trees planted in a sodic soil (pH: 10.4, ESP: 90) showed considerable improvement in growth and biomass production upon gypsum addition compared to control trees indicating that gypsum application may be advantageous in situations where initial soil pH and ESP are too high to suppress the tree growth. Soil pH and salt content decreased while SOC and NPK contents improved with tree age; obviously due to litter fall and rhizospheric depositions. Although intercropping of Karnal grass reduced biomass production in mesquite; improvements in soil properties were faster and greater in mixed system than sole mesquite stand. Kaur *et al*. (2000) found that microbial biomass carbon, SOC, inorganic N and N mineralization rates were much higher in *Acacia*, *Eucalyptus* and *Populus*-based agrisilvicultural systems than both single species stands and rice- barseem rotation in a sodic soil. Soil carbon increased by 11-52% in integrated tree-crop systems. Singh *et al*. (2011) noticed that *Prosopis juliflora, Acacia nilotica* and *Casuarina equisetifolia* plantations significantly reduced soil pH, EC, ESP, and increased SOC and available NPK than control soil (pH_2: 8.8-10.5, ESP: 85-92). Some studies also hint that cultivation of Karnal grass, with or without gypsum application, leads to steady reductions in pH and ESP of degraded sodic soils that seems attributable to *in situ* biomass decomposition and root-mediated improvements in soil quality (Batra *et al*. 1997; Kumar *et al*. 1994). Aromatic grasses like palmarosa (*Cymbopogon martinii*) and lemon grass (*C. flexuosus*) also exerts ameliorative effects in sodic soils without any appreciable reduction in essential oil yield (Dagar *et al*., 2004).

Considering relatively less returns from agro-forestry trees, efforts have been made for raising more profitable fruit crops in sodic lands. Dagar *et al*. (2001) evaluated 10 different fruit species in a highly sodic soil (pH: 10) using auger-hole and pit methods of planting and 5-20 kg of gypsum as amendment. Based on long-term observations, Indian jujube (*Ziziphus mauritiana*), jamun (*Syzygium cuminii*), guava (*Psidium guajava*), aonla (*Emblica officinalis*) and karonda (*Carissa congesta*) were found the promising fruit species for such soils.

Bio-drainage in Irrigated Lands

In bio-drainage (*i.e*., biological drainage), salt tolerant trees having higher transpiration rate are planted to arrest salinity build-up in irrigated lands. It is, however, pertinent to mention that bio- drainage is essentially a preventive measure and trees provide best results when planted in the beginning. Some of the suitable tree species found effective in bio-pumping of salty water are eucalyptus, popular and bamboo (Heuperman *et al*. 2002). Besides irrigated areas, planting of perennial trees and shrubs can also arrest the rise of saline groundwater in dryland areas. Nonetheless, shallow saline watertables in discharge zones often hinder such revegetation plans. Even if revegetation is successful, the maximum reduction in watertable depth in discharge areas is ≈2.5 m suggesting the practical utility of bio-drainage for localized salinity management in recharge areas (George *et al*. 1999). While the roots of annual crops mostly remain confined to upper few cm of the soil, tree roots extend to greater depths (>2 m) and rapidly transpire the groundwater such that watertable may decrease by 1-2 m over a period of 3-5 years. Many tree species have dimorphic roots consisting of surface and sinker components. While surface roots have a horizontal spread, sinker roots penetrate vertically to 10 m depth or more. Together, they form an integrated conduit in the soil that causes upward hydraulic redistribution of the deep soil water (Devi *et al*., 2016).

Although precise quantitative information on biodrainage potential of different tree species is lacking, *Eucalyptus* has emerged as the tree of choice under Indian conditions. *Eucalyptus* trees of 3-4 y ages can biodrain over 5000 mm of water from non-saline, moderately deep (~1.5 m) water tables. Relatively shallow (~1 m) or deep (~2 m) water table depths reduce the trees bio- drainage capacity that also declines with increase in the salinity of groundwater. However, at salinities as high as 12 dS/m, *Eucalyptus* trees can remove ~50% of the water compared to that under non-saline conditions. *Eucalyptus tereticornis* trees could control water table rises up to 1.95, 3.48, 3.76 and 3.64 m in first, second, third and fourth years of planting, respectively. After tree planting, salinity up to 45 cm depth did not exceed 4 dS/m even at saline (12 dS/m) water table depth of 1 m. Similarly, bamboo (*Bambusa arundinacea*) plants could control water table rises up to 1.09, 1.86, 2.46 and 2.96 m in first, second, third and fourth years of growth, respectively (Chhabra and Thakur, 1998). Strip plantations of *Eucalyptus tereticornis* on ridges in north-south direction not only lowered the water table by 0.85 m in 3 years but also sequestered 15.5 t ha-1 carbon during the first rotation of 64 months. B: C ratio of the first rotation of strip-plantations was 3.5: 1. Wheat yield in the tree interspace was over threefold higher than in adjacent waterlogged soils (Ram *et al*. 2011). These observations suggest that trees capable of extracting saline water from deeper layers can control water table rise in irrigated commands to prevent the formation of waterlogged saline lands.

Salt Tolerant Cultivars

Genetic improvement programmes have led to the development of several salt tolerant cultivars (STCs) in staple crops like rice and wheat that are being cultivated over a large salt-affected area. Seven salt tolerant varieties of rice CSR 10, CSR 13, CSR 23, CSR 27, Basmati CSR 30, CSR 36, CSR 43, five varieties of wheat KRL 1- 4, KRL 19, KRL 210, KRL 213 and KRL 283, seven of Indian mustard CS 52, CS 54, CS 56, CS 58, CS 60, CS 62 and CS 64 one in chickpea Karnal Chana-1 have been released by CVRC for affected areas of the country. Three rice varieties have also been released for coastal region as Sumati, Bhutnath and Amal mana. Several potential genetic stocks have also been developed for the use as parents in future selection and hybridization programmes. Importance of high yielding STCs is best illustrated by rice, a salt- sensitive plant inefficient in controlling the influx of Na^+ through the roots, where high yielding STCs can provide a yield advantage of 1.5-2 t ha^{-1}. Many promising salt tolerant genotypes have also been identified in fruits (mango, bael, ber, guava and pomegranate) and vegetables (chilli, capsicum, okra and tomato). Technique for utilizing saline groundwater (ECIW up to 10 dS/m) in vegetables crops under low-cost protected structure has been standardized. A germplasm repository consisting of diverse medicinal and aromatic plants has been established in a partially reclaimed sodic land. Success has also been achieved in raising fruits like guava, bael, Indian jujube and pomegranate under saline shallow watertable conditions that are otherwise considered to be unsuitable even for field crops.

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CHAPTER 2

Origin, Classification and Distribution of Salt-affected Soils in India

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India is endowed with abundant natural resources such as land, water, vegetation and climate to meet food requirements of burgeoning human and livestock populations. Overexploitation of these precious resources during last about four decades has set in the processes of degradation in soil, water, climate and biodiversity resources. Unscientific and over use of soil resources led to physical, chemical and biological degradation causing irreversible loss to soil quality. The intensive agriculture which ushered during green revolution is now becoming a serious threat to sustainable agriculture due to deteriorating soil quality. The total degraded area of the world is presently reported to occupy about two third of the potentially cultivable land while annual loss of arable land is reported as 5-7 million hectare (Mha). The magnitude of soil loss through degradation is in several cases much higher than the additional area brought under cultivation. The problem is alarming in the developing countries suffering with stiff increase of population, unemployment and poverty.

Salt affected soils are widespread in about 120 countries encompassing all continents and cover a total area of 953 Mha reducing productive capacity of 7-8% of the land surface of the world (Yadav, 2003). More than 50% of the salt affected soils are reported sodic with largest area in Australia. Similarly, sizeable area is located as saline seeps in dry land and secondary salinity in irrigated region (Tanji, 1995). According to Ghessami and Nix (1995) one fifth of the total irrigated land was affected by waterlogging and soil salinization at global scale while World Watch Institute (1990) reported an estimated area of 39.9 M ha in Asia and Pacific. In India, it occupies about 2% of the geographical area located prominently in the Indo-Gangetic plain, arid and semiarid region in central India and in the humid coastal region affected primarily due to ingression of saline sea water. Variable extent of salt affected soils were reported by different authors ranging from 7.0 to 26.1 M ha because of different criteria, methodology, and source of information employed in absence of any countrywide systematic survey.

The first survey of salt affected soils was initiated by Leather (1914) identifying soil alkalinity and salinity problems in the Gangetic alluvium located at Etah district in Uttar Pradesh. Agarwal *et al.* (1957) later detected salt affected soils as patches in the lower Ganges canal areas of Uttar Pradesh where absence of drainage as primary factor controlling soil salinization and alkalization. Joshi and Agnihotri (1984) compiled extent of areas under waterlogging and soil salinity and estimated productivity losses due to the twin problems in various irrigation commands of the country. Minhas and Bajwa (2001) estimated that poor (saline/sodic) quality ground water occupied 41-84% area in North Western India representing arid and semi-arid climatic condition.

Categories of salt affected soils

Globally, five categories of salt affected soils were identified based on the nature and composition of salts (Szabolcs 1980):

1. Saline soils dominated by natural salts
2. Alkali soils influenced by salts capable of alkaline hydrolysis (Na_2CO_3 and $NaHCO_3$)
3. Gypsiferous salt affected soils
4. Acid sulfate soils dominated by ferric and aluminum sulfates

5. Other salt affected soils *viz.* strongly degraded, subsoil salinization, and potential salinization

In certain countries of Eastern Europe these soils were known as Solonchaks, Solonetzs and Solodi. Singh (1989) reported that the alkali soils of the Indo-Gangetic plain in India are deteriorated to a great extent in the surface horizon to a depth of 60-100 cm while the alkali soils of Europe and erstwhile USSR have a good A horizon but a *natric* (sodic) subsurface B horizon. The differences were ascribed due to quality of aquifers the former with sweet and the latter with poor quality aquifer. A build-up of soluble salts in the soils influence its behavior through changes in proportion of exchangeable cations, the soil reaction, the physical properties and the effects of osmotic and specific ion toxicity for crop production. To facilitate soil management and the influence of salts on soil properties and plant growth, two broad categories of soils *viz.* saline and sodic were identified (Abrol and Bhumbla, 1978; Abrol *et al*. 1988).

Source and causes of salt accumulation

The main causes of salt accumulation include:

- Capillary rise from subsoil salt beds or from shallow brackish ground water
- Indiscriminate use of irrigation water of variable qualities
- Weathering of rocks and the salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials
- Ingress of sea water along the coast
- Salt laden sand blown by sea winds
- Lack of natural leaching due to topographic situation, especially in arid and semi-arid regions
- Poor quality underground water

Diagnostic criteria

The pioneering work of United States Soil Salinity Laboratory compiled by Richards (1954) proposed criteria for distinguishing sodic with saline and saline-sodic soils based on the critical limits of electrochemical conductivity (ECe) of saturation extract, ESP (Exchangeable Sodium Percentage) and soil reaction (pHs) of saturated soil paste. It was followed by the Soil Science Society of America (1987) considering ECe and SAR (Sodium Adsorption Ratio). The classification criteria are given in Table 1.

Table 1: Categories of salt affected soils

Class	Categories suggested by USSL			Proposed by Soil Science Society of America (1987)	
	pHs	ECe (dS/m)	ESP	ECe (dS/m)	SAR
Normal soil	<8.5	< 4.0	<15	<2.0	<13
Saline Soil	<8.5	>4.0	<15	>2.0	<13
Sodic Soil	>8.5	<4.0	>15	variable	>13
Saline-Sodic Soil	>8.5	>4.0	>15	>2.0	>13

Agarwal and Yadav (1956) found pHs 8.2 as more appropriate limit than pHs 8.5 for characterizing sodic soils of the Indo-Gangetic Alluvial Plain (IGP). Based on the extensive research on the adverse effect of sodicity on crop growth at CSSRI, Abrol *et al.* (1980) reported pHs 8.2 as critical limit for alkalinity/sodicity in soils. Similarly, the ECe values of 2 dS/mand ESP value of 5 were found as critical limits for characterizing sodic soils dominated by higher content of clay with smectitic mineralogy in black soils (vertisol) regions. Australian workers preferred parameters of soil physical conditions and its harmful effects on plant growth for diagnosing commonly occurring sodic soils in Australia. Northcote and Skene (1972) proposed ESP 6 as a limiting value to impairment of physical condition in a swell shrink soil. In India, Balpande *et al.* (1996) suggested ESP 5 as the limit for sodic subgroups of vertisol dominated by smectitic clay mineral.

Extent and distribution of salt affected soils in India

The Extent and distribution of salt-affected soils in different states of India is presented in Table 2.

Indo-Gangetic Alluvial Plain

A sizeable amount of salt affected soils (SAS) were commonly found in alluvial plains of the Indo-Gangetic Plain (IGP) in India. It occupies 2347658 ha (2.3 M ha) in the IGP, of which 1787939 ha (76%) is sodic and 559719 ha (74%) is saline. The SAS were distributed in five states such as Haryana (232556 ha, 9%), Punjab (151717 ha, 6.4%), Uttar Pradesh, (1368960 ha, 58%), Bihar (153153 ha, 6.5%) and West Bengal (441272 ha, 19%). The soils were saline in Bihar (65%) and West Bengal (100%) but variable and complex saline-sodic in Uttar Pradesh (92%), Punjab (100%) and Haryana (54%). In West Bengal the soils were slight and moderately saline located in deltaic plain of coastal areas (47%), while soils in mud flats/mangrove swamps (53%) were moderate and strongly saline in nature. The soil characteristics in Bihar showed slight salinity (65%) and sodicity (35%) apparently of recent origin. The soils were characterized strongly (66%) and moderately (32%) sodic in Uttar Pradesh. Soils were sodic of variable degrees (slight 42%, moderate 44% and strong 14%) in Punjab. These soils were saline (22%), sodic (77%) in Haryana.

Western and Central Arid Region

It is comprised of four states *viz.* Rajasthan, Gujarat, Madhya Pradesh, and Maharashtra. The total area under salt affected soils was 3330550 ha**.** It was distributed in Central Region comprising of Madhya Pradesh and Maharashtra States covering 733608 ha (22%) and Western region (Rajasthan and Gujarat States) covering 2596942 ha (78%). The saline and sodic soils occupied 193144 ha (26%) and 540465 ha (74%) in the Central region and 1876141ha (72%) and 720801 ha (28%) in Western region. The total area under saline and sodic soils was 2069285 ha (62%) and 1261266 ha (38%) in the entire Western and Central India

Peninsular Region

It is comprised of five states *viz.* Tamil Nadu, Karnataka, Andhra Pradesh, Kerala and Orissa States. The total area under salt affected soils was 959389 ha in Peninsular India. The soils were distributed in alluvial, peninsular, coastal, deltaic plains and mud flats/ mangrove swamps. State wise distribution showed that 368015 ha (38%) was distributed in Tamil Nadu**,** 274207 ha (27%) in Andhra Pradesh, 150029 ha (16%) in Karnataka, 147138 ha (15%) in Orissa and 20000 ha (2%) in Kerala State. Saline and sodic soils occupied 329087 ha (34%) and 630302 ha (66%) of the entire region.

Table 2: Extent and distribution of salt-affected soils in India

States	Saline	Sodic	Total
Andhra Pradesh	77598	196609	274207
Andaman & Nicobar Islands	77000	0	77000
Bihar	47301	105852	153153
Gujarat	1680570	541430	2222000
Haryana	49157	183399	232556
Karnataka	1893	148136	150029
Kerala	20000	0	20000
Madhya Pradesh	0	139720	139720
Maharashtra	184089	422670	606759
Orissa	147138	0	147138
Punjab	0	151717	151717
Rajasthan	195571	179371	374942
Tamil Nadu	13231	354784	368015
Uttar Pradesh	21989	1346971	1368960
West Bengal	441272	0	441272
Total	2956809	3770659	6727468

Coastal and Deltaic region

This region is comprised of eleven States *viz*. Andhra Pradesh, Goa, Gujarat, Karnataka, Kerala, Maharashtra, Pondicherry, Tamil Nadu, West Bengal and the Andaman & Nicobar islands. The total area under SAS was 1237406 ha and was distributed in three physiographic units *viz*. coastal plain, deltaic plain and the mud flats/mangrove swamps. Significant area under SAS was found in West Bengal (441272 ha (35%) followed by the Gujarat State occupying 413868 ha that covered 33% of the total SAS. Among the other States, Orissa (12%), Andhra Pradesh (6%) and Andaman and Nicobar (6%) showed significant area under coastal saline soils. Compilation of salt affected soils showed that these were distributed in 15 States occupying 6727468 ha (6.73 Mha). The saline and sodic soils covered 2956809 ha (34%), and 3770659 ha (56%) respectively. These were distributed in five physiographic units. Most of the soils in alluvial (A), Peninsular (F), Arid (B) and others (H) regions were sodic in nature while those located in Coastal (D), deltaic (C) and Mud flats/Mangrove swamps (G) were commonly saline.

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CHAPTER 3

Sodic soils: Characteristics, Identification and Reclamation Technologies

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Soil sodicity is a serious environmental concern leading to land degradation and reduced crop growth and yield in arid and semi-arid regions across the world. In India, soils covering 6.73 m ha are salt-affected, with sodic soils comprising 3.77 Mha (Sharma *et al*., 2015). The excessive accumulation of exchangeable sodium (Na) adversely affects soil structure and properties, thereby constraining agricultural production. The degree of adverse effects depends upon the type and quantity of salts, soil texture, type of crop, variety, stage of growth, cultural practices, and other environmental factors. Reclamation or improvement of sodic soils requires the removal of part or most of the exchangeable sodium and its replacement by the more favourable calcium ions in the root zone. Attempt to reclaim such alkali soils have been made either by treating with chemicals such as gypsum, dilute sulphuric acid, ferrous sulphate or elemental sulphur. The choice of an amendment at any place will depend upon its relative effectiveness as judged from improvement of soil properties and crop growth and the relative costs involved. The time required for an amendment to react in the soil and efficiency to effectively replace adsorbed sodium is also a major consideration in the choice of an amendment. Gypsum was the obvious choice owing to its availability, low cost and high efficiency of reclamation. With the passage of time availability of quality gypsum for agricultural usage is limited and development alternate reclamation technology is needed urgently to address the most important land degradation issue.

History of gypsum application in sodic soil reclamation

Gypsum has a wide history regarding its role in the reclamation of sodic soils. The oldest known use of gypsum is found in Mohan-Jodaro. Since then gypsum has been used extensively all over the World. First large scale use of gypsum in India was in the Mugal period, though totally for building purpose. Gypsum was known as chemical fertilizer in Lothal and Kalibangan civilization and it was used for the production of the ammonium sulphate fertilizer in Sidar near Dhanbad in 1945 (Sinha and Verma, 1978). Leather (1906) reporting on the reclamation of Usar land through the application of gypsum. Henderson (1914) marked the need for the application of gypsum for reclamation of some soils in Sind. Barnes and Ali (1917) and Nasir (1923) used gypsum to study the increase in ammonification activity of soil microorganisms in alkali soils. Use of gypsum as amendment for alkai soil reclamation was started after proper understanding of the cation exchange phenomenon.

Mechanism for formation of sodic soil

From agricultural aspects, sodic soil deleteriously impacts crop growth and development as it is rich in exchangeable sodium and often contains measurable to appreciable quantities of sodium bicarbonate, carbonate and silicate. These salts upon alkaline hydrolysis show pHs (pH of soil saturation paste) > 8.2 and electrical conductivity of the saturation extract variable to less than 4 dS/m at 25°C. Some advanced attempts had been made by researchers for distinguishing alkali soil from other salt-affected soils. These are: dominance of Na^+ as cation and CO_3^{2-}+HCO_3^- in the saturation extract (Chhabra, 2004); or the ratio of $[Na^+]/([Cl^-] + [SO_4^{2-}])$ in soil solution more than 1.0. Because of high pH, soil organic matter gets dissolved and forms black organic-clay coatings on soil aggregates and on the surface, giving the term “black-alkali” for such soils. Formation of carbonates of Na and alkalization in the soil takes place as a result of carbonation of alumino-silicate minerals in the presence of water.

$$NaAlSi_3O_8 + HOH + CO_2 \longrightarrow HAlSI_3O_8 + NaHCO_3$$

$$2NaHCO_3 \longrightarrow Na_2CO_3 + CO_2 + H_2O$$

Na_2CO_3 is highly soluble and its hydrolysis results in high alkalinity upto pH 12.0

$$Na_2CO_3 + 2HOH \longrightarrow 2Na^+ + 2OH^- + H_2CO_3$$

Further, in the presence of CO_2, pH is lowered as the formation of bicarbonate of Na.

$$Na_2CO_3 + CO_2 + H_2O \longrightarrow 2NaHCO_3$$

In arid and semi-arid regions, soils contain $CaCO_3$ in the profile in some form, and constant hydrolysis of $CaCO_3$ favour the release of OH^- ions in the soil solution. Therefore, the OH^- ions so released result in the maintenance of higher pH in calcareous alkali soils than that in non-calcareous alkali soil. Therefore, a build-up in the exchangeable sodium in the absence of an appreciable quantity of neutral soluble salts will always result in high pH; the exact value depending on the concentration of Na_2CO_3, formed or the level of ESP.

$$CaCO_3 + H_2O \longrightarrow Ca^{2+} + HCO_3^- + OH^-$$

Besides these, one of the major factors responsible for the formation of sodic soils in the Indo- Gangetic region includes irrigation with groundwater containing excessive quantities of carbonate and bicarbonate ions, rise in groundwater due to introduction of canal irrigation and salt-laden run-off from the adjoining areas and un-drained basins. Water having residual sodium carbonate (RSC) >2.5 and sodium adsorption ratio (SAR) >10 is classified as sodic water (Chhabra, 1996).

Characteristics and impact of sodic soil

- Alkalinity largely results in indirect influences on soil physical properties, low permeability of water and air due to dispersion of aggregates and clay particles; growing plant faces adverse effects not only due to high ESP but also due to high pH and associated poor physical properties such as low hydraulic conductivity and degraded soil structure (Figure 1).
- Sodic soils typically appear as convex surfaces at field conditions after an irrigation or rainfall. The soil a few centimeters (cm) below the surface may be saturated with water while at the same time the surface is dry and hard. Upon dehydration cracks, 1-2 cm across and several cm deep form and close when wetted. The cracks, generally, appear at the same place on the surface each time the soil dries unless it has been disturbed mechanically.
- Hard crust on the surface layer generally hinders seedling emergence resulting in poor plant population.
- Deficiency of Ca; So, Na appears as major competitive cation affecting Ca nutrition
- Toxicity of HCO_3^- and CO_3^{2-} reduces the solubility and availability of Zn and Fe.
- Hydroxyl (OH-) ions have toxic effects on plant growth are noticed at soil pH more than 10.5.

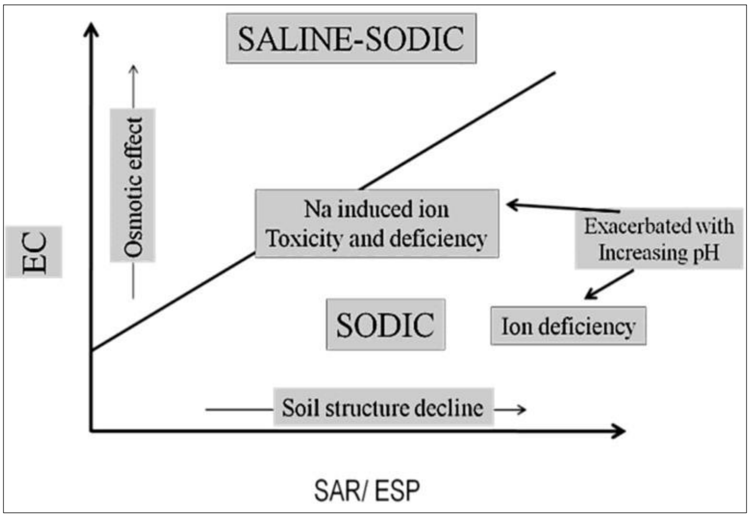

Figure 1: Typical characteristics of alkali and saline-alkali soil in relation to Na^+ ion

Gypsum technology

Gypsum is a major soil amendment used for reclamation of sodic soil. The cost for the reclamation depends upon the quantity of gypsum required for reclamation. Quantity of gypsum required depends upon the soil pH and intended depth of reclamation. ICAR-CSSRI research showed that application of 50% of the gypsum requirement estimated in the soil testing laboratory in top 15 cm soil depth is sufficient to meet the reclamation need of the most of cultivated crops. Based on this recommendation, the tentative cost of reclamation for one ha land is mentioned in Table 1.

Table 1: Cost component of sodic soil reclamation.

Sl. No.	Cost component	Approximate Amount (Rs./ha)
1.	Gypsum cost* (10 t/ha) @ Rs. 3000/ton as supplied by Haryana Land Reclamation and Development Corporation	30000.0
2.	Transportation cost of gypsum @ Rs 500/ton (for a distance of 35 km from source to field)	5000.0
3.	Land Development $	
3.1	Laser leveling (Moderate leveling)**	3500.0
3.2	Bunding (using tractor operated bund maker and one labourer)	1000.0
4.	Operational cost	
4.1	Soil sampling and analysis	500.0
4.1	Spreading of gypsum in field (12 man days @ Rs. 450/man days in Haryana)# †	5400.0
4.2	Mixing of the amendment at least two harrowing and planking (@Rs 2000/harrowing)	4000.0
4.3	Irrigation to leach/flush out the salt at least two irrigation of 10 cm depth (Ponding of water for one week before transplanting of rice)	5000.0
4.4	Seed (Rice varieties CSR 23, CSR-36, CSR-43) @ 25 kg/ha	1250.0
4.5	Cost of fertilizer:	

	• Urea-350 kg • DAP-150 kg • MOP-100 kg • Zinc Sulphate-50 kg	2065.0 3750.0 1450.0 3000.0
4.6	Weed management	500.0
4.7	Nursery raising and labour cost for transplanting rice	9000.0
Total††		75415.0
Approx. Total (Rs)		76000.0

*Based on the average gypsum requirement 20 t/ha (soil to soil it may vary)
$Assuming irrigation facility available near the field
**Cost may increase for undulating land need more leveling
#labour cost changes from state to state † This cost can be reduced to Rs 2000.0 if gypsum spreader is available on hiring basis
†† Dhaincha Green manuring will add an additional cost of Rs. 4500.0 (Cost of seed, sowing and irrigation charges)

In the adoption of gypsum technology following steps are involved:

- Land leveling and bunding for rainwater storage and uniform distribution of irrigation water
- Soil sampling and analysis for determination of gypsum requirement
- Uniform application of the powdered gypsum as per the soil test recommendation (10-15 t/ha)
- Mixing in the surface 10 cm soil by ploughing
- Ponding water for minimum of one week before transplanting of rice
- Transplanting of salt tolerant rice varieties
- Adopting proper agronomic practices

Investment on alkali land reclamation involves short to medium gestation period. Considering 12% opportunity cost of capital the benefit-cost ratio may vary from 1.34 to 2.47. About 18% to 67% internal rate of return is expected with 2 to 3-years payback period for this technology.

Various technological options for management of Sodic soils

Gypsum, pyrites, aluminium chloride, inorganic sulphur etc. was initiated for reclamation of sodic/ saline-sodic soils (CSSRI, 2006). Based on the source, and potentiality to neutralize sodicity, amendments are broadly categorized into: inorganic/chemical and organic agents (Figure 2). Chemical amendments for sodic soil reclamation can be broadly grouped into three categories: (a) soluble calcium salts, e.g. calcium sulphate (mineral gypsum/ processed $CaSO_4.2H_2O$ in industrial plants in chemical reaction, calcium chloride; and (b) acids or acid forming substances, e.g. sulphuric acid, iron sulphate, aluminium sulphate, lime-sulphur, sulphur, pyrite *etc*. Besides, organic sources such as farmyard manure, press mud, corn stalks, municipal solid waste compost (Sundha *et at*., 2018), sewage sludge, crop residue (Choudhary *et al*, 2011) are being used as alternate amendment sources.

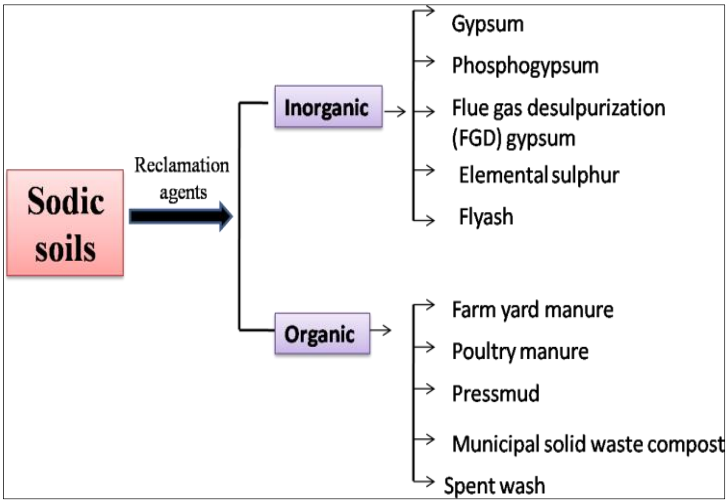

Figure 2: Schematic diagram of categories of sodic soil reclamation agents.

Besides mineral gypsum, seawater and some chemical plants are sources of by product marine gypsum and by-product chemical gypsum, respectively. The latter is obtained as by product phospho-gypsum or fluoro-gypsum or boro-gypsum, FGD (flue gas desulfurization) gypsum, depending upon the source. Fluoro-gypsum obtained as by-product during the manufacture of aluminium fluoride and hydrofluoric acid using fluorite at different units in Surat, Mumbai and Thane. Another by-product, boro-gypsum is obtained at the plant which refines calcium borates (colemanite and ulexite) to produce borax and boric acid manufactured in districts of Maharashtra and Chennai. Fluoro-gypsum and borogypsum are not used as amendment sources but other forms such as marine gypsum, phosphogypsum and flue gas desulfurization gypsum are being researched for agricultural usage in different parts of the world (Table 2).

Table 2: Commonly used amendment for reclamation of sodic soil

Amendments	Nature and mechanism to neutralize soil sodicity
Gypsum ($CaSO_4$. $2H_2O$)	Sparingly soluble in water and wide spreading nature as soil component and advantages with gypsum is relatively faster reclamation $Na\text{-}Clay\text{-}Na + CaSO_4 \longrightarrow Ca\text{-}Clay + Na_2SO_4$
Ground limestone ($CaCO_3$)	Supply Ca on dissolution
Native or industrial wastes (pressmud)	Mobilizing inherent calcite
Sulphuric acid (H_2SO_4)	Dilute acid use as sodicity reclamation amendments
Pyrite (FeS_2); Iron sulphate ($FeSO_4$, $7H_2O$); Elemental sulphur (S); Lime sulphur (CaS_5)	Acids forming amendments; The oxidation of elemental S/ Pyrite is mediated by *Thiobacillus thiooxidans,* which require a warm, well aerated and moist soil with low pH condition. $2S + 3O_2 = 2SO_3$ (microbiological oxidation) $SO_3 + H_2O = H_2SO_4$ $NaHCO_3 + H_2SO_4 = Na_2SO_4$ (Leachable) + $H_2O + CO_2$ $Na_2CO_3 + H_2SO_4 = Na_2SO_4$ (Leachable) + $H_2O + CO_2$ $Na^+\text{-[Soil]-}Na^+ + H_2SO_4 = H^+\text{-[Soil]-}H^+ + Na_2SO_4$ (Leachable
Farmyard manure (FYM)	Organic amendments carry organic acid which mobilize

and, Green manuring (GM)	Ca from inherent and precipitated $CaCO_3$ in calcareous soils and consumption of mineral gypsum decline for sodicity reclamation in sodic water irrigation for achieving sustainable yields
Compost	Gypsum (GR25) and 20 Mg ha^{-1} city compost are recommended for reducing alkalinity and salinity stress of soil under use of poor quality water (Sundha et al., 2018)
Flue gas desulfurization (FGD) gypsum	FGD gypsum is small particle size facilitate the reaction between gypsum and sodic soil. The corn emergence ratio and yield in FGD amended soil was 1.1-7.6 and 1.1-13.9 times than control. FGD improved aggregation, declined pH and ESP in saline-sodic soils (Wang *et al*., 2017).
Arbuscular mycorrhizal fungi (AMF)	The AMF is the obligate biotrophs deriving mutual benefits of the partnership by the improved acquisition of water and mineral nutrients, in exchange for photosynthetically fixed carbon, ultimately helping in plant growth and development and mediating the terrestrial nutrient cycling. The symbiosis with AM fungi can also ameliorate abiotic stresses including salt stress in plants (Chandra *et al*, 2022)

Conclusions

Soil sodicity is a serious environmental concern leading to land degradation and crop failure in arid and semi-arid regions. Gypsum being easily available, cheaper and easy to handle is most common for the amendment of sodic soils. But, ongoing rapid infrastructure developments, the country‟s gypsum consumption is rising and it is expected to grow at a cumulative annual growth rate of 6.5% from 2016-17 to 2021-22. Thus, the agriculture sector is facing issues of low availability and inferior quality of agricultural grade gypsum across the nation. Other alternate sources like phosphogypsum, pyrites, pressmud and distillery spent wash are also used in some areas for the reclamation of sodic soils. In future, scientifically managed municipal solid waste compost, elemental S and nanoscale materials and polymers can also supplement the sodic soil reclamation programme.

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CHAPTER 4

Crop Varieties Suitable for Salt Affected Soils and Poor Quality Waters

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The occurrence of salts in soil and water pose a serious constraint to crop productivity especially in those areas where irrigation is essentially required. Agricultural salinity affects about 900 million hectares (Mha) land globally and therefore poses a formidable task of taking up agriculture and enhancing productivity in these areas. In India, studies on mapping of salt affected areas indicate that about 6.73 M ha land area is salt affected out of which 3.77 and 2.96 M ha are afflicted, respectively by sodic and saline soils. In Haryana, a total of 3.1 lakh ha of land is affected by salts. Moreover, ground water in all most all the districts of Haryana are facing the problem of salinity and RSC. Harnessing the potential of such salt affected areas can play a significant role in increasing and sustaining our food security. Moreover, these disadvantageous agro-ecosystems are often inhabited by resource-poor inhabitants and any improvement in the agricultural productivity is directly linked with poverty alleviation. The salt affected soils can be reclaimed by adopting soil chemical amendments, waterlogged saline soils through sub-surface drainage but the saline soils can not be corrected by any single measure. Financial constraints are also faced by small and marginal farmers for land reclaimation programmes.The only effective way is to adopt salt tolerant crop varieties on such soils with additional technological interventions, if required.

The Division of Crop Improvement ICAR-CSSRI, Karnal started work on development of salt tolerant material and screened the already available germplasm of different crops on the alkali soils during initial years of the institute's establishment. The division identified the tolerant crops including genotypes providing economic returns under degraded lands, besides focusing on the physiological mechanisms conferring salt tolerance. The strategy initiated was to collect germplasm, evaluation on salt affected soils and conservation through national and international network. The programme was started with collection of traditional land races from target areas, their cataloguing after screening. The exotic germplasm, particularly, wild relatives of important crops, being rich sources of important genes for abiotic stresses were also included in the improvement program. The research activities over a period of time identified the salt tolerance limits of different crops with various physiological mechanisms under salt stress, low sodium uptake and better regulation of toxic ions by the plant tissues. Eventually, a systematic program on the development of improved, salt tolerant and high yielding varieties of crops was formulated. Initially major crops were evaluated for their salt tolerance potential with final focusing on rice, wheat, Indian mustard and chickpea.

Rice varieties

Right from its inception, CSSRI Karnal collected and evaluated approximately 20,000 germplasm lines consisting of introductions, land races, improved type material of rice developed in India and at International Rice Research Institute, Philippines. Developed more cross combinations by involving diverse parents *viz*. exotic lines, land races, genetic stock and elite lines with respect to salt tolerance, yield, quality, and pest and disease resistance in rice. Experiments on rice in the precisely controlled microplots filled with soils of desired levels of salinity and sodicity were conducted. Use of this system enables precision, control and monitoring of stress levels enabling more accurate and efficient genotypic evaluation besides minimizing problems caused by soil heterogeneity. Screened 10000 rice germplasms for seedling stage salinity tolerance in hydroponic solution and identified many high tolerant rice accessions. Screened 1000 transgenic progenies of IR 64 for salinity and sodicity tolerance in the controlled transgenic glass house facility and selected the best two transgenic progenies for salinity and sodicity tolerance. Many elite rice genotypes were identified at CSSRI after thorough systematic phenotyping at micro plot and field conditions. Molecular markers are becoming important tools for accelerating breeding progress.

CSSRI has developed 10 salt tolerant rice varieties (Table 1 and 2). Out of these, the rice varieties CSR10, CSR23, CSR27, Basmati CSR30, CSR36, CSR43, CSR46, CSR56 and CSR60 have been released for sodic soils and CSR 13 and CSR 27 released for saline soils. CSR 36 recommended during 2005 for the sodic soils of Haryana, UP and Pondicherry. It can tolerate soil sodicity up to pH_2 9.9 and salinity up to 10.0 dS/m and yields about 40 q/ha under stress situation. CSR 43 released during 2011 for the sodic soils of Uttar Pradesh. It has intermediate plant height and takes about 110 days for maturity and yields about 35 q/ha under stress condition (pH_2 9.9 and salinity up to 7 dS/m). The rice variety CSR46 slender grain. This variety yields app. 6.5 t/ha under non stress and app 4.0 t/ha under sodic stress (pH_2 9.8) situation. The rice variety CSR56 was recommended (CVRC) during 2018 for the sodic soils of Uttar Pradesh and Haryana. This variety has intermediate plant height (95 cm) and takes about 120 days for maturity with long bold grain and yields app 7.0 t/ha under non stress and app 4.3 t/ha under salt stress situation.

Another rice variety CSR60 recommended (CVRC) during 2018 for the sodic soils of Uttar Pradesh and Pondicherry. This variety takes about 125 days for maturity and have long slender grain with yield potential of approximately 7.0 t/ha under non stress and 4.5 t/ha under salt stress situation. CSSRI, Karnal also led the country wide program on rice improvement for salt affected soils encompassing different salinity centres which resulted in the development of other genetic stock with salt tolerant rice varieties. Under scented rice, Basmati CSR 30 is the first salt tolerant variety in the world developed by CSSRI, Karnal and most popular among farmers. This variety released and notified in 2001 as CSR 30 and again in 2012 as Basmati CSR 30. The yield potential is 30 q/ha under normal soils and 20 q/ha under salt affected soils (ECe 7 dS/m and pH_2 9.5). This variety fetches higher market price compared to other basmati rice varieties due to its higher aroma and other quality parameters.

Wheat varieties

Four decades of salinity research at CSSRI has resulted in identification of germplasm and development of varieties tolerant to salinity, alkalinity and water logging stresses. These efforts led to the development and release of five salt tolerant wheat varieties, namely KRL 1-4, KRL 19, KRL 210, KRL 213 and KRL 283 for salinity/sodicity tolerance. Besides these varieties, three salt and water logging tolerant genetic stocks (KRL 35, KRL 99 and KRL 3-4) have been developed through CSSRI, Karnal and registered with NBPGR, New Delhi for salt and water logging tolerance. These genotypes were developed following the conventional breeding techniques supplemented by information on genetics and physiology of the salt tolerance mechanisms. In that way, these will be aiding us to tailor and develop the desired genotypes suitable for salt and water logging situations. Uptake and exclusion of sodium, uptake of potassium, sodium/ potassium ratio and tissue tolerance are some of the important traits governing plant salt tolerance. The salient features of salt tolerant wheat varieties are given below.

Table 1: Salt tolerant rice varieties developed by ICAR-CSSRI, Karnal

Name	**CSR10**	**CSR13**	**CSR23**	**CSR27**	**CSR30**	**CSR36**	**CSR 43**	**CSR46**
Year of release	1989	1998	2004	1998	2001	2005	2011	2016
Plant height (cm)	85	115	115	115	155	110	100	110
Maturity days	120	145	130	125	155	140	110	130
Tolerance limits Salinity (ECe:dS/m) Sodicity (pH_2)	<11.0 <10.0	< 9.0 <9.9	<10.0 <9.9	<10.0 < 9.9	<7.0 <9.5	<7.0 <9.8	<7.0 <9.5	<9.0 <9.9
Yield (t/ha) Non stress Salt stress	>6.0 >3.0	>6.0 >3.0	>6.5 >3.5	>6.5 >3.5	>3.0 >2.0	>6.5 >3.5	>6.5 >3.5	>7.0 >4.0
Grain type	Short Bold	Long Slender	Long Slender	Long Slender	Basmati	Long Slender	Long Slender	Long Slender
Recommended ecology	HR & U P	UP, HR, GJ & MS	HR & UP	MS GJ, TN, KR and WB	UP, HR and PB	HR, UP, and Pondi-cherry	UP	UP

Table 2: Salt tolerant rice varieties developed by CSSRI, Karnal

Name	**CSR49**	**CSR52**	**CSR56**	**CSR60**	**CSR 101**	**CSR104**	**CSR105**
Year of release	2017	2017	2018	2018	2024	2024	2024
Plant height (cm)	115	90	100	110	100-110	85-105	90-100
Maturity days	120	125	125	125	135-140	110-120	110-120
Tolerance limits Salinity (ECe:dS/m) Sodicity (pH_2)	<8.0 <9.9	<8.0 <9.9	<8.0 <9.9	<8.0 <9.9	<8.0 9.5	<8.0 <9.9	Suitable for Aerobic and DSR condition
Yield (t/ha) Non stress Salt stress	>7.5 >3.5	>7.5 >3.5	>7.5 >4.1	>7.5 >4.3	>6.0 to 6.5 >4.0	>7.0 to 7.5 >4.5	>7.5-8.0 >5.0-5.5 (DSR)
Grain type	Long Slender	Long Bold	Long Bold	Long Slender	Long bold	Long slend	Long Slende
Recommended ecology	UP	UP	UP & Haryana	UP & Pondich-erry	Saline and sodic soils of Kerala, Karnataka, and Tamil Nadu	Sodic soils of Uttar Pradesh and Haryana	Suitable for aerobic conditions in Haryana and Gujarat.

KRL 283: KRL 283 have been identified by UP State Variety Release Committee for sodic soils of Uttar Pradesh in 2015. This variety has amber coloured grain with 11.9% protein content, 74.7 kg hectoliter weight and sedimentation value of 31. It takes about 139 days to mature. Under normal conditions its yield potential is 58-62 q/ha while in sodic soils (pH 9.0-9.3) it gives 45-48 q/ha. KRL 283 has shown multiple stress resistance (Abiotic Stresses-Sodicity/Alkalinity/Waterlogging/ lodging/Biotic Stresses-Stripe Rust/Brown Rust/Stem Rust/Karnal bunt/Aphid/Shoot fly).

KRL 210: Notified for irrigated, timely sown conditions facing salt stress (saline/alkaline) situations of North Western and North Eastern Plain Zones in 2011. KRL 210 is a semi dwarf variety and takes about 143 days to mature. The grains are amber in colour, bold in size and contain about 11% protein. The hectolitre weight of the grain is 77 kg with sedimentation value of 39. The yield potential of KRL 210 is 5.5 tonnes/ha in normal soils, whereas its yield potential in salt affected soils (having pH_2 up to 9.3 and ECe up to 6 dS/m) is 3 to 5 tonnes/ha. KRL 210 is resistant to Yellow and Brown rusts, loose smut, Karnal bunt and flag smut. The variety has also shown tolerance to shoot fly.

KRL 213: KRL 213 has an excellent plant type with semi dwarfness. It was notified for irrigated, timely sown conditions under salt affected soils of North Western and North Eastern Plain Zones in 2011. It takes about 147 days to mature. It is specifically bred for salt tolerance to saline (ECe 6.0 dS/m) as well as alkaline soils (up to pH_2 9.2) conditions. It also does well in areas where the ground water is either brackish and/or saline (EC_{iw} 15 dS/m; RSC 12-14 meq l^{-1}). This variety has amber coloured grain with 11% protein content, 77 kg hectoliter weight and sedimentation value of 29. It has a good yield potential under salt stress condition (Average yield 3.3 tonnes/ha). However, the variety can produce up to 5 tonnes/ha in normal soils.

KRL 19: It was notified for irrigated, timely sown conditions under salt affected soils of North Western and North Eastern Plain Zones in the year 2000. It is highly responsiveness to fertilizers as well as resistant to lodging and shattering even under high input, irrigated and timely sown conditions. Even moderately late sowing does not affect the yield significantly. The variety has amber grain colour with good grain appearance, high protein content, hectoliter weight and sedimentation value. KRL19 has been specifically bred for salt tolerance and can tolerate saline (EC_e 5-7 dS/m) as well as alkaline soil (up to pH_2 9.3) conditions. It also does well in areas where the ground water is either brackish and/or saline (EC_{iw} 15-20 dSm^{-1}, RSC 12-14 meq l^{-1}). Though KRL19 has been specifically bred for adverse saline/alkali soils, however, its yield potential under normal soil conditions is more than 5.0 t ha^{-1}

KRL 1-4: KRL 1-4 was the first wheat variety released in the year 1990 for saline and sodic soils of the north western plain zones of the country. This variety is a dwarf type with 135 days of maturity. The grain texture is hard, medium bold and amber in color. This has good yielding ability upto 4.8 t ha^{-1} under normal soil condition and 3.4 t ha^{-1} under sodic stress upto pH_2 9.3. It also tolerates the salinity stress upto EC_e 7.0 dSm^{-1}.

Mustard varieties

Mustard (*Brassica juncea*) is the second most important edible oilseed crop in India after Soybean mostly grown in Rajasthan, Uttar Pradesh, Madhya Pradesh, Haryana, Punjab and

Gujarat. This is mainly cultivated on rainfed, arid, semi-arid and salty soil and water conditions in these states. The average seed yield of mustard varieties recommended for normal conditions is 6-8 q/ha and oil yield 300 kg/ha in salt affected areas of these states having soil salinity of ECe>8 dS/m or irrigation water salinity EC_{iw}>10 dS/m and pH ≤ 9.5, on the other hand, salt tolerant mustard varieties are producing 18-22 q/ha seed yield and 800 kg/ha oil yield. Mustard is one of the promising oilseed crops in mitigating the effect of the climate change, greater magnitude of interspecific variation for salt stress tolerance, low input requirement, and low cost but very healthy oil having good consumer preference. This challenge has given us an impetus to improve salt stress tolerance and start work on the development of salt tolerant and high yielding Indian Mustard varieties. The salt tolerant varieties perform better under salt stress conditions due to manipulation in various mechanisms through physiological, genetic and molecular modules to combat salinity led harmful effects.

CS 52: CS 52 is released by CVRC in 1997 for salt affected soils. This is a tall (170–180 cm), bearing basal branching, and relatively late maturing (7-10 days) as compared to checks and less prone to aphid and pests attack. This variety is recommended for cultivation in saline and sodic soils up to a critical limit of EC_e 6.0-8.5 dS/m and pH_2 9.3, respectively. The average yield of this variety, within the critical limits of soil salinity, is around 1.5-1.6 t ha^{-1} with 36% oil.

CS 54: CS 54 was released by CVRC for cultivation in salt affected soils in 2005. It was identified on the basis of superior performance (nearly 20%) over high yielding checks. Its plant height is around 160 cm, bearing basal branching, matures in around 121 days and is less prone to aphid and pests attacks. This variety is recommended for cultivation in saline and sodic soils up to a critical limit of EC_e 6.0-9 dS/m and pH_2 9.3, respectively. The average yield of this variety, within the critical limits of soil salinity, is around 1.6 t ha^{-1} having more than 38% oil content.

CS 56: CS 56 (Triveni) is released by CVRC in 2008 for the late sown conditions of Zone II of the country comprising the states of Punjab, Haryana, Rajasthan and Delhi. This variety can be sown up to 15th November with the minimum yield reduction and can yield upto 1.6 t ha^{-1}. This variety is also recommended for cultivation in saline and sodic soils up to a critical limit of ECe 6.0-9 dS/m and pH_2 9.3 respectively. The average yield of this variety, within the critical limits of soil salinity, is above 1.6 t ha^{-1} with 38% oil content.

CS 58: CS 58 was released and notified by Central Sub-Committee on Crop Standards, Notification & Release of Varieties (CVRC) in 2017 for salt affected areas of the mustard growing regions of the country Zone–II comprising the states of Haryana, Punjab and Uttar Pradesh. It matures on an average in 132 days and takes 60 days to flower. The plant height is approximately 180 cm and produces high number of primary branches (6), secondary branches (9), main shoot length (85 cm) and 1000-seed weight (5.5 g). The productivity of this variety under normal soils is about 2.6-2.8 t/ha which slightly decrease in salt affected soils to 2.0-2.2 t/ha. Seeds contain about 40% oil.

CS 60: CS 60 was released and notified by Central Sub-Committee on Crop Standards, Notification & Release of Varieties (CVRC) in 2018 for salt affected areas of the mustard growing regions of the country Zone–II comprising the states of Haryana, Punjab, Rajasthan and Uttar Pradesh. This variety gave 25% higher seed yield and 27% higher oil yield per hectare over the national check CS 54 and high yielding varieties Kranti and Giriraj under soil salinity EC_e 10-11 dS/m, irrigation water salinity EC_{iw} 10-12 dS/m and alkalinity pH 9-9.5. It matures, on an average, in 125-132 days and takes 58 days to flower. The height of CS 60 is 182-187 cm and 1000-seed weight is 5-5.5 g. The productivity of this variety under normal soils is 25-29 q/ha, while under salt affected soil is 19-22 q/ha with 41% oil content. CS 60 showed resistance to *Alternaria* blight, white rust, powdery mildew, downy mildew, stag head, *Sclerotinia* stem rot and mustard aphid under field conditions.

CS 61: This variety CS 13000-3-2-2-5-2 (CS 61) has been released by the Uttar Pradesh State Sub-Committee Seeds and Crop Varieties (UP-SVRC) during the year 2022 (office order: SF/296.T/SVN-08/2019-20/रा.बी.उ.स.2020-22/2022-23) and notified by Central Sub-Committee on Crop Standards, Notification & Release of Varieties (CVRC) vide Gazette notification S.O. 1056(E), dated on 6th March, 2023, for irrigated, sodic soils and timely sowing (by 25 October) of Uttar Pradesh. Its yield is 21-22 q/ha in sodic soil (pH up to 9-9.3) and 25-28 q/ha in normal soil and water and has about 39 percent oil content. This variety matures in about 132 days. The height of its plants is 181 cm. This variety is resistant to Alternaria blight, white rust, powdery and downy mildew, stag head and sclerotinia stem rot and also less infestation of aphid.

CS 62: This variety CS 15000-1-1-1-4-2 (CS 62) has been released by the Uttar Pradesh State Sub-Committee Seeds and Crop Varieties (UP-SVRC) during the year 2022 (office order: SF/296.T/SVN-08/2019-20/रा.बी.उ.स.2020-22/2022-23) and notified by Central Sub-Committee on Crop Standards, Notification & Release of Varieties (CVRC) vide Gazette notification S.O. 1056(E), dated on 6th March, 2023, for irrigated, sodic soils and timely sowing (by 25 October) of Uttar Pradesh. Its yield is 21-22 q/ha in sodic soil (pH up to 9-9.4) and 25-27 q/ha in normal soil and water and has about 39.5 percent oil content. This variety matures in about 136 days. The height of its plants is 168 cm. This variety is resistant to Alternaria blight, white rust, powdery and downy mildew, stag head and sclerotinia stem rot and also less infestation of aphid.

CS 64: The salt tolerant Indian Mustard CS 64 developed by ICAR-CSSRI, Karnal and was released and notified by Central Sub-Committee on Crop Standards, Notification & Release of Varieties (CVRC) vide Gazette notification S.O. 4222(E), dated on 25th September, 2023, for salt affected area of the Haryana, Punjab, Rajasthan, Delhi and Uttar Pradesh, Plains of Jammu and Kashmir and Himachal Pradesh. The productivity of this variety under normal soils is 27-29 q/ha, while under salt affected soil and irrigation water ($EC_{e/iw}$ 13 dS/m) and sodicity (pH 9.4), is 20-23 q/ha with 40-41% oil content. It matures in 130-138 days. The height of CS 64 is 160-168 cm and 1000 seed weight is 5.0-5.3g. This variety showed resistance to *Alternaria* blight, White rust, Powdery Mildew, Downy Mildew, Stag head, *Sclerotinia* stem rot and mustard aphid under field conditions also.

Chickpea verities

Chickpea has been known in this country for a long time. It is said to be one of the oldest pulses known and cultivated from ancient times both in Asia and in Europe. Over a period of time, the crop has experienced drastic reduction in area mainly due to creation of extensive irrigation network for promoting rice-wheat production, and biotic stresses like

Ascochyta blight, *Fusarium wilt* and root rot complex, and *Helicoverpa* pod borer, besides abiotic stresses like salinity, temperature extremities and terminal drought. The farmers in salt affected areas have stopped growing pulses specifically chickpea due to increasing soil salinity or poor quality waters.

Keeping these aspects in mind, the pulse breeders of the division collected a large germplasm of chickpea. After screening this germplasm and hybridization of promising materials, CSSRI released first salt tolerant chickpea variety Karnal Chana-1(CSG8962) in year 1998. The yield potential of Karnal Chana-1 is 21-24 q/ha in normal soils, whereas its yield potential in salt affected soils of EC_{iw} 6 dS/m or pH_2 9.0 is 14-16 q/ha. Seeds of Karnal Chana-1 are bold and 100-seed wt. is around 15 g. This variety matures in 150-155 days after sowing. The variety is popular in salt affected areas of Haryana, Rajasthan and Gujarat.

Lentil varieties

Lentil (*Lens culinaris* Medik) is an essential pulse crop that is widely grown for its high nutritional value, notably its high protein content, making it an important dietary component for vegetarians and vegans. Despite being the world's fifth most produced pulse, with large contributions from Canada and India, lentil production confronts obstacles such as poor productivity due to limited genetic improvement against abiotic stresses specially tolerance to salt stress conditions. Salinity in soil and irrigation water is the main limiting factor for lentil productivity, especially in dry and semi-arid tropic (SAT) conditions. The lentil crop is mainly grown in dry and SAT of the Indian-sub-continent as well as in the Middle East. Excessive salts in soil affect the growth of the lentil by disturbing water and nutritional balance of crop plants. Earlier studies have indicated that the lentil crop is sensitive to salinity stress. Significant genetic variation for salinity tolerance prevails among the genotypes of lentil. The development of saline tolerant cultivars can be an appropriate approach for minimizing yield losses under salinity stress condition. ICAR-CSSRI Karnal in collaboration with IARI, New Delhi has developed two salt tolerant varieties for salinity affected areas of UP and Haryana

PDL-1: It has a plant height of 30–32 cm, flowering on 75–80 days, maturity of 103–118 days. Number of pods/plant varies from 55-58 and 100 seed weight is 1.9 g. Its yield is 1.1–1.2 t/ha in saline-affected soil (up to ECe 6 dS/m) and 1.6-1.8 t/ha in normal soil.

PSL-9: This variety has a plant height of 31-33 cm, flowering on 69-77 days, maturity of 108-116 days. Number of pods/plant varies from 60-64 and 100 seed weight is 2.6 g. Its yield is 1.1–1.3 t/ ha in saline-affected soil (up to ECe 6 dS/m) and 1.7–1.9 t/ha in normal soil.

CHAPTER 5

Sub-surface Drainage Technology for Reclamation and Management of Waterlogged Saline Alluvial and Black Soils

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Soil salinity has been threatening some of the most productive irrigated lands of country. Nearly 2.95 million hectares (M ha) area in the country is turned as saline or saline-sodic soils in arid, semi-arid and sub-humid regions due to intensification of irrigated agriculture. Saline soils are adversely affecting crop productivity and sustainability of agriculture in irrigation commands. These saline soils are spread across mainly 16 states *viz.* Punjab, Haryana, Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Telangana, Tamil Nadu, Kerala, Madhya Pradesh, West Bengal, Bihar, Odisha and Uttar Pradesh. ICAR-CSSRI estimated the annual crop production and monetary losses due to the soil salinity problem at the national level as 16.84 million tonnes and Rs. 23,020 crores. Saline soils (ECe> 4 dS/m, pHs< 8.2 and ESP <15 in the root zone) in irrigation commands are accompanied by shallow water table (≤ 2 m below the soil surface) termed as waterlogged saline or saline sodic soils. Moderately to highly waterlogged saline or saline-sodic soils (8<ECe<62 dS/m) is reclaimed by improving salt leaching with sub-surface drainage system to dispose of saline effluent water horizontally. Such waterlogged saline soil poses challenge of their reclamation and providing management options for the farmers to sustain high yield and farm income. In order to reclaim and manage waterlogged saline or saline-sodic soils, sub-surface drainage (SSD) technology is successfully implemented on large scale in 8 states during the last 30 years and has significantly enhanced the crop yield and farm income. Three success stories of SSD technology from different parts of India are presented below.

Sub-Surface Drainage Technology

The SSD technology has been standardized and successfully implemented for reclamation of irrigation induced waterlogged saline alluvial soils in Haryana for enhancing the crop productivity. Subsequently, this technology has been extended to other alluvial areas of Punjab, Rajasthan and other states. Further, after the refinement, this technology has been implemented successfully in reclaiming waterlogged saline Vertisols/black soils in parts of Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh and Telangana. The SSD system consists of an underground network of flexible corrugated and perforated PVC lateral pipes and perforated/ blind collector pipes wrapped with appropriate synthetic filters. This is installed by drainage trencher or hydraulic excavator at the designed spacing and depth below the soil surface. Saline drainage water is disposed off under gravity or by pumping from a sump well into link/main drains, streams, rivers or evaporation ponds. The technology package includes cleaning of surface drains, construction of field bunds and land grading, installation of SSD system, salt leaching, improved pumping operation and maintenance, selection of salt tolerant crop and cropping sequences, improved irrigation management and cultural practices.

The SSD technology reclaims moderately to highly waterlogged saline or saline-sodic areas in alluvial and black soil regions in 2-3 year period. The soil salinity (ECe) reduces from

10-52 to 2-5 dS/m in 2-3 years period after implementation of SSD system. This technology has larger implications in terms of increasing cropping intensity, crop yields and farm income by 25-80%, 30-120% and 200-300% for paddy, wheat, cotton and sugarcane in eight states of India leading to B/C ratio of 1.5-3.2 and internal rate of return of 20- 58%. It also generates additional employment around 128 man-days per ha per annum. Up to June 2024, the technology has reclaimed 75,335 hectares waterlogged saline alluvial and black/ heavy soils in eleven states (i.e. 11,384 ha in Haryana; 4,000 ha in Punjab; 16,500 ha in Rajasthan; 1,300 ha in Gujarat; 7,350 ha in Maharashtra; 33,700 ha in Karnataka; 1,200 ha in Andhra Pradesh and Telangana, and 1,000 ha in three other states) under various national developmental schemes. Farmers of Maharashtra, Karnataka and Gujarat and have paid the cost of SSD technology at their own for reclamation of salt affected soils realizing the economic benefits of the technology for cash crop cultivation (sugarcane, cotton, turmeric, etc). More than 280 farmers have installed SSD systems on their farms having an area ranging from 0.5 ha to 20 ha. About 15-16% of total area, reclaimed in three states, are contributed by farmers own fund.

SSD installation cost

Cost of SSD systems is quite high and varies greatly from the state to state depending on climate, drain depth and spacing, layout and design, machinery to be used, crop factors, outlet condition and so on and so forth. The cost of SSD system on 2023 price level is about Rs. 122,000-132,500/- per hectare for alluvial soils with pumped outlet (Drain spacing, 60 & 67 m and depth, 1.5 m), and Rs. 188,500/- per hectare for heavy soils/vertisols with gravity outlet (drain spacing, 20 m and depth, 1.2 m). The drainage material cost and mechanized installation cost are 50-55 and 31-33% of the total system cost, respectively. The SSD technology has been implemented through public-private partnership (PPP) mode for large scale reclamation in Maharashtra and Karnataka for doubling the crop yield and farmers' income from waterlogged saline alluvial and heavy soils. Twenty-five drainage contractors from Maharashtra and Karnataka, and about 160 officers from state line departments of Haryana, Punjab, Maharashtra, and Karnataka have been trained for designing and implementing SSD technology, and post-project operation and maintenance. About 5,000 farmers of Haryana, Punjab, Maharashtra, Karnataka and Gujarat have been trained for efficient operation and maintenance of SSD systems.

Success stories

Looking to the potential of SSD systems, this technology was implemented at community scale in 8 states of the country involving multi-stakeholders. The Success Stories of Haryana, Maharashtra and Karnataka are presented below.

Haryana

Haryana state is facing twin problems of irrigation induced water logging and soil salinity. During the year 2020 the area under critical water logged saline soils (water table depth < 1.5 m) was 69,788 hectares. However, the recent estimate suggests that the extent of saline soils in the state has increased to 1.45 lakh hectares. The soil salinity resulted in annual production loss of 1.2 lakh tonnes with corresponding monetary loss of Rs 124.00 crores. These waterlogged saline soils are distributed mainly in 12 districts (Rohtak, Jhajjar, Charkhi Dadri, Sonipat, Bhiwani, Hisar, Jind, Kaithal, Fatehabad, Sirsa, Palwal and Faridabad) located in the Western Yamuna, Bhakra and Agra canal commands of the state. About 11,384 ha waterlogged saline lands in Haryana have been reclaimed through SSD technology till June 2024 which benefitted 8,266 farmers by doubling crop yield and farm income.

In Haryana, 47 villages representing to 200 blocks of 11 districts are covered with this technology. The Jagsi cluster of Sonipat district in the western Yamuna canal command receiving average annual rainfall of 650 mm. The area is predominated by rice-wheat, cotton-wheat and cotton-mustard cropping systems in alluvial soil with sandy loam texture. Total area affected by waterlogging and salinity in Jagsi village and Sonipat district was 950 ha and 2,892 ha, respectively.

To reclaim waterlogged saline soils, Haryana Operational Pilot Project (HOPP), ICAR-CSSRI, village Panchayat and farmers were the stakeholders who took part in planning, execution and operation and monitoring of SSD systems. The role of HOPP project authority was to select the sites jointly for SSD project, site survey and project design and preparation of DPR. The technical guidance in site identification, approval of SSD design and layout and monitoring and evaluation were made by CSSRI. The sensitization of farmers and providing farmers' training were responsibility of CSSRI team whereas formation of farmers' drainage society, obtaining farmers' agreement for project implementation, implementation of SSD system, supply of pump set and diesel fuel, operation and maintenance for the first year and transfer of completed drainage blocks/project to farmers was done by HOPP and Soil Conservation unit. Some selected sites in Haryana where SSD was intervened with success are shared further.

The intervention of SSD technology in Jagsi village was done for 6 drainage blocks (S-25 to S-30) while for 4 drainage blocks (S-31 to S34), works were carried out in May 2011. The total area reclaimed with SSD in village was tuned to 430 ha (10 drainage blocks). From the analysis of periodic data of water level and salinity, and soil ECe and pHs at SSD site, Jagsi from the pre to post project period, it was concluded that there has been significant periodic changes in water table and soil salinity after implementation of SSD project (Table 1; Figure 1).

Table 1: Periodic changes in water level and salinity in Jagsi site.

Parameter	Pre-project	Post- project
Water table depth, m	1.05-1.50	2.05-2.45
Water salinity (dS/m)	3.90-4.30	2.5-3.00
Soil ECe (dS/m)	4.30-27.6	2.62-5.23
Soil pHs	7.53-8.16	7.81-8.20



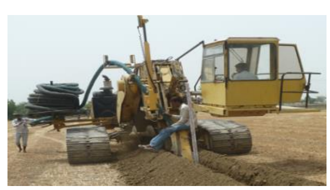


Figure 1: Pre-project waterlogged saline soil with shallow water table (left), execution of SSD project (third), post-project bumper wheat crop at Jagsi site (right).

From the pre-project Landsat imagery of taken at different intervals, it was found that 63-80% area in 10 drainage blocks at Jagsi site (Sonipat) was affected by moderate soil salinity (EC >8 dS/m) on 12 February 2007 (Table 2). After the SSD intervention in 2009 and 2011 (post-project period), the distribution of soil salinity was reduced to 26% of the area on 4 April, 2011 in imagery and disappeared completely from Landsat imagery of 28 May 2014 and 22 February 2020. This is mainly attributed due to the proper pumping of saline water through SSD systems by the suffering farmers who owned the salinity affected lands. After about 2 years of gap, the drainage water was also reused for irrigation by farmers during the needs both in rice and wheat in Jagsi.

Table 2: Periodic changes in spatial distribution of surface soil salinity at Jagsi site.

Site	**Distribution of surface soil salinity using satellite data (%)**		
	Pre-project	Post- project (April 2011)	Post- project (May 2014 & 2020)
Moderate salinity	63-80	26	0

Table 3: Periodic changes in cropping systems and cropping intensity of which site.

Cropping systems	**Cropping intensity (%)**	
	Pre-project	Post- project
Rice-wheat	80	168
Cotton-wheat	100	170
Cotton-Mustard	125	170

Cropping intensity in rice-wheat, cotton-wheat and cotton-mustard systems improved significantly from 80 to 125 to 168 to 170% (Table 3). The recorded yields of rice and wheat was observed to increase in the range of 3.50 to 4.2 and 4.90 to 5.64 t/ha, respectively at Jagsi site during *Kharif* 2017 and *Rabi* 2016-17. This technology has benefitted 290 farmers' owning 430 ha salt affected lands. To make pumping of saline water effective and manage the entire process at farmers' level, 10 farmers' drainage societies were formed. Out of these a total of 4 societies became more effective who could deliver the jobs in better way. The major constraints experienced at this location were the poor collection of farmers share for diesel fuel required for effective operating pumping unit, and irregularity meeting of drainage society.

Maharashtra

In Maharashtra, SSD works were implemented in Sangli district under RECLAIM-I & II and RECLAIM–III (RKVY). A SSD project under RECLAIM-III (RKVY) was designed and intervened in 362 ha of at Urun Islampur village of Sangli district of Maharashtra in 2013-14 with support from RKVY (Rashtriya Krishi Vikah Yojna). The soil of Urun Islampur is waterlogged saline-sodic vertisols in the commands of cooperative and private lift irrigation projects operated by farmers in the Krishna river catchment. This was implemented by Rex Polyextrusion Pvt. Ltd in coordination with Small Scale Irrigation Unit under Water Conservation Department, Govt. of Maharashtra. Out of total of 362 ha, an area of 190 ha benefitting 224 farmers was monitored for impact evaluation. The analysis of water table data indicated that water table was near the ground surface (0.3-0.5 m) and soil salinity was in moderate class (ECe< 15 dS/m). The design of SSD system, approved by CSSRI, was installed in the identified saline black soil (Figure 2). Lateral pipe at spacing 30 m and depth of 1.0-1.5 m (average 1.2 m), and depth of collectors ranging from 1.50 to 2.0 m (average 1.75 m) were installed. The outlet type was gravity for disposing off the drain water into a surface drain. Lateral pipes were perforated PVC material of 80 mm diameter and non-perforated collector pipes are of 80-100 mm dia. Lateral pipes were installed by small drainage trencher and collector pipes by hydraulic excavator suitable for black soils.

Although, refinement of SSD technology with narrow drain spacing has led to over-drainage in longer run which was further managed by implementation of controlled drainage provision. In controlled SSD system, 80 & 100 mm diameter non-perforated PVC pipes are used for collector installed for every 2.5-4.0 ha area (for 4-6 farmers) with a control valve at the collector pipe end and inside the manhole (900 mm dia RCC pipe) for regulating drainage discharge from each collector or at lateral pipe level by the farmers. Pipe main drain was installed using HDPE Double Wall Corrugated (DWC) pipes with diameter varying from 135 to 500 mm towards the outlet to dispose off saline drainage water from the project area to nala/ river.

Fig. 2: Pre-project field condition, execution of SSD technology, and saline water flow in collectors to open drain (top row); Bumper sugarcane, cotton and turmeric crops after SSD technology (bottom row)

Table 4: Pre and post-project change in water table, soil salinity & sodicity at Urun Islampur site

parameter	Phase	
	Pre-project	Post- project
Water table depth (m)	0.5-0.60	1.85-2.00
Soil salinity (dS/m)	3.4-16.3	1.2-3.13
Soil ESP (%)	7-17	5-6
Sugarcane yield (t/ha)	40-55	95-110

After a gap of 5 years of SSD intervention, the impact of the project was assessed. The results indicated that sugarcane, turmeric, cotton and others major crops could be grown successfully from the first year of SSD installation itself by the farmers (Fig. 2). Earlier, these crops were not performing well in the same fields. Water table, soil salinity and soil ESP reduced significantly from 0.55 to 1.90 m, 3.4-16.3 to 1.20-3.13 d S/m and 12 to 5%, respectively (Table 4). Overall, there was a significant increase of yield by 80 to 150% in sugarcane, turmeric, and cotton crops. The benefitted farmers have interacted with the scientists of CSSRI and shown their satisfaction for the impact of SSD technology. Before the intervention of SSD technology, sugarcane yield was 50-55 t/ha and after implementation of SSD system, the crop yield could increase to 80-85 t/ha and 95-110 t/ha from first year and second year, respectively. This technology was intervened with support of Central Government, State Government and the farmers in the ratio of 60:20:20 under the RKVY project. Ultimately, SSD technology had a benefit-cost ratio ranging from 1.5 to 3.1 and internal rate of return (IRR) of 20-56% and payback period of 2-3 years.

During the process of intervention and reclamation of saline soils, there was a problem of clogging of lateral pipe by the sugarcane roots as reported by farmers. It was found that water leakage at lateral and collector junction was responsible and this was fixed accordingly. Realizing the quick returns of SSD technology by farmers in terms of reducing water table and soil salinity control, enhancement of crop yields (income), to the date, about 260 farmers have installed SSD systems on their farms having an area ranging from 0.5 ha to 20 ha with their own funds. Farmers' drainage societies are formed for sensitizing on benefits of SSD technology, capacity building and maintenance of SSD system as no pumping operation is involved. Farmers have refined the drainage system by introducing close lateral spacing at 15-20 m for faster reclamation, however, it leads to over drainage in longer run. Here lies further refinement in technology by involving all the stakeholders. During the last year, SSD installations have picked up in black cotton soils of Maharashtra in a very impressive way.

Karnataka

Insights gained from the SSD technology in various parts of India could help to move in Karnataka state. The intervention of SSD technology was made at Ugar Budruk of Belgavi district (Formerly Belgaum) of Karnataka. The total area of waterlogged saline vertisols was 925 ha owned by over 605 farmers in the lift irrigation command of the Krishna River. By involving the state agencies and farmers, the SSD technology was successfully implemented in partnership mode in Karnataka. The project was monitored for a period of 3-4 years for impact assessment. It was found that the yield of sugarcane crop after SSD system in new planted and ratoon crops could increase to 119.0 and 82.0 t/ha, respectively as compared to those of 42.0 and 26.0 t/ha in the pre-SSD phase. Overall, sugarcane yield increased by up to 300%. The benefit-cost ratio of SSD technology ranged from 1.5 to 3.2 and internal rate of return (IRR) was 20-58% with payback period of 2-3 years. A total of 605 farmers have benefitted from SSD technology. Refinement was made in the drainage system by introducing close lateral spacing at 15-20 m for faster reclamation of waterlogged saline-sodic soils. Although, this refinement has led over-drainage in longer run which was further managed by implementation of controlled drainage. Subsequently, several SSD projects with or without controlled drainage have been implemented in 8 districts under Tungabhadra

Project (TBP), Upper Krishna Project (UKP) and other irrigation command areas in Karnataka state.

Conclusions

The SSD technology has larger potential to reclaim and manage waterlogged saline soils across the different agro-climatic regions of the country. It has large scale benefits in terms of enhancing crop productivity, famers' income and agriculture sustainability directly. In Haryana, inadequate capacity building of farmers for effective pumping operation and maintenance, and delay in supply of pumping unit, transfer of drainage blocks to farmers after completion of SSD installation were the impediments in utilizing full potential of the technology. From the community level, the role of farmers in terms of monitoring and evaluation, and refinement during the reclamation process was relatively poor. The landscape in Maharashtra and Karnataka where gravity outlets are easily available, even the individual farmers have realized the benefits of SSD technology and come forward to adopt it using their own funds. This technology has been further refined into controlled drainage for addressing excessive drainage from SSD systems with narrow spacing and open drain pollution.

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CHAPTER 6

Management Practices for Coastal Salinity

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The coastal agro-ecosystem of the country occupies an area of about 10.8 million ha and is spread over the 7517 km long coastline along the Bay of Bengal in the East coast and Arabian sea in the West coast. The coastal zone of the country covers 9 states (*West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Maharashtra, Gujarat and Goa*), 2 union territories (*Puducherry and Daman & Diu*) and 2 groups of islands (*Andaman & Nicobar* group in the Bay of Bengal and *Lakshadeep & Minicoy* group in the Arabian sea) in the country. The hinterland of the coastline has varied geomorphic and topographical features of mountains, valleys, coastal plains, riverine systems, climatic conditions, soil conditions and water budgets and a wide range of cultivated crops. It also supports diverse vegetation ranging from rich tropical rain forests to coastal mangroves. The vast deltaic region on the East coast forms the rice-bowl of the country. Agriculture, agroforestry, silviculture and pisciculture are few of the major activities in this zone, but the productivity is very low due to a variety of constraints which warrants special attention. The degradation of the soil and water of coastal areas is caused due to phenomena like saline water flooding following cyclonic storms and the presence of shallow brackish ground water table near the soil surface due to the influence of seas or saline water rivers as in the delta region of Ganga (Sundarbans), Mahanadi, Godavari, etc. and other major rivers. The degraded soil and water of the coastal region will be further endangered due to sea level rise following global warming.With proper scientific planning and management of the vast natural resource of the coastal region it is possible that the agricultural productivity of the degraded soil and water can be considerably increased. Based on research on coastal saline soils, several technologies have been developed and tested at research farm as well as in farmers' fields by ICAR-CSSRI, RRS, Canning Town. Following are the excerpts of some of those relevant technologies suitable for coastal saline region of West Bengal and similar other areas.

Reducing salinity build up in coastal saline soil through mulching/cover crop

The salinity build up in soil can be controlled by:

- Growing crops with large foliage cover rather than leaving fallow.
- Mulching of soil during dry season; rice husk and straw, organic farm waste or any other suitable materials can be used as mulch.
- When mulching materials are not available, the soil is to be kept ploughed instead of leaving unploughed.
- Ploughing of soil on initiation of pre-monsoon shower and sowing of green manuring like *Sesbania.*

	
Cover crop: Sesbania	Paddy straw mulch
Management of salinity build up through cover crop and paddy straw mulching	

Benefits: Less buildup of soil salinity, increase in yield of *kharif* crops by 25-30 % and improvement in soil fertility

Enhancing productivity of acid sulphate soil in the coastal areas

Acid sulphate/ acid saline soils (pH < 4.0) are highly under-utilized and show very poor yield of crops. Good yield can be obtained from such soils by applying lime @ 50% of recommended dose and higher P fertilizer (double or more of recommended dose) along with green manure or other organic manures. Oyster shell can be used as locally available cheap source of lime. Rock phosphate can also be used as an alternative cheap source of P.

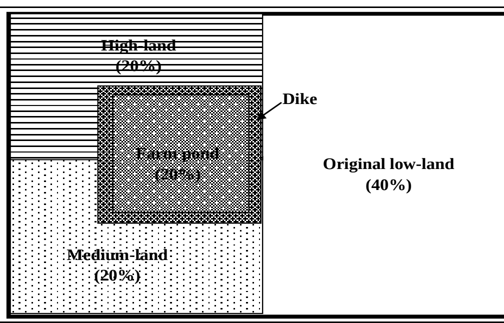
Rice production on acid sulphate soil with lime, higher doses of P fertilizer & green manure

Benefits: Improvement in soil fertility and crop productivity by 100% or more.

Land shaping techniques for salt affected coastal lands

Farm pond technique

About 20% of the farm area is converted into on-farm reservoir (OFR)to harvest excess rainwater. The dug-out soil is used to raise the land to form high and medium land situations besides the original low land situation in the farm for growing multiple & diversified crops throughout the year instead of mono-cropping with rice in *Kharif* season. The pond is used for rainwater harvesting for irrigation and pisciculture. Poultry/ livestock farming can also be practiced in the farm along with crops and fishes with the use of pond water. The high land free from water logging in *Kharif* with less salinity build up in dry seasons and thus can be used for multi & diversified crop cultivation throughout the year.



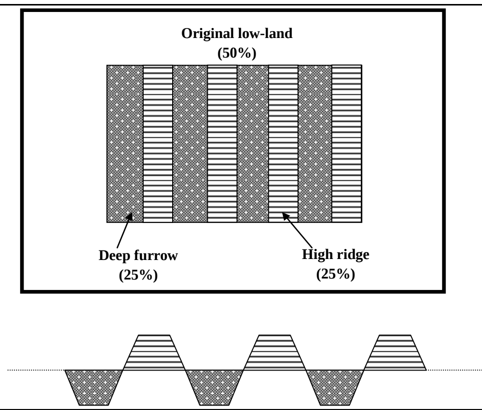
Schematic diagram

Crop + fish+ livestock farming

Farm pond land shaping technique

Deep furrow and high ridge technique

About 50 % of degraded farm land is shaped into alternate high ridges (1.5 m top width x 1.0 m height x 3m bottom width) and deep furrows (3m top width x 1.5 m bottom width x 1.0 m depth). The rainwater is harvested in the deep furrows and the harvested rainwater is used for initial irrigation during *Rabi*. The water stored in furrows is also used for fish cultivation and supplementary irrigation in *Kharif*, if required. Due to higher elevation and presence of fresh rain water in furrows these ridges remain free of waterlogging during *Kharif* with less soil salinity build up in dry seasons. The ridges are used for cultivation of vegetables and other horticultural crops/ multi-purpose tree species (MPTs) round the year instead of mono-cropping with rice in *Kharif*. Remaining portion of the farmland including the furrows is used for growing more profitable paddy + fish cultivation in *Kharif*. During *Rabi*/ summer season farm land (non-furrow and non-ridge area) is used for low water requiring crops.

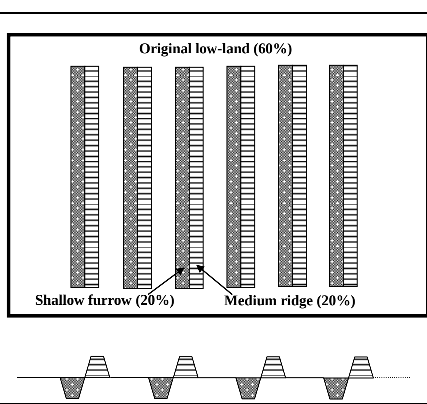


Schematic diagram Crop+ fish cultivation

Deep furrow and high ridge land shaping technique

Shallow furrow & medium ridge

About 75 % of the farm land is shaped into medium ridges (1.0 m top width ×0.75 m height × 2.0m bottom width) and shallow furrows (2.0m top width × 1.0 m bottom width × 0.75 m depth) with a gap of 3.5m between two consecutive ridges and furrows. The furrows are used for rainwater harvesting and paddy-fish-cultivation during *Kharif*. The cropping schedule is similar to that followed in deep furrow and high ridge except rice can be grown in furrows in *Rabi*/summer with lesser supplementary irrigation.



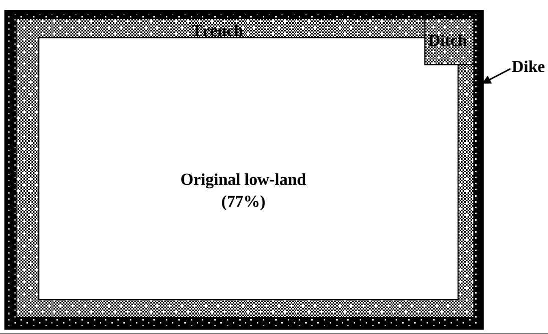
Schematic diagram Paddy +fish+ MPTs cultivation

Shallow furrow & medium ridge land shaping technique

Benefits: Creating irrigation resources with harvested rainwater, improvement in cropping intensity upto 200%, reduction of soil salinity and improvement of surface drainage, multi-cropping with crops, fishes and animals, improvement of income by 6-9 times, employment generation.

Paddy-cum-freshwater fish cultivation

In this technique, trenches (3m top width x 1.5 m bottom width x 1.0 m depth) are dug around the periphery of the farm land leaving about 3.5m wide outer from boundary and the dugout soil is used for making dikes (about 1.5 m top width x 1.0 m height x 3m bottom width). A small ditch is dug out at one corner of the field for sheltering of fish when water will drain out in trenches. Dikes protected free flow of water from the field and trenches are used for harvesting rain water. The dikes are used for growing vegetables and / or green manuring crops/fruit crops/multi-purpose tree species (MPTS) round the year. Remaining portion of the farm land including the trenches is used for more profitable paddy + fish cultivation in *Kharif*. The farm land (non-trench and non-dike area) is used for low water requiring crops during dry (*Rabi*/ summer) season with the rain water harvested in trenches. Deep trenches in the field provided better drainage condition in the field during the non-monsoon months.



Schematic diagram

Paddy +vegetables+ fish cultivation

Paddy-cum-fish cultivation land shaping technique

Paddy-cum-fish + brackish water fish cultivation

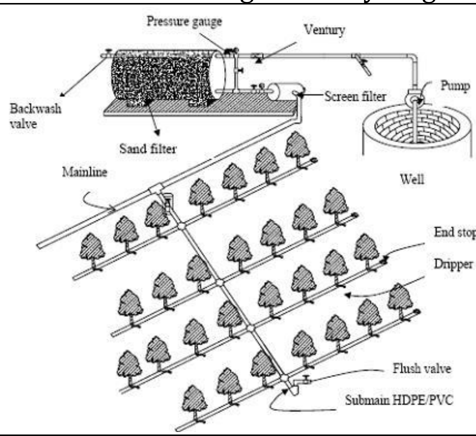
Land is shaped as in paddy-cum-fish cultivation and crops and fishes were grown as in paddy-cum-fish cultivation during wet season. However, during winter/ summer seasons the land was used for more remunerative brackish water fish cultivation with the ample supply of surface and sub-surface brackish water available in the area. After brackish water fish cultivation, the same land was also used for normal paddy-cum-fish cultivation during wet season on allowing few initial pre-monsoon showers to wash away the salts from soil. This model can be used only to the farm situation where there is good provision of outlet of pump out brackish water from the field after brackish water fish cultivation and the wash out of the field from pre-monsoon rains.

Rice + fish cultivation in *kharif* season

Paddy-cum-fish + brackish water fish cultivation land shaping technique

Efficient water utilization through drip irrigation system

Fresh water scarcity is the main problem for cropping in the non-monsoon period in coastal region. The drip system can be efficiently used for orchard (Coconut, mango, guava, banana, sapota, etc.), growing crops like vegetables (tomato, brinjal, cauliflower, cabbage, chilli, knoll-khol, potato etc.), field crops (sugarcane, cotton etc.) and others (berries, melons, alfalfa, flowers etc.) with the limited available fresh water in the *Rabi* season. Drip system is designed based on water source, type of soil, crops and area of cultivation. For cultivation of vegetable crops like okra, lateral spacing will be 70 cm and crop spacing will be 30 cm. The system can be operated with a one HP pump. Salinity of water may be less than 1.5 dSm^{-1}.The irrigation may be given at IW/CPE ratio 1.



Schematic diagram

Okra crop under drip irrigation

Drip irrigation system

Benefits: Saving of irrigation water by 40~50%, increase in crop yield by more than 20, 60 %saving of labour

Summer rice crop establishment through drum seeding of pre-germinated seeds

The eight-row drum seeder is 1.8 m wide, the diameter and length of each drum are 0.18 m and 0.25 m, respectively. Distance between rows 0.20 m. Each drum has a capacity of 2 kg of pre-germinated seeds, however, the drums should not be filled completely and about 1/3rd of each drum should be kept empty for easy flow of seeds through the perforated holes. The seeds are soaked in water for a day and then incubated for another 24 hours for sprouting. To prevent sprouts intermingling with each other, sprout length should not be more than 7-8 mm. The sprouted seeds are air-dried in the shade for about 10-15 minutes before sowing to facilitate proper dropping of seeds. The land is puddled as usual, leveled carefully and excess water is drained out. Drum seeder is drawn manually over the puddle soil with triangle marks on the drums pointed towards the pulling direction. The field is not irrigated for 2-3 days after sowing to allow roots to anchor and then the depth of water is increased gradually as the seedlings grow.

Drum-seeding | Pre-germinated rice seeds

Drum-seeding of pre-germinated rice seeds on the puddle soil during summer season

Benefits: Reduction in cost of cultivation by about 10%, no need of preparation of nursery bed, increase in grain yield by about 33%, less labour requirement.

Improved crop establishment and nutrient management

Optimum main field management practices like balanced fertilizer dose of (50-20-10 kg N-P_2O_5-K_2O + 5 t FYM ha^{-1}), 2 seedlings per hill, spacing of 15 cm x 15 cm and rice variety Amalmmana. Rice variety Amal-Mana (developed by CSSRI RRS Canning Town), a promising variety for *Kharif* season with a grain yield potential of about 4.0 - 5.0 t ha^{-1}, 145-155 days duration, a height of 130-140 cm, long slender grain, and salt tolerant (4.0-6.0 dSm^{-1}). New improved rice variety Amal-Mana has the capability to withstand abiotic stresses prevailing in the coastal agro-ecosystems of rice-based lowlands, and to also provide higher and stable yields, especially when coupled with above improved agronomic practices. These cost-effective approaches on management options have great potential of enhancing rice yield in stress-prone rainfed coastal areas.

Amal-Mana with improved agronomic management practices

Benefits: Increase in grain yield by 70% and increase in net return.

Improved nursery management for wet season (Kharif) rice in coastal areas

Farmers of the coastal region often practice suboptimal nursery management,which leads to reduced plant population due to seedling mortality and hence, poor yields (≈ 1.5-2 t ha^{-1}), below the national average. A lower seed density of 25 g m^{-2} with application of 50-30-15 kg N-P_2O_5-K_2O + 5 t FYM ha^{-1} produce healthy and robust seedlings with high seedling vigour. The full dose of phosphorus and potassium and 50% of nitrogen were applied as basal at sowing. The rest of nitrogen was applied in two equal splits at 15days of sowing and 7days before uprooting. Forty-days-old seedlings of the improved rice variety Amal-Mana produce higher yield than 25-days-old seedlings.

Kharif rice seedlings with improved nursery management practices

Benefits: Increase in seedling vigour and grain yield over farmer's practice by about 30% and increase in net return.

Direct seeding technology for wet season rice

Rainfed shallow lowland sometimes suffers from flash flood water stagnation for 8 to 10 days. The problem of stagnant flooding in coastal areas generally coincides with transplanting of rice, which is the establishment stage of the crop and damage occurs as the crop is still in the transplanting shock stage. To solve this problem, direct seeding technology can be practiced. Before the on-set of monsoon during last week of May, lines are made 20 cm apart after ploughing the field thoroghly and rice seeds are sown dry in the field. With the first shower of monsoon, the seeds with the heat of the soil start germinating. About 15 days after sowing thinning and gapfilling is done to maintain an optimum plant population. Selective herbicide is used to reduce the weed population in the direct seeded plot.

Dry direct sowing of rainfed lowland rice during kharif season

Benefits: Reduction of risk of crop damage by waterlogging, reduction of cost of cultivation by about 65%, increase in net return by about 46%.

Modified System of Rice Intensification (MSRI) for summer rice

The entire set of management practices of SRI as evolved in other rice production environments are not suitable under coastal salt affected areas. The MSRI includes nursery in raised beds, with irrigation facility to wash out salts, optimum FYM application. Under the salinity stress condition, the seedling stage of rice is very sensitive, therefore very young seedling as suggested did not sustain this stress, similarly the problem of mortality of single seedling transplanting per hill needs to be addressed. Relatively older seedling (15-18 days old) instead of 8-12 days old seedling transplanting and gap filling in case of mortality should be done at appropriate stage to fill the hills, which fall open due to mortality of seedlings. Extra water is used for washing out the salts from the root zone. Application of FYM along with fertilizer, cultivation of *Azolla* along with rice, use of *Azospirillum*, Phosphate Solubilizing Bacteria and *Trichoderma*

Cultivation of rice during summer season following Modified SRI method

Benefits: Maintenance of optimum plant population, increase in grain yield by about 33% and increase in water use efficiency by 19%.

Zero Tillage Potato Cultivation with Paddy Straw Mulching

Mono-cropped coastal saline soils can be converted into multiple cropping through the adoption of zero tillage (ZT) potato technology. In this practice, potato is sown in the wet field just after the harvesting of the preceding monsoon or *Kharif* rice. As a result, there is efficient use of residual soil moisture. The tubers are sown at 10-15 cm hill to hill and 30-35 cm row to row distance. The tubers are covered with dry compost/farm yard manure (FYM), and then NPK fertilizer (10-26-26) is applied. Over the compost a thick layer (15-20 cm) of paddy straw is laid to cover the entire area. Foliar spray of water soluble compound fertilizer such as 19-19-19 kg N-P_2O_5-K_2O is given one month after sowing. Second spray is given at one and half months after sowing with the above fertilizer and third spray is given with water soluble fertilizer 13-0-45 kg N-P_2O_5-K_2O for better tuber growth. Three irrigations are required under ZT method, whereas conventional cultivation practices require five to six irrigations to raise a successful crop. Early sowing and harvesting achieved by this practice helps in taking another *rabi* pulse crop like green gram.

ZT potato with paddy straw mulching

Benefits: Significantly reduces the irrigation requirement, efficient use of residual soil moisture, prevent soil salinity development and improve soil health, better quality of produce, increases the cropping intensity, yield and profit of farmers. The mean tuber yield is about 18.0 t ha^{-1} under conventional tillage and about 19.0 t ha^{-1} under ZT cultivation, with cost of cultivation of Rs. 1,06,000 ha^{-1} and Rs.73,000ha^{-1} under conventional and ZT technology, respectively.

Cultivation of vegetables in paddy field by bag technology

This technology increases the income of marginal farmers through intensification of low land rice fields by introduction of vegetable crops. Plastic bags of 100 kg capacity are filled with 90 kg soil, 10 kg FYM along with basal fertilizers. Climbing types of vegetable crops such as cucumber and bitter gourd were grown in these bags. The bag spacing should be at least 3m x 3m and were kept more than 1ft above water level. Bamboo poles were erected in the 4 sides and the entire area was covered by the plastic net (fishery net), so that the vegetables cover the area. Top dressing of urea solution was done with 50 g in 3 splits per bag.

Cultivation of vegetables in waterlogged rice fields increase income of small and marginal farmers in coastal salt affected region

Benefits: Improvement in family nutrition and crop diversity. This technology reduction in risk of rice crop failure. Increase in income substantially to at least ₹ 1,12,585 ha^{-1} by this technology from the existing level of ₹ 35,374 ha^{-1} from sole rice cultivation.

Improved salt tolerant rice varieties

Rice is the most important crop during both *Kharif* and *Rabi* seasons in the coastal areas of India. Waterlogging or submergence as well as salinity during *Kharif* and soil water salinity along with scarcity of good quality of irrigation water are the major constraints for rice cultivation in this region. To cope up with this situation, improved tolerant varieties have been developed at ICAR-CSSRI, RRS, Canning Town (Table 1).


Amal-Mana


Bhutnath

Improved salt tolerant rice varieties

Table 1. Improved tolerant varieties of rice

Variety	Plant height (cm)	Maturity (days)	Tolerance to salinity (ECe) (dS/mm)	Grain type	Grain yield (q/ha)	Remarks
Mohan (CSR 4)	75	125	6.0-8.0	Medium bold	40-45	Photo-insensitive
Canning 7	70-77	130	6.0-8.0		33-40	
CST 7-1	90-95	135	6.0-8.0		45-50	Photo-sensitive
Sumati (CSRC (S) 2-1-7)	95-105	145	6.0-8.0	Long slender	45-50	
Utpala (CSRC (S) 11-5-0-2)	90-100	145	6.0-8.0		40-45	
Bhutnath (CSRC (S) 5-2-2-5)	100-115	145	6.0-8.0		40-50	
Amal-Mana (CSRC (S) 7-1-4)	130-145	155	4.0-6.0		35-40	
CSR 6	Tall *indica*	150	6.0-8.0		30-35	
CSRC (S) 21-2-5-B-1-1	90-100	140	4.0-6.0	Medium bold	35-40	

CHAPTER 7

Salts-affected *Vertisols* and Associated Soils: Genesis, Characteristics and Sustainable Management

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Salinity development in the country charts a parallel path with irrigation development. As inadequate attention has been paid in the planning stage of irrigation projects, the problems of water logging and salinity have increased at an alarming rate in canal command areas. Degraded land *i.e.* soils affected by salts lost its productivity. Among all the causative factors responsible for salinization, water is one of the major factors for causing it and therefore water management is most important aspect for restoring the productivity of these salt affected soils. Black cotton soils, taxonomically classified as *Vertisols* are montmorillonite-rich clays soils spread over in about 76.0 million ha (Mha) land area which is 22% of the total geographical area of the Country. *Vertisols,* are found mostly in peninsular region of India extending from 8°45'N to 26°0'N latitude and 68°0'E to 83°45'E longitude (Murthy *et al.*, 1982). These soils are distributed in the state of Maharashtra (24.2 Mha)**,** Madhya Pradesh (21.2 Mha), Andhra Pradesh (9.4 Mha)**,** Karnataka (5.8 Mha), Gujarat (4.9 Mha), some parts of Tamil Nadu (2.6 Mha), Rajasthan (1.1 Mha), Bihar and Odisha. These soils are potentially fertile soils having high clay content, cation exchange capacity and good reserve of potassium. *Vertisols* also possess good water holding properties and supports *rainfed* agriculture. But due to some of intrinsic properties like poorly drained and low hydraulic properties cause constraint in crop production. The development of salinity and sodicity in *Vertisols* is generally associated with poor drainage and water logging. The advent of new irrigation projects and unscientific use of irrigation water in the command area is responsible for secondary salinisation of these black cotton soils. Extent of salt affected *Vertisols* and associated soils having different degree of salinity/sodicity is about 1.1 Mha in the country. Restoration of productivity of salt affected *Vertisols* and associated soils and prevention of further degradation is need of the hour to achieve land degradation neutrality.

Salt affected *Vertisols* and associated soils in India

In India the extent of salt affected *Vertisols* and associated soils having different degree of salinity/sodicity is about 1.1 Mha which is largely distributed in Maharashtra (0.54 Mha), Gujarat (0.12 Mha), Karnataka (0.29 Mha) and Madhya Pradesh (0.034 Mha). Advent of new irrigation projects and unscientific use of irrigation water would further aggravate the problem in the region. Black cotton soils (*Vertisols* and associated soils) due to their inherent properties like poor hydraulic conductivity, low infiltration rates, high clay content and narrow workable moisture range pose serious problems for arable farming.

Salt affected *Vertisols* and associated soils in Gujarat

The black cotton soils of Bara tract in Sardar Sarovar canal command of Gujarat have significant concentration of soluble salts in the sub-soil, though the concentration is low in surface layer (Chinchmalatpure *et al.,* 2011). Salt accumulation was observed in surface layer when saline ground water (EC_{iw} of 10.6 dS/m) was used for irrigation on saline *Vertisols*. Accumulation of salts in surface horizon took place in soils which were irrigated with saline water and also likely to accumulate in the landscape due to saline ground water combined with the influence of climate i.e. high temperature and evaporation, upward flux and landscape features (ridge and furrow) and human activities like amount of irrigation water, fertilizer applications etc. The development of secondary salinization as groundwater salts contribute to secondary soil salinity through saline water irrigation from tube well which was observed in soils studied in Bara tract during pre-canal irrigation (Table 1). This salinization was observed in the soil profiles irrigated with saline ground water but at the same time when soils irrigated with fresh canal water, showed reduction in soil salinity. Although yield of crops grown in the study area showed improvement due to availability of good quality water from canal but excess and un-judicious use of canal water for irrigation leads to increase exchangeable sodium percentage (ESP) of soils and formation of sub-soil sodicity in the lower horizon which indicated the initiation of pedogenic process *i.e.* sodification. The different properties of soils under *rainfed* as well as irrigated conditions are given in the table 1. Bulk density of soils under canal irrigation (1.6 Mg m^{-3}) is higher than those of soils under tube well irrigation/*rainfed* condition (1.4 Mg m^{-3}) (Chinchmalatpure *et al.* 2015, 2018) whereas hydraulic conductivity is drastically reduced in soils under canal irrigation. Therefore, farmers of the Bara tract area are advised for judicious use of canal water. To avoid further degradation of soil resources *i.e.* sodification due to irrigation using canal water having low salt concentration on these saline *Vertisols*, suitable water and crop management practices like conjunctive use of saline water with canal water, cultivation of low water requiring crops, use of pressurized irrigation system are to be adopted.

Table 1. Variation in properties of *rainfed* cultivated, tubewell water irrigated and canal irrigated soils in Bara tract

Soil properties		Tube well irrigated	Rainfed cultivated	Canal irrigated
Clay content (%)	Range	55.0 – 72.0	54.0-72.0	52.0 - 73.0
	Mean	58.0	59.0	56.0
	SD	0.56	0.45	0.59
CEC, cmol(p^+)/kg	Range	36.4 - 64.9	33.0-56.8	37.3 - 51.2
	Mean	45.2	42.0	46.0
	SD	0.40	0.52	0.58
Organic carbon (%)	Range	0.24 - 0.48	0.12-0.51	0.24 - 0.43
	Mean	0.28	0.26	0.28
	SD	0.10	0.12	0.07
pH_2	Range	8.0 - 9.2	7.9-9.0	7.9 - 9.2
	Mean	8.2	8.4	8.6
	SD	0.42	0.39	0.40
EC_e, dS/m	Range	0.6 - 3.3	0.52-1.76	0.26 - 1.72
	Mean	1.98	0.86	0.80
	SD	1.02	0.45	0.35
ESP	Range	1.5 - 10.3	2.2-13.9	2.27 - 18.50
	Mean	4.62	4.56	5.12
	SD	4.01	3.88	4.21
	Range	1.3 - 1.5	1.34-1.45	1.4 -1.8

Bulk density (Mg/m^3)	Mean	1.40	1.40	1.60
	SD	0.04	0.04	0.06

Source: Chinchmalatpure *et al.* (2018)

Salt affected *Vertisols* and associated soils in Maharashtra

Varade *et al.* (1985) reported that more than 10% of irrigated shrink-swell soils in each irrigation project of Maharashtra is affected by increased salinity and sodicity. An estimate reported by Challa *et al.*, (1995) indicated that 0.6 million ha soils in Maharashtra State is under the influence of salinity and sodicity. Black cotton soils occurring in the Purna valley, covering the part of Amravati, Akola and Buldhana districts in Vidarbha region of Maharashtra and having the extent of 2.7 lakh ha area are affected by salts. This valley is an oval shaped basin drained by Purna river system. Soils along the both banks have reported to be salt affected (Adylkar, 1963). The initiation of sodification is operative in these soils in subsurface layers as a consequence of salt accumulation and its progress in upward direction along with capillary rise of soil solution during dry period (Kharche *et al.,* 2017). Sodicity development is also linked with semiarid climatic conditions that have induced the pedogenic process of calcium carbonate thereby resulting in an increase of both SAR and ESP with pedon depth. (Balpande *et al.,*1996). Kharche *et al.* (2012) ascertained the soil degradation in *Vertisols* of Purna valley and pointed out that despite low level of sodicity (ESP 4.8 to 11.1), the soils had severe drainage problems because of low hydraulic conductivity. Also notices the high amount of semctite clay leads to increase in bulk density and thus result into hard and compact soil structure. Gypsum application (@100%GR) and land configuration (Opening of furrow after two rows of cotton crop) helped in reducing ECe, ESP and SARe significantly (Sagare *et al*., 2001). Broadcasting of gypsum in powder form @2.5 t/ha (50%GR) before sowing of crop and mixing it with surface soil is recommended for increasing the productivity of cotton, sorghum and green gram as well as improving properties of sodic soils.

Black soils (*Vertisols* and associated soils) in canal command areas of Maharashtra state pose severe problems of salinity and sodicity due to non-scientific use of irrigation water coupled with cultivating high water requiring crop like sugarcane, increasing aridity problem, and restricted drainage due to reduced hydraulic conductivity. The soils of Mula canal command area in Ahmednagar district were productive soils before introduction of canal (Somavanshi and Patil, 1986) and now these soils are suffering from degradation due to salinity and sodicity (Durgude, 1999 and Kharche *et al.,* 2004). Irrigation induced degradation is causing serious quality deterioration in Mula command area (Kharche and Pharande, 2010) and Godavari command area (Dongare, 2011) which warrants the immediate attention for their reclamation and management using conventional and innovative approaches like subsurface drainage, crop residue incorporation (sugarcane trash@5t/ha), green manuring with dhaincha (Bharambe *et al*., 2001). Application of the spent wash press mud compost (10 t/ha) from sugar industries in combination with gypsum (@25% GR) has been found very effective in reducing pH, ECe, ESP, bulk density and improving other properties like hydraulic conductivity and dehydrogenase activities of saline-sodic soils, Combined use of compost with gypsum increase hydraulic conductivity which intern helps in dissolution of calcite which releases more calcium in addition to the calcium from gypsum casing flocculating effect. Restoration and reclamation of these degraded black soils for getting optimum production on sustainable basis is essentially required to achieve land degradation neutrality.

Soils of lift-irrigated non-command areas like in Sangli and Kolhapur districts of Maharashtra are degraded due to twin problem of waterlogging and salinity. Soils in this area are deep *Vertisols* and are once upon a time was very fertile and productive. Irrigation availability in these areas has changed the cropping pattern and farmers shifted from dry land farming to irrigate farming without taking into consideration the management options. With advent of irrigation scheme, the area under irrigation has been increased with profitable crop production during initial period and at present these soils are suffering from land degradation. The soils are so salinized that the production from these land is reduced to half or even nil. Some land has been left uncultivated by the farmers and become barren for years together. This resulted in decrease in land value and also farmers started migrating for want of job. The soils are sampled and analyzed for its properties. The electrical conductivity of these soils goes as high as 37.8 dS/m and pH ranged from 7.4 to 7.9. To restore the productivity of these salt affected and waterlogged black soils, subsurface drainage technology with added intervention has been found beneficial in terms of yield improvement along with enhancing fertility of soils, augmentation in soil organic carbon and improvement of soil physical properties. In some areas even after SSD installation, the desirable yield is not harvested by the farmers and soil remains salt affected. The reason for such situation is to be identified by doing soil analysis before installation of SSD for the soil parameter like pH, ECe, ESP and also leaching study in the laboratory to assess the soil behavior towards sodicity. If soil shows sodic behavior after leaching, in such situation these soils are to be treated with amendments like gypsum, press mud, etc. for controlling sodicity.

Salt affected *Vertisols* and associated soils in Karnataka

Black cotton soils occur in Deccan trap lime stone regions, in parts of Gulbarga, Bijapur and Belgaum districts and considerable areas in parts of Raichur, Bellary, Dharwad, Chitradurga, and Mysore districts of Karnataka state. These are very deep (more than 90 cm), dark brown, dark greyish brown to very dark grey or black in colour. The texture is usually clayey throughout the profile. These are calcareous and are weakly to strongly alkaline, highly cracking montmorillonitic clayey soils. These are highly moisture retentive and moderately well drained to imperfectly drained with low to very low permeability. In Northern Karnataka, where the black cotton soils predominate, irrigation systems brought about by Tungabhadra, Upper Krishna, Ghataprabha and Malaprabha projects, have ushered in a new era of intensified agriculture. But, mainly due to canal water irrigation, without adequate facilities for drainage, the yield levels have either declined or stagnated through the formation of salt affected soils. According to a soil characterization study conducted by Goroji *et al.* (2008) for both normal and salt affected soils of *Vertisols* in Dharwad district, the clay content in salt affected soils was higher than normal soils.

Decline in soil productivity due to salinity continues to be the striking concern of the farming community of northern Karnataka, where an estimated 2.2 lakh ha area is affected by various degrees of soil salinity. In Upper Krishna Project (U.K.P.) command, dominated by black soils (77 percent), an area of 27 thousand ha is salt affected, thus seriously hampering the crop production on these otherwise potentially productive soils.

About 17,153 ha land in Malaprabha and 45,527 ha land in Ghatprabha projects are affected by waterlogging / soil salinisation (CADA, 2012-13) resulting partial / total loss of crop productivity. The problem in Malaprabha canal command is limited to seasonal waterlogging and slight soil salinity whereas acute waterlogging and severe soil salinity is observed in large patches of land which became barren in Ghatprabha canal command.

Apart from canal command area, a large area mostly under sugarcane crop in non-command area irrigated by lift irrigation directly from river Krishna is severely affected by waterlogging /soil salinisation (As per Dept of Agriculture, 38,469 ha land in non-command area in Belgaum district alone is affected).

Surface irrigation induced seepage losses, low permeable black cotton soils, prevalence of high water requiring sugarcane crop due to assured marketing by adjoining sugar factories, chocked and encroached surface drains for crop cultivation and faulty/excessive irrigation in canal command/lift irrigated non-command area are the major reasons of soil salinization and waterlogging.

Reclamation and management salt affected *Vertisols* and associated soils

Cultivation of *Salvadora persica* on highly saline land

This species was found to grow well on saline black soils having salinity up to 55 dS/m and found to yield well. Based on the studies conducted, the National bank for Agriculture and Rural Development (NABARD), Mumbai in association with the Station has developed a bankable model scheme for cultivation of *Salvadora persica* on salt affected black soils through the project sponsored by NABARD. Re-greening of highly saline black soils which hitherto remain uncultivated; reduction in salinity by 4th year onwards that enables to take up intercropping with less tolerant crops/forages. Planting of *Salvadora persica* would fetch about 7000 Rs./ha (Rao *et al.,* 2004). Apart from this, the species provide a dwelling place for birds and enhances the environmental greening.

Cultivation of Dill (*Anethum graveolens*)

Non-conventional crop like dill can be grown using residual moisture resulting in 2.6 q/ha seed yield with net returns of Rs. 8000/-. This crop forms an ideal option for the state in general and the region in particular, which *by and large* faces water scarcity problems (Rao *et al*., 2000). Under saline water irrigation, crop would yield net returns of 16500/- Rs./ha with 6000/- Rs./ha as cost of cultivation. The benefit: cost ratio works out to be 2.75. This crop thus would help farmers of the region to go for the second crop in the *rabi* season on lands, which hitherto remain fallow due to water and salinity constraints. Thus dill crop can be taken up using residual moisture and/or with saline ground water. The green can be used as leafy vegetable, an additional source of income.

Integrated Farming system model for salt affected black soils

The farming system model comprised of a rain water harvesting structure, fruit species like papaya and vegetables on dykes, other fruit crops like banana, jamun, aonla, seed spices, woody biomass species like *Eucalyptus* and *Pongamia* and a compost pit has been developed with aim to get farmers a staggered income throughout the year. Water productivity of banana, papaya, dill, coriander, brinjal, bottle gourd and tomato has been worked out along with benefit : cost ratio. Papaya followed by banana amongst different fruit species; dill followed by ajwain and coriander amongst spices, and bottle gourd followed by tomato and brinjal amongst vegetables showed higher B:C ratios. The B/C ratios of vegetables and spices were more than that of the fruit species. The productive components like fruits, vegetables and spices could provide a net income of about 52258/- Rs./ha. In view of low water requirement, spices, vegetables and papaya are better suited for water scarce regions like Bara tract of Gujarat with saline black soils (Rao *et al.,* 2009, Chinchmalatpure *et al.,* 2020).

Cultivation of forage grasses on saline black soils

Gujarat state has one of the largest dairy industries in the country. As the fodder produced on arable lands and grasslands is not sufficient to meet the demands of the cattle population, cultivation of forage grasses, *Dichanthium annulatum* and *Leptochloa fusca* in a ridge-furrow planting system with 50 cm high ridge and 1 m between midpoints of two successive ridges was found ideal in saline black soils having salinity up to 8-10 dS/m. For maximizing forage production on saline black soils, *Dichanthium* on ridges and *Leptochloa* in furrows form ideal proposition Cultivation of salt tolerant grasses like *Dichanthium annulatum* and *Leptochloa fusca* on moderate saline soils result in 1.9 t/ha and 3.2 t/ha, respectively (Rao *et al.,* 2011). Another two species of forage grasses namely *Echinochloa crusgalli and Pennisetum purpureum* have been identified as salt tolerant and grows better on saline Vertisols with saline water irrigation of EC_{iw} 16 and 8 dS/m, respectively. These species showed better biochemical attributes like sugar, chlorophyll, proline, protein content and therefore it is concluded that both the grasses are suitable for cultivation in saline *Vertisols* under saline water irrigation*.*

Cultivation of desi cotton and wheat on saline *Vertisols*

Studies conducted by the Station has revealed that *desi* cotton line (G Cot 23) as salt tolerant and high yielding even at 11.2 dS/m salinity and identified as salt tolerant desi cotton variety. On-farm Trials were undertaken on farmers' fields in Bhal area (Rajpara village, Dholera taluka, Ahmedabad district) and Bara tract (Bojadra and Kalak villages of Jambusar taluka, Bharuch district), where G Cot 23 recorded yield of 1.8 to 1.9 t/ha. Field trials were also taken up on farmers' fields with G. Cot 23 on saline Vertisols in four villages namely Rajpur, Mingalpur, Shela and Kamatalav in Dhandhuka taluka of Ahmedabad district indicated seed cotton yields in the range of 1.7-1.8 t/ha and the salinity ranged from 9.4 to 10.2 dS/m (Success Story-ICAR website, 2015). Two herbaceum cotton genotypes (CSC025 and CSC 057) are identified as salt tolerant (ECe 9.0 dS/m) and are registered with ICAR-NBPGR, New Delhi. In case of wheat three superior, high yielding and salt tolerant bread wheat (*Triticum aestivum*) genotypes for salt affected *Vertisol*s of Gujarat viz. KRL 210, KRL 351 and KRL 345 based on grain yield, biomass yield, test weight and shoot ion content have been identified.

Cultivation of medicinal plants on saline *Vertisols*

These soils can also be put under the cultivation of an economically important medicinal plant (Senna, *Cassia angustifolia* Vahl.) using integration of organic and inorganic fertilizer alone or in combination with microbial consortium on saline *Vertisols* of Gujarat (Basak, *et al,* 2022). Yield improvement as well as sennocide content in leaf and pod was significantly improved by organic as well as integrated application of organic and inorganic fertilizer on saline *Vertisols*. Integrated application of organic and chemical fertilizer was found effective in restoring organic carbon, increasing the amount of available nutrients (N, P, and K), and enhancing the biological activity of the saline *Vertisols*.

Cultivation of guava on salt affected *Vertisols*

Experiments conducted to evaluate the interaction effect of pruning, irrigation and fertilizer on yield characteristics and fruit quality in nine-year-old guava cv. *Allahabad Safeda* on salt affected *Vertisols* of Gujarat using saline water of 4 dS/m salinity along with 25% pruning and fertilizer application (750g: 250g: 250g NPK/tree/year + 50kg FYM/tree/year) without affecting the soil properties (David *et al.,* 2018).

Conclusions

Black cotton soils (*Vertisols* and associated soils) of India are fertile and productive under *rainfed* farming system. Irrigation availability in the black soil regions of India through canal and/or groundwater has been found beneficial in terms of increase in yield of crops in initial years of cultivation but subsequently these soils showed various kind of degradation like initially salinization, waterlogging, and rising of water table and then sodification of these soils and thereby reducing the productivity of these soils, if proper management and reclamation measures have not been taken on time. Enhancing of productivity of these degraded soils for improving food security and livelihood for resource poor farmers under increasing demand of food for country's increasing population, changing climate and declining soil and water resources is the biggest challenge. For sustainable management of these soils in black soil regions of India has to be counterbalanced with land improvement, which is mostly achieved by applying different interventions, available technologies and new approaches for reclamation and management of these degraded land for restoring productivity. When soil degrades, the processes that take place within it are damaged. This causes a decline in soil health, biodiversity and productivity of land. For achieving the UNCCD's goal of land degradation neutrality (LDN) requires three concurrent actions: firstly, avoiding new degradation of land by maintaining existing healthy land; secondly, reducing existing degradation by adopting sustainable land management practices that can slow degradation while increasing biodiversity, soil health, and food production; and thirdly, ramping up efforts to restore and return degraded lands to a natural or more productive state.

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CHAPTER 8

Saline Water Irrigation: Classification and Management

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Approximately half of India's irrigated land relies on groundwater extraction, with the quantity and quality of groundwater being crucial factors influencing land productivity, particularly in the north-western states. In semiarid and arid regions, irrigation water is both essential and scarce, making its efficient management critical for sustainable agriculture. Poor-quality groundwater is a widespread issue, accounting for 32–84% of irrigation water surveyed across various Indian states. The poor quality water is grouped into two categories i.e. saline water (with excess salt) and alkali water (Minhas, 1996). Indiscriminate use of poor quality waters in the absence of proper soil-water-crop management practices pose risks to soil health and environment. The use of saline groundwater for irrigation purpose leads to development of root zone salinity (Rhoades *et al*., 1992). The removal of this root-zone salinity is very important to minimize the adverse impacts of poor quality ground waters in agriculture (Gideon *et al*., 2002; Katerji *et al*., 2003).

Under salt stress plant growth is affected through (i) reduced water availability, due to an osmotic effect from high concentrations of soluble salts in the root medium (ii) ion toxicity, as a result of the accumulation of Na^+ and Cl^- (iii) oxidative stress, resulting from an overproduction of reactive oxygen species (ROS) and (iv) acute K^+ deficiency as a result of massive K^+ leak from depolarized cells (Shabala, 2013). Removing soluble salts from the soil using chemical amendments is challenging. The most effective approach is to manage salinity through agronomic practices that help maintain the lowest salt concentration in the root zone. Additionally, selecting salt-tolerant plant species suited to these soils and water conditions can improve crop resilience. By adopting appropriate agronomic techniques, making strategic crop selections, and implementing growth-promoting and stress-mitigation measures, sustainable crop production can be achieved even in saline environments.

Classification of saline water

The classification of irrigation water based on salinity (EC_{iw}) is presented in Table 1.

Table 1. Classification of waters based on salinity

Water class	EC_{iw} (dSm^{-1})	Water type
Non-saline	<0.7	Drinking /irrigation
Slightly saline	0.7-20	Irrigation water
Moderately saline	2-10	Drainage/groundwater
Highly saline	10-25	Drainage/groundwater
Very Highly saline	25-45	Very saline groundwater
Brine	>45	Sea water

Source: Gupta *et al*. (2019)

The irrigation water also classified based on degree of salinity hazards to crops as mentioned in Table 2.

Table. 2 Classification of saline water based on salinity hazards

Saline hazard	Class	EC_{iw} (dS/m)
Low	C1	0.1-0.25
Medium	C2	0.25-0.75
High	C3	0.75-2.25
Very high	C4	2.25-5.0

Gupta *et al*. (2019)

The effect of salinity also depends of sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) of irrigation water if higher than threshold limits. Accordingly, irrigation water has also been categorized taking into account salinity, SAR and RSC together (Table 3).

Table 3. Classification of irrigation water quality based on ECiw, SAR and RSC

Irrigation water quality	EC_{iw} (dS/m)	SAR_{iw} (mmol $L^{-1})^{1/2}$	RSC(meq L^{-1})
Good quality	<2	<10	<2.5
Saline water			
Marginally saline	2-4	<10	<2.5
Saline	>4	<10	<2.5
High-SAR saline	>4	>10	<2.5
Alkali water			
Marginally alkali	<4	<10	2.5-4.0
Alkali	<4	<10	>4.0
High-SAR alkali	variable	>10	>4.0

Source: Sharma and Minhas (2003).

Water Quality Guidelines for management of saline groundwater

Success in irrigating with poor-quality water depends on integrating factors such as rainfall, climate, water table depth, water quality, soil conditions, and crop selection with effective crop and irrigation management practices. 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 irrigated soil, but several practices interact and should be considered in an integrated manner. The guidelines for use of saline ground waters for irrigation are given in Table 4.

Agro-techniques for managing salinity hazards due to saline water application

The number of practices has been advocated to manage salt accumulation in the crop root zone. Seed priming with water or chemical substances augments germination and early growth of crop provides salt stress mitigation mechanism to the crop. Management practices such as night irrigation to reduce evaporation loss, pre-sowing seed treatments to enhance germination under saline water irrigation, conjunctive use of saline water, land configuration such as sowing on raised bed, increased seed and fertilizer rates, and mulching etc. are found as good management practices for successful crop production in saline environment.

Table 4. Guidelines for use of saline water (RSC < 2.5 meq/l)

Soil texture (% clay)	Crop tolerance	Upper limits of EC_{iw} (dS/m) in rainfall regions		
		< 350 mm	**350-550 mm**	**550-750 mm**
Fine (>30)	S	1.0	1.0	1.5
	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Moderately Fine (20-30)	S	1.5	2.0	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Moderately Coarse (10-20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse (<10)	S	–	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

RSC: residual sodium carbonate; S: sensitive; ST: semi-tolerant; T: tolerant

Seed priming

Salt stress adversely affects the physiological and biochemical processes of germinating seeds. It can affect the seed germination and stand establishment through osmotic stress, ion-specific effects and oxidative stress. The salinity delays or prevents the seed germination through various factors, such as a reduction in water availability, changes in the mobilization of stored reserves and affecting the structural organization of proteins. Seed priming is a pre-sowing treatment that exposes seeds to a certain solution for a certain period that allows partial hydration, but radicle emergence does not occur. When dry seeds are soaked in water or chemical solutions, the quiescent cells get hydrated and germination initiated. It also results in enhanced mitochondrial activity leading to the formation of high energy compounds and vital biomolecules. The latent embryo gets enlarged. When the imbibed seeds are dried again, triggered germination is halted. When such seeds are sown re-imbibition begins and the germination event continues from where it is stopped previously. Seed priming have various techniques for improving the performance of the growth, emergence, and yield of the crop.

There are some techniques which are used i.e. hydro-priming, halopriming, osmopriming and hormonal priming. Hydro-priming involves soaking the seeds in water before sowing which may or may not be followed by air-drying of the seeds. The process of halo-priming involves prior exposure to an abiotic stress, making a seed more resistant to future exposure. Halo-priming involves soaking of seeds in solution of inorganic salts i.e. NaCl, KCl, KNO_3, $CaCl_2$, $CaSO_4$ before sowing at 1-3% concentration. A number of studies have shown a significant improvement in seed germination, seedling emergence and establishment and final crop yield in salt affected soils in response to halopriming. In osmopriming seeds are soaked for a certain period in solutions of sugar, polyethylene glycol

(PEG), glycerol, sorbitol, or mannitol followed by air drying before sowing. Osmopriming not only improves seed germination but also enhances general crop performance under normal as well as saline conditions.

Pre-Sowing Irrigation

Under saline water irrigation, salt added often accumulate in the top few centimeters of the soil during non-crop periods. Where high water table exists, fallowing may result in excessive salt accumulation in the root zone particularly in arid and semi-arid regions. Under these conditions both germination and yields are adversely affected. A heavy pre-sowing irrigation to leach the accumulated salts from the root zone is very useful and essential to improve germination and early growth. Wherever available, pre-sowing irrigation should be given with good quality canal water or low salinity water.

Sowing on beds

Sowing or planting of crop in such a manner that root zone remains with low salt accumulation and diversion of salts away from root zone helps in minimizing the salt stress. Suitable land configuration like ridge and furrows and raised bed sowing found to save 20-30% irrigation water, increase water use efficiency and can provide opportunity to leach the salt from furrows. However, under saline conditions, increased salt accumulation on top of the beds has been reported by Choudhary *et al.,* (2008) due to the upward movement of salts through capillary rise in response to evaporation gradients. Therefore, residue retention on raised beds is more effective than the effect of either of these practices alone for managing salts (Devkota *et al*., 2015). They observed that when retaining crop residues, the soil salinity under permanent beds was reduced by 32% in the top 10 cm and by 22% over the top 90 cm soil profile compared to conventionally sown cotton without crop residue retention. To protect the crop from deposited salts, sowing should preferably be done on sides of the beds.

Furrow irrigation

Furrow irrigation is most commonly practiced in fine textured soils. In furrow irrigation, soil salinity buildup varies widely from the base of the furrows to the tops of the ridges. There two ways to provide irrigation under furrow irrigation system like irrigation to every furrow and skip furrow irrigation. In furrow irrigation system if every furrow is irrigated then salt accumulation takes place on top of ridges of soil between the furrows. So, under every furrow irrigation method, it is better to plant/sow crop either in furrows or on side of the ridges. If alternate furrows are irrigated, the maximum zone of salt accumulation will be on the sides of the un-irrigated furrow. In this situation, it is safe to place the seed or transplant seedlings away from the salt accumulation zone i.e. seed should be sown on side of the ridge towards irrigated furrow.

Mulching

Mulching, among the other soil and water management approaches has potential to enhance soil quality over the long-term, as well as increase production. Crop residues placed on the soil surface shade the soil, serve as a water vapor barrier against evaporation losses, slow surface runoff, and increase infiltration (Mulumba and Lal, 2008) with reduction in salt build-up in the upper soil layer. Salinity buildup was 20% lower in crop residue mulched (1.5

t/ha) treatment compared with the non-mulching treatment in the upper 0.15 m depth after three cotton seasons.

Conjunctive use of good quality and saline groundwater

In saline groundwater areas, conjunctive use practice can ensure judicious use of canal water, which is available in limited quantities along with saline ground water. Under such situation, two options are available with the users. Dilution or mixing of available poor quality water with good water in such proportions that resultant EC is acceptable for the range of crops to be grown in a given area. The salinity of resulting water can be easily calculated from their respective volumes and salinities.

If canal water (CW) or good quality water is available during initial crop growth stages, maximum possible irrigations are to be given by canal water before switching to saline water (SW). Suppose wheat crop requires 4 irrigations. The 2CW: 2SW mode can be a good option as root zone salinity under this mode remains low for almost two months (during initial crop growing period). Then CW: SW alternate mode ensures low salinity for initial month. The mix (1:1) mode might be preferable over SW: CW option. Though the amount of salt load added under different conjunctive use modes is same, temporal changes in root zone salinity are different. Therefore, selection of proper mode of conjunctive use is required for suitable salinity management at the root zone for optimum crop yields.

The preference order for conjunctive water use for wheat crop requiring 4 irrigations can be 2CW: 2SW; CW: SW alternate mode; Mix (1CW:1SW) mode and SW: CW alternate mode (Kaledhonkar and Keshari, 2006). The relative yield of crop generally remains highest for 2CW: 2SW and lowest for SW: CW mode. Singh *et al.* (2004) demonstrated that saline water with an electrical conductivity of up to 14 dS/m can be used alternately with canal water for cotton–wheat rotation in sandy loam and loamy sand soils. However, pre-sown irrigation must always be followed using canal water to ensure proper crop establishment. Additionally, if groundwater salinity exceeds 10 dS/m, it is recommended to use it alternately with canal water for post-sown irrigation to mitigate potential negative effects on soil and crop health.

Generally, the crop yields are 10-15% higher in cycling use of water compared to the mix use. Dilution of saline groundwater through rainwater recharge and subsequent use for life saving irrigation in mustard and wheat crops enhances crop yield by 5 to 20% respectively (CSSRI, 2019). It indicates the importance of pre-sowing irrigation by canal (good quality) water. The above discussion suggests that initial salinity, quality of pre-sowing water and conjunctive use practices have a great influence on temporal changes in root zone salinity and these changes affect the wheat yield.

Some important guidelines for management of conjunctive:

- Analysis of saline water to evaluate its use potential
- Selection of crops/ crop varieties that can produce satisfactory yields with saline water irrigation
- Selection of tree species/ medicinal plants in adverse condition
- Pre-sowing irrigation by good quality water so that germination and seedling emergence is not affected
- Adequate leaching of accumulated salts

- Improved cultural and nutrient management practices
- Gypsum application is necessary for sensitive crops if saline water (SAR > 20 and / or Mg: Ca ratio > 3 and rich in silica) induces water stagnation in rainy season.
- Fallowing in rainy season under high salinity (SAR > 20) is helpful for low rainfall areas.
- Fertilization with additional phosphorus is beneficial especially when C1:SO_4 ratio in waters is > 2.0.
- Canal water should be used preferably at early growth stages including pre-sowing irrigation in conjunctive use mode.

Fertilizer management

Under salinity, the availability of nutrients to the plants is low due to presence of salts, low soil moisture content, high soil pH, presence of toxic elements, and ionic imbalances in soils and plants may be becoming limiting (Choudhary and Yaduvanshi, 2016). So, even the presence of sufficient total quantities of essential nutrients in saline root zone environment does not guarantee the availability of these nutrients to growing plants for optimum crop yields.

Salinity affected areas are considered to be universally deficient in N and low availability of P and, therefore, crops grown thereon greatly respond to 20-25% higher levels of N and P than the commonly recommended rates. These soils often contain medium to high amounts of available K. Soil K application should be followed based on soil test. Salinity also limits micro nutrients availability based on their area of occurrence. So, need based micronutrient fertilization should be followed on the basis of deficiency.

Micro irrigation

The limited availability of good quality waters restricts the leaching of excess salts. Therefore, it is indicated that use of micro irrigation will be useful to minimize salt build up thereby adverse effects on crop growth can be minimized by lowering the salt load. Irrigation method can play an important role in controlling salts in the root zone. The application of irrigation water through drip provides better soil moisture regime in the root zone and thus lowering the salinity under drip irrigation than conventional surface irrigation (Saggu and Kaushal 1990).

According to Kang *et al.* (2004) the high frequency and low quantity applications of saline water through drip irrigation over a long period of time, can maintain high soil matric potential in root zone, compensating for the decrease of osmotic potential introduced by the saline water irrigation, and constant high water potential can be maintained for the crop growth. Besides this, in drip irrigation system crops tolerated higher level of irrigation water salinity, with lower salt accumulation in the crop root zone and lower leaching requirement as compared to surface irrigation system. Minhas (1996) regarded drip system as the most advantageous method for applying saline water to crops and also for maintaining well aerated conditions in the soil. Singh (2011) observed that the fruit yield of okra in sandy loam soil irrigated with 8 dS/m salinity decreased by 99.9% while the decrease was 73.8% under drip irrigation over good quality water. However, care should be taken while selecting sprinkler irrigation as application of highly saline (EC >12 dS/m) water through sprinklers could cause leaf burn in many crops. The leaf injury due to Na and Cl is given in Table 5**.**

Table 5. The concentration of Na and Cl based on foliar injury to crops

Ion	Na or Cl concentration (mg^{-1} L) causing foliar injury			
	Low	Medium	High	Excessive
Na concentration	<46	46-230	231-460	>460
Cl concentration	<175	175-350	351-700	>700

Source: Gupta *et al.* (2019).

Irrigation Intervals

During intervening periods between two irrigation cycles, crop evapo-transpiration reduces soil water, matric potential and solute potential at a rate which is governed by rate of ET and soil moisture characteristics causing variable effects on crop yields. These effects are more pronounced and set very aggressively in saline environments, so, irrigation in saline soils should be more frequent to reduce the cumulative water deficits. It has been found that frequent irrigations are helpful in saline soils in maintaining adequate availability of soil water. As the soil progressively dries out, due to evapo-transpirational losses, the salts concentration in soil solution and osmotic pressure increase causing difficulty in absorption by the plants. More frequent irrigations, by keeping the soil at higher soil moisture content prevent the concentration of salts in the soil solution and tend to minimize the adverse effects of salts in the soil. For these reasons crops grown in saline soils must be irrigated more frequently compared to crops grown under non-saline conditions.

Salt tolerant crops and varieties

Crops plants have variable levels of tolerant to salinity. Selection of crops based on their threshold tolerant minimizes the crop failure risks to certain extent. The ICAR-CSSRI has released the more than 35 varieties of rice wheat, Indian mustard and gram by central varietal release committee for salt affected areas of the country. Further, the intragenic variations are also existing in crop varieties and plant species in response to the salinity stress. This can also be utilized for selecting the crops, crop varieties, and plant species under various ranges of salinity stress. The salinity limits of irrigation waters for crops and some of the promising tree species are given in Table 6 and Table 7.

Table 6. Salinity limits of irrigation waters for agricultural crops

Crops	Soil Texture	Pervious crop	EC_{iw} (dS/m) for yield (%)	
			90	75
Wheat	Silty clay loam	Sorghum	3.4	7.0
	Sandy loam	Bajra	6.6	10.4
	Loamy sand	Fallow	8.3	11.7
Barley	Sandy loam	Fallow	7.2	11.3
Rice	Silty clay loam	Rice	2.2	3.9
Maize	Slay loam	Wheat	2.2	4.7
Pearl-millet	Sandy loam	Wheat	5.4	9.0
Italian-millet	Sand	Sunflower	2.4	4.6
Sorghum	Sandy loam	Mustard	7.0	11.2
Sorghum Fodder	Sandy loam	Berseem	5.2	10.2

Mustard	Sandy loam	Sorghum	6.6	8.8
Safflower	Silty clay loam	Maize	3.3	6.8
Sunflower	Sandy loam	Mustard	3.5	7.2
Groundnut	Sand	Italian-millet	1.8	3.1
Soyabean	Silty clay loam	Mustard	2.0	3.1
Pigeon Pea	Sandy loam	Onion	1.3	2.3
Clusterbean	Sandy loam	Variable	3.2	4.5
Cowpea	Loamy sand	Variable	8.2	13.1
Berseem	Sandy loam	Sorghum	2.5	3.2
Onion	Sandy loam	Pigeonpea	1.8	2.3
Potato	Sandy loam	Okra	2.1	4.3
Tomato	Sand	Variable	2.4	4.1
Okra	Sandy loam	Potato	2.7	5.6
Chillies	Sand	Variable	1.8	2.9
Brinjal	Sand	Variable	2.3	4.1
Fenugreek	Sandy loam	Potato	3.1	4.8
Bitter gourd	Sand	Variable	2.0	3.4
Bottle gourd	Sand	Variable	3.2	4.5

Source: Sharma and Minhas (2003).

Table 7. Salinity limits of trees species for saline waters

Saline water irrigation (EC_{iw} up to 15 dSm^{-1})	
Very Promising	*Acacia nilotica* (*keekar*), *Acacia tortilis* (Israeli *kikar*), *Acacia farnesiana* (*pisi babul*), *Azadirecta indica* (*neem*), *Capparis decidua* (*kair*), *Eucalyptus camaldulensis* (*river-red gum, safeda*), *Feronia Lemonia* (*Kainth, kabit*), *Melia azedarach* (*bakain*, *dhrake*), Prosopis juliflora (pahari kikar), *P. cineraria* (*khejri*, *jand*), *Phoenix dactylifera* (datepalm, khajur), *Salvadora persica* (*jaal*), *S. oleoides* (*jaal*), *Tamarix articulate* (*faranash*), *T. troupe, T. eridoides*
Promising	*Cassia javanica* (cassia), *C. siamea* (*kassod*, Cassia), *Casuarina glauca* (casuarina, *saru*), *Dalbergia sissoo* (*shisham*), *Eucalyptus tereticornis* (mysore gum, *safeda*), *Jatropha curcas* (*jamalghota*), *Pithecellobium dulce* (*jangal jalebi*), *Punica granatum* (*anar*), *Tecomella undulate* (*rohira*, Rajasthani sal), *Zizyphus mauritiana* (*ber*), *Z. jujuba*
Poor	*Acacia auriculiformis* (Australian *kikar*, *akash mono*), *Bauhinia variegata* (*kachanar*), *Cassia glauca* (cassia), *Cassia fistula* (*amaltas*), *Crescentia alata*, *Pongamia pinnata* (*papri*), *Sizygium cumini* (*jamun*)

Conclusions

Salinity hinders the crop growth right from germination to maturity of crop plants by altering the water relations, nutrient balance, specific ion toxicity etc. Agronomic practices, though cannot reclaimed or remove the salts from the soil, but have potential role in managing the salt and water balance in the crop root zone and apart escaping and tolerance mechanism to the crop plants grown. Adoption of package of best agro-techniques like selection of appropriate crop and its varieties, priming of seed prior to sowing, sowing with appropriate methods, irrigation with minimized salt load in soil, balanced fertilization etc. can sustain the yield under saline water application.

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CHAPTER 9

Significant Technologies of All India Coordinated Project for Research on Use of Saline Water in Agriculture

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The All India Coordinated Research Project on Management of Salt Affected Soils & Use of Saline Water in Agriculture was first sanctioned during the Fourth Five Year Plan under the aegis of Indian Council of Agricultural Research, New Delhi at four research centres namely Agra, Bapatla, Dharwad and Nagpur to undertake researches on saline water use for semi-arid areas with light textured soils, arid areas of black soils region, coastal areas and on the utilization of sewage water, respectively. During the Fifth Five Year Plan the work of the project continued at the above four centres. In the Sixth Five Year Plan, four centres namely Kanpur, Indore, Jobner and Pali earlier associated with AICRP on Water and Soil Salinity Management were transferred to this Project whereas the Nagpur Centre was dissociated. As the mandate of the Kanpur and Indore centres included reclamation and management of heavy textured alkali soils of alluvial and black soil regions, the Project was redesigned as All India Coordinated Research Project on Management of Salt Affected Soils and Use of Saline Water in Agriculture. Two of its centres located at Dharwad and Jobner were shifted to Gangavati (w.e.f. 1.4.1989) amd Bikaner (w.e.f. 1.4.1990), respectively, to work right at the locations having large chunks of land afflicted with salinity problems. During the Seventh Plan, the project continued at the above locations. During Eighth Five Year Plan, Two new centres at Hisar and Tirruchirapalli were added. These centres started functioning from Ist January 1995 and 1997, respectively. During the Tenth Plan, the project continued with the same centres with an outlay of Rs. 1090.00 lakh. During the Eleventh Plan, Project Continued with an outlay of Rs. 2125.15 Lakh with the Coordinating Unit at Central Soil Salinity Research Institute, Karnal. Further, during Twelfth Five Year Plan, four new Volunteer centres namely Bathinda, Port Blair, Panvel and Vyttila were added to this AICRP. These four centres started functioning from 2014.

As per recommendations of QRT (2011-2017) of ICAR-CSSRI, Karnal, the status of Indore centre was changed from main centre to volunteer centre. The Kanpur and Port Blair centres were discontinued w.e.f. 31 March 2020. Akola has been approved as volunteer centre w.e.f. 02 January 2025. On the approval of Cabinet Committee name of this AICRP has been revised to AICRP on Management of Saline Water & Associated Salinization in Agriculture w.e.f. January 2025.

Cooperating Centres with addresses

1. Raja Balwant Singh College, Bichpuri, Agra, Uttar Pradesh
2. Regional Research Station, ANG Ranga Agricultural University Bapatla, Andhra Pradesh
3. Agricultural Research Station, SK Rajasthan Agricultural University, Bikaner, Rajasthan
4. Agricultural Research Station, University of Agricultural Sciences, Gangavati, Karnataka
5. Department of Soils, CCS Haryana Agricultural University, Hisar, Haryana.
6. AD Agricultural College and Research Institute, TN Agri. Univ. Tiruchirappalli, Tamil Nadu

Volunteer Centres

1. Dr. Punjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra
2. Regional Research Station, Punjab Agril University, Bathinda, Punjab
3. Agriculture College, RVS Krishi Vishwa Vidyalaya, Indore, Madhya Pradesh
4. Khar Land Research Station, Dr. BS Konkan Krishi Vidyapeeth, Panvel, Maharashtra
5. Rice Research Station, Kerala Agricultural University, Vyttila, Kochi, Kerala

Revised mandate of the scheme

- Survey, characterization and mapping of groundwater quality for irrigation purpose.
- Evaluation of effects of poor quality groundwater irrigation on soils and crops under different agro-climatic conditions.
- Develop standards/guidelines for assessing the quality of irrigation waters.
- Development of management practices for irrigation induced salinization/guidelines for saline water irrigation (including micro irrigation) under different agro-climatic regions.
- Screen crop cultivars and tree species appropriate to saline/alkali soil conditions.

Research priorities for different centres

Name of Centre	Priority Areas of Research
Main Cooperating Centres	
Agra	• Survey and mapping of groundwater quality • Use of poor quality water use including waste water • Screening for salt tolerance • Survey and mapping of Salt Affected Soils (with ICAR-CSSRI)
Bapatla	• Survey and mapping of groundwater quality of AP • Conjunctive use of fresh and saline water with emphasis on *doruvu* technology upscaling • Reclamation and management of irrigation induced salinization (including sodification). • Alternate land use
Bikaner	• Survey and mapping for ground water quality of Rajasthan • Use of saline water through micro irrigation for vegetables/field/horticultural crops etc.
Gangavathi	• Reclamation and management of irrigation induced salinization (including sodification). • Subsurface drainage including controlled drainage • Micro irrigation in drainage areas/ shallow water areas/ poor quality area • Map of SAS of TBP command area
Hisar	• Groundwater quality mapping of Haryana • Micro irrigation for saline water use along fertility treatments • Screening for salt tolerance
Tiruchirappalli	• Survey and mapping for groundwater quality in coastal Tamil Nadu

	• Reclamation and management of alkali water and irrigation induced sodification • Rain water harvesting based conjunctive use • Screening of crops and varities for sodicity tolerance
Volunteer Centres	
Akola	• Survey and mapping of groundwater quality • Management of saline/alkali groundwtaer for irrigation • Dryland salinity/sodicity management • Screening for salt tolerance
Bathinda	• Groundwater quality mapping of South West Punjab • Land Shaping Technology for waterlogged saline soils (in collaboration with CIFE Rohtak Centre and CSSRI fishery scientist)
Indore	• Control of Resodification in Sodic Vertisols • Revised/Updated map of groundwater quality and SAS in MP • Irrigation water management for sodic Vertisols • Alternate land use • Updated map of SAS in Madhya Pradesh (with ICAR-CSSRI)
Panvel	• Survey and mapping of groundwater quality of Konkan region • Rainwater harvesting based IFS models • Increasing cropping inetnsity during rabi season (Establishment of vegetable crops during the Rabi season through management practices)
Vytilla	• Mapping of groundwater quality/SAS in the coastal Kerala • Integrated farming system including management of acid sulphate soils

Within the mandated tasks, following activities were initiated or strengthened at various centers:

- Generation of data bases on salt affected soils and poor quality waters
- Environmental impacts of irrigation and agriculture in irrigation commands and at benchmark sites
- Micro-irrigation system for saline water use to high value crops; to develop crop production functions with improved irrigation techniques
- Crop production with polluted (Agra Canal) and toxic water and bio-remediation strategies
- Water quality limits for new cropping pattern
- Development of new sources of fresh water for conjunctive use (Rainwater harvesting) and groundwater recharge
- Pollution of surface and ground water including modelling
- Reclamation and management of salt affected soils and water in Nagaur area in Rajasthan
- Management of abandoned aquaculture ponds
- Seawater intrusion and modelling
- Extension of Doruvu technology and test cheaper alternatives for skimming of fresh water floating on saline water
- Survey and characterization of toxic elements in coastal groundwater

- Re-sodification of reclaimed alkali lands and comparative performance of various amendments
- Dry land reclamation technologies
- Land drainage of waterlogged saline lands for cost minimization
- Conservation agriculture/multi-enterprise agriculture/ multiple use of water
- Alternate land management including cultivation of unconventional petro-plants, medicinal, aromatic and plants of industrial application

Presently, there are six main coordinating centers (Agra, Bapatla, Bikaner, Gangavathi, Hisar and Tiruchirappalli) and four volunteer centres (Bathinda, Indore, Panvel and Vyttila) were spread in length and breadth of the country under different agro-ecological regions and irrigation commands as under:

Location of AICRP Centres in Agro-ecological regions and irrigation commands

Name of Centre/University/State	**Climate**	**Ecology**	**Agro-ecological region**	**Irrigation Command**
Raja Balwant Singh College, Bichpuri, Agra (UP)	Semi-arid	Inland	Northern plain, Hot semi-arid	Agra Canal
Regional Research Station, ANG RAU, Bapatla (Andhra Pradesh)	Semi-arid	Coastal/ Inland	Eastern coastal plain Hot sub-humid to Semi-arid	Nagarjuna Sagar Project & Krishna
Agricultural Research Station, SK RAU, Bikaner (Rajasthan)	Arid	Inland	Western plains	IGNP
Agricultural Research Station, University of Agril Sciences, Gangawati (Karnataka)	Semi-arid	Inland	Deccan plateau, Hot semi-arid	Tunga Bhadra
CCS HAU, Hisar (Haryana)	Arid	Inland	Western plains	Bhakhra Canal
AD Agricultural College & Research Institute, Tamil Nadu Agril Univ, Tiruchirrappalli (Tamil Nadu)	Semi-arid	Coastal/ Inland	Eastern Ghats and Tamil Nadu uplands and Deccan plateau, Hot semi-arid	East Kattalai Canal
Dr. Punjabrao Deshmukh Krishi Vidyapeeth, Akola (Maharashtra)	Semi-arid	Inland	Deccan plateau, Hot semi-arid	Katepurna Reservoir
Regional Station, PAU, Bathinda (Punjab)	Semi-arid	Inland	Western plain, Hot arid	Rajasthan Canal
Agriculture College, RVS KVV, Indore (Madhya Pradesh)	Semi-arid	Inland	Central highlands	Omkeshwar
Khar Land Research Station , Panvel, Dr. BS Konkan	Humid	Coastal/ Inland	Western Ghats and coastal	Rajnala Karjat

Krishi Vidhypeeth (Maharashtra)			plain, hot humid-perhumid	
Rice Research Station , Kerala Agril Univ. Kochi (Kerala)	Humid	Coastal	Western Ghats and coastal plain, hot humid-perhumid	-

Significant technologies developed under this AICRP

'Dorovu' Skimming Well technology for coastal areas

Technology for efficient use of fresh water floating over saline ground water in coastal sands (Skimming well Technology) locally called as *"Dorovu"* comprises installation radial corrugated perforated pipes and sump at centre for skimming of fresh water without disturbing underlain saline groundwater in coastal areas.

- Designed with intention to skim freshwater layer floating over saline water aquifer.
- Generally designed for irrigation or drinking water purpose.
- Rate of pumping of groundwater is a crucial decision, because unregulated pumping often results in increasing salinity of pumped groundwater.
- Regulated pumping is carefully implemented in such a way that relatively less saline water is skimmed from saline water aquifer beneath the fresh water layer in the coastal aquifer.
- Electrical conductivity (EC) of skimmed water is found to be 0.16 to 0.54 dS/m, and the water table depth varied from 1.39 to 2.04 m at Bapatla.
- The improved fresh water skimming techniques have promising future prospects for sustaining crop production and potable water supply along the coastal belts.
- Skimming wells at 92 locations were installed including six drinking water wells covering an area of 198 ha in twenty-five villages in Prakasam, Guntur and West Godavari districts of Andhra Pradesh.

Low cost recharge technology for poor quality groundwater areas

An individual farmer based "low cost technology" is developed for dilution of poor quality ground water in aquifer through rain water recharge. The groundwater recharge helps to improve availability and quality of groundwater.

- Agra – Bharatpur in Uttar Pradesh and Rajasthan are endowed with poor quality groundwater aquifers. Shallow aquifers are relatively more saline (10-15 dS/m) compared to deeper aquifers (2-6 dS/m).
- Resource poor farmers who cannot afford deeper bore well are compelled to use saline groundwater available at shallow aquifers to give 1-2 life saving irrigation to mustard.
- The salinity of the ground water is reduced to less than 4-8 dS/m in most cases but, eventually reaches to its original value at time of 3^{rd} or 4^{th} irrigation.
- The salinity (EC_{iw}) of well water at I^{st} irrigation is very low as compared to initial water salinity of the bore well. The first irrigation with this good quality water helps to increase crop yield.
- Grain yield of mustard and wheat increased by 6.3 to 18.3% as compared to without recharge water.
- Technology has been tested on 8 farmer's fields. The diluted ground water is used to irrigate *rabi* crops such as mustard / wheat.


Conjunctive mode of canal and alkali water irrigation

Conjunctive use of canal and alkali waters (RSC 15 meq/l) under different cyclic, mixing, seasonal cyclic, long-term annual cyclic modes has been tried and identified for best utilization of limited canal water supplied along with saline irrigation

Subsurface drainage technology

The subsurface drainage system for reclamation of saline soils and to improve agricultural productivity has been tested at Uppugunduru and Appikatla in Krishna Western Delta in 1.3 lakh hectares of waterlogged saline soils of coastal and major irrigation command areas of Andhra Pradesh. The system leached a total of 184.4 tons of salts through the drainage system during the period of 7 years with a mean of 24.6 t/ha/annum. The soil salinity reduced to 1.7 to 8.4 dS/m and consequently increased the paddy yields from initial level of 1.8 t/ha to 6.75t/ha at the end of 7 years. The average discharge from the pipe drains laid at 30 m spacing was highest as compared to the pipe drains laid at a spacing of 60 m. The drain discharge decreased as the spacing increased

Raised and sunken bed technology

Developed Raised and Sunken bed technology for reclamation of rainfed alkali Vertisols wherein cotton crop was planted on raised beds whereas paddy crop was transplanted in sunken beds. The results indicated that raised and sunken bed system is good to conserve soil, water and nutrients and provides good surface drainage to upland crops grown on the raised beds. The system helped in water (50%), soil (95%), nutrients (90%) conservation and improved crop production and the system is economically viable

DSR on laser leveled fields in TBP command of Karnataka

"Laser land leveling is used for enhancing water productivity in Tungabhadra command area" and DSR (Direct Seeded Rice) is adopted. The TBP command area in Karnataka is mainly associated with soil salinity, soil erosion and shortage of irrigation water, particularly during *Kharif* season. Soil moisture cannot be distributed uniformly due improper leveling.

- 20–25 % irrigation water saved in case of DSR on laser leveled land compared to transplanted rice (PTR).
- Higher Paddy yield (87.5 q/ha) was recorded under PTR in laser leveled land followed by DSR on laser leveled land (78.75 q/ha).
- Soil erosion is reduced and soil moisture distribution was uniform over entire DSR laser leveled land.

Controlled sub-surface drainage technology

In this subsurface drainage system, drainage water volume is controlled. TBP command area in Karnataka is mainly associated with soil salinity, soil erosion and shortage of irrigation water, particularly during *Kharif* season. The subsurface drainage is provided with device to maintain water table, reduce drainage volume and prevent loss of nitrogen fertilizer.

Reclamation of sodic soils using distillery spent wash in Tamil Nadu

Technology for reclamation of sodic soils by applying Distillery Spent Wash (DSW) has been developed. In India about 257 distilleries generate 40.72 million-kilo litres of spent wash annually. It can be utilized as an amendment for reclaiming sodic soil. Its application @ 5.0 cm in the first year of reclamation helps to lower ESP and increase in yield of rice. The technology has been perfected at Trichy centre. Application DSW on sodic soil for its reclamation @ 1.25 lakh lit/ ha

- The gypsum requirement in the area was 9.5 t ha (50% GR) costing around Rs. 20,000.
- To reduce this cost, Distillery Spent Wash (DSW) can be used with gypsum (DSW).
- DSW for reclamation is available free of cost.
- The soil was highly sodic and sandy clay loam in texture. The initial soil pH, EC and ESP was 11.2, 1.7 and 42, respectively.
- After reclamation with DSW, the postharvest soil pH was reduced to 8.46 and ESP was 17.2.
- The yield obtained in control plot was 1.5 t/ha whereas in DSW reclaimed field, the grain yield was 4.5 t/ha
- Feasibility of managing alkali water with distillery spent wash (DSW) has also been demonstrated and found effective to reclaim alkali waters. One litre of DSW in 250 litres of alkali water is sufficient to neutralize RSC of 10 meq/L and could be used to irrigate the sugarcane crop without any adverse effects.

Reclamation of sodic Vertisols using lagoon sludge and raw spent wash application

- Application of Lagoon Sludge (LS) 5 t/ha + Raw Spent Wash (RSW) @ 2.5 lakh L/ha was recommended for effective reclamation of sodic Vertisols and improvement in yield of paddy and wheat as an alternative of gypsum.
- The farmers of the adjoining areas of distilleries and sugar industry may use raw pent wash (RSW) @ 2.5 lakh L/ha + Lagoon Sludge (LS) 5 t/ha in paddy-wheat cropping sequence to reclaim sodic Vertisols of Nimar Valley of Madhya Pradesh.

Integrated farming system (ifs) on salt affected soil areas of Tamil Nadu

Integrated Farming System (IFS) including poultry and fisheries with the crop component can help to improve water and land productivity by including crop, fisheries and livestock.

- Soil and groundwater in the area are not good.
- Farmer is getting normal rice yield during Kharif season by utilizing the canal water. But he could not cultivate any second crop due to poor quality groundwater (Highly sodic RSC 6.8; SAR 9.0; EC 1.8).
- The farmer is getting the income throughout the year.
- He is effectively utilizing the resource from his farm.
- Now he is getting the additional income of Rs. 75,000 (net profit) per year and smoothly running his family.

Rice-prawn integration on pokkali lands in Kerala

Farmer applies lime at the time of field preparation. Seeds of *Pokkali* sown on the ridges and after one month when the conditions become favourable. The ridges are dismantled and the seedling are distributed evenly in the field using spade. The rice crop is grown exclusively without any fertilizers and pesticides. The only intercultural operation is weeding. The threats for this crop are flash floods and increase in salinity during low rainfall periods during cropping season.

- In the coastal area of Kerala, acid saline soils are dominated, which has very poor productivity and profitability of rice crop.
- The farmer has been advised to integrated Pokkali rice with prawn cultivation.
- Rice-prawn integration-success story of *pokkali* farmer
- There was an increase in all soil chemical properties sulphur content after the cultivation of prawn.
- Farmer got an average yield of 2-3 t for rice and 400 kg/ha for prawn without applying chemical fertilizer and organic manure.

Land shaping for controlling waterlogging and salinity in a & n islands

Alternate land management system for waterlogged and saline soils. Water from the pond was drained to leach salts and from second year onwards rainwater has been harvested and stored.

- The coastal areas of Andmans suffer from the twin problem of salinity and waterlogging.
- Sea water inundation during high tide makes life and livelihood very difficult as in the case of Padmaspahad village of South Andaman.
- Salinity reduced to less than 1.5 dSm^{-1} from the initial value of 4.6 dSm^{-1} and the pH improved to 6.4 with in the one year.
- Polyculture of Indian Major Carps was practised in the pond with the production of 520 kg/year.
- Banana cultivation gave a net return of Rs. 18,000/- and veetable Rs.10,000 in one year after meeting home consumption of farmer.

Commercial vegetable production under naturally ventillated polyhouse structures using saline water drip irrigation

- Micro-environment in poly house reduces salinity stress on vegetable crops.
- Pest and disease are controlled to a greater extent automatically.
- Despite of use of saline water for irrigation, performance of capsicum and chilli was good for initial two years, while tomato continues to produce significantly better yield consecutively for three years under high saline water irrigation.
- Vegetable cultivation with saline irrigation water under naturally ventilated polyhouse structures may ensure livelihood security to resource poor farmers of salt affected conditions.
- The experiment was carried out for three years (2015-16, 2016-17 and 2017-18) at the research farm of ICAR-CSSRI Karnal under naturally ventilated polyhouse structure.
- During first year the fruit yield (116.3 t/ha) was obtained at EC_{iw} 6 dS/m was at par with yield (110.9, 100 and 111.1 t/ha) at EC_{iw} 4, 8, 10 dS/m respectively while during second year, significantly higher fruit yield (114.0 t/ha) was obtained at EC_{iw} 10 dS/m as compared to all other salinity levels.
- During third year at highest salinity of irrigation water (EC_{iw} 10 dS/m) the fruit yield (138.6 t/ha) was higher than BAW and reduced only by 7 percent in comparison to best yield obtained at EC_{iw} 4 dS/m during third year of cropping cycle which showed that tomato is more tolerant and salinity loving plant. Similar findings were also reported by several workers.

- The average fruit yield of tomato was highest (121.2 t/ha) at EC_{iw} 10 dS/m followed by fruit yields (119.7 and 118.1 t/ha) obtained at EC_{iw} 4 and 6 dS/m respectively.
- This clearly showed that tomato could be successfully grown with saline water drip irrigation under naturally ventilated polyhouse structures with the advantage of better fruit yield and quality under salinity stressed conditions.

CHAPTER 10

Groundwater Recharge for Sustaining Groundwater Resources

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About 60% of irrigation and 80% of drinking water requirements of India are met from groundwater resources. Though groundwater has played a vital role in stabilizing Indian agriculture, indiscriminate use has resulted in fast depletion and degradation of this key natural resource. Due to easy access, operational convenience and private ownership, the groundwater development has been quick but unregulated and has resulted in alarming decline of water tables in about one seventh (15%) geographical area of India accompanied by degradation of its quality at several locations. The north-western states of Haryana, Punjab, Uttar Pradesh and Gujarat account for 27% of country's over-exploited groundwater blocks (Kamra et. al., 2010).

The sustainability of agriculture in north-western Indian states is threatened due to alarming decline of water table, increase in pumping cost and deterioration in groundwater quality. This is particularly true for highly productive, water intensive and widely prevalent rice-wheat system in Haryana and Punjab, which contribute significantly to nation food security. The major cause of rapid groundwater decline is the paddy crop which consumes extremely high quantities of fresh water (~3000 litres for producing 1 kg of rice). Climate change is likely to increase uncertainty of highly variable rainfall patterns, requiring greater efforts in managing both water scarcity and floods. There is an urgent need to gradually diversify from rice to other less water requiring crops to reduce burden on groundwater use. The rate of declining groundwater can be slowed down to some extent either by replacing high water demanding crop like rice with the crops having less water requirement or by enhancing groundwater recharge (GR) through surface spreading and well injection techniques (Kamra *et al*., 2013). It helps in utilizing flood water that otherwise goes waste or causes damage to standing crops and also in improving groundwater quality. About two-third area of Haryana and one third each of Punjab and Gujarat are underlain with saline groundwater, a major part by high residual sodium carbonate (RSC) waters. For such and other areas having problems of fluoride contamination, groundwater recharge structures can help in improving water quality by dilution.

Enhancement of groundwater recharge

One of the ways to arrest and sustain the decline of water table is by enhancing artificial recharge of groundwater using rain and available excess canal water through various surface spreading and well injection techniques. Central Ground Water Board (CGWB) and a number of other agencies including research institutes, universities and NGOs have undertaken a number of artificial recharge studies in India and other countries (CGWB, 2002; 2004; Bouwer, 2002). Chadha (2002) presented a broad categorization of these systems based on hydro-geological conditions and source of water to be recharged. The most notable for north-western states include CGWB studies on well injection and induced recharge in Ghaggar river basin in Haryana, well injection in Mehsana District, and subsurface dykes in Kutch region of Gujarat, a number of pilot studies on vertical and lateral recharge shafts in combination with injection wells in Punjab and Haryana including a major study in Dhuri

Link drain in Punjab, integrated watershed management studies in *Shivalik* foothills of Punjab, Haryana and Uttrar Pradesh and a regional IWMI study involving use of diverted excess monsoon water of river Ganga in western Uttar Pradesh.

In hard-rock regions of eastern Rajasthan, Gujarat, Madhya Pradesh and Andhra Pradesh, groundwater depletion has invoked widespread community based mass movement for rainwater harvesting and recharge (Sharma *et al*., 2005). Renovation of village ponds, a common feature in most villages of India, by de-silting its bed can result in considerable enhancement in infiltration and groundwater recharge (Bouwer *et al*., 2001). Well injection techniques are, however, getting increasingly accepted due to failure or delay in arrival of natural or artificially recharged water with surface methods to deeper aquifer zones. An overwhelming inference, emerging out of a recently concluded project on groundwater skimming and recharging for saline ground water regions at CSSRI (Kamra *et al*., 2006) was that individual farmer based recharging schemes can be more widespread and socially viable and socio- economic issues and farmer involvement are vital in enhancing groundwater replenishment in semi-arid regions.

Groundwater recharge technologies

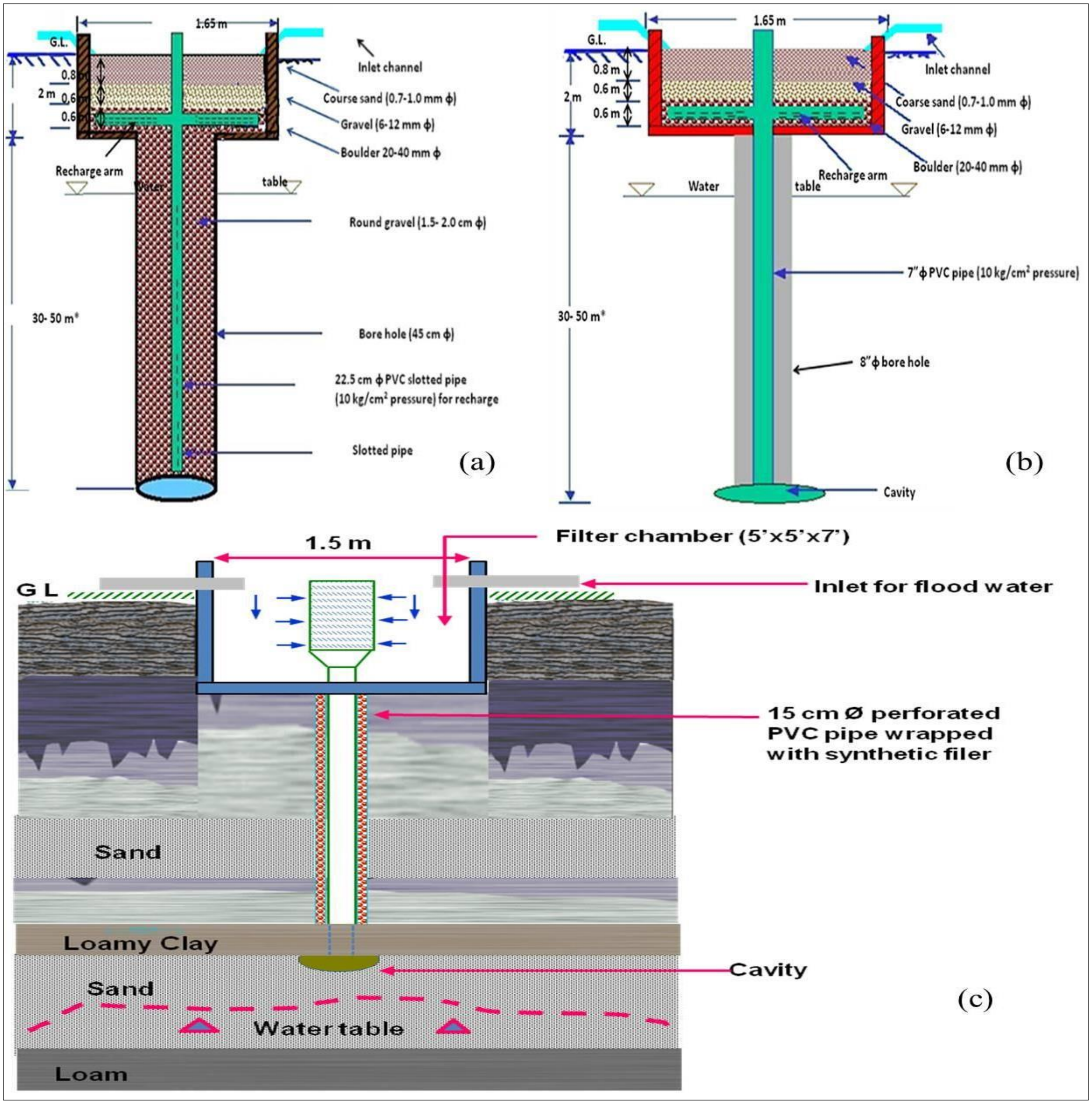
Artificial groundwater recharge systems are based on well injection techniques and involve passing of excess rain and canal water under gravity to suitable aquifer after filtration at faster rate than natural process. The type of recharge structures of different designs, depths and costs (recharge shafts, recharge cavities, recharge wells, dry cavities, and abandoned wells) is based on hydro-geological investigations and quantum of potential runoff water available at specific locations. The sites are being identified based on interaction with farmers, local tubewell mechanics and NGOs. ICAR-Centre Soil Salinity Research institute, Karnal has also designed and developed small recharge structures which can be adopted by an individual farmer at his field where runoff water from 20-25 ha area or more gets accumulated and posing problem for standing crop.

Design details

The design feature of developed recharge shaft, recharge cavity and abandoned cavity types structures are described in figure 1. The *recharge shaft* consists of a bore hole of 45 cm □□and varying depths filled with gravel pack of 1.5 – 2.0 cm □ to carry filtered recharge water to subsurface sandy zones. To safeguard against clogging, the surface runoff from rainfall or excess canal water is first passed through a graded recharge filter consisting of layers of coarse sand, small gravel and boulders in a small brick masonry chamber. A high pressure PVC pipe, of 12.5 cm □ and slotted in sandy zones, is provided in the middle of the shaft to circulate compressed air for cleaning of clogged sediments in the shaft after a couple of years. The depth of recharge shafts is decided based on the criterion to provide 10-15 m cumulative sand layers for recharge.

The *recharge cavity* consists of a conventional cavity tube well coupled with a recharge filter similar to the one described above in recharge shaft for recharging of excess water and can also be used for occasional pumping. Abandoned tube well can also be converted into drainage cum recharge structure by providing suitable option for retaining physical impurities carrying with the runoff water. Filtration option consists of brick masonry and larger size perforated pipe wrapped with nylon net which is fixed with abandoned tube well pipe. The perforation is in upper 3 ft and 1.5 ft pipe length at the bottom is kept blind to facilitate sedimentation.

Figure 1: Detail design features and dimension of developed a) recharge shaft, b) recharge cavity, and c) abandoned cavity type artificial groundwater recharge structures



Recharge Filters

The clogging of the recharge filter is a major constraint in the performance of recharge structures. Field and lab studies have indicated the thickness of upper sand layer of recharge filter to be the primary factor influencing clogging, while size of gravel in the middle layer also influences effectiveness of sand as a filter (Kumar *et al*., 2012). The vertical sand filters consisting of layers of coarse sand, gravel and boulders, have practical problems in cleaning of clogged sediments during high rainfall events. Without cleaning of deposited clogged material from upper sand layer, the recharge rates are reduced drastically, sometimes virtually to zero rates. Recently the recharge wells installed at new sites in Haryana, the vertical filters have been replaced by horizontal filters consisting of synthetic and fiber layers wrapped on concentric pipes of larger sizes around the well pipe. The filter chamber in horizontal filters is similar to that for vertical sand based filters; it however is empty with about 2.5 m well pipe in the middle. The lower 1 m pipe is blind while the upper 1.5 m pipe of either same or preferably larger size is perforated and wrapped with synthetic or jute material. The concentric larger size pipes of PVC or other materials around the well pipe have perforations all along its length and are wrapped with same or different material as on the well pipe.

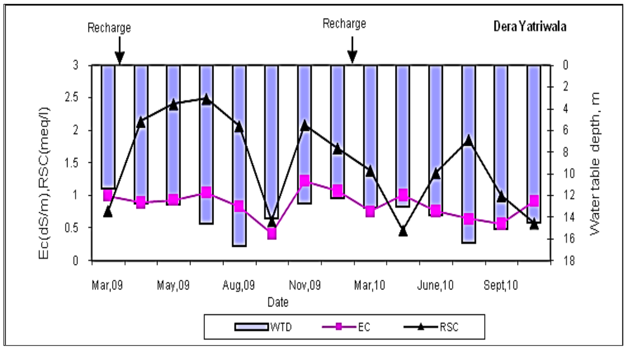
Performance Appraisal of Recharge Technologies

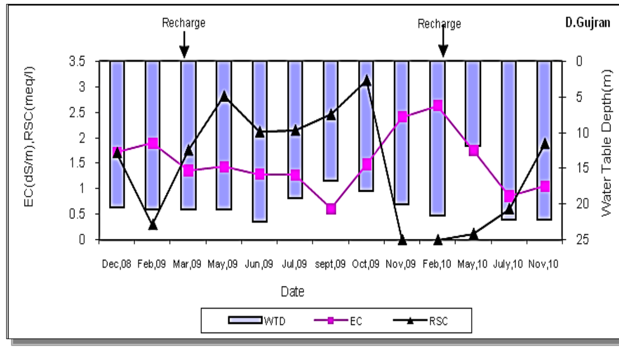
Initially, shaft and cavity type structures depending on type of aquifer strata, were designed and installed at farmer fields with a financial support of MoWR, Govt. of India under Farmer Participatory Action Research Project (FPARP). Abandoned tube wells as a result of decline in groundwater table exist in large number in Haryana and Punjab. One such abandoned cavity was also successfully converted and used for recharging aquifer and disposing rainwater during intense rain with suitable arrangement of filtration at the top. Performance appraisal of few sites based on farmers feedback and data collected periodically is described below.

Recharge shaft and cavity

ICAR-CSSRI installed 41 recharge structures at farmers field in Haryana and Punjab under different projects funded by various agencies. At selected sites in Haryana and Punjab, runoff water from 10-20 ha surrounding area was available during 2009 and 2010 monsoon months for recharge through these structures. There are encouraging results on the effectiveness of recharge shaft and recharge cavities to replenish groundwater and improve its quality. Recharge rates of 6-10 litre/sec were estimated during August 2012 for 4 recharge cavities (2 abandoned, 2 new) provided with differently designs and timely cleaned radial filters in Haryana. In one farmer's field in Karnal district, the groundwater recharge structure was found very effective in saving maize crop from water submergence during heavy rains. These results highlight the possibility of taking *kharif* maize in conjunction with small recharge structures as a crop diversification option to high water demanding rice in the area. The temporal changes in depth, EC and RSC or pH of groundwater at another 2 representative sites are presented graphically in Figure 2. It is seen that recharge events, indicated by arrows, cause both a rise in water table depth and reduction in EC as well as

RSC of groundwater. The improvement in salinity and RSC of groundwater at different





selected sites in Haryana and Punjab ranged from 0.3- 2.4 dS/m and 0-4.46, respectively.

Figure 2: Temporal change in depth, EC and RSC/pH of groundwater at two sites.

Abandoned tube well

ICAR-CSSRI renovated existing abandoned tube well into drainage option at agricultural field (Latitude 29.5178 N, longitude 76.7692 E) with filtration option to retain physical impurities carrying with runoff water in 2011. It contains brick masonry of 4.4 x 4.5 x 4.5 ft. The tube well pipe was extended up to the field surface with perforated pipe of larger diameter. After creation of drainage option, farmer went for crop diversification and successfully cultivated maize in *kharif* in place of water exhaustive rice crop. The rate of recharge of concerted abandoned cavity was found to be 4-6 liters per second. The economics worked out on the basis of observation recorded and feedback received from the farmers is presented in Table 1. Due to sensitivity of water logging during establishment and vegetative stage, maize crop was earlier damaged to the extent of 50-75% every year. However, with drainage option, he saved more than 50% of maize and 30% of wheat crop when heavy rainfall occurred. In monitory term, he could get additional income of Rs. 40000/- and Rs. 48000/- by saving his maize and wheat crops, respectively from submergence.

	
Renovated groundwater drainage cum recharge structure	Working of renovated groundwater dainage cum recharge structure

Table 1: Economic analysis of recharge well during high intensity rain

Crop	Area (ha)	% saving	Additional production from saved crop (q)	Income from saved crop (Rs.)	Payback period
Maize	1.0	50-75	35-50	40,000/-	In one
Wheat	2.0	30	30	48,000/-	season
Total				98,000/-	

Conclusions

The groundwater recharge structures have been designed and developed with simplicity in mind, specifically to meet the needs of individual farmers. Compared to larger, more expensive recharge schemes, these systems are more likely to succeed and be widely adopted, as they allow farmers to maintain the recharge filters themselves. These structures have proven to be highly effective in increasing groundwater levels, improving water quality, and boosting both water productivity and farmers' incomes. At CSSRI, Karnal, ongoing research is focused on optimizing practical and efficient recharge filter designs and ensuring the quality of the water being recharged.

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CHAPTER 11

Bio-drainage and Agroforestry Models Suitable for Salt Affected Soils

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Agroforestry is a land-use system that integrates trees (woody perennials), crops, people, and/or animals on the same piece of land in order to get higher productivity, greater economic returns and more social benefits on sustained basis. The requirement of woody perennials was reduced gradually due to more demand of food grains on limited land resources in entire world in general and India in particular. The National Commission on Agriculture, 1976 has suggested for implementation of social forestry program, which covered farm forestry, extension forestry, reforestation in degraded forests and recreation forestry. To promote agroforestry, various major policy initiatives such as 'National Agriculture Policy 2000', 'Planning Commission Task Force on Greening India 2001', 'National Bamboo Mission 2002', 'National Policy for Farmers 2007', 'Green India Mission 2010' and finally, a dedicated 'National Agroforestry Policy' was approved by Government of India in 2014. The aim of the policy is to expand the tree coverage on farmland in complementary with agricultural crops. The growing of tree on farms for market seemed to farmers in many regions of India a more profitable option than field crops. However, in spite of relative higher profitability to farmers and several concerted efforts made by government but, the adoption of agroforestry has not yet reached the expected desired level. The current area under agroforestry is 25.32 M ha, or 8.2% of the total geographical area of India. This includes 20.0 M ha in cultivated lands (7.0 M ha in irrigated and 13.0 M ha in rainfed areas) and 5.32 M ha in other areas such as shifting cultivation (2.28 M ha), home gardens and rehabilitation of problem soils (2.93 M ha) (Dhyani *et al.*, 2013).

Soil salinity is a major constraint in crop production, affecting more than 100 countries, worldwide. In India, the total degraded land due to salinity and sodicity is estimated to be 6.73 M ha and it is likely to increase to 16.2 million ha by 2050 and 20 m ha by the end of 21st century. With new challenges cropping up, soil salinity related stresses can be more pronounced and more damaging to existing crop production systems in coming years. ICAR-Central Soil Salinity Research Institute (CSSRI) at Karnal, Haryana, India has made significant contributions in developing technologies for reclamation of salt affected soils at large and particular in alternate land use systems (Agroforestry) by developing suitable tree based landscapes. The agroforestry models suitable for saline, alkali and waterlogged soils are discussed here in this chapter. A special focus was also on bio-drainage technology for managing the waterlogged saline soils.

Bio-drainage

Expansion of canal irrigation in India lead to increased agricultural production, boosting crop yields and colonization of population in irrigated areas on one hand and also result in negative consequences like waterlogging, salinization, and potential environmental hazards if not managed appropriately on the other hand. The rising water table, a consequence of excessive deep percolation losses from irrigation fields and/or seepage from irrigation networks results in waterlogging in root zone leading to build-up of soluble salts causing twin problems of waterlogging and soil salinity, simultaneously. Such situations are common in Indian northern plains covering states like Uttar Pradesh, Punjab, Haryana, Rajasthan and Bihar which account for about half of canal irrigated areas of the country (Pandey 2013). So, waterlogging and salinization are the major outcome of the canal irrigation that too in irrigation command areas of arid and semi-arid regions of the country. Twin problem of waterlogging and salinity affecting sustainability of agriculture in irrigation commands not only in India but across the world with similar situations.

Biodrainage can be used either as a corrective measure by lowering water tables or as a preventative measure by intercepting soil water before it arrives at the water table (Kapoor 2001). Although the term biodrainage is relatively new, Indian farmers are using vegetation to dry out soil profiles for a long time. The first documented use of the term biodrainage is credited to Gafni (1994). Before that date, the term bio-pumping was used to describe the application of trees to control water table (Heuperman 1992). However, in India, the biodrainage research is attributed to start at Central Soil Salinity Research Institute (Haryana) as a Lysimeter experiment (a microcosm experiment) in 1990s and the term biodrainage was first time documented by Chhabra and Thakur (1998).

Biodrainage may be defined as “Pumping of excess soil water into the atmosphere by deep-rooted plants using their bio-energy”. It is analogous to energy-operated water pumps and is proven technology to arrest salinity build-up in canal commands with growing of suitable tree species. The trees absorb water from the capillary fringe located above the groundwater table. The absorbed water is translocated to different parts of plant and finally more than 98% of the absorbed water is transpired into the atmosphere mainly through the stomata (Akram et al 2008). This combined process of absorption (by roots), translocation (through xylem) and transpiration (through leaf stomata) of excess groundwater into the atmosphere by the deep rooted vegetation describes biodrainage (Figure 1) (Dagar 2014).

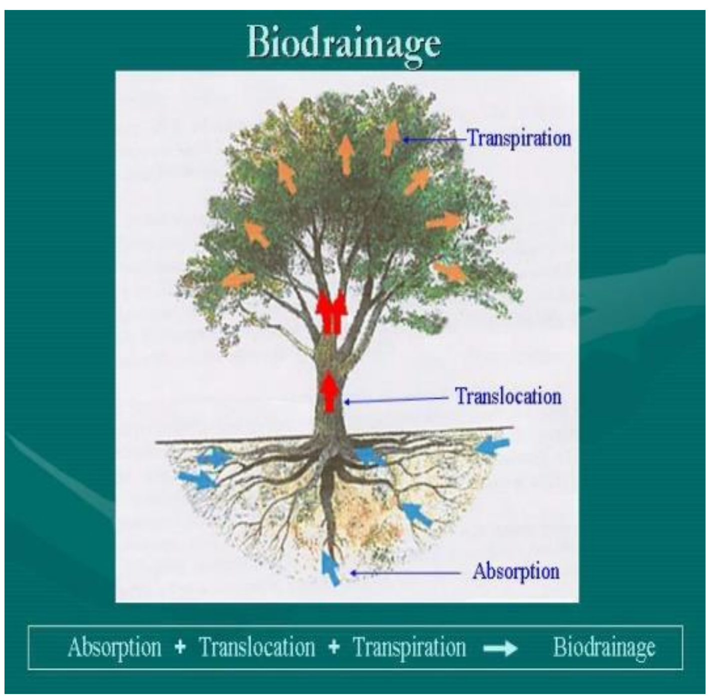

Figure 1: Bio-drainage

Plants use the water from the saturated part of the water table is called phreatophytes. Tree roots intercept seepage and leakage when planted along the canal banks. The application of bio-drainage is not only restricted to irrigated areas but also extended to rain fed areas where water (and salt) balances get disturbed by land use changes.

Agroforestry models

Salt affected lands can be productively used for agroforestry by adopting certain changes in reclamation technologies. Despite the availability of technical know-how, the rehabilitation of the salt affected land is progressing at a very slow pace. Therefore, agroforestry systems are now considered as viable alternatives. Although, the salinity stresses can also be as hostile for the woody tree species but are known to better tolerant than the annual crops. Therefore, the available information is collated on site-specific agroforestry systems and appropriate afforestation technologies for saline and alkali environments of the varied agro-climatic situations. The commonly prevalent agroforestry systems in salt affected soils are presented in Table 1.

Table 1: Agroforestry systems developed for salt affected soils

Agroforestry systems	Location	Soil type	System components		Sources
			Agronomical crops	Tree	
Agri-silviculture	Haryana, India	Moderately alkali	Rice–Berseem, Rice–wheat	*Eucalyptus/ Poplar/Acacia*	Singh et al 1997
Agri-silvi-pasture	Haryana, India	Alkali	Rice–Berseem, cowpea–Berseem	*Eucalyptus/ Poplar/Acacia*	
Agri-silvi-pasture	Haryana, India	Alkali	Turmeric/Guinea grass/Oats	*Eucalyptus/ Poplar/Acacia*	
	Haryana, India	Saline	Pearl millet/ Mustard	*Eucalyptus/ Melia composita*	Banyal et al 2018
Silvi-pastoral	Haryana, India	Highly alkali	Kallar grass (*Leptochloa fusca*)	*Prosopis juliflora*	Singh et al 1994
	Kurukshetra, India	Highly alkali pH ≥ 10.2	*Desmostachya bipinnata, Sporobolus marginatus*	*Acacia nilotica/ Dalbergia sissoo/ Prosopis juliflora*	Kaur et al 2002
	Lucknow, U.P. India	Highly alkaline pH of 10.2	*Leptochloa fusca* (4-years) followed *Trifolium alexandrium* (6-years)	*Prosopis juliflora/ Acacia nilotica*	Singh et al 2014
	Karnal, Haryana, India	Moderately alkaline	Rice–Wheat, Rice–Berseem, Pigeon pea – Mustard	*Acacia nilotica/ Eucalyptus tereticornis/* and *Populus deltoides*	Kaur et al 2000
Agri-hortisystem	Semiarid regions Hisar, Haryana	Saline soil and saline irrigation water	*Hordeum vulgare, Brassica juncea, Cyamopsis tetragonoloba, Pennisetum typhoides,*	*Carissa carandas/ Emblica officinalis/ Aegle marmelos*	Dagar et al 2015

Saline agro-ecosystem

Agroforestry approaches can check the further expansion in the land degradation besides augmenting the supply of food, forage, feed, timber, fuelwood and above all ecosystem services. The types of possible agroforestry systems for productive utilization of saline ecologies are discussed in the light of system components and outputs.

Sequential agroforestry system (Trees and/or arable crops)

Trees and arable crops can be grown in sequence rather than concomitantly. In this system fast growing nitrogen fixing trees (NFTs) can be grown for at least 4 to 5 years and then felled for fuel wood, fodder or other requirements. After this, the land can be put under arable farming due to its improved and nutrient enriched nature. In this ways it is helpful in improving the soil fertility status. *Sesbania sesban* was grown initially for 4 years and then followed by rice-wheat cropping sequence. Only P and Zn were applied to the crops @ recommended rates and the response to applied N was separately determined in the plots fertilized with urea-N. The rice as first crop yielded 6.4 Mg ha^{-1} in *Sesbania* plots without additional fertilizer application. Similarly, wheat yielded 2.2 Mg ha^{-1} in *Sesbania* plots compared to only 1.35 Mg ha^{-1} in the control plot. (Rao and Gill,1990).

Agri-silvicultural systems (Trees + arable crops)

This system involves the conscious and deliberate use of land for the concurrent production of agricultural crops along with woody perennial (trees). Multipurpose trees (MPTs) are raised along with agricultural crops in the alley space.

Eucalyptus and Melia based system

Eucalyptus tereticornis and *Melia composita*-based agri-silviculture system for saline ecologies were developed by ICAR-CSSRI as presented in Plate 1 (Banyal *et al*, 2018). Low water intensive crops like pearl millet and mustard have been taken as intercrops. Both the trees and under crops were given saline irrigation with varying salinity of ECiw from <1.0 dS/m (good quality water) to 12.0 dS/m. The soil of experimental site was saline with poor quality of ground water and the soil ECe ranged from 4 to >30 dS/m. The plantations of *Eucalyptus tereticornis* and *Melia composita* were done in line geometry with 4 x 3 m and 6 x 3 m spacing. Plantation was managed through sub-surface furrow irrigation method. *Eucalyptus* is well known agroforestry tree species with rice-wheat cropping system on reclaimed salt affected soils. But, it is not tested with low water intensive crops. *Melia composita* could be the potential plant due to its wider adaptability and multidimensional uses.

The yield of pearl millet was higher (0.86 t/ha) in the plots irrigated with best available water (BAW) (ECiw <1.0 dS/m) and showed decreasing trend with the increase in salinity level in irrigation water in *Eucalyptus* plantations up to ECiw 12.0 dS/m. The lowest yield (0.54 t/ha) was obtained in the plots irrigated with higher salinity (ECiw 12.0 dS/m) water. The pearl millet yield was higher (0.64 t/ha) under the plantations (alley crop) than open area (without plantations) (0.48 t/ha) for initial two years in *Eucalyptus* based systems. The highest yield (0.79 t/ha) was observed in the plots irrigated with best available water (ECiw<1.0 dS/m) and the lowest (0.54 t/ha) was with higher salinity level.

Saline soils' reclamation under the influence of trees and intercrops could be the viable option to increase the production function of these soils. The establishment of both the tree species especially *Melia* on such ecologies is the uniqueness of the developed agroforestry systems from others. The synergistic effect of trees and intercrops certainly make such soils of service use and results in the economic and ecological security of the farming communities facing the problem of salinity.

Plate 1: *Eucalyptus* and *Melia* based agroforestry systems with Pearl millet

Agri-horti system (Fruit trees + arable crops)

Majority of fruit trees are sensitive to salinity but some of them can be grown on saline soils satisfactorily. *Zizyphus mauritiana*, *Emblica officinalis*, *Carissa carandas, Aegel marmelos, Punica granatum*, *Sygygium cumini* and *Tamarindus indica* could be grown in moderately saline soils. The research work carried out at ICAR-CSSRI, Karnal Haryana revealed that different fruit based agroforestry systems have been developed and commonly practiced by the farming communities of the region (Plate 2). The system comprised of Bael (*Aegel marmelos*), Aonla (*Emblica officinalis*) and Karonda (*Carrisa carandas*) as tree components and cluster bean (in Kharif) and barley (in Rabi) as subsidiary components have been found practically and economically feasible with the moderate (ECiw 4.0 to 5.80 dS/m) to high salinity (ECiw 8.2 to 10.5 dS/m) water (Dagar et al 2016). Saline soils under long term tree cover exhibit overall improvement in soil quality which paves the way to increase in soil organic carbon, nitrogen contents, microbial biomass and above all micro climate modification by uptake of roots from deeper soil layers.

Plate 2: Aonla based agri-horticulture system with cluster bean

Silvo-pastoral system (Trees + grasses)

The growing of woody plants in pasture is referred as silvo-pastoral system. The trees and shrubs may be used primarily to produce fodder for livestock or they may be grown for timber, fuel wood and fruit or to ameliorate the saline soil. Most suited tree species for the system in saline soils are *Prosopis juliflora*, *Salvadora* spp., *Acacia nilotica*, *Pithocellobium dulce*, *Parkinsonia aculeata, Casuarina equisetifolia*, *Terminalia arjuna*, *Tamarix articulata* and *Pongamia pinnata.* Similarly, the grass species such as *Leptochloa fusca*, *Chloris gayana*, *Brachiaria mutica* and *Sporobolus* spp. are used on such soils. In silvo-pastoral system where *P. juliflora* and *Leptochloa fusca* were grown concomitantly found to decrease the soil EC and pH and increase in soil nutrients *viz.* organic carbon (%), available NPK at soil depth of 0-15 cm and 15-30 cm in six-year-old plantations. This system also improved the physical properties of soil such as bulk density, porosity, soil moisture, and infiltration rate over sole tree plantation.

Homestead/multi-enterprise agriculture model

The multi-enterprise model is developed in ICAR-CSSRI, Karnal for post reclamation phase specifically suitable to small and marginal farm stakeholders. The model consists of diverse components like multiple combinations of horticultural species, MPTs, arable crops, vegetables, fishery, poultry, animal component, beekeeping depending upon the land availability and financial inputs. The main outcome features of the developed system are sustainable resource use efficiency, regular income and above all employment generation (Gajender et al 2016 and Sharma *et al*., 2016). Such models are standardized for highly saline black soils of Gujarat and coastal saline soils of West Bengal (Sharma and Chaudhari 2012).

Energy plantation

There is tremendous scope of bio-fuels/ energy plantations in the prevailing scenario of climate change. The production of woody biomass based on carbon neutral technology from areas not suitable for any traditional agriculture production would therefore be a unique opportunity. Unlike fossil fuels, biomass does not add carbon to the atmosphere but it absorbs the same amount of carbon dioxide while growing. Therefore, it is the cheapest, eco-friendly and renewable source of energy. In India, fuel-wood accounts for 20-30 % of all energy needs and more than 90% of this is in domestic sector. India needs 6-7% energy growth per year. Wood energy can be technically efficient, economically viable and environmentally sustainable fuel option during the current energy deficit scenario. In saline areas salt-tolerant trees can be potential alternative to conventional agriculture. Trees on saline wastelands produce timber for construction or for energy i.e. charcoal for cooking or electricity production through gasifier techniques. Such landscape fashion also functions as windscreens, protect the soil against erosion, add organic matter and nitrogen to soil and above all sequester carbon helping in mitigating climate change adversities.

Alkali/Sodic agro-ecosystem

Based on the performance of tree saplings in alkali soils (pH 7-12), relative tolerance of some species was in the order of *Prosopis juliflora>Acacia nilotica>Haplophragma adenophyllum>Albizia lebbeck >Syzygium cuminii. Prosopis juliflora, Acacia nilotica* and *Tamarix articulata* recorded good growth and thus found economically suitable in highly alkali (pH 10.1–10.6) soils. After 14 years of plantation, Singh et al (2008) observed the maximum bole biomass of 231, 217, 208 and 197 kg per plant in *Eucalyptus tereticornis, Prosopis juliflora* and *Casuarina equisetifolia*, respectively. It was followed by 133, 100, 97, 84, 83 and 52 kg per plant in *Prosopis alba, Pithocelbium dulce, Terminalia arjuna, Pongamia pinnata, Azhadirachta indica* and *Cassia siamea*, respectively. In addition to appreciable reduction in soil pH, *P. juliflora* and *Eucalyptus* plantations increased soil organic carbon from initial 0.8 to 2.4 and 4.3 g/kg, respectively. Among fruit trees, *Ziziphus auritiana, Syzygium cuminii, Psidium guajava*, *Emblica officinalis* and *Carissa carandas* produced 12 to 25 Mg/ha fruits per annum after 10 years of growth. Based on the evaluation of > 60 species through series of experimentation on sodic soils in Indian sub-continent), it could be concluded that *Prosopis juliflora* was the best tree for high pH (>10) sodic soils followed by *Tamarix articulata* and *Acacia nilotica*. Species such as *Eucalyptus tereticornis, Terminalia arjuna, Salvadora oleoides, Cordia rothii* and fruit trees such as *Carissa carandas, Emblica officinalis, Syzygium cuminii* and *Psidium guajava* could be grown with great success on moderate alkali (pH < 9.5) soil. Wider spaced (row to row 4-5 m, plant to plant 4 m) agroforestry/agri-horticulture, with arable crops in the interspaces can be viable option. Egyptian clover (*Trifolium alexandrinum*), wheat, onion (*Allium sativum*) and garlic (*Allium cepa*) could be grown successfully for three years with *Carissa carandas, Punica granatum, Emblica officinalis, Psidium guajava, Syzygium cuminii* and *Ziziphus mauritiana*. Understory intercrops such as *Leptochloa fusca* for forage, wheat for grain, and onion and garlic for bulbs can produce 10.6-16.7, 1.6-3.0, 1.8-3.4 and 2.3-4.1 Mg/ha, respectively. Some of the prominent agroforestry models developed for alkali soils are:

Silvi-pastoral model

This type of model is well suited to highly alkali soils having pH 10.4 and ESP 90. *Prosopis juliflora*, *Acacia nilotica* and *Tamarix articulata* could be grown successfully along with grasses namely *Leptochloa fusca, Chloris gayana, Brachiaria mutica, Sporobolus spp.* and *Panicum spp. Leptochloa fusca* in association with *Prosopis juliflora* produced 46.5 t/ha green fodder in 15 cuttings over a period of 15 months without applying any fertilizer and amendment. *Prosopis juliflora* produced 160 t/ha air dried firewood in 6 years when planted at 2x2 m spacing. This system improved the soil to greater extent after 6 years. After four years palatable fodder species (*Trifolium resupinatum*, *Trifolium alexandrium* and *Melilotus parviflora*) were grown successfully.

Plate 3: Silvi-pastoral model (*Prosopis* with grasses) for highly alkali soils

Agri-silviculture model (Partially reclaimed soils)

Populus deltoides, Eucalyptus tereticornis and *Acacia nilotica* were successfully grown on partially reclaimed alkali soils along with rice and wheat crops. *Eucalyptus* and *Poplar* gave maximum height, girth and biomass in six years when inter cropped with rice-wheat for 4 years followed by *Panicum maximum-Avena sativa* for-years and rice-berseem for 4-years followed by cowpea-berseem for 2 years. *Acacia* gave maximum growth in absence of inter-crops. The order of soil amelioration under 5-year old plantations was *Acacia* > *poplar* > *Eucalyptus* > sole crops. The benefit cost ratio was highest (2.88) in *Poplar* based system and lowest (1.86) in *Acacia* based system. Growing trees and agricultural crops together is better landuse option in terms of productivity, soil reclamation and income. The B:C ratio of single cropping system is lesser compared with the trees and agriculture crops (Table 2).

Table 2: The B:C ratio of *Poplar*, *Eucalyptus* based agroforestry systems in partially reclaimed soils

Agroforestry sytem	B:C ratio
Poplar-rice-wheat	3.30
Poplar-rice-berseem	2.95
Poplar alone	2.38
Rice-wheat	2.79
Rice-berseem	2.39
Eucalyptus-rice-berseem	2.23
Eucalyptus-rice-wheat	2.06
Eucalyptus alone	1.99

In India, using auger hole technique different state forest departments have reclaimed about 60 thousand ha of highly deteriorated sodic soils through agroforestry plantations on village community lands, adjoining roads, railway lines and canals (CSSRI, 2011). The salt-affected black soils (saline/sodic vertisols) can successfully be cultivated with forest and fruit trees. *P. juliflora* and *Azadirachta indica* are the most successful species for these soils. Among fruit trees, gooseberry (*Emblica officinalis*), *ber* (*Ziziyphus mauritiana*) and sapota (*Achras zapota*) can be grown on sodic vertisols (ESP 25-60). Fruit trees like pomegranate (*Punica granatum*), Jamun (*Syzygium cuminii*) and goose berry (*Emblica officinalis*) can successfully be grown on raised bunds with rain-fed rice during rainy season and suitable winter crops in residual moisture in sunken beds. Among grasses, *Aeluropus lagopoides, L. fusca, B. mutica, C. gayana, C. barbata, Dichanthium annulatum, D. caricosum, Bothriochloa pertusa* and species of *Eragrostis, Sporobolus* and *Panicum* are among the most suitable for silvopastoral system on sodic vertisols. In addition to their economic values, *L. fusca, B. mutica* and *Vetiver zizanioides* assimilated high amounts of sodium from soils. During three years, these grasses removed 144.8, 200.0 and 63.5 kg ha-1 sodium from soil, respectively. The salt affected lands where profitable returns are not possible from conventional crops can be successfully utilized for the cultivation of high value medicinal and aromatic species. Aromatic grasses such as palmarosa (*Cymbopogon martini*) and lemon grass (*C. flexuosus*) tolerate moderate soil sodicity (pH ~9.2) while vetiver (*Vetiveria zizanioides*) withstands both high pH and water stagnation. Isabgol (*Plantago ovata*) produced 1.47 - 1.58 Mg ha^{-1} grain (including husk) at pH 9.2 and 1.03 to 1.12 Mg ha^{-1} at pH 9.6 showing its potential for cultivation on moderate alkali soil. *Matricaria chamomile, Catharanthus roseus* and *Chrysanthemum indicum* are other interesting medicinal and flower yielding plants for moderate alkali soil. All these crops can be blended suitably as understory inter-crops in agroforestry systems. Mulethi (*Glycyrrhiza glabra*), a leguminous medicinal crop was found quite remunerative in moderate alkali soil (up to pH 9.6). Besides, 2.4-6.2 Mg ha^{-1} forage per annum, a root biomass (medicinal and commercial) of 6.0-7.9 Mg ha^{-1} could be obtained after three years of growth fetching INR 6-8 lakhs ha^{-1} i.e. 2.0-2.6 lakhs ha^{-1} per annum and the soil was ameliorated in terms of reduction in pH and ESP and increase in organic carbon substantially.

Agroforestry in waterlogged saline soils

In India, the bio-drainage is being talked about in the context of prevention and control of waterlogging in irrigated areas. In pure blocks of *Eucalyptus,* the spacing was 1.5x3.0 m, 1.5x4.0 m and 1.5x6.0 m. *Eucalyptus* trees were grown along with agronomical crops under higher spacing *i.e.* 1.5x4.0 and 1.5x6.0 m. Some farmers have incorporated additional row of *Eucalyptus* in the recommended spacings. Parallel ridges are constructed for planting the trees in the north-south (N-S) direction along the bunds of agricultural waterlogged fields and two ridges in the field 66 m apart on *killa* lines (bunds separating one-acre field area; 66 m × 60 m). In single row, the spacing was 1.5 m between plant to plant and 1.5x2.0 m and 1.5x1.5 m in parallel and staggered row strip plantations.

Introduction of canal irrigation in arid and semi-arid regions without provision of adequate drainage caused rise in groundwater leading to waterlogging and secondary salinization. Installation of sub-surface drainage is essential to overcome the aforesaid twin problems; however, it is very costly and disposal of saline effluents has inherent environmental problems. Tree plantations 'pumping of excess soil water by deep rooted plants using bio-energy' can be a viable alternative. There are evidences which show that trees help in reducing salinity, lowering water table and checking seepage depending upon their salt-tolerance (Ram et al 2011). Trees have two major benefits: (i) interception and evaporation of rainfall and (ii) transpiration of soil water. Several plant species, from salt bush (*Atriplex*) to tall trees like species of *Eucalyptus, Casuarina equisetifolia, C. glauca, Pongamia pinnata* and *Syzygium cuminii*, are used for this purpose. The main physiological feature of such vegetation is profuse transpiration whenever the root system meets ground water. The most promising tree species used for biodrainage is *Eucalyptus tereticornis* which is widely distributed and fast-growing under a wide range of climatic conditions. In waterlogged non-saline areas, it can be successfully grown by ridge planting. In saline waterlogged areas, sub-surface or furrow planting is more successful as compared to ridge method. *Eucalyptus tereticornis* block plantations, along Indira Gandhi Nahar Paryojana area, effectively lowered the water table by 1.57 m over a period of six years (Kapoor, 2014). Likewise, strip plantations at 1 x 1m space on acre-line lowered shallow saline water table by 0.85 m during a period of 3 years and ~ 2 m after 5 years (Ram et al 2011). The results of six years old cloned *Eucalyptus* plantation when raised in different spacings on acre-line and as block plantations along canal produced 193 Mg ha^{-1} biomass as compared to 49.5 Mg ha^{-1} under 1 x 1m space planting on acre-line. The plantations maintained the water table < 2 m throughout the growing season and thus helped farmers to cultivate both rice and wheat crops in time. Among the six-tree species assessed for canal seepage interception in saline vertisols, *Acacia nilotica* (with 4.22 m canopy width) effectively intercepted the maximum i.e. 86% followed by *Dalbergia sissoo* (84%), *Sesbania grandiflora* and *Casuarina equisetifolia* each 72%. When planted with grass, Hybrid Napier (*Pennisetum purpurium*) the interception was more as grass also played a role in transpiring water. The most of trees were effective in reducing soil salinity, increasing organic carbon and available N, P and K in soil. The transect of *Eucalyptus tereticornis, E. camaldulensis, Acacia nilotica, A. ampliceps, Populus deltoides, Prosopis juliflora, Casuarina equesetifolia, Pongamia pinnata, Terminalia arjuna, Dalbergia sissoo, Morus alba* and *Syzygium cuminii* when planted along canals successfully checked seepage and thus waterlogging. *Eucalyptus tereticornis* and *Casuarina equisetifolia* plantations are equally good in reclamation of waterlogging conditions in Deltaic Orissa. Toky et al (2011) also observed water table drawdown in strip plantations of 10 tree species grown on sites with water table at 95 cm in semi-arid regions of northwest India. In six years' old plantations, they found the maximum water table depression of 9.7, 9.5 and 8.4 cm in *Eucalyptus tereticornis* hybrid, clone C-10 and clone C-130, respectively followed by *Prosopis juliflora* (8.2 cm) and *E. tereticornis* clone C-3 (8.0 cm). Among other trees, *Tamarix articulata*, *Callistemon lanceolata, Melia azedarach*, *Terminalia arjuna* and *Pongamia pinnata* lowered water table by 7.9, 6.5, 5.0, 4.4 and 3.3 cm, respectively.

Plate 4: Block planting geometry on farm acre land in waterlogged soils

Plate 5: Boundary planting geometry (parallel strip and single row) on farm acre land in waterlogged soils

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CHAPTER 12

Horticultural Crops for Salt-affected Soils

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Soil salinity has long been a silent adversary of Indian agriculture, tracing its roots back to the irrigation practices of ancient civilizations along the Indus and Ganges rivers. Today, it poses a formidable challenge to the nation's food security and rural livelihoods (Kumar and Sharma, 2020). Salt-affected soils-laden with excessive salts or sodium-span approximately 6.73 million hectares (Mha) across India. With nearly 50% of Indian agricultural land dependent on irrigation, and climate change intensifying drought and salinization, the need to cultivate crops that can endure these conditions is more urgent than ever (Sharma, 2021). In this context, salt-tolerant horticultural crops offer a promising pathway to sustain productivity and prosperity in salt-affected regions.

Horticultural crops including fruits, vegetables, spices, and medicinal plants are a cornerstone of agricultural economy in India, contributing over 30% to agricultural GDP (Satisha, 2023). In salt-affected regions, where staple crops like rice and wheat falter under salinity stress, salt-tolerant horticultural species provide a lifeline. Crops such as ber (Indian jujube), pomegranate, and drumstick (moringa) thrive in the saline wastelands of Gujarat and Rajasthan, offering nutritious produce and marketable goods (Rajkumar *et al*., 2020; Meena *et al*., 2022; Singh *et al*., 2021). Vegetables like beetroot and cluster beans (guar), grown in the sodic soils of Uttar Pradesh, bolster local diets, while medicinal plants like aloe vera and isabgol (psyllium) from saline patches in western India cater to growing pharmaceutical demand.

The significance of these crops is magnified in India's socio-economic landscape. For small and marginal farmers, who constitute 86% of the country's farming population, horticulture on marginal lands can diversify income and reduce dependence on water-intensive cereals. In coastal Andhra Pradesh, for instance, salt-tolerant coconut varieties sustain livelihoods despite saline groundwater. Beyond economics, these crops enhance nutritional security-crucial in a nation where malnutrition remains a concern and support India's rich tradition of spice and medicinal plant cultivation (Singh *et al*., 2018).

The presence of large amounts of soluble salts that can adversely affect plant growth makes salt-affected soils a major concern for agriculture. Nonetheless, it has been revealed that a number of horticultural crops can withstand salt stress to differing degrees. In areas where soils are impacted by salt, being aware of these crops and how they adapt to saline conditions might help in improving food production. While salt-affected soils pose a challenge for horticulture, there are several crops that can tolerate saline conditions to varying degrees (Niu *et al*., 2019). By selecting appropriate crops, improving soil conditions, and employing efficient irrigation and management techniques, it's possible to grow horticultural crops in saline soils and maintain productivity in regions affected by salinity (Machado *et al*., 2017).

Horticultural crops suitable for cultivation in salt-affected soils

Salt-affected soils may seem like a farmer's enemy, but many horticultural crops can turn this challenge into an opportunity. These hardy plants have special ways of surviving salty conditions some keep salt out of their roots, others store it safely in their leaves, and a few even use it to grow better. In India, where salty lands stretch from the deserts of Rajasthan to the coastal fields of Tamil Nadu, these crops offer hope. They provide food, income, and even beauty, proving that salty soil can still yield a sweet harvest. This section explores three main groups of salt-tolerant horticultural crops namely fruits, vegetables, and ornamental/flower plants, and lesser-known options focusing on examples that Indian farmers can grow and benefit from (Singh *et al.*, 2024). Some the examples of salt-tolerate horticultural crops are listed in the Table 1.

Fruit crops

Several fruit trees can tolerate salt-affected soils, making them suitable for cultivation in coastal or arid regions with saline soils. Trees like olive, date palm, pomegranate, guava and grapevine are some of the best candidates for growing in such environments (Singh, 2018; Rajkumar *et al*., 2017). By using appropriate management practices such as soil amendments and proper irrigation techniques, it's possible to grow these fruit trees successfully even in areas with high salinity.

Vegetable crops

Several vegetables are capable of tolerating salt-affected soils to varying degrees. These salt-tolerant vegetables are crucial for agriculture in areas where soil salinity is a challenge, such as coastal regions or arid zones with high levels of evaporation. While salt-affected soils can pose challenges, many vegetables are well-suited to growing in moderately saline conditions. Vegetables like beetroots, spinach, chard, and tomatoes are some of the best options for cultivating in saline environments. Below are some vegetables that are known to perform well in saline conditions:

Flower crops

Several flowering plants and ornamental crops can tolerate salt-affected soils, making them suitable for cultivation in coastal or arid regions with saline soils. Many flowering plants can tolerate salt-affected soils, making them ideal for cultivation in coastal or saline environments. Flowers like Bougainvillea, Sunflowers, and Marigolds are among the best options for coastal or salt-affected areas. With proper care and management, these flowers can thrive in challenging environments, providing vibrant colour to gardens and landscapes. Below is a list of some fruits, vegetables and flower crops that are known to have tolerance against salinity:

Management strategies for growing horticultural crops in salt-affected soils

Reclaiming salt-affected soils is a process that requires a combination of techniques based on the type of salinity (saline, sodic, or saline-sodic) and the severity of the issue. Leaching, gypsum application, the use of organic matter, and proper irrigation management are all essential practices to restore the fertility and structure of salt-affected soils. It's important to assess soil conditions regularly and apply these amelioration methods in a balanced and sustainable manner to prevent further degradation.

Table 1: Salt tolerant Horticultural Crops

Crop type	Crop Name
Fruit crops	Date Palm, Pomegranate, Fig, Tamarind, Jujube, Guava, Sapota, Aonla, Bael, Jamun, Phalsa, Karonda, Coconut, Grapevine
Vegetable crops	Tomato, Spinach, Beetroot, Cabbage, Carrot, Radish, Asparagus, Kale, Peas, Onions, Peppers
Flower crops	Bougainvillea, Lantana, Portulaca, Marigold, Zinnia, Lavender, Geranium, Daylillies, Canna lily, Oleander, Vinca, Aloe vera, Ice plant, Petunias, Snapdragons, Gerbera Daisies, Coreopsis, Cosmos

Application of soil ameliorant

The application of gypsum, organic matter, or other soil amendments can help to reduce the salinity of the soil and improve its structure, making it more suitable for horticultural crops.

Gypsum: Gypsum is commonly used to amend sodic soils (soils with high sodium content). Sodium in the soil binds with clay particles, leading to poor soil structure and reduced water infiltration. Gypsum displaces sodium from the soil, allowing it to be leached away, improving soil structure. Gypsum supplies calcium (Ca^{2+}), which replaces sodium (Na^{+}) on the soil exchange sites. It helps flocculate (bind together) fine soil particles, improving soil structure and water infiltration. It also increases the soil's ability to hold nutrients. The rate of gypsum application depends on the level of sodium in the soil. Typically, 2-5 t/ha is used for reclamation, but it can vary based on soil conditions.

Organic matter: Organic matter addition to salt-affected soils helps improve soil structure, water retention, and microbial activity. Organic matter can also aid in the reduction of soil salinity over time by improving the soil's ability to hold and release water. Increases soil porosity, reducing compaction and improving water infiltration. Enhances microbial activity, which can help degrade salts over time. Improves the nutrient-holding capacity of the soil, making it more fertile. Helps to buffer pH levels, which is particularly beneficial in saline-alkaline soils. Incorporate well-rotted organic matter like compost, farmyard manure, or green manure into the topsoil. Add organic material regularly, especially in areas with high evaporation rates, to maintain healthy soil structure.

Elemental sulfur: Elemental S is often used to lower the pH in saline-alkaline soils (soils with both soluble salts and high sodium content), especially in sodic soils. Sulfur reacts with water to form sulfuric acid, which can neutralize alkaline soils (soils with a high pH). This process helps to displace sodium ions from the soil and improve water infiltration. The amount of sulfur required depends on the soil pH and texture. For moderately alkaline soils, about 500–1,000 kg/ha of elemental sulfur can be used. The sulfur needs to be incorporated into the soil and requires time to lower the pH.

In some cases, the application of **acidifying fertilizers** such as ammonium sulphate or ammonium nitrate can help in lowering the soil pH. These fertilizers provide nitrogen and also acidify the soil, which can help displace sodium in sodic soils. They release hydrogen ions (H^{+}), which can neutralize excess sodium and improve soil structure. However, excessive use of these fertilizers may lead to soil acidification, so it should be done cautiously.

Selection of salt-tolerant cultivars and rootstock

Planting salt-tolerant cultivars can significantly improve the chances of success in saline environments. Varieties like *Arbequina olives*, Troyer Citrumelo citrus, Stanley plums, and Wonderful pomegranates offer good resistance to salinity. There is on-going research to develop more salt-tolerant varieties of common horticultural crops. The horticultural crops and their cultivars suitable for the salt-affected soils are presented in the Table 2.

In some cases, using salt-tolerant rootstocks for grafting can improve the salt tolerance of certain fruit trees. Salt-tolerant rootstocks can make a significant difference in fruit tree production in areas with saline soils. By selecting rootstocks like Troyer citrumelo for citrus, Myrobalan plum for stone fruits, or Oleaster for olives, growers can improve the chances of successful fruit production in coastal or saline-prone areas. Appropriate rootstock selection, combined with proper irrigation and soil management, can help mitigate the effects of salinity and ensure healthy, productive fruit trees.

Table 2: Salt-tolerant Cultivars of Horticultural Crops

Crop Name		**Salt-tolerant cultivar(s)**	**Salinity Tolerance (dS/m)**	**Remarks**
Fruit crops	Date palm	Medjool, Deglet Noor, Khar, Sayer, Aseel	10–15	Thrives in arid, saline conditions
	Sapota	Kalipatti, Baramati	8-10	Moderately salt-tolerant
	Olive	Arbequina, Kalamata	8–10	Moderately salt-tolerant
	Dragon fruit	White Pitaya, Red Pitaya	6-10	Moderate tolerance to salinity
	Pomegranate	Wonderful, Mollar de Elche, Bhagwa, Mridula, Ganesh, Arakta	6–8	Tolerates moderate salinity
	Fig	Black Mission, Kadota	6–8	Drought & salt-tolerant
	Jujube	Gola, Banarasi	6–8	Drought & salt-tolerant
	Aonla	Banarasi, Kanchan, Chakaiya	6-8	Moderately tolerant to saline soils
	Bael	*Aegle marmelos*	5-6	Thrives in low to moderate salt levels
	Guava	Allahabad Safeda, Beaumont, Lucknow-49/Sardar	4–6	Moderately tolerant, tropical crop
	Grapevine	Thompson Seedless	1.5-3	Moderate salt tolerance
Vegetable crops	Asparagus	Jersey Giant, UC 157	8–10	Highly tolerant, perennial crop
	Beetroot	Detroit Dark Red, Bull's Blood, Chioggia	6–8	Accumulates salts in leaves
	Artichoke	Green Globe, Imperial Star	6–8	Perennial, thrives in coastal areas
	Swiss Chard	Bright Lights, Fordhook Giant	6–8	Leafy crop with good salt tolerance

	Tomato	VF 36, Red Bounty, Sundrop, Rutgers and Tiny Tim	4–6	Moderately tolerant
	Spinach	Winter Bloomsdale, Tyee,, Indian Summer	4–6	Moderate tolerance, sensitive to sodicity
	Kale	Lacinato, Red Russian	4–6	Hardy, tolerates moderate salinity
	Cabbage	Savoy cabbage, Green Acres, and Golden Acre	1-2	Low salinity tolerant
	Radish	Cherry Belle, White Icicle, Daikon	1-2	Low salt-tolerant
	Peppers	California wonder, Jalapeño and Habanero	1.5-2.5	Low salt-tolerant
Ornamental/ Medicinal	Saltbush	Old Man Saltbush (Atriplex nummularia)	10–15	Dual (fodder and ornamental) -purpose
	Portulaca	Sundial, Happy Hour,	10-15	Moderate to high salinity tolerant
	Sea Lavender	Limonium perezii, Limonium sinuatum	8–10	Ornamental, thrives in saline coasts
	Aloe Vera	Aloe barbadensis Miller	6–8	Medicinal, thrives in poor soils
	Rosemary	Tuscan Blue, Arp	6–8	Aromatic, salt- and drought-tolerant
	Purslane	Golden, Green	6–8	Edible and ornamental, succulent
	Lavender	Munstead, Hidcote	4–6	Tolerates dry, saline soils
	Bougainvillea	Barbara Karst, Raspberry ice,	4-6	Highly tolerant
	Lantana	New gold, Confetti	4-6	Thrive in high salt content, such as coastal regions
	Sage	Berggarten, Tricolor	4–6	Medicinal, tolerates moderate salinity
	Zinnia	*Zinnia elegans*, *Profusion Zinnia*	3-4	Moderate salinity tolerant
	Geranium	Zonal Geranium and Ivy Geranium	2-4	Moderate salinity tolerant

Irrigation management

Water management is a critical component in managing salt-affected soils, especially in regions where salinity is a significant problem. By employing strategies such as efficient irrigation, leaching, drainage, and the use of quality water, it's possible to reduce salinity and restore soil productivity. Careful monitoring of water quality, soil moisture, and salinity levels is essential to maintaining a sustainable approach to water management and ensuring long-term soil health.

Drip irrigation: Using drip irrigation helps to minimize water wastage and keeps salts from accumulating at the soil surface. This is an efficient irrigation method that delivers water directly to the plant roots, reducing water wastage and preventing the buildup of salts on the soil surface.

Avoiding overhead sprinklers: Sprinkler irrigation can cause salt accumulation on the soil surface, leading to evaporation and increased salinity.

- **Saline water management**: In regions with saline groundwater, using blended irrigation (mixing saline water with fresh water) can reduce the concentration of salts in the soil.
- **Improved water management:** Managing irrigation schedules to avoid the build-up of salts in the root zone can help in reducing the negative impacts of salinity on crops.

Leaching

Leaching is the process of applying water to the soil to flush out soluble salts. This is especially effective in saline soils where salts are soluble and can be moved away with irrigation. Regular leaching of the soil (flushing out excess salts with irrigation) can help in managing salinity, especially when combined with proper drainage systems. However, in arid regions with limited water, leaching might not be sustainable. In areas with poor drainage, leaching can lead to waterlogging.

- Apply water in excess to move the salts deeper into the soil profile or out of the root zone.
- Use freshwater for leaching, as saline or brackish water can exacerbate the salinity issue.
- Ensure good drainage so that the water can carry away the salts.
- It's essential to monitor the salinity of irrigation water to ensure it doesn't add more salts to the soil.

Mulching

Mulching around crops can reduce evaporation, which helps to prevent salt from accumulating on the soil surface and damaging plants. Applying mulch to the surface of salt-affected soils helps prevent surface evaporation, reducing the upward movement of salts.

- **Organic mulches**, such as straw or wood chips, are effective at reducing evaporation and protecting soil from salt accumulation.
- **Inorganic mulches**, such as gravel or stone, can also be used but may not provide the same long-term soil benefits as organic mulches.

Cover cropping and green manure:

Growing salt-tolerant cover crops or green manure helps improve soil structure, increase organic matter content, and enhance nutrient cycling in salt-affected soils.

- Cover crops help reduce erosion, enhance soil structure, and improve moisture retention.
- They also provide organic matter that can eventually decompose and contribute to soil improvement.

Shaping and land levelling:

Proper **land grading and levelling** helps manage water flow and prevents the accumulation of salts in low-lying areas, which can lead to salt stress on plants.

How It Helps:

- Ensures even water distribution, preventing areas from becoming waterlogged or overly saline.

- Increases the effectiveness of irrigation and leaching by directing excess water to the lower parts of the field

Conclusions

The cultivation of horticultural crops on salt-affected soils represents a critical intersection of challenge and opportunity within the realm of sustainable agriculture. As discussed throughout this chapter, soil salinity significantly hampers crop productivity, yet it is a hurdle that can be overcome through strategic interventions. The selection of salt-tolerant horticultural species—such as date palms, olives, pomegranates, and certain resilient vegetable varieties—offers a practical foundation for transforming these degraded lands into productive agricultural systems. Advances in plant breeding and biotechnology further enhance this potential, enabling the development of cultivars better equipped to thrive under saline conditions. Complementing these efforts, innovative soil management practices, including the use of organic amendments like compost and biochar, play a pivotal role in improving soil structure and reducing salt stress.

Beyond crop selection, effective irrigation techniques—such as drip irrigation and the use of brackish water with proper leaching—can maintain a balanced soil environment conducive to growth. These strategies not only mitigate the immediate impacts of salinity but also promote long-term soil health and fertility. The economic benefits of such approaches are substantial, providing farmers in salt-affected regions with viable livelihoods while contributing to regional food security. Environmentally, the reclamation of saline lands through horticulture supports biodiversity and reduces land degradation, aligning with broader goals of ecological sustainability. As climate change exacerbates soil salinization globally, the lessons drawn from this chapter highlight the urgency of continued research and investment in adaptive agricultural technologies. Ultimately, the successful integration of these practices demonstrates that salt-affected soils, often dismissed as wastelands, can be reimagined as valuable resources. By leveraging science and innovation, horticultural production in these challenging environments holds the promise of meeting the nutritional and economic needs of a growing world population while fostering resilience in the face of environmental adversity.

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CHAPTER 13

Socio-economic Impact Assessment of NRM Technologies for Management of Salt-affected Soils

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Salt-affected soils affects (SAS) the growth of most crop plants is limited due to excess of soluble and insoluble salts. Soil salinity is one of the most devastating among all kinds that causes land degradation. Unless preventive/ameliorative attempts are taken, the areas under SAS are estimated to increase to 16.2 M ha (million hectare) by 2050 i.e., an increase from 5 % to 11% of total net sown area of the country (141 M ha). SAS in India spread over 6.74 M ha of land, either saline or sodic (alkaline), out of which 2.14 M ha (2.07 M ha sodic and 0.07 M ha of saline) soils have been reclaimed. ICAR-CSSRI has is involved in conducting basic research for understanding problems of salt and water dynamics & balance, causes of salt accumulation and plants behaviour under such stresses. After decades of experiments, the research institute has evolved and recommended a number of technologies for reclamation and management of salt affected soils such as, robust gypsum technology for reclamation of sodic soils, developing salt tolerant crop varieties, guidelines for use of poor quality waters and rehabilitation of salty lands using forestry species. Specifically, the major CSSRI technologies for managing SAS are, (1) Gypsum use for reclamation of sodic (alkali) soil, (2) Sub-surface drainage (SSD) for reclamation of saline soil, (3) Land shaping models for coastal saline and land modification models for waterlogged sodic soil, (4) Salt tolerant crop varieties – rice, wheat, mustard, chickpea (5) Growth enhancer (microbial consortia formulation) – CSR-BIO, ICAR-FUSICONT, Halo-Azo, Halo-PSB, (6) cut-soiler technology for reducing soil salinity, (7) sulphur based formulation as reclamation agent alternative to gypsum and (8) Zero-tillage potato cultivation. Many out of these technology options have contributed towards improving livelihoods conditions and gainful engagements of farming communities in salt-affected areas of the country. Some are emerging to have great potential to contribute, which require policy support for large scale out-scaling. The economic impact of these technologies has multiple dimensions covering economic, social and environmental aspects. Economic impact has been attaining incremental yield, profitability, and increase in cropping intensity, cropping systems output and reducing agricultural risk (yield/return instability and crop losses). Social impact has been increased contribution to food production, employment generation, gender participation, nutritional security, livelihood security, inclusiveness and community engagement. Environmental impact has been improving soil quality (in terms of OC, ECe, pH, SAR), water quality (in terms of ECe, pH), carbon sequestration and good agricultural practice, water saving, input savings (NPK use), soil and water conservation, positive externalities, energy saving and management of waterlogging and drainage conditions of land for productive purposes.

Salt-affected soil management technology and impact

Salt tolerant crop varieties

ICAR-CSSRI has developed salt tolerant rice, wheat and mustard varieties have become popular and are being grown in salt-affected soils in many states. These varieties provide a viable option for the farmers who are growing crops in saline/sodic/water logged environment. ICAR-CSSRI has developed salt tolerant rice varieties viz., CSR 10, CSR 13, CSR 23, CSR 27, CSR 30, CSR 36, CSR 43, CSR 46, CSR 56, CSR 60 and CSR 76, out of which some varieties have spread across many states in India. These varieties can tolerate sodicity up to pH_2 ~10.2 and salinity up to 11 dS/m. The grain yield in normal soils ranges from 6 to 6.5 t/ha and in salt affected soils is 3 to 4 t/ ha. CSR 30 is the first salt tolerant basmati variety, developed and recommended for sodic areas of UP, Haryana and Punjab. It performs very well in normal soils also. The grain average yield in normal soils is 3.0 t/ha and in salt affected soils is 2.0 t/ha. CSSRI has developed five salt tolerant wheat varieties viz., KRL 1-4, KRL 19, KRL 210, KRL 213 and KRL 283. These varieties can tolerate sodicity up to pH_2 ~9.3 and salinity up to 7.3 dS/m. The grain yield in normal soils ranges from 4 to 5.8 t/ha and in salt affected soils is 3 to 4.1 t/ ha. CSSRI has developed five salt tolerant mustard varieties viz., CS 52, CS 54, CS 56, CS 58, CS 60, CS 61 and CS62. These varieties can tolerate sodicity up to pH_2 ~9.4 and salinity upto 11 dS/m. The grain yield in normal soils ranges from 1.8 to 2.8 t/ha and in salt affected soils is 1.5 to 2.2 t/ ha.

Gypsum Technology for sodic Land reclamation

So far about 2.07 M ha of sodic land has been reclaimed with the application of gypsum (10-15 t/ha), which is contributing around 16.60 M tonnes of additional food-grains to the national food basket annually. Farmers can harvest 4 t/ha of rice and 2 t/ha of wheat (5 t/ha and 3 t/ha during subsequent years, respectively for rice and wheat) with an incremental cost of Rs. 76500 per ha. Financial viability for investment on gypsum technology has been found positive with favourable, Net Present Value/NPV (Rs. 2,80,000 per ha), Benefit Cost Ratio/BCR (2.47), Internal Rate of Return/IRR (67 %), Payback period of 3 years. This also provides an employment opportunity to about 2.8 million man-days annually.

Sub-surface drainage (SSD) technology for reclamation of waterlogged saline soils

Developed in 1980, the SSD technology has been successfully implemented over 71734 ha in Haryana, Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra and Karnataka. The per hectare cost of adoption was estimated to Rs. 74000 for medium to light textured soils with 67 m spacing and Rs. 1,15,000 for heavy textured black soils with 30 m spacing. The SSD resulted in 3-folds increase in farmers' income after installation. The financial feasibility analysis showed that the Payback period was 2 years, NPV (Rs. 113000 per ha), BCR (2.71) and IRR (40%).

Land shaping/modification models for waterlogged sodic/saline soil

ICAR-CSSRI has developed different types of land shaping technology (LST) for management of coastal saline soil and waterlogged sodic land. Most suitable ways of crop-fish integration system and financially viable land shaping technologies have been tested (2079 ha) in coastal salt-affected areas in West Bengal, Andaman & Nicobar island. The different types of popular LST are, (1) Farm pond, (2) Paddy-cum-fish and (3) Deep-furrow & high ridge types. Initial investment is estimated as Rs. 0.88 - 1.45 lakh /ha (primarily on land excavation at 2014-15 prices) on various LST. Financial feasibility criteria on these form of LST favoured the investment propositions as profitable with IRR (36-46 %), NPV (Rs. 0.97- 2.85 lakh per ha), BCR (1.20 - 1.58) and Payback period (1.41 - 2.13 years). Similarly, land modification technology (pond based and raised & sunken bed) demonstrated under waterlogged sodic soil (high pH) in Uttar Pradesh also generated favourable return and financially viable.

Emerging technology for salt-affected soil management

Cut-soiler technology for waterlogged soil management

Cut-soiler is a machine that cuts and opens V-shaped furrow at desired depth and fills it back with scattered straw and residue lying on the soil surface and further covered with soil. Such Cut-soiler lines serve as drainage channels and thus have potential to manage surface waterlogging and soil salinity. This technology can serve as remunerative option for management of salt affected soils and also helpful in crop residue management in North West Indo-Gangetic plains. ICAR-CSSRI and JIRCAS initiated a collaborative project for evaluation of cut-soiler to provide sustainable resource management system for surface waterlogged saline soils in India. To see the effect of cut-soiler on salt and water dynamics under fluctuating water table along with an irrigation experiments are beings undertaken at ICAR-CSSRI, Karnal. Results revealed the desalinization effect of cut-soiler in saline (6.73 to 5.5 dS m^{-1}) and heavy textured soils (0.86 to 0.34 dS m^{-1}). The cut-soiler technology reduced the soil salinity by 18% and thereby an improved yield of ~23% was recorded under pearl millet and mustard crop as compared to control. In farmer's participatory trials in Punjab, soil ESP was decreased by ~ 18.3% at 40 cm depth up to a lateral distance of ~0.7 m from cut-soiler line. Significant improvement in grain and biological yield of wheat was also recorded with decreasing cut-soiler spacing.

Sulphur based formulations: New reclamation agent for sodic soils

Sodic soils occupied more than 3.77 m ha area of India and this area is likely to increase in cultivated irrigation commands of the country by 2030. The reduced availability of the quality gypsum for sodic soil reclamation is now a major challenge in productive utilization of these lands. Presently, gypsum available for agricultural use is not meeting the minimum standard (70% purity) of BIS set for agricultural gypsum. To address this issue of non-availability of quality gypsum, ICAR-CSSRI, Karnal in collaboration with Reliance Industries Ltd, Mumbai has developed three categories of sulphur based formulation (RFS) suitable for different soil sodicity conditions. The elemental S based base formulation evaluated in Punjab, Haryana, UP, MP and Rajasthan showed 8% (very low sodicity) – 225% (high sodicity) increase in yield of wheat, rice, cotton and berseem (fodder crop). These formulations are highly reactive and get oxidized within one crop season by the soil microrganisms to help in alleviating the stress developed because of excess of the alkaline salts present in soils and provide conducive environment for root proliferation. It has quick response, about six times less bulky and consistent quality with >90% purity compared to mined gypsum. This reclamation agent can be recommended for management of sodic soils popularly known a *usar*/*kallar* soils. It is likely to reduce the dependence on the mining material and also promote the circular economy by utilizing the by-products from petroleum industries.

Flue gas desulfurization gypsum (FGDG)

Flue gas desulfurization gypsum (FGDG; calcium sulfate dihydrate, $CaSO_4 2H_2O$) is a by-product of coal-fired power generation plants where sulphur get scrubbed from combustion of gases. FGDG widely used in building materials, such as wallboard, plaster coatings, and concrete, and also has the potential to reclaim sodic soils as an alternative to mined gypsum presently being used. Applications of FGDG in cultivated soil improve physicochemical properties, decline nutrients loss, supplement nutrients for soil and improve crop yields; thereby increasing the overall productivity. Recognizing the role of FGDG in the reclamation of sodic soil as an alternative to mine gypsum, ICAR-CSSRI and NTPC jointly initiated a collaborative work to study the efficiency and efficacy of FGDG in the reclamation of sodic soils. Also, heavy metal(s) uptake, crop growth and soil quality and leachates in FGDG amended soils were monitored. Experiment on reclamation of sodic soils with the application of FGD gypsum in the lysimeters with sodic soils was conducted with four locations varying in soil pH. Results showed that the soil pHs declined by 8-11% after one year of FGDG application at 0-15 cm depth. Similarly, a significant change in pHs was also observed at 15-30 cm depth. The neutralization of soil alkalinity over the period has improved paddy crop growth and yield. The paddy grain yield increased by ~40% with FGDG compared to control. The wheat grain yield increased by ~60% with the application of FGDG in sodic soil. The FGDG product was evaluated in Haryana, Uttar Pradesh, and Punjab for their reclamation potential of sodic soils and shown the promising results.

Zero Tillage Potato Cultivation with Paddy Straw Mulching in Coastal Saline Soils

Potato is sown in the wet field just after the harvesting of the preceding monsoon or *kharif* rice. The tubers are covered with paddy straw, which act as thick mulch to conserve applied irrigation water and prevent soil salinity development. Early sowing and harvesting achieved by this practice helps in taking another *rabi* pulse crop like green gram (rice-ZT potato-green gram). This system increases the cropping intensity, yield and profit of farmers. It significant reduces irrigation requirement, efficiently uses residual soil moisture and prevents soil salinity development and improves soil health. Cost of cultivation (2017-18 prices) of Rs. 1,05,900 ha^{-1} and Rs. 72,833 ha^{-1} under conventional and ZT technology respectively. Net return was Rs. 45,465 ha^{-1} under conventional ridge and furrow method, whereas it was Rs. 98,520 ha^{-1} under ZT with paddy straw mulching technology. With adoption of this technology benefit-cost ratio can be increased from 1.43 to 2.35. This zero till potato cultivation is now also started in coastal region of Bangladesh under ACIAR project and the technology is getting popularized in the Ganges delta region. The production method is also becoming popular in other parts of the country.

Stakeholders' engagement for out-scaling of technologies

The ICAR-CSSRI is involved in development of technologies for gainful management of salt-affected soils in the country. The development and application of such technologies needs to be complemented by desired policy initiatives to benefit larger farming communities inhabiting in SAS of the country. It requires involvement of multiple agencies and also streaming with several ongoing schemes or even new schemes for management of such problem soil can be launched at country level. Some of the institutions or schemes that can be engaged/streamlined with, are indicated in Table 1.

Table 1: Process and institutions involved in adoption of ICAR-CSSRI technologies

Technology	Process	Institution involved
Salt-tolerant crop variety (rice, wheat, mustard)	The ICAR-CSSRI regularly receives indent for breeder seed production from DAC, MoA&FW, Govt. of India and supplies the salt tolerant seeds as per the requirement. Breeder seeds are, multiplied by various states agricultural department or private seed companies and then supplied to the framers. ICAR-CSSRI also produce some quantity of seeds and supplies to farmers directly from the institute a farmers demand.	ICAR-CSSRI, Karnal It is spread through, DAC, MoA&FW, various state government agencies, private players, farmers etc.
Gypsum application for reclamation of sodic soil, Sulphur based formulations: New reclamation agent for sodic soils AND Flue gas desulfurization gypsum- A potential amendment for reclamation of sodic soils	Gypsum is a widely used amendment for reclaiming the sodic soils having structural problems and impeded water flow. Gypsum treatment markedly improves soil physical conditions, as evident from better soil flocculation, aggregate stability and improved infiltration rate. Specific features of gypsum technology are (i) Land leveling and bunding for rainwater storage and uniform distribution of irrigation water; (ii) Soil sampling for determination of gypsum requirement; (iii) Uniform application of gypsum (10-15 t/ha) followed by mixing of surface (10 cm) soil; (iv) Ponding water for minimum of one week before transplanting of rice; and (v) Adopting proper agronomic practices. Beside gypsum alternative reclamation agent as developed by ICAR-CSSRI may be made available to farmers in the affected areas.	ICAR-CSSRI, Karnal It is spread through various state government agencies, RKVY (reclamation of problem soil), NGOs, private players, farmers etc.
Sub-surface drainage and Cut-soiler technology	The system consists of perforated corrugated PVC pipes, covered with synthetic filter, installed mechanically at a design spacing and depth below soil surface to control water table depth and drain excess water and salts out of area by gravity or pumping from an open well called sump. The depth and spacing of drainage systems are governed by rainfall, irrigation, hydro-geology, texture and salinity of soil and outfall conditions in the affected area. The technology developed by ICAR-CSSRI during	ICAR-CSSRI, Karnal It is spread through various state government agencies, RKVY (reclamation of problem soil), NGOs, private players, co-operatives, farmers etc.

	1980s initially for Haryana has been widely adopted and replicated in Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra and Karnataka. Delineating of potential areas for cut-soiler technology is required to benefit farmers in the similarly affected areas wherever feasible.	
Land shaping model (coastal saline), Land modification models (waterlogged sodic), Zero-tillage potato	Land shaping model is about 20-50% of the farm area (depending on types of land shaping and actual area) is converted into on-farm reservoir to harvest excess rainwater. The dug-out soil is used to raise the land to form high and medium land situations, besides the original low land situation in the farm for growing multiple & diversified crops throughout the year instead of mono-cropping with rice in *kharif* season. The pond is used for rainwater harvesting and utilised for irrigation and pisciculture. Poultry/ livestock farming are practiced in the farm along with crops and fishes with the use of pond water. The high land becomes free from water logging in *kharif* with less salinity (40-60%) build up in dry seasons and used for multi & diversified crop cultivation throughout the year. This is suitable for management of coastal saline soil. Land modification model is construction of ratio of raised and sunken bed with 1:1, width 10-25 m according to actual field conditions and depth of the pond is maintained 2 m. Excess seepage water from canal is harvested in pond/sunken area along both sides of the canal (up to 300 m distance from canal). Such land modification is successful in in management of waterlogged sodic soil and feasible to grow crop and fish through the year in the system, which otherwise remain almost barren.	ICAR-CSSRI, RRS, Canning Town It is spread through various state government agencies, RKVY (reclamation of problem soil), NGOs, SAUs, farmers, KVKs etc. ICAR-CSSRI, RRS, Lucknow ICAR-CSSRI, Private investors and Govt. of Uttar Pradesh. International collaboration for spread in Ganges delta and in other areas

Conclusions

It was observed that despite having high impact, there are some key issues those constrain out-scaling of salinity management technologies. These include, sometime management options are technically feasible, but challenged by socio-economic perspectives, such as, high investment cost, land size, instability in return, Additionally, the salinity induced crop losses are often quite high at farm/plot-level, however, this is not recognized at macro scale due to the reasons, for instance, that normal and problem soils co-exist and part of the crop losses are seen to be compensated by the production from good land at aggregate level. Further, the cost of land degradation is high, and replacement of input cost or amelioration is also high. As a result, the trade-offs between action and no-action often remains unfavourable at private cost, and benefits of ecosystem services gained through good agricultural practices remains intangibles. An urgent need arises to undertake a proactive strategy for diagnosing future problems areas well ahead of time which can enable the stakeholders to undertake precautions as well as reclamation measures sustainably. In addition, this could also open a pathway to identify and promote good agricultural practices embedded with incentive measures, and restrictions on exploitative practices through regulatory measures. With the concerted efforts by engaging with key stakeholders such as farmers, technology developer and implementing agencies, these issues can be addressed and research output can be turned into social benefit by large scale adoption by farmers.


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