ICAR-Winter School
Advances in Salinity and Sodicity Management under Different Agro-Climatic Regions for Enhancing Farmers' Income

4-24 September, 2018

Editors
MJ Kaledhonkar, RL Meena, BL Meena, N Basak, PC Sharma

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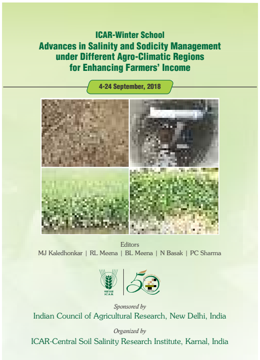

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Dr. P.C. Sharma
Director

FOREWORD

At national level around 6.73 million ha (M ha) area has been characterized as salt affected, out of which 3.77 M ha is sodic and the remaining 2.96 M ha is saline. Besides, use of poor quality water in different states varies from 32-84%. Uttar Pradesh, Gujarat, Maharashtra, Tamil Nadu, Haryana and Punjab are having about 80% of the total sodic lands. Similarly, salinity is a serious problem across 13 states of the country with Gujarat having largest area of 1.68 M ha. Gujarat, West Bengal, Rajasthan and Maharashtra are severely affected states. Also crop production loss due to salinity at the national level is 5.66 million tonnes (M t), accounting for the annual monetary loss of 8,000 Crores, at prevailing Minimum Support Prices (MSP) of different crops during 2015. To address salinity and sodicity issues, the ICAR-CSSRI was established at Karnal (Haryana) in 1969. Since then, the Institute has made significant contributions towards management of saline and alkali environments for crop production. At present, institute has three regional research stations at Canning Town in West Bengal, Bharuch in Gujarat and Lucknow in Uttar Pradesh. Besides, AICRP on Salt Affected Soils and Use Saline Water in Agriculture, established 1972, contribute towards vision of ICAR-CSSRI. During initial phases, attempts were made for understanding the problems and developing technologies for reclamation of alkali soils of the Indo-Gangetic Plains focusing on rice-wheat cropping system. Alternate use of alkali lands for agro-forestry and afforestation, subsurface drainage for waterlogged saline soils, sustainable use of poor quality waters in crop production; salt tolerant varieties of rice, wheat and mustard were added to the list later on. Use of microbial consortia for salinity and sodicity management is recent development.

I am happy to mention that ICAR-CSSRI is celebrating its Golden Jubilee Year during 2018-2019. This is the time to share knowledge gained by the institute over the years with other partners at national level. Therefore, the institute is organizing 21 days ICAR sponsored Winter School on Advances in Salinity and Sodicity Management under Different Agro-Climatic Regions for enhancing Farmers Income at ICAR-CSSRI, Karnal during 04- 24 Sept.2018. I learnt that 24 participants from ICAR institutes and SAUs are attending this winter school and they are from Punjab, Haryana, Rajasthan, Bihar, Madhya Pradesh, Maharashtra, Tamil Nadu, Andhra Pradesh, Goa, A&N Islands. The course content has been designed considering needs of participants and addressing all aspects of sodicity and salinity management. There is sufficient time allocation for theory classes, practical classes and field visits. The resource persons were identified from experienced professionals who have spent reasonable time of their life spans for salinity research. Best quality learning environment is provided to participants with nice boarding and lodging in green and beautiful landscape of CSSRI. The lecture notes and practical protocols are compiled in this manual. I feel, this compilation can be very useful participants in future at their places of work.

At the end, excellent team effort by Dr MJ Kaledhonkar, Project Coordinator & Course Director; other Course Coordinators Dr RL Meena, Pr. Scientist, Dr BL Meena, Sr. Scientist and Dr. Nirmalendu Basak, Scientist (Sr. Scale) and PC Unit Staff, Shri AK Sharma, SrTO, Smt Dinesh Guganani, Shri Sukhabir Singh is appreciated.

(PC Sharma)
Director

PREFACE

The soil sodicity and soil salinity are considered as land degradation processes in agricultural lands and both affect crop yields adversely on 6.73 m ha. Management of such lands includes reclamation including salt leaching, improved agronomic, irrigation water and nutrient practices, alternate land uses and use of salt tolerant varieties. The ICAR-Central Soil Salinity Research Institute along with three regional stations and AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture with network of twelve centres have made significant contributions towards characterization and monitoring of salinity problems of soils and of ground waters under a wide range of situations such as arid, semi-arid and coastal as well as reclamation and management of salt affected soils and poor quality waters considering prevalent agro-climatic conditions in the regions. All these efforts have helped in creating greater awareness about sodicity and salinity issues in the country.

The reclamation and management of salt affected soils, whether sodic or saline, require special skills and multi-disciplinary team is always desired to find optimal solution. Very interestingly, these soils were of good quality before degradation. If land degradation processes of such lands are reversed, the soils can be very productive after reclamation. Therefore, benefit cost ratio remains always favourable in case of reclamation activities of sodic and saline soils. This fact has been proved through large scale reclamation of sodic soils in state of Haryana, Punjab and Uttar Pradesh as well as reclamation of waterlogged saline soils in state of Haryana, Rajasthan, Karnataka, Maharashtra and Punjab. The large scale reclamation programmes create employment, improve crop productivity and production, enhance land value, promote other allied activities and finally enhance farmers' income and their social status. The Government of India and different state governments are providing financial support to reclamation activities. Under such situations small team of under leadership of ICAR-CSSRI is not sufficient to address all issues related reclamation and management of salt affected soils at different agro-climatic regions of the country. This ICAR sponsored 21 days winter school on Advances in Salinity and Sodicity Management under Different Agro-Climatic Regions for enhancing Farmers' Income at ICAR-CSSRI, Karnal during 04- 24 Sept.2018, gives an opportunity to ICAR-CSSRI for capacity building of agricultural scientists, university teachers and extension specialists on this important topic, particularly in Golden Jubilee Year of the institute. Course content of the winter school is designed meticulously considering all practical aspects of the topic. The experienced resource persons are invited to explain important technological milestones in the history of ICAR-CSSRI. All those details are compiled in this manual with intention that 24 participants will promote reclamation of salt affected soils in their respective states.

I take this opportunity to express my sincere thanks and gratitude to Dr T Mohapatra, Secretary, DARE and DG, ICAR for providing financial support to this winter school. I also express my deep sense of gratitude to Dr K Alagusundaram, DDG (Agricultural Engineering) & DDG (NRM) (Acting), ICAR for guiding us all the way. Heartfelt thanks are due to Dr SK Chaudhari, ADG (SWM), Dr. M.B. Chetti, ADG (HRD) and Dr PC Sharma, Director, ICAR-CSSRI for their excellent support and cooperation in all spheres. Thanks are also due to ICAR institutes and State Agricultural Universities for nominating their staff for this training. We also express thanks to all resources persons who gave lecture notes and agreed to deliver lectures. The help provided by different divisions, sections including PC Unit and administration of the institute is thankfully acknowledged.

M J Kaledhonkar, RL Meena, BL Meena, Nirmalendu Basak

CONTENTS

Harnessing Salt Affected Soils for Sustainable Crop Productivity

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Introduction

'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 (EC_e), pH (pH_s) 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 pH_s values >8.5 and >8.2 are considered sodic in the United States and India, respectively. In India, pH_s 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 pH_s 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: EC_e ≥4 dS m^{-1}, pH_s <8.2, ESP <15; and sodic: EC_e <4 dSm^{-1}, pH_s >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 EC_e (≥ 4 dS m^{-1}) 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 M 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 (watertable 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 spill over 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.

Despite a pan-India mandate, the immediate focus was on reclaiming the sodic areas of Punjab and Haryana states so that they could also benefit from targeted initiatives made during the Green Revolution days. Successive field and laboratory experiments shortly culminated into standardization of gypsum-based package for sodic soils. By mid-1970s, it also became evident that irrigation-led yield revolution in north-western India has its own flip side: while groundwater development helped accelerate the pace of sodic soil reclamation in fresh water areas, excessive irrigation slowly turned many fertile tracts saline and sodic.

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). An examination of past trends in agricultural salinity management makes it evident that in order to become popular among the farmers a particular technology should meet the criteria of '*feasibility*' (low cost and easy to adopt), '*compatibility*' (location-specific and ecologically compatible) and '*adaptability*' (amenable to refinements to suit the changing needs). Taking these considerations into account, the strengths and weaknesses of different such technologies have been discussed in the succeeding paragraphs.

Reclamation and Management of Sodic Soils

Chemical and Organic Amendments: Sodic soils of IGP owe their origin to rapid alternate wetting and drying cycles conducive to alkali hydrolysis, sodium saturation and high pH development. Nonetheless, regular irrigation with high RSC groundwater has aggravated sodicity problem in many areas. Very high water requirements of RWCS make it extremely susceptible to sodicity hazard. Soils of RWCS in IGP display almost twofold higher soil pH and ESP values compared to those under low water requiring crops like maize-wheat (Minhas and Bajwa, 2001). Because of very high water needs, application of even normal (canal) water would add ≈3-4 tons of salts ha^{-1} annually to these soils (Sharma and Singh, 2017). In the last few decades, irrigation with untreated and treated wastewater (TWW) has also increased manifold in areas grappling with fresh water shortages. However, due to relatively higher SAR compared to the fresh water of origin, soils irrigated with TWW tend to become sodic as evidenced by elevated ESP levels and subsequent clay dispersion (Bardhan *et al*., 2016). Amendment applications and other soil management practices intend basically to improve the infiltration rate (IR) and lower ESP of sodic soils. Advantages and limitations of conventional and alternative amendments for sodic soils are discussed in the following paragraphs:

Gypsum: 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%. However, factors such as low cost, easy availability, ease of application and better efficacy compared to other chemicals have shifted the balance in favour of gypsum ($CaSO_4.2H_2O$) making it the amendment of choice to overcome sodicity-induced anomalies in soil physical conditions. 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 alleviating 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 EC_e from 43 to 1.5 dS m^{-1} 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 Ca^{2+} 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^{-1} 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; EC_2: 3.09 dS m^{-1}; ESP: 77.5) compared to sole gypsum application (GR_{50}) (Sundha *et al*., 2017).

Engineered nanoparticles: Engineered nanoparticles (ENPs) are increasingly being used for the amelioration of SAS. ENPs currently used for different soil applications can be classified into: metal ENPs (*e.g*., elemental Ag and Fe), fullerenes (Buckminster fullerenes and nanocones), metal oxides (TiO_2, CuO and FeO_2), complex compounds (Co-Zn-Fe oxide), polymer coated quantum dots (cadmium-selenide and polystyrene) (Dinesh *et al*. 2012). Available evidence suggests that ENPs decrease surface run-off and structural anomalies in sodic soils by improving the aggregate stability and IR. Application of polyacrylamide (PAM) (10 ppm) increased water movement throughout the root zone and decreased $CaCO_3$ concentrations in the top 45 cm layer by enhancing calcite solublization. These effects led to Na^+ leaching, reduced soil EC_e and SAR. Soil pH, bulk density and $CaCO_3$ content decreased while saturated hydraulic conductivity increased from 0.05 mm d^{-1} to 40.01 mm d^{-1} in a highly dispersed hard saline-sodic soil treated with polymeric aluminum ferric sulfate (PAFS). Soil ESP and EC_e also decreased by 63.23% and 45.61%, respectively, in 0-8 cm layer and by 34.57% and 37.47%, respectively, in 8-16 cm layer. Rice yields with PAFS application in the first year of cultivation were as high as 4.66 t ha^{-1} compared to only 0.83 t ha^{-1} in control treatment (Luo *et al*. 2015). Ghodsi *et al*. (2015) found that combined application of urban solid waste compost coated sulfur (15 t ha^{-1}) and nano iron oxide powder (20 mg kg^{-1}) decreased the pH and SAR of a saline-sodic soil resulting in increased availability of nutrients to sunflower plants. Solitary applications of both the amendments marginally increased soil EC_e. Kumar and Thiyageshwari (2018) compared the effects of nano-gypsum and mined gypsum at 4 levels of GR (25, 50, 75 and 100%). Application of nano-gypsum 100% GR was very effective in reducing soil pH and ESP compared to mined gypsum at varying levels.

Wang *et al*. (2011) compared 17 different soil conditioners for their ability to promote seed germination and plant growth under saline conditions. Of the tested compounds, addition of Hydrolyzed Polymaleic Anhydride (HPMA) significantly increased germination percentage and plant growth rate in saline-sodic soils by decreasing soil pH, EC and bulk density and increasing clay flocculation and water infiltration rate. HPMA increased $CaCO_3$ to release Ca^{2+} in soil solution to remove the excess Na^+.

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. SSD installation has turned the fortunes of farmers in salinity affected Ugar Budruk village of Belgaum District, Karnataka. This project covers ≈925 ha area benefitting ≈650 farmers. Cropping intensity increased from 62.64% (pre-SSD) to 77.62% (post-SSD) due to decline in mean soil salinity from 6.6 to 2.5 dS m^{-1}. Similarly, B: C ratio increased from 0.54 to 1.21 in the ameliorated lands (ICAR-CSSRI, 2017a).

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 (watertable < 2.0 m) that constitute ≈15% of the total sodicity-affected area of the state. Watertable 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 watertable 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, watertable 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 watertable 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 month^{-1} (*kharif* rice) to as high as INR 11999 month^{-1} (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 agri-silvicultural 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.

Biodrainage 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 centimetres 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 bio-drain over 5000 mm of water from non-saline, moderately deep (≈1.5 m) watertables. Relatively shallow (≈1 m) or deep (≈ 2 m) watertable 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^{-1}, *Eucalyptus* trees can remove ≈50% of the water compared to that under non-saline conditions. *Eucalyptus tereticornis* trees could control watertable 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^{-1} even at saline (12 dS m^{-1}) watertable depth of 1 m. Similarly, bamboo (*Bambusa arundinacea*) plants could control watertable 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 watertable 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 watertable 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 toleraant 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, five of Indian mustard CS 52, CS 54, CS 56, CS 58 and CS 60 and 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 (EC_{IW} up to 10 dS m^{-1}) 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.

Of late, molecular and genomic tools are increasingly being employed to understand the biochemical and molecular basis of salt tolerance in different crops. Identification of such traits can pave the way for their introgression in popular (but salt sensitive) cultivars through conventional and marker-assisted breeding approaches. Ravikiran *et al*. (2017) screened 13 SSR markers associated with *Saltol* region on chromosome 1 in 192 rice genotypes. Based on polymorphism and genetic diversity indices, markers RM 493 and RM 10793 were found to be highly useful for distinguishing genotypes.

Technologies for Sustainable Intensification in Reclaimed Lands

Besides rising threat of secondary salinization, repeated instances of resodification and resalinization of reclaimed lands have set alarm bells ringing in many areas. Reversion of reclaimed lands to the pre-reclamation state implies that efforts made for reviving the soil productivity were in vain. Resodification refers to the reappearance of sodic patches in a sizeable area of reclaimed sodic soils. In Etawah district of Uttar

Pradesh, out of total (3,905 ha) reclaimed sodic area, nearly one fourth had relapsed showing the signs of degradation (Yadav *et al*. 2010). It appears that lands in immediate vicinity of canals; especially those suffering from problems of hard sub-soil pan, drainage congestion and shallow watertable, are extremely susceptible to resodification. Similarly, resalinization of ameliorated saline lands can be ascribed to climate- and human-induced redistribution of salts to the surface soil. In both the cases, poor on-farm water management seems to accentuate the extent of salt build-up. Available evidence also suggests that indiscriminate irrigation and agro-chemical use have led to many second generation problems such as groundwater depletion and contamination, loss of soil organic carbon and nutrients, pest and disease outbreaks and crop residue burning in several parts of RWCS covering nearly 12 M ha area in India. These problems together with stagnant and/or declining crop yields have wide ranging ramifications for the food, environmental and economic security of the country. Several options are available to contain these problems.

Integrated farming: An integrated crop-fish-livestock model has been standardized for the small landholders (2 ha land area) of reclaimed sodic areas. This model consists of field and horticultural crops, fish culture, cattle, poultry and beekeeping. Available resources can efficiently be recycled among different components for reducing the environmental foot prints and lessening the production costs. Integration of different components ensures higher and regular incomes to the farm families who otherwise derive incomes from rice and wheat crops only. Generation of round-the-year employment and nutritional security of farm families are the added benefits of this model (Sharma and Singh, 2015).

Adoption of conservation agriculture: Conservation agriculture (CA) practices coupled with the replacement of rice with low water requiring crops like maize may be helpful in achieving sustainable crop intensification in IGP of India. Gathala *et al*. (2014) compared four cropping system scenarios including the farmers' practice and found that resource conservation technologies such as reduced tillage, residue management, crop substitution and innovative crop establishment methods efficiently enhanced the system productivity and profitability. Direct-seeded rice with residue retention provided equivalent or higher yield with 30-50% saving in irrigation water use than farmers' practice of puddled transplanted rice. Replacement of rice with zero-tillage maize gave similar profits while saving ~90% irrigation water. Choudhary *et al*. (2018) observed that CA-based sustainable intensification of maize-wheat systems was a better alternative to RWCS as it could save 79% of precious water while enhancing crop and water productivity by 12 and 145%, respectively along with high (34%) economic benefits. Tirol-Padre *et al*. (2016) found that switching from conventional to CA-based practices in rice crop can reduce global warming potential (GWP) for rice by 23% or by 1.26 Tg CO_2 eq y^{-1}. An intensive CA-based rice-wheat and maize-wheat system reduced GWP by 16-26% or by 1.3-2.0 Tg CO_2 eq y^{-1} compared with the conventional rice-wheat system mainly due to reduction in diesel and electricity consumption.

Carbon Sequestration: Soil organic carbon (SOC) pool is an important measure of soil health. Salt-affected lands generally have very low SOC stock that can be explained by the virtual absence of vegetation cover and, consequently no organic carbon input to the soil. In sodic soils, clay dispersion increases SOC mineralization. Saline conditions can hasten organic matter decomposition but flocculation of aggregates due to high salinity often restricts access to substrates for microbial respiration. Presence of carbonates may further complicate the carbon dynamics (Wong *et al*. 2010). Low SOC stock, in turn, results in lower levels of soil microbial biomass (SMB) and microbial respiration rates. Addition of organic material activates the salt tolerant microorganisms that otherwise remain dormant in salt-affected soils. Organic material (kangaroo grass; 10 t ha^{-1}) treated acidic and alkaline saline-sodic soils had the highest levels of SMB and soil respiration while their lowest levels were noted in untreated (control) soils (Wong *et al*. 2009). A laboratory incubation experiment conducted on non-salt-affected and salt-affected soils from India and Australia showed that EC was the main factor influencing soil respiration. Particulate organic carbon, humus-C and clay were also found to influence soil respiration with the degree of influence depending on whether the soils were salt affected or not. Cumulative CO_2-C emission was negatively correlated with EC in saline soils from both regions. SAR was negatively related with cumulative CO_2-C emission only for the unamended saline-sodic soils of Australia (Setia *et al*., 2011).

A study conducted in China revealed that in croplands converted into tree plantations, secondary forests and grasslands SOC stock built up at an average rate of 36·67 g m^{-2} y^{-1} in the top 20 cm layer; albeit with large variation. After land use change, SOC stocks decreased during the initial 4-5 years, followed by an increase after above ground vegetation restoration (Zhang *et al*. 2010). Several studies conducted in India have also shown that revegetation of SAS with trees/grasses raises their SOC level. Soil organic matter, total carbon storage and biological productivity were much higher in the silvipastoral system consisting of trees (*Acacia nilotica*, *Dalbergia sissoo* and *Prosopis juliflora*) and grasses (*Desmostachya bipinnata* and *Sporobolus marginatus*) compared to sole grass blocks in a highly sodic soil (Kaur *et al*. 2002). SOC storage up to 1 m depth over a period of 15 years was 16.7-24.7 t C ha^{-1} in a natural grassland ecosystem in sodic soils (pH: 8.0-10.2). Integration of trees with grasses further enhanced carbon storage by 15-57 %. It has been found that rice-*Eucalyptus camaldulensis* system can sequester 24 t CO_2-eq. ha^{-1} on moderately saline soils in coastal Bangladesh over the plantation lifetime. Similarly, rice-wheat- *Eucalyptus tereticornis* and *Acacia nilotica* plantations on saline-sodic soils of Haryana (India) and Punjab (Pakistan) can sequester 6 and 96 t CO_2-eq. ha^{-1}, respectively, over plantation life time (Wicke *et al*., 2013). Among different land use systems, *viz*., fruit trees (guava, litchi, mango, jamun), agro-forestry systems (*Eucalyptus tereticornis* and *Prosopis alba*) and RWCS system in a partially reclaimed sodic soil of north-western India, guava land use exhibited the highest SOC storage (133 Mg C ha^{-1}) as well as the maximum passive C pool (76 Mg C ha^{-1}) due to decomposition of leaf litter and subsequent deposition in the root zone over the years (Datta *et al*., 2015).

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Protocols for Diagnosis, Characterization and Delineation for Saline and Alkali Soil Mapping

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Application of RS and GIS for Diagnosis of Salt Affected Soils

Geo-informatics broadly deals with measurement and analysis of the geographic data and its basic technologies are-Remote Sensing, Geographical Information System (GIS) and Global Positioning System (GPS). Remote Sensing provides synoptic, multi-spectral information of earth resources, GPS enables the users to know about the precise location on earth surface and GIS combines maps (spatial information) and attribute data together. The tools and techniques in GIS help to integrate various technologies for data generation and also to perform spatial analysis. In agriculture and soils, the application of remote sensing was initiated with the introduction of aerial photographs in 1928. Initially, these photographs were commonly used for delineating salt affected soils using visual interpretation based on the differentiating tone, texture, size, shape, patterns of image elements. With the advent of digital technology and launching of the first Earth Resources Technology Satellite (ERTS 1) later renamed as LANDSAT 1, the mapping and monitoring of earth resources such as salt affected soils becomes quite reliable and efficient. Subsequently, satellites with improved spatial and spectral resolution in LANDSAT (4, 5, and 7) *Multi-spectral Scanner* (MSS), *Thematic Mapper* (TM), *Enhanced Thematic Mapper* (ETM), *Enhanced Thematic Mapper Plus* (ETM+) sensors with 79/82 m, 30 /120 m and 30/15 m resolution; the Indian Remote Sensing (IRS) satellite *Linear Imaging Self-scanning System* (LISS I, II, and III) with 72 m, 36 m and 23 m resolution and SPOT (1, 2 and 3) *high resolution visible* (HRV) imaging system with 10m resolution in panchromatic (PAN) and 20 m resolution in multi-spectral (color IR) range; SPOT 4, HRVIR (*high resolution visible and infrared*) with 10 m resolution in PAN and 20 m in mid-IR range and SPOT 5 with two *high resolution geometric* (HRG) instruments with 5 m resolution in PAN and 10 m resolution in green, red and NIR and 20 m in mid-IR range are included to enhance mapping efficiency.

Due to the higher spectral contrast of salt affected areas with winter crop during March –April and maximum occurrence of waterlogging in the post monsoon season during October- November, the ideal time for selecting a Remote Sensing data is March –April and October – November for salt affected and waterlogged areas respectively. Two methodologies, viz, visual interpretation and digital analysis are carried out using hard copies of the remote sensing data such as false color composite (FCC) and digital remote sensing data available in separate bands. A FCC is prepared using the combination of blue, green and near infrared bands. The differential spectral characteristics of image elements in terms of tone, texture, pattern, shape etc are used for detecting salt affected soils. The differential tone between cropped and non-cropped or cropped with stress (salinity or waterlogging) facilitates in distinguishing a normal cropped with a salt affected or waterlogged crop. The brighter tone of a barren surface facilitates in detecting a barren salt affected area. Often barren sandy surfaces confuses with a salt affected soil. The criteria such as brighter one, topographic situation, landform characteristics, salinity/ alkalinity stress on soil and crop are commonly used for differentiating a salt affected and a sandy surface. The prominent indicators of waterlogging are low reflectance and high absorption in the near infrared band due to the presence of excess moisture. On the FCC these areas are commonly found with dark gray to blue-black color, smooth texture and a clear shape often associated with low-lying flats/ depressions where surface ponding occurs and a gray to dark gray color for waterlogging intermixed with light to moderate red color for vegetation where high water table prevails. The salt crust formation is often associated with a barren surface with prominent reflectance of salt accumulation on a dry surface. The salt efflorescence associated with an irrigated area is identified with mixed reflectance of localized salt accumulation on surface and the high absorption due to higher moisture content for waterlogged areas.
Apart from visual interpretation, digital analysis is being carried out with digital RS data. The image elements are characterized with the range of digital number (DN values) or the spectral reflectance (5) or brightness index ratio calculated from the DN values with sensor characteristics. The digital data is classified with suitable statistical algorithms for automated classification. In both the methodologies, the incorporation of ground truth data is essential to quantify the interpreted units. During field survey and ground truth collection, the marked homogenous units of visual interpretation are verified for the presence or absence and form of salty surface, topography, slope, land use, irrigation/drainage condition, waterlogging at surface or high water table, local / human influences etc along with its location information using a GPS. Incorporation of the ground truth data thus facilitates increase in the mapping accuracy using remote sensing data. Using such technique, the

detection and delineation of salt affected soils are easily carried out in the moderate to strongly salt affected soils with moderate to coarse texture in the Indo_Gangetic Plain. Due to high absorption from the dark colored (black) soil surface and less contrast of vegetation with salty surface, the delineation of salt affected areas in the black soil region becomes difficult. Remote sensing data with higher spectral resolution in the thermal and microwave region are useful to detect salt affected areas for the black soils. Under the NATP project, an attempt was made to prepare a spectral library for salt affected and associated normal soils based on the spectral reflectance data of soils collected from the field and laboratory condition. Such study was carried out with a mission to prepare a satellite sensor with appropriate spectral resolution for detecting salt affected and waterlogged soils with less time and higher efficiency.

The GIS is primarily been used for preparation of infrastructure of spatial and non-spatial resource data in the form of digital database. Based on the salt affected soils maps of NRSA (1997), digital database of salt affected soils is prepared in GIS. The layers of infrastructure, administrative and political boundaries, irrigation /drainage, settlements and SAS polygons are combined to prepare State maps on 1: 250, 000 scale The geo-referenced data in digital format thus facilitates in integrating a number of State maps in GIS to prepare regional and zonal maps for Indo_Gangetic plain, arid and semiarid region, peninsular region and agro-climatic zones suitable for regional planning. Relational database is prepared using spatial and attribute data to facilitate easy retrieval of information for characteristics, distribution and extent of salt affected soils. Due to geo-referencing with universal projection, such datasets allows superimposition of related datasets such as climate, water table depth, water quality, land sue, land form etc. for analysis and spatial modeling required for decision making in reclamation and salinity management. Similar databases are prepared by the National Natural Resource Information System by Indian Space Research Organization (ISRO); National Spatial Data Infrastructure (NSDI) prepared by the Survey of India, the Geological Survey of India (GSI), NBSS&LUP, Central Ground Water Board (CGWB), National Remote Sensing Agency (NRSA), Forest Survey of India (FSI), Central Water Commission (CWC), National Atlas & Thematic Mapping Organization (NATMO) and Indian Meteorological Department (IMD) under the National Spatial Data Infrastructure (NSDI) program for sustainable development and economic growth of the country. Similarly, other countries also prepared national databases on suitable scales to aid in the management of natural resources, for example SSURGO, STATSGO, and NATSGO in USA by Lytle (1993); CanSIS, NCDB and AAFC of Canada by Coote and MacDonald (2000) and ASRIS of CSIRO in Australia by Johnston *et. al*. (2003).The FAO-UNESCO Soil Map of the World is a unique soil prepared at global scale (FAO, 1996). Others such as GLASOD, SOTER, WISE and ISIS are some useful databases prepared by Oldeman and Van Englen (1993), Batjes (1996), King *et*. *al.* (1994) and Stolbovoi *et al*. (2001). Currently, the Land and Plant Nutrition Management Services of FAO created databases on the distribution and extent of salt affected soils under the Global Network on the integrated soil management for sustainable use of salt affected soils.

Diagnosis and Characterization of a Salt Affected Soil Profile

Soil profile study is the first step in understanding soil genesis or formation and is also considered as a basis for soil classification. A soil profile is a freshly prepared exposed undisturbed pit with a dimension of approx. 5’X5’X6’. It is used for studying observable and measurable characteristics of soil called soil morphology, under field condition. The soil morphology is expressed by the number, kind and arrangement of soil horizon. The diagnostic layers, called soil horizon, reflect essentially the soil formation processes. During soil profiles studies, a soil horizon is commonly identified using differentiating characteristics such as color, texture, structure, consistence and the presence or absence of carbonates. Other properties such as presence of absence of concretions, mottles, salts; distribution of roots, pores and slickensides, gilgai, micro-relief, drainage and lithological parameters are studied for characterizing specific landscape.

The fundamental soil formation processes include the addition of organic and mineral matters to the soil, losses of these minerals from the soil, translocation of these mineral from one point in the soil profile and deposition at another and transformation of the mineral and organic matter in the soil and formation of definite layers or specific features by means of a variety of reactions. The processes by which organic materials are decomposed and synthesized to a new organic substance *(humus*) are called humification. The humus largely controls fixation and release of nutrients to maintain soil optimum fertility status. The processes of mobilization and translocation of inorganic and organic soil constituents such as humus, Fe_2O_3, Al_2O_3, SiO_2, $CaCO_3$ and soluble salts is called *eluviation*. The reverse process which is immobilization and accumulation of mineral and organic soil components at a depth below the soil surface is called *illuviation*. Apart from these, important processes such as salinization, alkalization, calcification, gypsification, argillation, gleization are occurring in salt affected and waterlogged soils. While salinization is the process of accumulation of soluble salts alkalization (*solonization*) refers to the process of developing higher exchangeable sodium percentage (ESP) and shift of soil pH showing alkaline character. It is usually associated with higher concentration of sodium carbonate and bicarbonates in soil saturation extract in a sodic soil. In the arid and semi arid climatic condition, accumulation of calcium carbonate and gypsum usually occur a depth below the soil surface. Such processes, called *calcification* and *gypsification,* are often found in the salt affected soils profiles restricting leaching and movement of salts. The movement and accumulation of clay and finer soil particles from the upper to the lower soil horizon is called *argillation* a typical process commonly found in the salt affected soils.

Selection and Description of Salt Affected Soil Profile

In India, salt affected soils are essentially characterized by the surface encrustation of soluble salts in semiarid and arid regions and surface salt efflorescence in the irrigated and coastal regions. Several methodology such as analysis of remote sensing data in the form of false color composites (FCC) and aerial photographs are used for detection and delineation of salt affected soils. The contrasting tone, texture and pattern of image elements pertaining to barren and partially cropped salty land are used for interpretation of salt affected soils. Typical spectral pattern of severely, moderately and slightly salty surfaces are generated from the computer aided analysis of digital remote sensing data and correlated with the field checks or ground truths data.

During ground survey, preliminary soil information such as landform, physiography, and topography, vegetation and land uses, elevation, slope and aspects, erosion and deposition and drainage patterns are studied for selecting a soil profile. The surface and sub-surface features and climatic conditions representative of the area are also considered prior to site selection. In general a profile pit to a depth of 1.5 m is exposed for such study. The soil horizons are identified based on the soil depth, horizon boundary, texture, structure, consistency and color followed by critical analysis of finer elements like concretions, mottling, cutans, roots, pores that reflect pedogenic processes (Fig. 1). The presence of clay cutans, iron (Fe) and manganese (Mn) mottling, and calcium carbonate concretions are typical indicators of the soil formation processes and genesis of salt affected soils. The textural analysis is carried out using feel method that needs a certain amount of soil mixed with a minimum quantity of water to prepare a ribbon with continuous pressing between thumb and the first finger. A loamy soil enables formation of a smooth ribbon while ribbon formed in a clayey soil is different due to higher stickiness and plasticity. Contrarily a sandy soil facilitates quick ribbon formation but lacks adequate stickiness and plasticity and stability. Soil structure refers to the aggregation of soils particles into compound particles or clusters of primary particles, which are separated from adjoining aggregates by surfaces of weakness. A natural aggregate is called a *ped*, in contrast to a *clod*, caused by the disturbance such as plowing or digging, a *fragment* caused by the rupture of a soil mass across natural surfaces of weakness and a *concretion* caused by the local concentration of compounds that irreversibly cement the soil grains together. A wide range of soil texture is available from various combinations of primary soil particles such as sand, silt and clay. Field description of soil structure includes shape and arrangement, the size, and the distinctness and durability of visible aggregates or peds. Thus, the terminology of various structures consists of separate sets of terms designating each of these three qualities which by combination form the names of structure. The shape and arrangement of structure is designed as *type*, size of peds as *class*; and the degree of distinctness, as *grades*. Thus, structure and texture studies of soils directly participate in soil classification and indirectly influence soil aeration and soil productivity (Fig 2). Soil color is the most obvious and easily determined soil characteristics. Although it has little direct influence on the functioning the soil, one may infer a great deal about a soil from is its color. The content of organic matter in soil is directly related to soil color. It is also associated with the drainage characteristics of soils. The presence of inorganic constituents of soils such as iron and manganese oxides, carbonates of calcium and sodium is also reflected by the increase or decrease of soil color. Similarly, it varies with the moisture content of the soil. Reproducible quantitative measurements of color are obtained at two moisture contents: air dry and field capacity. The later may be obtained with sufficient accuracy for color measurements by moistening a sample and reading the color as soon as visible moisture films have disappeared. The color of soil is measured using a Munsell color chart prepared by the 175 different colored papers or chips, systematically arranged according to their Munsell notations. The arrangement is made by the hue, value and *chroma* that combine to give all soil color. *Hue* is the dominant spectral (rainbow) color; it is related to the dominant wavelength of light. *Value* refers to the relative lightness of color and is a function of the total amount of light. *Chroma* is the relative purity or strength of the spectral color and increases with decreasing grayness. The symbol for hue is the letter abbreviation of the color of the rainbow ranging from R (red), YR (yellowish red) and Y (yellow) preceded by numbers from 0 to 10. The notations for value consist of numbers from 0 for absolute black to 10 for absolute white. The notations for chroma consist of numbers beginning at 0 for neutral gray and to a maximum of about 20.

Codes and Description of Soil Horizons

The master horizons usually present in the salt affected soils are designated as O, A, E, B, C, R. The detailed description of the horizons and its symbols is presented as follows:

Master Horizon

O: It is the organic horizon of a mineral soil formed by the accumulation and decomposition of an organic matter derived from plants and animals and deposited on the surface or at any depth beneath the surface in buried soils. Due to arid and semiarid climate the formation such horizon is meager in salt affected soils. However, such horizon is prominent in the coastal zone under humid tropical climate.

A: The mineral horizon consisting of humified organic matter intricately mixed with mineral fraction, and a transitional horizons to an underlying E, B, or C with properties resulting from cultivation, pasturing, or similar other disturbances.

B: The dominant fraction constitutes one or more of the following:

- Illuvial concentration of silicate clay, iron, aluminum oxides, humus, carbonates, gypsum, or silica alone or its combination,
- Evidence of removal of carbonates
- Coatings of sesquioxides adequate to give conspicuously darker/ redder color,
- Alteration that forms silicate clay or liberates oxides or both and that forms granular, blocky, or prismatic structure if volume changes accompany changes in moisture content, or
- Brittleness

C: A mineral horizon or layer, excluding bed rock, that is either like or unlike the mineral from which the solum is presumed to have formed, relatively little affected by pedogenic process.
R: Hard bedrock

Transitional and Combination Horizons:

The master horizons may not be uniform in character by which they have been designated and may be having subordinate properties of other. These horizons are subdivided using the symbols as AB, EB, BE, BC, etc. The master horizon symbol that is given first designates the kind of horizon whose properties dominate the transitional horizon. An AB horizon, for example, has characteristics of both an overlying A horizon and an underlying B horizon, but it is more like the A than like the B. Horizons in which distinct parts have recognizable properties of the two kinds of master horizons indicated in the capital letters. The two capital letters are separated by a virgule (/), as E/B, B/E, or B/C. Most of the individual parts of one of the components are surrounded by the other.

Subordinate distinctions within the master horizons and layers

Lower letters are used as suffixes to designate specific kinds of master horizons and layer. The symbols and their meanings are as follows:

c: *Concretions and nodules.* This symbol is used to indicate significant accumulation of concretions or nodules. Cementation is required. The cementing agent does not include silica, dolomite or calcite, or more soluble salts, but includes minerals that contain iron, aluminum, manganese, or titanium,
k: *Accumulation of carbonates.* This symbol is used to indicate the accumulation or higher concentration of alkaline earth carbonates, commonly calcium carbonate,
m: *Cementation or induration.* This symbol is used to indicate continuous cementation by 90% and is physically root restrictive. If the horizon is cemented by carbonates, “km” is used; by silica, “qm”; by iron, “sm”; by gypsum, “ym”; by both lime and silica, “kqm”; by salts more soluble than gypsum “zm”;

n: *Accumulation of sodium.* This symbol is used to indicate an accumulation of exchangeable sodium,
q: *Accumulation of silica.* This symbol is used to indicate the accumulation of secondary silica,
t: *Accumulation of silicate clays.* This symbol used to indicate an accumulation of silicate clay that has formed and subsequently translocated within the horizon or has been moved into the horizon by illuviation or both,
y: *Accumulation of gypsum.* This symbol is used to indicate the accumulation of gypsum,
z: *Accumulation of salts more soluble than gypsum.* This symbol is used to indicate the accumulation of salts more soluble than gypsum.

Diagnostic Subsurface Horizons of Salt Affected Soils

Taxonomy is a unit of classification that is concerned with relationships and is the systematic ordering and naming of type groups within a subject field. *Taxon* reflects soil properties or a set of soil properties that are diagnostic for differentiation of pedons. The differentiae are the soil properties that can be observed in the field or measured in the laboratory or can be inferred either from other properties that are observable in the field or from the combined data of soil science and related disciplines. The diagnostic both surface and subsurface, a number of soil properties, soil moisture and temperature regimes have been used to define soil *taxa.* Among the diagnostic subsurface horizons, the argillic and nitric horizons are important in classifying salt affected soils.

Argillic horizon: *Argillic* (L. *argilla*, white clay) is an illuvial horizon in which layer lattice silicate clays have accumulated to a significant extent by illuviation. The process of illuviation does not preclude concurrent formation of clay in the illuvial horizon. It has a variety of forms It has two important features. If it is associated with a overlying Ap horizon the textural difference between the eluvial and illuvial horizons would be distinct and the boundary between the two would be clear or abrupt in general. In some soils it is gradual and commonly irregular. The illuvial horizon has distinctly finer texture than the overlaying *eluvial* horizon or the underlying parent material if the mantle is uniform throughout its depth. The ration of clay content is in general close to 1.2 or larger. In general, an increase in clay content to an extent of 20% or more clay occurs within a vertical distance of 15 cm. In some cases, it is 30 cm associated with a transition zone. The lower boundary of the argillic horizon is gradual and commonly irregular. There is a coating of oriented clay on the surface of pores and of peds. Commonly, it is present at the base of the horizon. The ratio of fine clay to total clay is usually larger in the illuvial horizon than in the eluvial horizon.

Natric horizon: The nitric (L. *natrium*, sodium) horizon is a special kind of argillic horizon enriched with sodium ion. It is commonly occurring in barren sodic soils. It has a prismatic or columnar structure in some part and hard enough to break into blocks. The SAR is > 13 (or 15% or more saturation with exchangeable sodium) in some sub-horizons within 40 cm of the upper boundary. Or contain more exchangeable magnesium plus sodium than calcium plus exchange acidity (at pH 8.2) in some sub-surface horizon within 40 cm of the upper boundary if the SAR is >13 (or ESP > 15) in some horizon within 2 m of the surface (Fig. 4).

Salic horizon: A salic horizon is a horizon of accumulation of salts that are more soluble than gypsum in cold water. A typical salic horizon is 15 cm or more thick and has been saturated for 90 consecutive days or more in normal year, the electrical conductivity (EC) equal to or greater than 30 dS m^{-1} in a saturated paste and a product of EC, in dS m^{-1} and thickness, in cm, equal to 900 or more.

Calcic horizon: It is an illuvial horizon in which secondary calcium carbonate or other carbonates accumulated to a significant extent. It is a 15 cm thick layer, contain 15% or more calcium carbonate equivalent which is 5% higher than that of an underlying or overlying horizon., less than 18% clay in the fine earth fraction and skeletal, coarse-loamy or loamy skeletal particle –size class.

Cambic horizon: A cambic horizon is the result of physical alterations chemical transformations or removals of a combination of two or more processes. It is an altered horizon of 15 cm or more thick, changes of texture ranging from very fine sand to loamy fine sand, aquic condition within 50 cm of the soil surface, higher chroma, higher value redder hue, or higher clay content than the underlying or an overlying horizon.

Gypsic horizon: Gypsic horizon is an illuvial horizon in which secondary gypsum has accumulated to a significant extent. It is 15 cm thick, not cemented or indurated, 5% or more gypsum and 1% or more (by volume) secondary visible gypsum, and has a product of thickness in cm multiplied by the gypsum content percentage of 150 or more.

Equipments: Equipments required for soil profile studies are as follows:

- Digging and excavating tools such as pick axe, shovel, spade, knife, khurpi
- Post hole and screw type augers with extension or attachments up to 2 m depth
- Global Positioning System (GPS) to record location and Abney level to record slope
- Hand lens or magnifying glass 10x20 x magnification for identification of structure, clay cutans etc.
- Measuring tape, dilute HCl (6 N), water bottle, soil pH kit (test tube, universal indicators, barium sulfate and pH chart), base maps, topo-sheets, satellite imageries etc.
- Munshell Color Chart, data recording books, profile examination forms, hard clip board, drawing / cartographic materials/marker pen, polythene bags, cloth bags, rubber bands, tray with shoulder.
- Brass cores, hammer, aluminum boxes for cores

Collection and Processing of Soil Samples

Soil samples are collected either by using an auger or from a soil profile (Fig. 5) scrapping each horizon uniformly from the lower to the upper boundary of the horizon separately up to the parent material. The soils are thoroughly mixed and transferred to a polythene bag with prior labeling for profile No. horizon designation, depth, location and date of sampling (Fig. 6). In the laboratory these soils are air dried and crushed with a mortar pestle and passed through a < 2mm sieve and collect the sieved soil sample in a polythene bag and store properly for laboratory analysis. The residue left from sieving is also collected if the soil contains adequate concretions collected from a Kankar horizon. Such materials are collected separately and weighed to record it as a percentage of Kankar material > 2mm size fraction.

Fig.1. Surface of a sodic soil: Cracking after drying

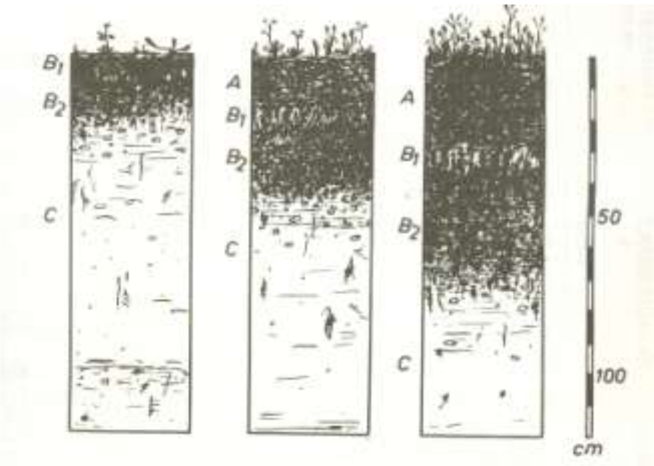

Fig.2. Schematic profile of an alkali soils with structural B horizon

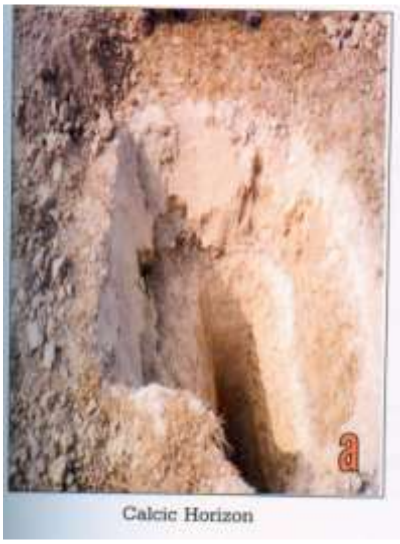

Fig. 4, 5. Typical Calcic and Natric horizon developed in an alkali soil profile

Fig. 6. Sodic soil with angular soil structure and hard $CaCO_3$ layer restrict water movement in soil

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Reclamation of Sodic Soils - Opportunities and Challenges

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Introduction

Sodic soils are most widespread problem in irrigated arid and semi-arid regions of the world. Coupled with this, presence of exchangeable sodium, soluble sodium carbonates and bicarbonates in irrigation water has a deleterious impact for raising salinity/ alkalinity in cultivated areas of these regions (Pal *et al.*, 2003). Salt stress imposes limits on plant growth and development by causing physiological abnormalities. 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 environmental factors (temperature, relative humidity, and rainfall) (Chhabra, 2004, Abrol and Bhumla, 1979). Sodic soils are characterized by high pH_s (>8.2) and high ESP (>15) variable electrical conductivity of soil saturation paste (EC_e, <4 dS m^{-1}).These soil contain high amounts of CO_3^{2-} and HCO_3^- salts of Na^+, Ca^{2+} and Mg^{2+}. Some cases soil pH_s may be as high as 10.5 or more. Sometime dissolved organic matter (OM) often accumulates on the surface imparting a dark colour. Such soils are commonly referred to as black sodic soils. Sub-surface layers remain saturated with water when the surface of sodic soils is often very hard and virtually impenetrable to water. Upon drying of sodic soil a deepand 1-2 cm wide cracks develop on the surface. Recent estimation made using Harmonized World Soil Database in a Geographic Information System (ESRI ArcGIS 9.3.1) pointed out that over 1100 M ha area globally affected by different degree of salinity of which 60%, 26% and 14% of area are under saline, sodic and saline-sodic soils, respectively. In India, about 6.73 Mha area is salt-affected; among them ~56% (3.77 M ha) and 44% (2.96 M ha) of area under sodic and saline soils in categories, respectively (CSSRI, 2006). Eleven states of country are severely affected by sodicity. Among them, Uttar Pradesh has largest area (1.35 M ha) under sodic soils constituting nearly 36% of the total. Next to Uttar Pradesh, Gujarat (14.36%), Maharashtra (11.21%), Tamil Nadu (9.41%), Haryana (4.86%) and Punjab (4.02%) have high sodicity problemand together represent about 80% of the total sodic lands in India.

Mechanism for formation of sodic soil

From agricultural aspects,sodic soil deleteriously impact crop growth and development as it is rich in exchangeable sodium and often contain 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 saturation extract variable to less than 4 dS m^{-1} 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 saturation extract; or the ratio of $[Na^+]/([Cl^-] + [SO_4^{2-}])$ in soil solution more than 1.0 (Bajwa and Swarup, 2009). 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 alunino-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 of the formation of bicarbonate of Na.

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

In arid and semi-arid regions, contain $CaCO_3$ in the profile in some form, and constant hydrolysis of $CaCO_3$ favour the release of OH^- ions in 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 formation of sodic soils in the Indo-Gangetic region include 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 (Gurung and Azad, 2013). Water having residual sodium carbonate (RSC) >2.5 and sodium adsorption ratio (SAR) >10 is classified as sodic water (Chhabra, 1996). Irrigation with sodic water high in carbonates and bicarbonates leads to increase in soil pH and soil sodicity, poor soil physical condition due to dispersion of soil clay and clogging of pores (Choudhary et al., 2011;Grattan and Oster, 2003; Levy et al., 2003). Continued application of sodic and high RSC water leads to drastic reduction in the crop productivity within 4-5 years of sustained sodic water application (Minhas et al., 2007;Choudhary et al., 2011). Such soils can be ameliorated for normal crop production by treating it with gypsum to replace excess sodium from exchange complex and restoring the soils normal soil physical condition conducive for plant growth (Qadir et al., 2007).

Characteristics and impact of sodic soil

- Alkalinity largely results in indirectinfluences 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 (Fig. 1).
- Sodic soils typically appear as convex surfaces at field conditions after an irrigation or rainfall. The soil a few centimeters 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 centimetres 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 effectingCanutrition (Table 2 and 3);
- 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
-

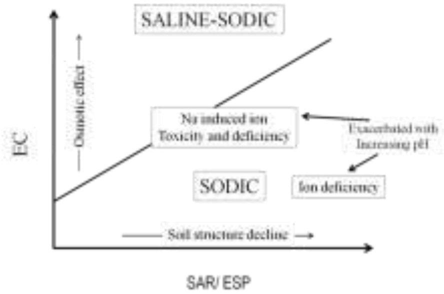

Fig. 1. The typical characteristics of alkali and saline-alkali soil in relation to Na^+ ion
(Source: Wong *et al*., 2010)

Indian perspective of sodic soil reclamation

Alkali land reclamation technology through chemical amendments developed by the institute has become quite popular and about 1.94 mha area has been reclaimed with the adoption of this technology. The reclaimed area alone is contributing approximately 15.52 million tonnes of paddy and wheat annually. The reclaimed lands now generate an annual employment of 155 million person days annually. Since future expansion agriculture is constrained by the limited availability of land resources. Since, there is little scope to expand the net sown area to achieve the targeted food production of 377 million tonnes by 2050, it would require increasing the cropping intensity and expanding gross area under irrigation from about 89 million ha to 117 mha in 2050. Sodicland constituting about 3.77 mha area distributed in different states can be easily brought under cultivation by adoption of different reclamation strategies. Apart from bringing new area under cultivation country is also facing the problem of protecting soil from sodication and gradual decline in productivity due to high RSC water irrigation. Presence of about 32-84 per cent poor quality water clearly highlights the urgency of the reclamation and rational utilization of these water resources. Successful utilization of these resources will greatly depend upon the development of efficient, effective and farmers' friendly reclamation technology

Soidic soil reclamation

Sodic soils reclamationrequires the replacement of part or most of the exchangeable sodium byfavourable calcium ions in the root zone. This can be accomplished in many ways depending upon available resources and the kind of crops to be grown on the reclaimed soils. For reasonably quick results cropping must be preceded by the application of chemical soil amendments followed by leaching for removal of salts derived from the reaction of the amendment with the sodic soil.The kind and quantity of a chemical amendment to be used for replacement of exchangeable sodium in the soils depend on the soil characteristics including the extent of soil deterioration, desired level of soil improvement including crops intended to be grown and economic considerations.

Kind of amendments

The suitability of different amendment for sodic soil reclamation will largely depend on the nature of the soil and cost considerations. Chemical amendments for sodic soil reclamation can be broadly grouped into three categories:

- Soluble calcium salts, e.g. gypsum, calcium chloride.
- Acids or acid forming substances, e.g. sulphuric acid, iron sulphate, aluminiumsulphate, lime-sulphur, sulphur, pyrite, etc.
- Calcium salts of low solubility, e.g. ground limestone.

Lime: Ground limestone, $CaCO_3$, is an effective amendment only in soils having pH below about 7.0 because its solubility rapidly decreases as the soil pH increases. Some soils that contain excess exchangeable sodium also contain appreciable quantities of exchangeable hydrogen and therefore have an acidic reaction, e.g. degraded sodic soils. But lime is not suitable amendment for most of the sodic soils containing high sodium carbonates (pHs>8.2-10.8). Lime reacts in such soils according to the reaction:

Na, H - clay micelle + $CaCO_3 \leftrightarrow$ Ca - clay micelle + $NaHCO_3$

Gypsum: Gypsum is chemically $CaSO_4.2H_2O$ and is a white mineral that occurs extensively in natural deposits. It must be ground before it is applied to the soil. Gypsum is soluble in water to the extent of about one-fourth of 1 percent and is, therefore, a direct source of soluble calcium. Gypsum reacts with both the Na_2CO_3, and the adsorbed sodium as follows:

$Na_2CO_3 + CaSO_4 \leftrightarrow CaSO_3 + Na_2SO_4$ (leachable)

$^{Na}_{Na}\text{clay micelle} + CaSO_4 \Leftrightarrow \text{clay micelle} + Na_2SO_4 \text{ (leachable)}$

Calcium chloride: Calcium chloride is chemically $CaCl_2.$ $2H_2O$. It is a highly soluble salt which supplies soluble calcium directly. Its reactions in sodic soil are similar to those of gypsum:

$Na_2CO_3 + CaCl_2 \leftrightarrow CaCO_3 + 2\ NaCl$ (leachable)

$^{Na}_{Na}\text{clay micelle} + CaCl_2 \Leftrightarrow \text{Ca clay micelle} + 2NaCl \text{ (leachable)}$

Sulphuric acid: Upon application to soils containing calcium carbonate it immediately reacts to form calcium sulphate and thus provides soluble calcium indirectly. Chemical reactions involved are:

$Na_2CO_3 + H_2SO_4 \rightarrow CO_2 + H_2O + Na_2SO_4$ (leachable)
$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2$

$^{Na}_{Na}\text{clay micelle} + CaSO_4 \Leftrightarrow \text{Ca clay micelle} + Na_2SO_4 \text{ (leachable)}$

Iron sulphate and aluminiumsulphate (alum): Chemically these compounds are $FeSO_4.7H_2O$ and $Al_2(SO_4)_3.18H_2O$ respectively. When applied to soils, these compounds dissolve in soil water and hydrolyse to form sulphuric acid, which in turn supplies soluble calcium through its reaction with lime present in sodic soils.

Chemical reactions involved are:

$FeSO_4 + 2H_2O \leftrightarrow H_2SO_4 + Fe\,(OH)_2$
$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$

$^{Na}_{Na}\text{clay micelle} + CaSO_4 \Leftrightarrow \text{Ca clay micelle} + Na_2SO_4\ \text{(leachable)}$

Similar reactions are responsible for the improvement of sodic soils when aluminiumsulphate is used as an amendment.

Sulphur (S): Sulphur is a yellow powder ranging in purity from 50 percent to more than 99 percent. Sulphuroxidized to form sulphuric acid which in turn reacts with lime present in the soil to form soluble calcium in the form of calcium sulphate:

$2\,S + 3\,O_2 \rightarrow 2\,SO_3$ (microbiological oxidation);
$SO_3 + H_2O = H_2SO_4;$
$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$

$^{Na}_{Na}\text{clay micelle} + CaSO_4 \Leftrightarrow \text{Ca clay micelle} + Na_2SO_4\ \text{(leachable)}$

Pyrite (FeS_2): Reactions leading to oxidation of pyrite are complex and appear to consist of chemical as well as biological processes. The following sequence has been proposed for the oxidation of pyrite. The first step in the oxidation is nonbiological and iron II sulphate (ferrous) is formed:

$2\,FeS_2 + 2\,H_2O + 7\,O_2 \rightarrow 2\,FeSO_4 + 2\,H_2SO_4$

This reaction is then followed by the bacterial oxidation of iron II sulphate, a reaction normally carried out by *Thiobacillus ferrooxidans*,

$4\,FeSO_4 + O_2 + 2\,H_2SO_4 \rightarrow 2\,Fe_2\,(SO_4)_3 + 2\,H_2O$
Subsequently iron III sulphate (ferric) is reduced and pyrite is oxidized by what appears to be a strictly chemical reaction.

$Fe_2\,(SO_4)_3 + FeS_2 \rightarrow 3\,FeSO_4 + 2\,S$

Elemental sulphur so produced may then be oxidized by *T. thiooxidans* and the acidity generated favours the continuation of the process

$2\,S + 3\,O_2 + 2\,H_2O$ Û $2\,H_2SO_4$
Summary: $4\,FeS_2 + 2\,H_2O + 15\,O_2$ Û $2\,Fe_2\,(SO_4)_3 + 2\,H_2SO_4$

Others: In some localities cheap acidic industrial byproducts may be available which can be profitably used for sodic soil improvement. Pressmud, flu gas desulfurized gypsum (FGDG), phosphogypsum are some material having potential for soil improvement.

Gypsum technology: CSSRI interventions

Sodic soils reclamation requires application of gypsum, the technology given by this institute. (CSSRI, 2006). The application rate is governed by the initial ESP of the soil, tolerance of crop to be sown, texture and mineralogy of soil depth to be reclaimed. Field studies have shown that mixing gypsum in shallow depths is more beneficial than mixing in deeper depths (Khosla et al., 1973). Gypsum is applied in conjunction with organic materials such as farm yard manure (FYM), wheat straw, groundnut husk, green manures, wild plantas an ameliorative agent. Organic matter results in the evolution of carbon dioxide and organic acids; lowering of soil pH and release of cations by solubilization of $CaCO_3$ and other minerals, thereby increasing the electrical conductivity and replacement of exchangeable sodium by cations like calcium, and magnesium and thus lowering the exchangeable sodium percent (ESP) (Chhabra and Abrol, 1977). Gypsum application in amounts equal to 50 % of gypsum requirement (GR) of soil is sufficient for the reclamation of sodic soils. (Singh et al., 1969)Gypsum application reduces the yield loss in rice and wheat by ~40% of theirmaximum potential yields in soils irrigated under high residual sodium water in a semi-arid region(Sharma et al., 2001).Literature support that the combined application of gypsum and organics *viz*., FYM and press mud along with NPK fertilizers significantly decrease the soil pH and SAR and improve the rice and wheat yields over NPK treatment alone under continuous use of sodic irrigationwater(Yaduvanshi and Swarup, 2005).

Cost and component of gypsum technology

In India, gypsum is the major soil amendment used toreclaim alkali soils. The cost for reclamation dependson quantity of gypsum required for reclamation. Thequantity depends on pH or ESP of soil, alkalinity toleranceand rooting depth of crop to be grown. ICAR-CSSRIestimates reveal that the capital investment of about76,000 per ha is required to reclaim alkali lands.

S.No.	Cost component	Amount (Rs)*
1.	Gypsum cost	43300.0
2.	Farm development cost including a bore well for each 4ha area	20500.
3.	Labour cost for amendment application and irrigation for flushing the salt and other other miscellaneous cost (seed, fertilizer, plant protection and green manuring)	12200
Total		76000.0

**depend upon the GR value and cost of the land preparation at specific site*

a. Approaches required

- Land lavelling 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

b. Expected outcome

Investment on alkali land reclamation involves short to medium gestation period. Considering 12 percent opportunity cost of capital the benefit-cost ratios 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.

History of gypsum application in sodic soil reclamation

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 Mugal period though totally for building purpose. Saxena (2008) reported that the gyspsum 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) reported the reclamation of Usar land through application of gypsum. Henderson (1914) marked the need for application of gypsum for reclamation of some soils in Sind. Barnes and Ali (1917) 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. Singh and Nijhawan (1932) and Puri (1934) compared the reclamation potential of the calcium chloride and gypsum.

Gypsum ($CaSO_4.2H_2O$) is a hydrated calcium sulphate widely used in industry because of its special property of losing three-fourth of the combined water of crystallisation when moderately heated (calcined) to about 130^0C. Besides, calcined gypsum can be spread out, cast or moulded to any desired surface or form after processing. Selenite is a colourless, transparent, crystalline variety of gypsum, whereas alabaster is a fine grained, massive variety, white or shaded in colour. Silky and fibrous variety of gypsum is called satin spar. Anhydrite ($CaSO_4$) is a calcium sulphate mineral found associated with gypsum commonly as a massive or fibrous mineral.

Gypsum that occurs in nature is called mineral gypsum. In addition to mineral gypsum, seawater and some chemical and fertilizer plants also produce gypsum. Seawater gypsum is knon as marine gypsum and others are by-product chemical gypsum. The later is obtained as by-product phospho-gypsum or fluoro-gypsum or boro-gypsum, depending upon the source. Phosphoric acid plants are important sources of by-product phospho-gypsum. Marine gypsum is recovered from salt pans during production of common salt in coastal region, particularly in Gujarat and Tamil Nadu. The recovery of by-product gypsum and marine gypsum together is substantial and is comparable with the production of mineral gypsum. Synthetic gypsum is recovered via flue gas desulphurisation at some coal fired electric power plants.Of the total resources, fertilizer/pottery grade accounts for about 82% and cement/paint grade 12%. The unclassified and not-known grades together account for 5% resources. The remaining one percent of resources is shared by surgical plaster and soil reclamation grades. Gypsum occurs in Rajasthan, Gujarat, Jammu & Kashmir, Himachal Pradesh, Tamil Nadu and Uttar Pradesh. The total all India resources of gypsum are assessed at 1204 million tonnes. Rajasthan alone accounts for 82% resources and Jammu & Kashmir 14% resources. The remaining 4% resources are in Tamil Nadu, Gujarat, Himachal Pradesh, Karnataka, Uttarakhand, Andhra Pradesh and Madhya Pradesh.

Challenges in sodic soil reclamation

- **Purity:** Gypsum is a mine product.Now a days pure gypsum is a question. Moreover, pure and fine quality gypsum is mostly consumed by Plaster of Paris (POP) and cement industries. The apparent domestic demand of gypsum was estimated at 5.66 by 2011-12 and 8.71 million tonnes by 2016-17 at 9% growth rate (12th Plan, Planning Commission of India). Around 1,286 million tonnes; of which 39 and 1,247 million tonnes placed under 'reserves' and 'remaining resources' category of gypsum (Indian Mineral yearbook, 2013).
- **Particle size:** 2 mm sieve, a mixture of fine and medium size particles is effective; as it requires less water to dissolute and less active to precipitate out with calcite.

Quality of the by-product gypsum:

- Phospho-gypsum: produced as a by-product during the manufacture of phosphoric acid by wet process.
- Fluoro-gypsum: obtained as by-product during the manufacture of aluminium fluoride and hydrofluoric acid using fluorite.
- Boro-gypsum: obtained at a plant which refines calcium borates (colemanite and ulexite) to produce borax and boric acid.
- Marine Gypsum: Marine gypsum is obtained as a by-product during the production of common salt by solar evaporation

Alternate reclamation strategies

The cost of alkali soil reclamation at constant prices is rising. Overdependence on finite and non-renewable resources as amendments (gypsum, pyrites) for reclamation is not sustainable in the long run. Due to economic restructuring, likely removal of subsidy on amendments or their reduced availability in future poses the single most serious threat to the progress of reclamation. Alternate technologies like biological reclamation by exploiting the use of microbes, application of organic materials like green manures, FYM, crop residues, municipal and industrial wastes, and diversification into silvi-pastoral systems will assume greater significance. Development of crop varieties capable of being cultivated with no gypsum or little dose of amendments will be an attractive biological reclamation option.

Conclusion

Adaptation of suitable reclamation and management options in sodic soils can provide the opportunities for agricultural in these areas. Selection of crop species and their varieties, application of secondary and micronutrients based on critical limit of the soil, balanced use of fertilizer based on soil test, use of farm residues/ bio-fertilizers with chemical fertilizers, use of amendments according to soil environments needs and soil-water conservation practices are the several measures that can be adopted on a given problem soil to make them productive and profitable resources. Enhancing the use efficiency of gypsum, quality assurance of mined gypsum, integrated approach for RSC water irrigated areas, arresting re-sodification, stewardship for partially reclaimed sodic soils for productive utilization and developing alternate to gypsum are some issues needs immediate attention of academia and policy makers to harvest rich dividend from these resources presently non-productive.

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Management of Waterlogged Saline Soils through Sub-surface Drainage: Indian Experiences

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Introduction

In a quest to ensure food security, clean water and healthy environment to its people, priority was accorded to investments in expansion of irrigation. As a result area under major and minor irrigation increased from 9.70 million ha during pre-plan to 42.77 m ha at the end of ninth plan. Area under minor irrigation also increased from 12.90 m ha in pre-plan period to 67.32 m ha at the end of annual plan 2000-01. It makes about 78% of the ultimate irrigation potential of the country. While these developments paid rich dividends in so far as food security is concerned, inadequacy of drainage in expansion plans made irrigation to be a mixed blessing. Water logging and soil salinity adversely affected agricultural lands so much so that doubts were raised on the sustainability of irrigated agriculture. Later on, it emerged that such a state of affairs occurred besides other factors, due to the negligence of drainage component in the project plans. On the contrary, pressure for resource conservation, economic justification to provide better drainage than in the past to sustain profitable crop production system, positive socio-economic impacts on rural populace and improvement in regional economy all motivated planners to advocate a fair share of artificial drainage in irrigation projects. Anticipating this change, drainage research continued to be one of the major thrust areas of the research organizations in the country. A large number of small-scale research projects were initiated that culminated into operational research projects in Rajasthan and Haryana (RAJAD, 1995; HOPP, 2004). This lecture deals with the recent advances made in developing the technology of subsurface drainage and highlights its current status in India.

Historical Perspective

As per documentary evidences, subsurface drainage has been experimented in India for the last 130 years or so. The first-ever subsurface drainage experiment to reclaim salt affected land was conducted by Mr. Robertson in 1873 (Gupta, 2002; Gupta, 2003). Stone drains and tile drains were laid out to reclaim the lands. In spite of the use of collars in laying these drains, silting problem was noticed. The recorded evidence of environmental degradation due to water logging is in the first decade of the last century. Increasing incidences of Malaria in the Amritsar city scared the people to migrate to safer areas. Subsurface drainage through tube wells was implemented to tackle the problem of water logging. Sixteen tube wells of 0.0425 cumecs capacity each were installed. The scheme, operated for 16-17 years, was reported to be successful. A subsurface drainage project implemented at Manjri in Maharashtra in 1920 is still operational. This is a good indication of the life of subsurface drainage provide it is designed and constructed with care. Notwithstanding the successful and not so successful attempts made in the past, major achievements could be accomplished during the last thirty years when a subsurface drainage based reclamation package was developed and implemented to cover about 40,000 ha of waterlogged saline lands.

Case Studies

Studies on subsurface drainage were initiated at CSSRI as early as in 1972 but a major thrust could be made in 1980 once a project site was taken on lease from village *Panchayat* Sampla. Since then there was no looking back and major initiatives were taken to perfect the technology with international and national cooperation. A list of major projects completed and in pipeline is given in Table 1. Since the sites are well spread over different agro-climatic conditions, this experience culminated in the development of guidelines on drainage design and evaluation.

Sampla

During the year 1979, a part of the land of the *Village Panchayat* Sampla was taken on lease to conduct experiments on reclamation of waterlogged saline lands. The first small scale experiment on open and pipe drains was established with a spacing of 25 m for open and 50 m for pipe drainage (design spacing). The successful operation of the two systems in reclaiming saline soils encouraged to take up this technology in a more theoretically sound manner and covering a relatively larger area to test various depths and spacing and to assess the performance of different drainage materials (Rao *et al.,* 1985). The land under reclamation got reclaimed right in the first year following leaching by rainfall and irrigation water applied before the sowing of the first crop. The good yields of different crops such as cotton, wheat, and barley could be taken even in the first year of cropping. The maximum yield was obtained in plots with drain spacing of 25 m and minimum in the plots with 75 m spacing. However, the differences in yield got blurred over the years such that within three years, yield even in plots with 75 m spacing was as good as that of the normal lands. During this period, pearl millet and mustard crops were also grown with good yields. Salinity of the soil after 10 years of cropping and average yield of wheat in the plots with different drain spacing revealed that the land reclamation program is sustainable. The drainage system was handed over to village *Panchayat* during the year 2000. Our experience of handing over the system to village *Panchayat* was not good in the sense that the system was not pumped from then onwards.

Table 1. Locations of the drainage research conducted since 1980

Location	State	District	Year	Area (ha)	Type of pumping arrangement
Kailanakhas	Haryana	Sonepat	1980-81	1.6	Pumped
Sampla	Haryana	Rohtak	1980-81	1.0	Pumped
Sampla	Haryana	Rohtak	1983-84	10	Pumped
Sampla	Haryana	Rohtak	1986-87	27	Pumped
Sampla	Haryana	Rohtak	1991-92	13	Pumped
Mundlana	Haryana	Sonepat	1984-85	50	Pumped
Ujana	Haryana	Jind	1986-87	32	Pumped
Bhana Brahamana	Haryana	Jind	1988-90	105	Pumped
Kolekhan	Haryana	Kaithal	1989-90	41	Pumped
Ishapur Kheri	Haryana	Sonepat	1989-90	58	Pumped
HLRDC Farm	Haryana	Hisar	1989-90	41	Pumped
Gohana	Haryana	Sonepat	1997-99	1236	Pumped
Kalayat	Haryana	Jind	1999-02	1000	Pumped
Dabuo	Gujarat	Kheda	1987-88	50	Pumped
Muraj	Gujarat	Kheda	1990-91	52	Pumped
Segwa	Gujarat	Surat	1998-1999		Gravity
CIRB Buffalo Farm	Haryana	Hisar	1990-91	40	Pumped
Konanki	A. Pradesh	Prakasam	1998-99	21.63	Gravity
Uppugunduru	A. Pradesh		1998-99	21.0	Pumped
Islampur	Karnataka		1999-2000	14.4	Gravity
Lakhuwali	Rajasthan	Hanumangarh	2000-2001	75	Pumped
Rori	Haryana	Sirsa	2004-05	1500*	Pumped
Jhajjar	Haryana	Jhajjar	2004-05	800*	Pumped
Sonepat	Haryana	Sonepat	2004-05	1500*	Pumped
Dadri	Haryana	Bhiwani	2004-05	800*	Pumped
Dhudgaon	Maharashtra	Sangli	2004-06	1100	Gravity
Kasabe Digraj	Maharashtra	Sangli	2006-2008	1065	Gravity

**Proposed*

Gohana/ Kalayat

Haryana Operational Pilot Project (HOPP), Haryana came into existence in 1995 with funding support from the Government of the Netherlands. Department of Agriculture, Haryana was the nodal agency to execute the work and the institutional support was provided by the Central Soil salinity Research Institute, Karnal and the CCS Haryana Agricultural University, Hisar for the Gohana and Kalayat Projects respectively. A total of 2300 ha was covered under subsurface drainage at the two sites. The results revealed that water table remained deeper in drained than un-drained (Fig. 1, Sharma and Gupta, 2006) and wheat crop yields improved after the land was treated with subsurface drainage in 1997-98 (Fig. 2). Following the closure and handing over of the project to the Farmers Drainage Societies (FDSs), a survey was conducted by the Department of Agriculture, the implementing agency, to estimate the net benefits to the farming community for the year 2002-03 for the Gohana site. As per this assessment, total benefits for the 23 blocks under subsurface drainage were Rs. 5.3 million over the un-drained control. Clearly, the benefits per year are to the tune of 10 % of the present day total cost to cover 1200 ha area under subsurface drainage estimated at 4.8 million (HOPP, 2004).

Tungabhadra Command in Karnataka

A number of subsurface drainage pilots were laid out in this command by the state CADA with funding from the Ministry of Water Resources, Govt. of India. The salt balance studies in one of the projects covering an area of 62 ha revealed a net outgo of salts from the root zone as a result of subsurface drainage with 340 tons of salts removed compared to 240 tons of salts applied during August 1998 to May 2000 (Manjunatha et al., 2004). Thereafter, the salts removal reduced considerably due to the blockage of the system at few places by the farmers to save water and prevent losses of valuable soil nutrients. It could also be attributed to lower salinity of the drainage water as a result of land reclamation. As a consequence, an increase in soil salinity was observed during December 2001 to April 2002. As a result of response lag time of two years, the salinity of the drainage water did not show the anticipated salinity increase. But, this information could be used to convince the farmers to clear the blockage of the drainage system as well as to create awareness for a properly maintained and operated drainage system to reclaim the salt-affected soils.

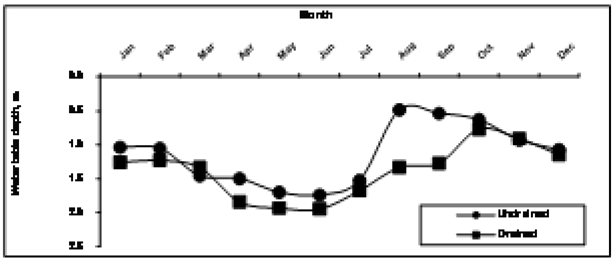

Fig. 1. Groundwater table behaviour in drained and un-drained lands at Gohana

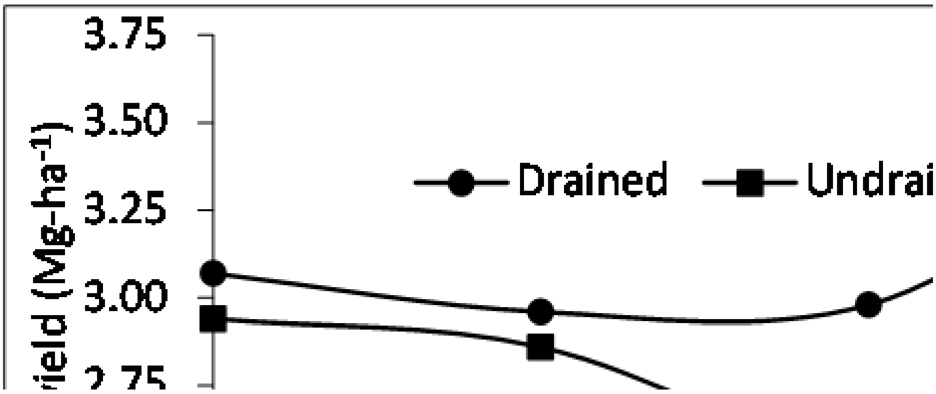

Fig. 2. Wheat crop yield in drained and un-drained fields at Gohana

Table 2. Impact of land reclamation on crop yield

Place	Crop	Crop production (t ha^{-1})		
		Before drainage	After drainage	Increase over pre-drainage (%)
Sampla (Haryana)	Cotton	0	1.4 – 1.8*	-
	Wheat	0	2.5 – 4.9*	-
	Barley	0	2.1 – 4.2*	
Ismaila (Sampla)	Wheat	0.9	1.9	111.3
Konanki (Andhra Pradesh	Paddy	3.7	5.6	51
Uppugunduru (Andhra Pradesh)	Paddy	3.6	5.2	45
Segwa (Gujarat)	Sugar cane	78-104	105-140	35
Islampur (Karnataka)	Cotton	3.3	10.4	215
	Paddy	1.4	5.5 – 6.2**	290 - 340
	Sunflower	3.0	7.4	146
	Sorghum	6.8	11.6	70

	Wheat	4.0	6.7	68
Gohana	Wheat	3.07	3.61	17.6
	Paddy	1.40	1.70	21.4
	Pearl millet	0.88	1.23	39.8
Vaddarathi	Rice	3.5	8.4	140
Gundur	Rice	2.8	8.1	189
Siddapur	Rice	2.4	7.3	204
Gangavathi	Rice	4.0	7.9	98
Sindhanur	Rice	2.2	3.7, 6.7-7.5***	223
Gorebal	Rice	2.3	7.2	213

In the first year influenced by lateral drain spacing
*** In phase I and Phase II respectively, All other crops in ORP*
-Since the land was highly saline with no production possible, it is difficult to calculate
**** First year and range during subsequent years*

Without going into individual case studies reported in Table 1, it would suffice to say that evidences are now available that with appropriate subsurface drainage yield could be increased by 20 to 340 % (Table 2) and maintained at the higher level, cropping intensity could be increased to 200 % in areas where nothing grew before (Table 3) and cropping patterns changed from subsistence type to more profitable ones. To keep the land under cultivation is the key word to the sustainability of a land reclamation programme.

Table 3. Cropping intensity as influenced by land reclamation

Area	Before drainage	After drainage	% increase over pre-drainage
Sampla	0	200	-
Ismaila (Sampla)	73	148	103
Konanaki	70	90*	29
Uppugunduru	130	165*	27
Islampur			
ORP	0	27, 35, 200**	-
Phase II	88	144, 156***	77
Gohana	117	175	50

**Cropping intensity did not increase as envisaged because of limited water resources*
***In first, second and third year; ***In first and second year*
- could not be calculated because initially there was no cropping in the area

Appikatla, Andhra Pradesh

A subsurface drainage system (SSDS) was installed in farmer's fields at Appikatla village in Guntur district covering an area of 7.5 ha. The soils are heavy textured clayey saline waterlogged with low rice productivity. The system was installed in 2002 at an average drain depth of 1 m using stoneware and corrugated PVC pipes with lateral drain spacing of 30 and 60 m. The drain discharge varied with drain spacing being 1.76 to 1.85 mm/day during 2007-08 in 60 m spacing whereas in 30 m spacing, the drain discharge ranged from 2.76 to 3.55 mm/day. Irrespective of the spacing, the total amount of salts leached during the last 6 years was assessed at 165 tons with an average of about 21.5 t/ha (Table 4). The NPK nutrients were also lost to the extent of 5.5 Kg N, 1.9 kg P, 6.6 kg K per annum during the period 2003-2008. The nutrients constituted only 0.3% of the total salts leached from the area.

Table 4. Quantity of water, salts and nutrients pumped from SSD

Year	Volume of water pumped (m^3)	Amount of salts leached (t/ha)	Nutrients (kg/ha)		
			N	P	K
2002-03	27448	7.3	-	-	-
2003-04	19377	3.1	5.30	2.91	11.2
2004-05	27327	4.0	5.40	2.30	8.5
2005-06	26784	3.2	3.10	1.71	5.9
2006-07	14374	2.0	9.70	2.31	3.9
2007-08	10493	1.9	1.77	0.23	3.3
Total	125803	21.5	25.27	9.46	32.8

The removal of salt through leaching reduced EC_e from an initial mean value of 16.2 dS/m to 3.0 dS/m, showing a reduction of 82% (Fig. 3). As such, rice productivity increased from initial level of 1.80 t/ha at the time of pre-installation to a level of 6.64 t/ha after six years of installation (Table 5). A 270% improvement in yield over control could be observed due to subsurface drainage system (AICRP, 2009). The differences in grain yield of rice due to different spacing were very marginal, only 0.06 t/ha (0.91%). Similarly, the differences in grain yield due to different drain materials viz., stoneware and CPVC were very marginal, only 0.21 t/ha (3.13%). Hence for the design of drainage systems for these soils, drain spacing of 50- 60 m could be used to minimize cost. Any material i.e. stoneware or CPVC pipes could be used depending upon the availability and cost.

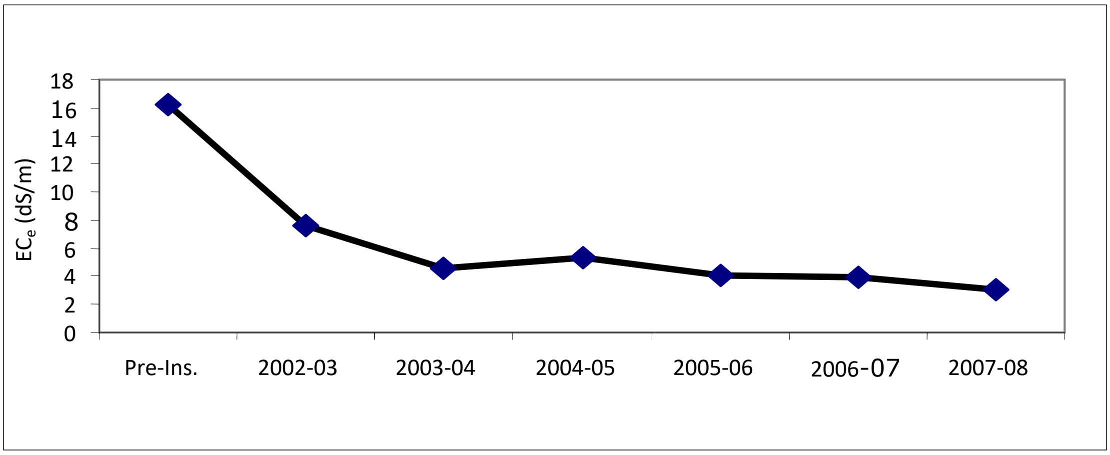

Fig. 3. Changes in soil EC_e (0-20cm) in treated plots

Table 5. Paddy yield in subsurface drainage system at Appikatla

Year	Grain yield (t/ha)	Straw yield (t/ha)
2002-03	4.10 (128)#	5.50
2003-04	4.24 (136)	5.90
2004-05	6.40 (256)	7.40
2005-06	5.78 (221)	7.32
2006-07	2.09 (16)*	4.94
2007-08	6.64 (269)	7.43

*Source: AICRP, 2009; # The values in parenthesis are percent increase over initial yield of 1.8 t/ha; * Due to Oogny cyclone at flowering stage of the crop, the paddy suffered badly*

Area was monocropped initially with rice-fallow cropping system. After drainage, crops like sun hemp (*Crotalaria juncea*), pillipesara (*Phaseolus trilobus*), sorghum fodder (*Sorghum vulgare*), mustard (*Brassica juncea*) could be grown with good yields resulting in higher cropping intensity and additional net benefits (Table 6).

Table 6. Influence of SSDS on yield of different crops after paddy

Year	Fodder sorghum (t/ha)	Pillipesara (t/ha)	Sun hemp (t/ha)	Mustard (t/ha)
2002-03	Germinated but failed			
2003-04	27.20	18.50	19.30	0.27
2004-05	25.40	19.00	20.60	0.28
2005-06	26.10	17.40	20.30	0.29
2006-07	25.20	17.85	18.70	0.67
2007-08	Germinated but failed due to heavy rains during Feb and Mar, 2008			
Mean	26.05	17.85	19.75	0.38

Case Studies of Subsurface Drainage in Non-commanded Areas

It is commonly believed that problems of water logging and soil salinization infest the commands of the major projects. Contrarily, if the situation is same, even the water brought into the command through minor irrigation works would result in rising water table and soil salinization would be a foregone conclusion. A large area of the black cotton soils in Maharashtra has been affected by the twin problems in lift irrigation commands operated by the farmers. Most recently, a private entrepreneur, has joined hands with the state department and initiated subsurface drainage activities in the lift irrigation commands of Maharashtra as a forward integration to his on-going activities of manufacturing irrigation and drainage pipes. The entrepreneur has already completed a project while another is just to begin (Table 7). A project is being planned for Distt. Belgaum in Karnataka.

The most important feature of this project is that the investments on these projects are shared by the Central Government, State Government and the beneficiary in ratio of 60:20:20. The beneficiaries have been provided with loans from the banks, which have come forward to extend the financial support.

Drained Versus Un-Drained

Besides the positive effects of drainage, a look at the data from un-drained areas also makes an interesting reading. It could be seen that un-drained plots continued to remain saline and barren (Table 8) while optimum yields could be obtained in the treated plots at Sampla. More than 1/3 rd of salts present in the soil profile leached down in treated area at Gohana, there has been a minor increase in the soil salinity in untreated area. In the same manner, wheat yield on an average declined in the untreated area at Gohana (Table 8).

Table 7. Subsurface drainage activities in Maharashtra under lift Irrigation schemes

Project	Project related information	
Reclaim - I Dudhgaon Project (Sangli)	Total project cost Total area Number of beneficiaries outlet Main drain Collectors Laterals	Rs. 446.51 lakh (including main drain) 1100 ha 1326 Gravity Open 80-455 mm diameter pipes 80 mm perforated pipes
Reclaim - II Kasabe Digraj Project (Sangli)	Total project cost Total area Number of beneficiaries Outlet Main drain Collectors Laterals	Rs.553.33 lakh (including main drain) 1065 ha 1159 Gravity Open 80-250 mm diameter pipes 80 mm diameter perforated pipes

Table 8. Soil salinity (EC_e, dS m^{-1}) and crop yield (t ha^{-1}) in un-drained plots at Gohana

Area	1983-84/1995-96*	1996-97/1999-2000*	% increase/decrease over year before drainage
Sampla			
Un-drained (Salinity)	55.2	66.0	+19.6
Un-drained (Yield)	Uncultivated	Uncultivated	-
Gohana			
Un-drained (Salinity)	9.0	9.2	+2.2
Un-drained (Yield)	2.9	2.8	-0.41

** Years are for Sampla and Gohana respectively*

Advances in Subsurface Drainage

Advances in drainage design: Based on large number of studies conducted at CSSRI and elsewhere in India, guidelines have been prepared to design a subsurface drainage system under different agro-climatic conditions of India (Gupta *et al.*, 2002; Gupta, 2018; Table 9).

Advances in construction technology: Tremendous achievements have been made in the construction technology. Initially, most pilot areas in India were laid out using manual labour. Here, both the digging of trenches and assembling the system were accomplished using manual labour. Contrarily, most large projects globally have been implemented by mechanical means since limited time is available to construct the systems. Studies in India revealed that the cost of the system installed through fully mechanical means depends to a large extent on the area to be covered under drainage and synchronization of various activities to avoid logistic problems. Besides, the initial investments on the import of the machinery are quite high. Recent experience with semi-mechanical means has been quite encouraging. In this technique, locally available machines are used to dig the trenches while the system is assembled manually. This strategy helps to reduce the time of construction and avoiding difficulties encountered in fully mechanical laying. This technology would help to keep a balance between mechanization and employment generation. Then the projects would have a better chance of funding by national and international organizations.

Table 9. Guidelines for drainage design under various agro-climatic conditions in India

Drainage Coefficient (mm/day)			Drain depth (m)			Drain spacing (m)	
Climatic conditions	Range (mm/day)	Optimum value (mm)	Outlet conditions	Depth of the drains	Optimum depth (m)	Soil texture	Spacing of drains
Arid	1-2	1	Gravity	0.9-1.2	1.1	Light	100-150
Semi-arid	1-3	2	Pumped	1.2-1.8	1.5	Medium	50-100
Sub-humid	2-5	3				Heavy/ Vertisols	30-50

Reuse of Drainage Effluent for Irrigation

Subsurface drainage projects have been criticized mainly on the basis of environmental degradation that would be caused through disposal of drainage effluents. This question has been addressed to a great extent in the studies conducted under various agro-climatic conditions. The salient observations that emerged from these studies are as follows:

- The quality of the drainage effluent gets improved over the years and after few years the quality is substantially good than at the beginning.
- Subsurface drainage effluent is a good source of water for irrigation either alone or in combination with canal water.
- Evaporation tanks could be used to dispose of drainage effluent in land locked areas. These tanks could also be used for brackish water aquaculture.

Socio-economic Impacts

So far technical issues were discussed with a focus on its impact on agricultural productivity. Realizing that social issues must not take a back seat to the technology component, socio-economic impacts of the projects were monitored both in terms of benefits and limitations. Some of the socio-economic impacts such as poverty alleviation and reduced disparity, employment generation, increase in land value, opportunities for regional industrialization, reduction in gender disparity, reduced migration from rural areas to urban centers were documented. The increase in land value alone was sufficient to play a catalytic role in the adoption of this technology. To illustrate some of these issues it was assessed that about 303 man days would be required to cover one ha of land when the lateral drain spacing of the system is 25 m. For a drain spacing of 100m, the requirement will reduce to about 128 man days ha^{-1}. If the digging of drains is done through machines and the system is laid manually, then the requirement could be about half of the requirement (65-150 man days) compared to a fully manually laid system. Considering employment opportunities in agricultural operations following reclamation, it has been estimated that a man could get employment for a year upon reclamation of about 3-5 ha of agricultural land. Moreover, out of the total investment on subsurface drainage, nearly 60 % is attributed to materials produced in the industrial sector. This distribution of cost is ample evidence that large-scale application of this technology would boost the industrial sector and rural based industries in the region.

Socio-economic Impediments

It should be realized that involving people's participation in development interventions, is not like turning on a light switch. It is a time consuming and often-frustrating process requiring determination, patience, compassion and understanding. Often conflicting needs and demands of the farming community are difficult to be reconciled. For example, within a block drainage requirement of the stakeholders are different due to location of the fields, topographical differences and due to different crops grown. A rice-growing farmer resents drainage while others prefer to drain following rainfall. Some progress on this front could be made when in a part of the project, individual controls were provided. Sometimes you need to experiment till a successful socially compatible solution is found. For example, three models were experimented to hand over the drainage blocks after institutional support was withdrawn. In the first case, drainage infrastructure was handed over to Village *Panchayat* as per lease agreement. Since, there was no pumping after the handover; this model could not generate confidence. In the second model, drainage blocks were handed over to FDSs with common sump constructed on the common property. The response was lukewarm and slowly the pumping activity came to a halt. No body in the society took responsibility of this state of affairs. The third model was also based on FDSs but with an identified farmer as its president with the block sump located in his field. The society members were free to approach him for pumping by contributing in terms of diesel. This model has consistently worked well over a period of more than 7 years. Notwithstanding the limitations and criticism by few farmers of this model, currently it seems to be the best bet for encouraging pumping in the drainage blocks. Technically, some progress still needs to be made in applying non-intrusive and non-destructive techniques for maintenance of the systems. Attracting capable and financially sound contractors is still a problem since private demand for drainage has yet to be generated.

Prospectus of Subsurface Drainage

Current state of the land and water resources has been worrying all the stakeholders considering precarious nature of the food security achieved so far. The concerns have multiplied in view of the recently enacted 'Food Security Bill" that makes it imperative to ensure food for all. As a result, India needs to produce significantly more food grains to meet the requirements of its burgeoning population. On the other hand, several problems ail our land and water resources impacting the production from these resources. Twin problems of water logging and soil salinity have emerged as the major abiotic stresses in irrigated lands that have worried the Ministry of Water Resources, Ministry of Agriculture and others organizations connected with natural resources management. The problems have been a cause of worry mainly because expansion of irrigation has been our best bet to increase agricultural production. It is assessed that if the 'Business As Usual' approach continues, area under water logging and soil salinity by 2050 may treble to 20.0 million ha from the current level of 6.73 million ha. During the past 40 years, a firm foundation for subsurface drainage has been laid. Capacity build-up has been in tune with the present requirement. Planners, government officers and farming communities have been sensitized to the need of drainage. Drainage Master Plans of several states have already been formulated. Government provides a subsidy of Rs. 60,000 or more per ha. With the percolation of local technical knowhow, private entrepreneurs are being attracted towards land drainage. Trench digging machines are already in place in every nook and corner of the country. These could be used as a part of the hybrid technology of constructing drainage systems. Developing a drainage ripe environment needs continuing attention and support of the government It is believed that there would be a large spurt in drainage activities in the next 2-3 decades because it is the only ray of hope to ensure sustainability of irrigated agriculture on which sustains hopes of food and nutritional security of the country.

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Lesson Learnt from Large Scale Sodic Soil Reclamation in Gangetic Plains in Uttar Pradesh

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Introduction

Global demand for food, fiber and bio-energy is growing at the rate of 2.5 per cent per year. For developing countries, rate is still higher at 3.7 per cent. Growth rate in agriculture in most developing countries has failed to catch-up with this rate. If this trend continues, the gap between demand and supply of food will grow rapidly. One of the major constraints in achieving the desired growth rate in food grains production is human induced land and water degradation. Salt-affected soil covers roughly 10 percent of the land surface in more than 100 countries. Based on the FAO/UNESCO Soil Map of the World, a total of 953 M ha covering about 7-8 percent of the land surface are suffering from this malady, more than 50 percent of which are sodic. The salt affected soils are reported to occupy 42.3% area of Australia, 21.0% of Asia, 7.6% of South America, 4.6 % of Europe, 3.5% of Africa, 0.9% of North America and 0.7% Central America. Australia has the world's largest area of sodic soils, equivalent to roughly 33% of the continent.

Out of 6.73 mha of salt affected soils, about 1.37 mha is in the State of UP. The productivity of these lands is severely restricted due to excess amount of salts and affecting the livelihood people. Sodic soils contain excess of salts capable of alkaline hydrolysis such as sodium carbonate, sodium bicarbonate, sodium silicate; and sufficient exchangeable sodium to impart poor physical conditions to soils and thus affecting growth of most plants. These soils have pH_s >8.2, ESP >15 and different levels of salinity (EC). The pH of the calcareous alkali soils is highly related to their ESP. Presence of calcium carbonate concretions beyond 50 cm depth causes physical impedance for root proliferation. Higher pH and ESP are causing poor physical and nutritional status and ultimately affecting growth and productivity of most of the crops. The sodic soils of the Indo-Gangetic plains are generally gypsum free but are calcareous with $CaCO_3$ increasing with depth, which is present in amorphous form, or in concretionary form or even as an indurate bed at about 1m depth. The accumulation of $CaCO_3$ generally occurs within the zone of fluctuating water table. The sodic soils are deficient in organic matter, available N, Ca, and Zn. Certain micro-nutrients present problems of either deficiency or toxicity.

Promising Technologies for Sodic Soil Reclamation

Chemical Amendments: As the nature and intensity of the problem vary depending upon the topographical situation, hydrologic and climate conditions, drainage availability, land use, soil texture, calcareousness and other features, the methods of amelioration and management have to be location – specific. There are 3 options to enhance rice productivity in these soils namely (1) to reclaim soils by adding recommended doses of chemical amendments like gypsum ($CaSO_4.2H_2O$), however this option invariably involves high costs and is beyond the access of poor farmers, (2) to develop tolerance in crop plants which is a continuous process and (3) to harness the synergy between above two approaches by growing salt tolerant varieties that thrive better and give higher grain yield under minimum amendment inputs. This approach is perceived to be the most economical and sustainable. Therefore, second and third options are economically sustainable and preferable particularly in view of poor resource endowment base of majority of the farmers owning sodic soils in UP.

Sodic soils require application of an amendment before most crops can be successfully grown. Nevertheless owing to various adaptive advantages, rice is preferred and recommended as a first crop to start with gypsum reclamation process of virgin sodic lands. The dose of an amendment required for reclaiming sodic soil is governed by its initial ESP, tolerance of crops to be grown, texture and mineralogy of soil and depth to be reclaimed. It also depends on the nature of soil, its stage to deterioration and crops to be grown. Field experiments further showed that for initiating the reclamation of sodic soils and for cultivation of shallow rooted crops like rice, wheat, barley and berseem, application of 50 percent GR, which amounts to 10-15 t/ha in 0-15 cm soil, is sufficient. Field studies have shown that mixing gypsum in shallow depths was more beneficial than mixing in deeper depths.

The results of various experiments conducted using different amendments such as gypsum, pyrite, sulphuric acid, nitric acid, pressmud, ferrous sulphate and FYM proved that gypsum followed by pyrite is most useful because of easy availability and cost considerations. Further, field studies have shown that the pyrite was less effective than gypsum. Experiments on highly alkali soils proved that single application of gypsum at lower dose before the first crop of rice proved as effective as higher and repeated dose in subsequent years.

Regarding management aspects, field studies indicated that gypsum application @ 25% GR (gypsum requirement) in conjunction with growing of salt tolerant varieties is the most beneficial and economically sustainable approach to begin with sodic land reclamation process. From the study it is observed that the maximum grain and biological yields were recorded with 50% GR level but the difference between 25% and 50% GR levels was statistically at par. Sodicity tolerant varieties of rice (CSR 13) yielded significantly higher grain yield over non-sodicity tolerant prevailing variety (Pant 4). In wheat, no significant difference in grain and biological yields between sodicity tolerant and non-sodicity tolerant varieties have been observed. However, higher grain and biological yields were obtained with sodicity tolerant variety (KRL 19). The pH_2 of surface soil and infiltration rate was not much affected due to rice and wheat varieties; however, it was affected remarkably with the application of gypsum. Application of reduced dose of gypsum (25% GR) and growing of sodicity tolerant varieties of rice and wheat fetched higher benefit cost ratio than that of application of 50% GR and growing of non-sodicity tolerant traditional varieties. Net saving of Rs. 10000 ha^{-1} accrued due to the application of reduced dose of gypsum (25% GR) during the first year of reclamation was not compensated even up to three years with 50% GR and growing of non-sodicity tolerant prevailing varieties of rice and wheat.

Phosphogypsum: Phosphogypsum (PG), the by-product of wet acid production of phosphoric acid from rock phosphate, contains more than 92% calcium sulfate and should be an excellent source of calcium, which may be used as a soil conditioner for sodic, solonetz, and solonetzic soils. Phosphogypsum is produced by the phosphate fertilizer industry and emanates from the production of phosphoric acid from rock phosphate through a wet process. In the wet process, production of 1 ton of phosphoric acid causes the formation of 4.5 to 5.5 tons of PG. Phosphogypsum consists primarily of calcium sulfate dehydrate ($CaSO_4.2H_2O$) with small amounts of silica, usually as quartz and unreacted phosphate rock. The centre has proved that the phospho-gypsum (a byproduct of the phosphate fertilizer industry) can be an alternative to the mineral gypsum without much radiation and heavy metal hazards (Nayak *et al.,* 2013, Sharma *et al.,* 2011). Application of PG results in a drastic reduction in surface soil pH and ESP, resulting in a higher yield of rice and wheat compared to equivalent dose of mined gypsum. The contents of soluble P, calcium P, and Fe-P were greater in PG-treated soil than initial soil and mined gypsum amended soil. A greater fraction of applied fertilizer P and/or P contained in PG precipitated as Ca-P in the PG-amended soils, and a small fraction of P entered into Fe-P. Besides this, application of PG resulted in an increase in available P and micronutrients such as Fe, Cu, Zn, and Mn in soil over the equivalent amount of mined gypsum. Phosphogypsum affected an increase in aggregation, soil organic carbon, MBC, and aggregate-associated carbon, leading to increased hydraulic conductivity and moisture retention capacity in soil over mined gypsum treated soil. Sodic soil reclamation may provide an alternate sink for PG disposal with additional value to farmers.

Tillage and other Management Practices

Agronomic research on resource conservation showed that zero tillage is a cost effective practice in wheat as compared to conventional method and saves 20% water (Sharma *et al.,* 2009). In another study Mishra *et al.,* (2009) evaluated the effect of tillage and crop residue management and found that combined effect of crop residue and tillage enhances rice yield in comparison to the sole effect of residue and tillage. Other agronomic research on multi-enterprise agriculture, crop diversification and land re-shaping has been encouraging. In rice, 35 day old seedlings planted @ three to four per hill proved better than young seedlings planted @ one or two per hill. Similarly, the field studies indicated that 15 to 20 per cent higher seed is required for upland crops such as sorghum, pearl-millet, cotton, wheat, barley and mustard during the initial reclamation period.

Alternate Land Use Systems for Salt Affected Soils

Productivity of conventional crops and cropping systems remains at a sub-optimum level and never touches to potential production level in salt affected soils. Also in severely degraded salt affected areas, crop production is limited by several factors including salinity stress. Under such conditions, research workers observed that agro-forestry are the better options, which help in bio-amelioration of marginal lands. A long-term field study was initiated during 1995 at Central Soil Salinity Research Institute, Regional Research Station, Lucknow to analyze the effect of agroforestry systems on amelioration of alkali soils. Three agroforestry systems (pastoral, silvipastoral and silvicultural) were compared with the control. Tree-based silvicultural and silvipastoral systems were characterized by tree species *Prosopis juliflora* and *Acacia nilotica* along with grass species *Leptochloa fusca, Panicum maximum, Trifolium alexandrium and Chloris guyana*. Growth of 10 year old *Prosopis juliflora* and *Acacia nilotica* planted in combination with grasses was significantly higher over the silviculture system with the same species. Tree biomass yields of *P. juliflora* (77.20 t ha^{-1}) and *A. nilotica* (63.20 tha-1) planted under silvipastoral system was significantly higher than the sole plantation (64.50 tha^{-1} and 52.75 tha^{-1}). Fodder yield under the pastoral system was significantly higher than the silvipastoral system during initial years but it was at par with that of silvipastoral systems after eight years of plantation. The microbial biomass carbon in the soils of silvipastoral systems was significantly higher than in soils under sole plantation of trees and control. The Prosopis based silvipastoral system proved more effective in reducing soil pH, displacing Na+ from the exchange complex, increasing organic carbon and available N, P and K. improvement in soil physical properties such as bulk density, porosity, soil moisture and infiltration rate was higher in the Prosopis based silvipastoral system than in the silviculture system or control. On the basis of biomass production and improvement in soil health due to tree + grass systems, silvipastoral agroforestry system could be adopted for sustainable reclamation of sodic soil.

Jatropha (*Jatropha curcas* L.) is recently introduced as a source of biomass and bioenergy in India. It can withstand and survive on a wide range of soils. However, information related to identification of a genotype tolerant to certain levels of sodicity is lacking. Five Jatropha genotypes (BTP 1-K, BTP 1-N, BTP 1-A, GCC-1, and TNM-5) were screened and evaluated for three years (2007–2010) at Lucknow in sodic soils having four ESP (20, 40, 60, and 80) levels. Plant mortality of all the genotypes increased significantly beyond ESP of 40. Among the genotypes screened, BTP 1-A recorded the maximum plant height (240 cm), girth (34·0 cm), biomass yield (14·00 ± 1·43 kg $plant^{-1}$), and number of fruits per plant (14·8) up to ESP 40. The highest seed oil content was found in BTP 1-K and BTP 1-N followed by BTP 1A and the minimum in TMN-5 and GCC-1. Soil amelioration in terms of soil pH, ESP, organic carbon, and microbial biomass was higher under genotype BTP 1-A than BTP 1-K, GCC-1, and TNM-5. Genotype BTP 1-A was found to be suitable for producing more biomass and bio-energy and rehabilitation of degraded lands.

Field study on intercropping model with *Jatropha curcas* L. as an alternative crop on degraded sodic lands were tried to optimize land use efficiency. The results revealed that the planting of *Jatropha* at 3 x 3 m spacing with inter-cultivation of sweet basil–matricaria (SB-M) cropping system for four years was more economically viable than planting at 3 x 2 m spacing (Singh *et al.,* 2016). Improvements in soil properties in terms of soil pH, EC and organic carbon were found with the SB-M cropping system with *Jatropha* as the main crop. Maximum soil microbial biomass carbon was recorded with the SB-M cropping system followed by sorghum-wheat and maize-linseed and the lowest values were found in control. This study showed that intercropping with *Jatropha* on sodic soils stimulated the soil microbial population, which in-turn led to increased biological activity in the rhizosphere soil. Growing of medicinal and aromatic crops as an intercrops between *Jatropha* plantations for four years appears to be more suitable land use system than *Jatropha* sole cropping.

Bio-remediation Measures for Sodic Soils

The CSR-BIO, a bio product has been developed using rhizospheric microbial diversity in saline-sodic soils with pH of 9.85 -10.2 at CSSRI, Regional Research Station, Lucknow. Compatible microbial consortia of elite candidates comprising CSR-B-2 (*Bacillus pumilus*), CSR-M-16 (*Bacillus subtilis*) and CSR-T-1 (*Trichoderma harzianum*) were identified after intensive screening based on crop growth vigour index in salt affected soils and higher plant growth promoting (PGP) properties. Simultaneously, a cost-effective patented media for mass multiplication of above consortia of microbes was also developed. This has significantly reduced the cost of multiplication while maintaining live count of final product at 10^7 to 10^9. The amalgamation of consortia of microbes with low-cost patented media has resulted in production of bio-stimulant (CSR-BIO) both in liquid and solid formulations (Damodaran *et al.*, 2015). The formulation also supplies micronutrients for crop growth because of the inherent nature of nutrient present in the substrate used in the dynamic media. The formulation has been intensively evaluated for banana, mango, vegetable crops like tomato, okra, capsicum, ornamental crops etc., under normal and sodic soil conditions.

Suitable Salt Tolerant Varieties

Regaining the agricultural potential of sodic soils in the Indo-Gangetic plains necessitates the development of suitable salt tolerant varieties. Evaluation of breeding lines through on-station and on-farm farmers' participatory varietal selection (FPVS) resulted in the identification of a short duration (110–115 days), high yielding and disease resistant salt-tolerant rice genotype 'CSR-89IR-8', which was released as 'CSR 43' in 2011. Several agronomic traits coupled with good grain quality and market value contributed to commercialization and quick adoption of this variety in the sodic areas of the Indo-Gangetic plains of eastern India. Management practices required for rice production in salt affected soils are evidently different from those in normal soils and practices for a short duration salt tolerant variety differ from those for medium to long duration varieties. Experiments were conducted at Lucknow during 2011 and 2013 wet seasons, to test the hypothesis that combining matching management practices (MMP) with an improved genotype would enhance productivity and profitability of rice in sodic soils (Singh *et al.,* 2016). MMP were developed on-station by optimizing existing best management practices (BMP) recommended for the region to match the requirements of CSR 43. The results revealed that transplanting 4 seedlings per hill at a spacing of 15 × 20 cm produced significantly higher yield over other treatments. The highest additional net gain was recorded at 90 kgN ha^{-1}. Above 150 kgN ha^{-1}, the additional net gain became negative. Hence, 150 kgN ha^{-1} was considered as economic optimum N application dose for CSR 43 in sodic soils. Using 150–60–40–25 kg $N–P_2O_5–K_2O–ZnSO_4·7H_2O$ ha^{-1} in farmers' fields grown CSR 43 produced an average of 5.5 t ha^{-1} grain yield. The results of on-farm trials of CSR 43 showed that matching management practices (MMP) increased yield by 8% over existing best management practices (BMP) recommended by ICAR-CSSRI for sodic soils and by 16% over framers' management practices; however, combining MMP with CSR 43 resulted in 35% higher yields over farmers' current varieties and management. This approach of combining cost effective crop and nutrient management options and a salt tolerant variety can maximize the productivity and profitability of sodic soils in the alluvial Indo-Gangetic plains and in neighboring salt-affected areas of the Ganges mega delta in South Asia.

Social Benefits of Sodic Soil Reclamation

There are number of success stories of the sodic land reclamation throughout the country. Land reclamation corporations were created in UP, Haryana and Punjab. The working aged adults were compelled to migrate in search of livelihood. Poor health, illiteracy and severe poverty were the natural consequences; social impact of sodicity on the village was to the extent that many men had to remain unmarried since they were facing difficult living conditions. The scenario of the village has changed completely after adoption of the sodic land reclamation programme with the financial help of an International Development Association. The villagers mobilized for group action to reclaim their sodic land by applying gypsum along with the package of practices. They are able to raise two crops on the reclaimed land each year. Such examples can be seen in more than 300 villages of the state. The social impact of sodic land reclamation is quite visible in terms of employment, food production, farm income, resource use efficiency, farm assets, capital formation, land value, improvement in soil properties and improvement in quality of life and environment. It helps in eliminating poverty and inequality amongst the rural society. The social indicators such as literacy levels, birth/death rates and life expectancy also witnessed a change for the better. A brief account of social benefits is as follows:

Additional food grains production: In late sixties and early seventies, there was a rapid increase in production of rice and wheat in U.P., Haryana and Punjab. During this period, various districts of these states witnessed a sharp spurt in production of rice output ranging between 14.4% and 23% per annum. The rapid increase in production was mainly due to introduction of high yielding verities on the one hand and acreage expansion due to reclamation, on the other. Additional annual food production of rice and wheat on sodic lands after reclamation was estimated to be 5 and 2.5 t ha^{-1}, respectively, after 3rd year of reclamation under farmer's resource constraints. It indicates that reclamation of sodic land played important role in augmenting the agricultural production in these states.

Employment generation: The reclamation of sodic soils has generated productive employment for the marginal farmers as well as landless laborers in rural sector. Roughly 165 man-days ha^{-1} employment could be generated in the first year of reclamation. The employment potential was estimated to be 30 man-days ha^{-1} in bunding, leveling and gypsum application whereas 94 and 41 days ha^{-1} in rice and wheat cultivation, respectively. In subsequent years, nearly 135 man-days ha^{-1} would be employed for rice-wheat cropping system at farmer's field (Joshi, 1984). The total employment in the 1st year of reclamation at full-fledged level of technology was estimated at 214 and 160 man-days ha^{-1} for the subsequent years. It is indeed encouraging that such barren lands generate tremendous employment opportunities after reclamation in the rural areas.

Enhancement in farm income: The land reclamation programme has not been limited to merely treatment of salt affected soils but also emphasized on proper soil and water management practices with the objective to achieve sustainable reclamation and develop at sustainable production system. Post-project changes triggered significant increases in family income. Annual household income of erstwhile landless households has increased more than 100%. Income from reclaimed land constitutes about 44 percent of incremental income for those households who did not have access to a productive land before reclamation. Their non-farm income confined mostly to wages, which has also gone up due to combined effect of rise in employment days and wage rate. Indian Institute of Management Lucknow reported that productively of rice has increased from 1.5 t ha^{-1} to 3.0 t ha^{-1} and wheat productivity from 1.7 t ha^{-1} to 2.6 t ha^{-1} in reclaimed sodic lands of U.P. It is noteworthy that due to project intervention, C-class barren lands have come under double crop from no-crop level and B-class mono-cropped lands turned to double cropped. The erstwhile landless labours (now marginal farmers) are enabled to produce 1.7 tons rice and 1.5 tons wheat (3.2 tons food grains) per annum.

Enhancement in land value: The value of land, besides giving a prestige in society to the owner, decides credit worthiness of the farmer and plays an important role in many decision making processes. The reclamation substantially increases value of the land due to increased production potential and source of income. The U.P. Sodic Lands Reclamation Project executed in ten districts of U.P. showed tremendous increment in value of land over a period of 7 years from 1993 to 2000. The value of reclaimed land has gone up by about 48 percent on B+ class and whereas value of B and C class land has risen by 108 and 317 percent, respectively, C class land recording maximum growth in value.

Poverty alleviation: The sodic land reclamation programme provided unique opportunity for alleviation of poverty, particularly of marginal and small farmers, who were delimited by the vicious circle of poverty, i.e. low investment – low output – low savings. Project intervention in U.P. resulted in decline of participant households below poverty line after reclamation. Thus, a sizable number of participants have crossed the poverty line and some households moved upwards.

Better living standard: The intervention through land reclamation has increased cropping intensity, employment and crop yield. These all have a positive impact on economic and quality of life of the participant farmers. The literacy has improved remarkably over the year in the selected village of U.P. It was higher among big and small farmers than among landless and marginal farmers. Male literacy was invariably more than female literacy irrespective of category of household and period. Rise in literacy ratio was higher among scheduled caste and landless and marginal farmers. The project has provided maximum benefits to such people. Male literacy improved by 7 percent and female literacy by 9 percent. It is attributed to the increased awareness among people about education. The number of children enrolled at school registered remarkably high as compared to the number registered before reclamation in those areas where reclamation project has been launched. The children aged less than 7 years enrolled at school registered three-fold increase over a period of 7 years following execution of the reclamation project.

Improvement in environment: The important social benefit of the sodic lands reclamation is improved quality of environment. Utilization of rainwater by reducing surface runoff and soil erosion during rainy season is the brighter aspect of sodic lands reclamation as about 40 percent of the total irrigation requirement of the newly reclaimed areas of rice and wheat is met from the rainwater conservation. It is ultimately resulting in increase in ground water recharge and improvement in the soil quality. It further helps in controlling flood hazards by reducing peak runoff during the heavy rainstorms. Another important environmental benefit is the change in landscape after reclamation of these unproductive barren, undulated and unmanaged lands. The properly managed soil, water, road, path, vegetation and landscape improve the overall micro-climate of the areas.

Future issues pertaining to reclamation of sodic soil of UP

Considerable success has already been achieved in management of salt affected soils. Many technologies have been developed for reclaimed and semi-reclaimed sodic soils.. However, there are several researchable issues, which are hitherto remained unaddressed. Some of the issues are described below:

- **Re-sodification of reclaimed sodic soils:** This is a concern in areas where reclamation took place before 2-3 decades. Though the causes of re-sodification are identified, yet concerted research efforts are to be made to avoid re-sodification of reclaimed lands.
- **Need for alternative to gypsum:** Gypsum being mineral in nature and mined from limited area, its availability in future will no longer be the same as it was in the past. Already there is crisis and several judicial and social issues involved in gypsum mining. Therefore, there is an urgent need to find out an alternative to mineral gypsum and standardize the agro-techniques for its use on sodic soils.
- **Harnessing synergy from modern science:** There are opportunities and avenues of reclamation and remediation of both salt affected soils and poor quality waters; and agronomic research in the area of nano-technology applications in salt affected soils.
- **Bio and phyto-remediation:** Bio-remediation and phyto-remediation of waste water/poor quality waters and their use in salt affected soils need to be explored on a major scale. This area has a great potential for agronomic research in future with limiting water availability for irrigation.
- **Micro-irrigation for enhanced resource use efficiency:** Till now cereal systems are dominant on salt affected as well as reclaimed salt affected soils. These soils are not exposed to high value horticulture production. Since these areas are affected by multiple stresses of salts, waters and nutrients, research efforts need to be diverted for enhancing the use efficiency of water and nutrients on salt affected soils. For this, micro-irrigation, drip fertigation, and use of liquid bio-fertilizer along with atomized irrigation need to be explored.
- **Resource conservation:** Entire Indo-Gangetic Plain and Trans-Indo-Gangetic Plain is engaged in rice-wheat cultivation for several decades. Exhaustive nature of rice-wheat cropping system depleted the natural resources and there is resource crunch disturbing agro-ecology of the area. The problem is aggravated in salt affected soils because of multiple stresses. This compels adaptation of resource conservation technology and conservation agriculture options need to be thoroughly evaluated for reclaimed as well as non-reclaimed salt affected soils.
- **Multi enterprise agriculture:** For small and marginal land holdings, multi enterprise agriculture provides an assurance of regular income as well as on-farm employment. Thus, the multi enterprise agriculture involving subsidiary components with conventional crop components in a synergy based recycling manner needs to be evaluated in different agro-eco systems on salt affected soils.
- **Integrated nutrient management:** It is well proved that higher nutrient application is beneficial in salt affected soils as compared to normal soils. But after reclamation soil pH of surface 30 cm layer is within the range of 7.5-8.5, therefore nutrient supply as per the recommended doses of fertilizer is advisable. However, in Haryana, Punjab and Western Uttar Pradesh, farmers use very high amount of nitrogen fertilizers than the recommended one. On the contrary, they do not use potassium fertilizers leading to imbalance nutrition for the crop, which affects soil health and quality. These issues need a fresh relook and to be critically addressed by location-specific research. Therefore, integrated nutrient management prescriptions need to be developed for different types of salt affected soils.

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Modelling for Saline Water Use in Agriculture

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Introduction

In arid and semi-arid regions of Indo-Gangetic plains farmers are using low quality groundwaters due to limited supplies of better quality irrigation waters (Singh *et al*., 1992). Irrigation waters containing high levels of salinity and sodicity may be detrimental to crop production and may reduce soil water intake rates (Tanji, 1997). Continuous use of saline water for crop production enhances the soil salinisation. High contents of soluble salts accumulated in soil can significantly decrease the value and productivity of agricultural lands. Also cases of irrigation induced waterlogging and soil salinisation have been reported in commands of many irrigation projects like Western Yamuna Canal System, Chambal System and Indira Gandhi Nahar Pariyojana (Rao *et al*., 1995; Aheer *et al*., 1995; Hooja *et al*., 1995).

Several research organisations and agricultural universities are conducting field experiments on different crops to provide water quality guidelines for irrigation purposes (Ayers and Westcot, 1985; Ayers and Tanji, 1981; Gupta *et al*., 1994), to assess the impact of poor quality irrigation water on soil quality, crop yield and, to find optimal management strategy for use of such waters. The guidelines for use of poor quality waters given by the Ayers and Westcot (1985) consider the number of criteria such as effects of salinity on the availability of soil water to plants and need to maintain the favourable water balance in the root zone; interactive effects of sodicity (SAR or sodium adsorption ratio) and salinity (EC or electrical conductivity) on soil water intake rates and soil permeability; specific ion toxicity to sensitive plants; and miscellaneous constituents of concern such as nitrogen and metals that have potential to leach into groundwater. These guidelines are based on assumption that at least 15% of the applied irrigation water percolates below the root zone. The guidelines apply not only to fresh waters but also to waste waters for evaluating their suitability for irrigation. All India Coordinated Research Project (AICRP) on Saline Water Use, Central Soil Salinity Research Institute (CSSRI), Haryana Agricultural University (HAU) and Punjab Agricultural University (PAU) recommended realistic guidelines on utilising poor quality waters applicable to Indian monsoon based agriculture. In addition to water quality parameters, importance of soil texture, crop tolerance, rainfall and concentration of soil solution due to evapotranspiration have also been recognised in developing these guidelines (Gupta *et al*., 1994). However, such guidelines are usually based on relatively simple and often empirical relations. Still there are many critical issues, which need special attention for solutions. Modeling has been found as a good tool in understanding the complex problems and finding the remedies. A number of models such as SALTMOD (Oosterbaan, 1989), SGMP (Boonstra, 1989), RAHYSMOD (Rao *et al*., 1994), model by Aslam and Skogerboe (1995), UNSATCHEM (Simunek *et al*., 1996), SWAP (Van Dam *et al*., 1997), model by Lamsal *et al*. (1999) and case studies (Aragues *et al*., 1985; Singh and Singh, 1997; Simunek *et al*., 1997; Smets *et al*., 1997; Prathapar and Qureshi, 1999) are available to address issues related to irrigation and salinity-alkalinity management in agricultural fields. Few examples of recent modeling studies are discussed below.

Prathapar and Qureshi (1999) modeled the effects of deficit irrigation on soil salinity, depth to water table and transpiration in monsoonal semi-arid zones in Punjab, Pakistan. The simulation results showed that provision of 80 percent of cumulative evapotranspiration requirements as irrigation might result in acceptable limits of root zone salinity and depth to watertable. Under this management option, subsurface drainage system might not be a necessity. Singh and Singh (1997) studied irrigation scheduling for wheat crop under deep water table condition to minimise the percolation loss. It was observed that light but frequent irrigations to light textured soils as compared to medium textured soils were required to maintain optimum crop yield and hydrodynamic equilibrium. Simunek *et al*. (1997) evaluated sodic soil reclamation strategies on the basis of the quantity of water needed, quantity of amendments used and time required for reclamation. Primarily chemical reactions such as cation exchange, precipitation and dissolution of solid phases (reclamation amendments), effect of solution composition on the soil hydraulic properties, and changes in water flow and solute transport rates were considered. Smets *et al*. (1997) assessed the impact of irrigation practices (defined in terms of irrigation quantity, quality and frequency) on soil salinity and crop transpiration of cotton and wheat in conjunctive use environment. The interval of irrigation appeared to be promising management option for farmers to control soil salinity and to optimise the crop transpiration. It was observed that the soil texture considerably affects the water and salt balances. Considering the importance of modeling in understanding the salinity-alkalinity processes and dealing the related management issues, in the present study, the UNSATCHEM model is calibrated and validated with experimental data of saline water use for wheat and cotton crops reported by Naresh *et al*. (1993). Further simulations were carried out by the model to have better insight about the effects of irrigation water quality, soil texture, conjunctive use strategies and saline water use guidelines on management of salinity in agricultural fields.

Input data for Calibration and Validation of UNSATCHEM for Saline Water Use

For calibration and validation of UNSATCHEM model, the input files were prepared by using field data reported by Naresh *et al*. (1993). These data are based on their experiment conducted on field plots (4.0×4.0 m size) at the farm of R.B.S., College of Agriculture, Bichuri (Agra) during 1989-1991 on a sandy loam soil to compare the crop responses and salinity build up in soils for cotton (*Gossypium hirsutum*) and wheat (*Triticum aestivum*) crops under mixing and cyclic modes of the saline and non-saline waters. The field plots were lined with polyethylene sheet down to a depth of 0.9 m to avoid lateral fluxes of water and salts. The submodels for transient flow, chemical transport and water extraction from the root zone were used in simulations. The options for root growth, heat transport, CO_2 production and its transport were not used due to lack of data. Cotton and wheat crops were grown in rotation for two years (May 1989-April 1991) on fixed plots and were irrigated under different irrigation water quality treatments. First wheat crop (12th November 1989- 22nd March 1990) and second cotton crop (22nd May1990- 6th November 1990) were considered for simulation study. The original experiment had eight treatments for different conjunctive use modes. Saline and canal waters used in the experiment had salinity equal to 12 dS/m and 0.6 dS/m, respectively. Details of the input data preparation for wheat and cotton crop simulations are discussed in following paragraphs.

Irrigation treatments: Data on two irrigation treatments of the wheat crop namely: Treatment A (the alternate irrigation with canal and saline water starting with application of canal water for pre-sowing irrigation) and Treatment B (the blending of canal and saline water in equal proportions 1:1) were used for calibration and validation of the UNSATCHEM, respectively. Wheat crop period received the rainfall of 5.6 cm. Three post-sowing irrigations (on 25th, 57th and 83rd day) of 7 cm each were applied besides the pre-sowing irrigation of 7 cm. Irrigation schedules were based on the recommendations for non-saline irrigated soils of the area. The conjunctive use mode was also applicable to pre-sowing irrigation. Rainfall events were incorporated with irrigation events. The electrical conductivity of rainfall water was assumed to be 0.1 dS/m. The USWB open pan evaporation during crop period was 384 mm, which was analysed to determine potential transpiration, soil evaporation and plant transpiration (Feddes et al., 1974; Singh, 1983). The average seasonal crop factor for wheat was taken as 0.61. The growth stage wise crop factors were adopted from Michael (1978). Appropriate time dependent atmospheric and solute boundary conditions were selected for top boundary. The ponding of water was allowed without surface runoff. The land at experimental site was well drained and the water table always remained below 4 m during study period. Free drainage condition was assumed at lower boundary. Saline water was synthesised by dissolving desired amounts of NaCl, Na_2SO4, $CaCl_2$ and $MgSO_4$ in canal water to achieve EC of saline irrigation water as 12.0 dS/m and SAR equal to 10 $(mmol_c/l)^{½}$. The EC and SAR of saline water were used to get approximate concentrations of different cations and anions in saline water. Quality parameters of saline, mixed and rainfall waters are given in Table 1. Other waters mentioned in Table I were also prepared artificially by adjusting cation and anion concentrations, and were used for the generation of different scenarios by the UNSATCHEM model.

Table 1. Quality parameters of saline, mixed and rainfall water

Water type	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO4^{--}$	Cl^{-}	Alk	EC
				$mmol_c/l$				dS/m
$SW_{C\&V}$	39.00	24.40	56.20	0.40	65.00	50.00	5.00	12.00
CW	2.76	1.73	1.20	0.31	1.00	4.00	1.00	0.60
Mixed	20.88	13.07	28.70	0.36	33.00	27.00	3.00	6.30
Rainfall	0.40	0.30	0.20	0.10	0.50	0.50	0.00	0.10
SW_{SAR5}	22.66	15.10	21.72	0.52	25.00	30.00	5.00	6.00
SW_{SAR25}	5.01	3.34	51.15	0.50	25.00	30.00	5.00	6.00
$SW_{Cl-Rich}$	22.66	15.10	21.72	0.52	20.00	35.00	5.00	6.00
$SW_{SO4-Rich}$	22.66	15.10	21.72	0.52	35.00	20.00	5.00	6.00
SW_{Long}	20.00	14.00	31.50	0.50	29.00	33.00	4.00	6.60

$Alk = 2\ CO_3^{--} + HCO_3^{-} + OH^{-} - H^{+}$

Soil data: The cation exchange capacity (CEC) of soil in the field plots for 0.00-1.05 m was 86-147 $mmol_c$/kg. The $CaCO_3$ was less than 1%, while organic matter was less than 0.5%. The initial soil salinity at the time of sowing of wheat crop was given. It was used to estimate the approximate dissolved and adsorbed quantities of different ions. The Gapon selectivity coefficient K_G for Na-Ca exchange was taken as 0.35 $molc^{-½}/l^{-½}$. The value was well within the range given by Poonia et al. (1990) for similar type of soils in nearby State of Haryana. The exchange coefficient for K-Ca exchange was taken as 0.35 $molc^{-½}/l^{-½}$. Average values of selected soil water retention and hydraulic conductivity parameters (θ_r, θ_s, α, η and K_s) for sandy loam soil textural class were selected according to Rawls (1982). Rao (1998) compared moisture content values on volume basis at field capacity and permanent wilting point for different textural classes of Indian alluvial soils with United States soils (Rawls, 1982). He found good agreement between the Indian and United States soils.

Root environment: The root depth for wheat crop was taken as 100 cm. Minhas and Gupta (1993) suggested the non-linear root water uptake pattern. However, Prasad (1988) used linear root water uptake pattern. By trial and error during calibration, linear root water uptake pattern was found better for this particular case. Field data related to the CO_2 concentration were not available. The CO_2 concentration ($cm^3\ cm^{-3}$) was assumed to increase linearly from 0.00033 at the soil surface to 0.022 at 30 cm depth. It reduced to 0.0025 (at 32 cm) and remained constant up to 50cm. Below, a constant concentration of 0.0008 $cm^3\ cm^{-3}$ was assumed considering some trapped air in sub layers. A time invariant CO_2 concentration was prescribed. The sensitivity to water and salinity stress was defined by the empirical parameters h_{50} = -2000 cm and h_{50} (osmotic) = -1.e+20 cm (Van Dam and Aslam, 1997). The parameter h_{50} represents the pressure head at which water extraction rate is reduced by 50 percent. The constant soil temperature of 25 degree Celsius and the dispersivity of 10 cm were assumed. Molecular diffusion was neglected. For simulation during validation run, all parameters, which were used for the calibration case remained unchanged, and only the irrigation water quality was adjusted. The model was calibrated and validated with observed salinity profiles of respective irrigation treatments at the time of wheat harvest.

Calibration and Validation of UNSATCHEM for Saline Water Use

In cotton-wheat crop rotation, second cotton crop came in between first and second wheat crop. In case of the cotton crop salinity profiles at the time of sowing and harvest were not reported by Naresh *et al*. (1993). For a particular irrigation treatment of cotton-wheat crop rotation, the first wheat crop was harvested on 22nd March 1990 and on the same plot the second cotton crop was sown on 22nd May 1990 after pre sowing irrigation. Similarly, after the harvest of second cotton crop on 6th November 1990, the second wheat crop was sown on 25th November 1990 after pre-sowing irrigation. The salinity profile at the harvest of first wheat crop and the sowing of second wheat crop were reported by Naresh *et al*. (1993), which might be treated as approximate initial and final salinity profiles for the second cotton crop. It was expected that depth wise salinity values at the harvest of first wheat and the sowing of second wheat crop would be slightly different than values at the sowing and harvest of second cotton crop due to pre-sowing irrigations applied to the second cotton and second wheat crop. However, trends of salinity profiles might find some similarity. Therefore, trends of simulated salinity profiles at harvest of second cotton crop were compared with trends of observed salinity profiles at sowing of second wheat crop. The simulations in case of cotton crop were carried out for two irrigation treatments namely: Treatment C (first two irrigations by canal water followed by rest of the irrigations by saline water) and Treatment D (an alternate irrigation with saline and canal water starting with application of saline water for pre-sowing irrigation). The Treatment C was used for calibration, while Treatment D was used for validation of the UNSATCHEM model. Two irrigation treatments selected for cotton crop were different than wheat crop treatments so that the UNSATCHEM model would be tested for different types of scenarios generally practiced by the farmers. The total amount of rainfall during cotton crop period was 58 cm. Two irrigations of 7 cm each on 15th and 147th day were applied besides the pre-sowing irrigation of 7 cm. The quality of irrigation water was decided as per conjunctive use strategy. Rainfall events were incorporated with irrigation events. The EC and SAR of saline water were 12.0 dS/m and 10 $(mmol_c/l)^{½}$. It was assumed that the rainfall water had electrical conductivity equal to 0.1 dS/m. The quality parameters of different waters are given in Table 1. The USWB open pan evaporation during cotton crop period was 1113 mm, which was analysed to determine potential transpiration, soil evaporation and plant transpiration (Feddes et al., 1974; Singh, 1983). The average seasonal crop factor for cotton was taken as 0.70. The crop stage wise crop factors were adopted from Michael (1978). As discussed above, the salinity profile at harvest of first wheat crop was treated as initial salinity profile for second cotton crop. Assumptions about the soil physico-chemical data, lower boundary, top boundary, CO_2 concentrations, dispersivity were kept same like wheat crop simulations. The root depth for the cotton crop was taken as 120 cm. By trial and error during calibration, non-linear root water uptake pattern was found better for this particular case. The simulated profiles from calibration and validation run were compared with respective pre-sowing salinity profiles for wheat crop.

Comparison of Simulated and Observed Salinity Profiles

The model was calibrated and validated with observed salinity profiles of respective irrigation treatments at the time of wheat harvest. Simulated and observed salinity profiles for Treatment A (calibration) are shown in Fig.1a. The good agreement between these profiles was obtained by adjusting the dispersitivity value and by assuming linear root water uptake pattern. Again without further adjustment in parameter values, simulated salinity profile for Treatment B (validation) was determined (Fig.1b). It is evident from this the figure that there is good agreement of simulated and observed salinity profiles and thus established the validity of the model and assumptions made for the calibration.

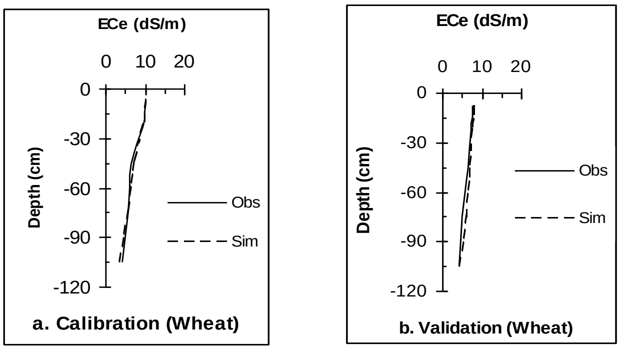

Fig. 1. Calibration and validation of UNSATCHEM for Treatment A and B

The simulated profile at the harvest of cotton crop was compared with observed salinity profile at the sowing of next (second) wheat crop. In case of calibration (Treatment C) and validation (Treatment D) trends of simulated profiles are matching well with observed profiles (Figure 2a and 2b). It is also important to note that observed salinity values are lower than the simulated values in both the treatments. It is mainly because of the pre-sowing irrigation. It also suggests that the assumptions made about the approximate initial and final salinity profiles for cotton crop are correct. Thus, the UNSATCHEM model can be used for different crops.

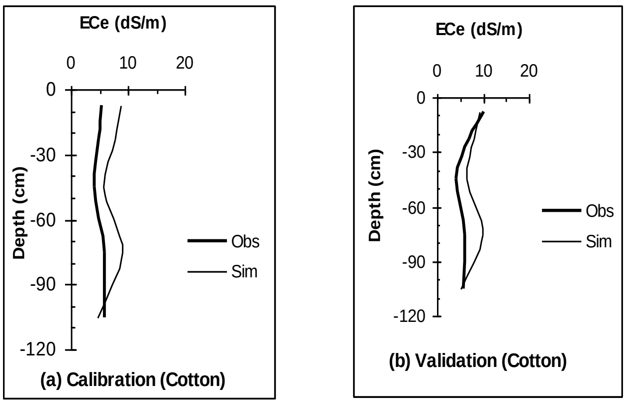

Fig. 2. Calibration and validation of UNSATCHEM for Treatment C and D

Simulation Scenarios

The calibrated and validated UNSATCHEM model was used for simulations to investigate effects of irrigation water quality, soil texture, temporal changes in irrigation water quality (conjunctive use practices) and long-term saline water use on soil salinisation. Details of these simulations are explained in subsequent paragraphs.

Effects of Irrigation Water Quality Parameters on Soil Salinity

Quality of saline irrigation water is generally defined by electrical conductivity (EC) assuming that its residual sodium carbonates (RSC) is less than 2.5. It is a necessary condition as per quality guidelines otherwise the irrigation water is treated as alkali water. Under special situations, other quality parameters like sodium adsorption ratio (SAR), Mg^{++}/Ca^{++} ratio and Cl^{-}/SO_4^{--} ratio are also considered. Using the input data of wheat calibration simulation, UNSATCHEM simulations for wheat crop with four saline waters having EC as 3, 4, 5 and 6 dS/m were carried out to assess the effect of irrigation water salinity on salinisation of root zone. The root zone was assumed of homogeneous sandy loam soil. The CEC and Gapon selectivity coefficient (K_G) were assumed as 86 $mmol_c$/kg and 0.35 $molc^{-½}/l^{-½}$. No rainfall event was considered during crop period. Pre-sowing irrigation and 3 post sowing irrigations were assumed by saline water. Other data related to initial conditions, boundary conditions and CO_2 concentration profile were adopted from the wheat calibration input and kept same for all simulations. Three additional simulations were done for above-mentioned each saline water assuming rainfall of 6, 9 and 12 cm during crop growing period. Average salinity values for 0-90 cm soil layer were determined from different simulations assuming effective root zone depth for wheat crop as 90cm. The weighted average of irrigation water in case of each simulation was determined assuming the salinity of rainfall water as 0.1 dS/m.

The weighted average salinity of irrigation water and the average root zone salinity at harvest of wheat crop determined from UNSATCHEM simulations are plotted in Fig. 3. The figure indicates that linear relationship exists between these two variables. Mieri (1986) applied irrigation waters of different salinities to potatoes and peanuts through drip system, alternately and after mixing. It was found that crop responded to weighted average salinity regardless to conjunctive use mode. Therefore, the average root zone salinity at harvest can be good indicator of the crop yield. Oosterbaan *et al*. (1990) developed a relationship between crop yield and root zone salinity at harvest for wheat, mustard and barley crops using field data at Sampla, Haryana. They found that the relation between yield and salinity is scattered and can be expressed with envelope curves. There exits a critical (threshold) value of soil salinity below which the yield is unaffected by salinity, whereas beyond this value the yield decreases with increasing salinity. It is important to note that the initial salinity of the soil also influences the salinity at harvest in case of winter crops.

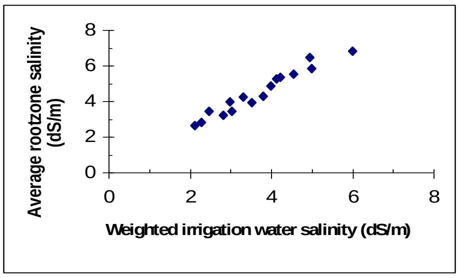

Fig. 3. Effect of irrigation water salinity on root zone salinity

Water quality guidelines also speak about the use of gypsum when the SAR of saline water is greater than 20 though the RSC is less than 2.5 $mmol_c$/l. Two simulations were conducted for wheat crop with saline waters having same EC as 6 dS/m, but different SAR values as 5 and 25 $(mmol_c/l)^{½}$. The root zone was assumed homogeneous and rainfall events were ignored. All other data were adopted from the wheat calibration input and kept same for both simulations. Two more simulations were done for wheat crop by adopting all data from earlier simulations expect little change in irrigation water quality. The EC of saline water was taken as 6 dS/m. However, Cl^{-}/SO_4^{--} ratios were assumed as 1.75 and 0.57, respectively.

The root zone salinity profiles for wheat crop due to different SAR waters (SAR=5 and 25 $(mmol_c/l)^{½}$) having same salinity (EC 6 dS/m) were studied using UNSATCHEM output. It is observed that root zone salinity in case of higher SAR water is higher though irrigation water salinity was same for both the waters. More precipitation of calcite is observed in low SAR water compared to high SAR. It might be due to more availability of Ca^{++} ions in irrigation water. The more precipitation of calcite may reduce root zone salinity in case of low SAR waters. The SAR and ESP are also higher in case of high SAR water. It suggests that high SAR saline water with no RSC also promotes the sodification and gypsum application might be required to reverse it.

The root zone salinity profiles for wheat crop due to two saline waters having same electrical conductivity (EC = 6 dS/m) but different Cl^-/SO_4^{--} ratio (1.75 and 0.57) were studied using UNSATCHEM simulations. It is observed that root zone salinity values are higher for water having higher Cl^-/SO_4^{--} ratio (chloride rich waters) though irrigation water salinity was same for both the waters. In case of lower Cl^-/So_4^{--} ratio (sulphate rich water), the complex aqueous species of SO_4^{--} with Ca^{++}, Mg^{++} and Na^+, K^+ might reduce the root zone salinity. Similarly, it is expected that the root zone salinity on use of HCO_3^- rich water would be less due to precipitation of $CaCO_3$. The alkalinity of water increases with HCO_3^- concentration. Simulations with saline waters having different Mg^{++}/Ca^{++} ratios were not done assuming that Ca^{++} and Mg^{++} might behave similarly. It means that more Mg^{++} ions would be added at exchange complex on use of Mg^{++} rich waters. It deteriorates the soil structure and decreases the soil productivity (Michael, 1978). Therefore, use of gypsum is recommended if and Mg^{++}/Ca^{++} ratio irrigation water is more than 3 (Gupta *et al*., 1994).

Effect of Soil Texture on Soil Salinity

Soil texture influences the permissible limit for electrical conductivity of saline irrigation water. It increases with decrease in clay percentage. It suggests that textural properties of the soil involved in solute transport be controlled by clay content. The solute transport under saline condition is a non-reactive transport. Therefore, soil properties like hydraulic conductivity and saturated water content are important than cation exchange capacity. To understand the relation between soil texture and salinisation, UNSATCHEM simulations for wheat crop with two textural classes (sandy loam and loam) were carried out. The initial and boundary conditions were adopted from wheat calibration simulation input. The average values of selected soil water retention and hydraulic conductivity parameters (θ_r, θ_s, α, η and K_s) for two textural classes were selected according to Rawls (1982) and Rao (1988). The irrigation water of 3 dS/m was used and four irrigations, each of 7 cm depth, were applied. The salt balance of entire flow region was calculated. The length of entire flow region was 120 cm. Assuming surface area of 1 cm^2, control volume for flow region became 120 cm^3. The salt balance calculations were done using $mmol_c$ as unit.

The salt balance calculations for control volume of the flow region based simulation results for two textural classes are given in Table 2. It suggests that the change in storage of the salts is higher for loam soil than the sandy loam soil. This may be due to higher saturated water content of loam soil (i.e. 0.434) compared to sandy loam soil (i.e. 0.412). The saturated hydraulic conductivity of sandy loam and loam soils are 62.16 and 16.32 cm/day. However, leaching amounts in both cases are negligible. The results suggest that the influence of saturated water content on salinisation process is higher in comparison to saturated hydraulic conductivity of the soil. The precipitation of calcite is also affected by saturated water content. The precipitation is quicker in case of sandy loam soil due low water content.

Table 2. Salt balance ($mmol_c$) components for wheat crop with different textures

Salt balance Component	Initial	Through Irrigation	At harvest	Change in storage	Leaching	Precipitation
Sandy loam	0.56	0.84	0.92	0.36	0.01	0.47
Loam	0.70	0.84	1.13	0.43	0.00	0.41

Effects of Temporal Changes in Irrigation Water Quality on Soil Salinity

Temporal changes in irrigation water quality can also influence the salinisation process. These changes generally occur when farmers get occasional supply of good quality canal water. In that situation, either alternate or mix mode of saline and canal water is preferred depending on the availability of canal water. Effects of these practices on soil salinisation were investigated by simulating with calibration and validation input data of wheat crop but ignoring rainfall events.

Salinity profiles under alternate mode (SW: CW) and mix (1:1) mode for wheat crop are studied. In case of alternate mode, there is salinisation and desalinisation of surface soil layers with application of saline and canal water, respectively. This process continues with alternate use of saline and canal water. In case of mix mode, depth of penetration of salinity profile and salinity values increase with amount of the mixed water. It is also observed that in alternate and mix modes salinity values below 40 cm are almost same. It indicates that conjunctive use modes influence the salinity in surface soil layers only. It might happen because saline and canal waters, which are applied separately, might be mixing thoroughly while penetrating to 40 cm depth. The above discussion provides the insight into salinisation process under alternate and mix modes.

Simulations were also carried out for five conjunctive use modes namely, SW: CW, CW: SW, 2CW: 2SW, 2SW: 2CW and Mix (1:1). Four irrigations (at pre sowing, on 25th day, 57th day and 83rd day), each of 7 cm, were applied under each mode. Post sowing irrigations were given on critical crop growth stages such as crop root initiation, tillering and late joining and flowering, respectively (Michael, 1978). The quality of the irrigation water was decided as per the conjunctive use mode. Conjunctive use mode was applied from pre sowing irrigation. The root zone was assumed homogeneous with CEC and K_G being equal to 86 $mmol_c/kg$ and 0.35 $mol_c^{-½}/l^{-½}$, respectively. The root water uptake pattern, initial and boundary conditions were adopted from the calibration simulation input. According to Mass and Poss (1989), Vegetative stages (crown root initiation, tillering and late jointing) are more sensitive than reproductive (flowering) and maturation (milk and dough) stages. The temporal changes in root zone salinity under different conjunctive use modes were investigated considering sensitivity of the wheat crop to decide preference of one conjunctive use mode over the other. The results of the two published field studies on conjunctive use of saline and canal water are analysed in view of the preferences among the conjunctive use modes.

The temporal changes in root zone salinity influence the root water uptake and crop yields. The average root zone salinity values with time under five different conjunctive use modes, for wheat crop, are shown in Figure 4. In case of mix (1:1) mode, the average root zone salinity is increasing linearly with time. For alternate (SW: CW and CW: SW) modes, salinity values are fluctuating depending on the irrigation water quality. In case of 2CW: 2SW mode, the root zone salinity decreases to 1.77 dS/m from initial value of 2.56 dS/m with application of two canal waters. However, it increases rapidly with two saline water irrigations. For 2SW: 2CW case, initially salinity builds up rapidly with two saline waters and decreases with canal waters. In all five modes, salt load added through irrigation water is same but the average salinity values at harvest are not same. It is interesting that salinity at harvest for CW: SW, 2CW: 2SW modes is almost same. Similarly, salinity at harvest for SW: CW and 2SW: 2CW modes is same. The salinity at harvest for mix mode (1:1) is in between above two categories.

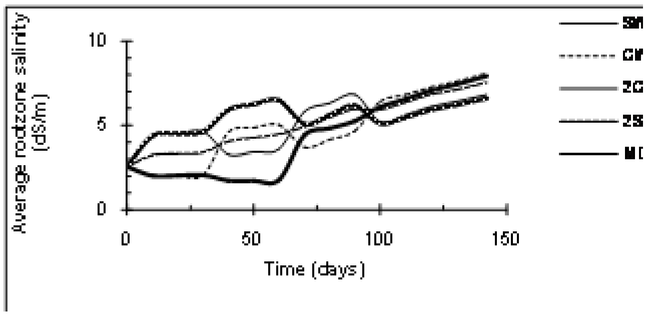

Fig. 4. Temporal changes in salinity under different conjunctive use modes

Preference order for conjunctive use practices

Considering sensitivity of wheat crop to salinity, among different conjunctive use modes (Figure 4), the 2 CW: 2 SW should be good option as root zone salinity under this mode remains low for almost two months during initial crop growing period. The CW: SW mode ensures low salinity for initial one month. The mix (1:1) mode should be preferable over SW: CW option. It is obvious that 2 SW: 2 CW mode would get least preference. The preference order for conjunctive use practices is given in Table 3. Though amount of salt load added under different conjunctive use modes is same, temporal changes in root zone salinity are different. Therefore, selection of proper conjunctive use mode is required for salinity management at root zone.

In case of wheat yields reported by Naresh *et al*. (1993), the highest yield of 5.45 t/ha was reported, where all irrigations were given by canal water. The yield under 2CW: 2SW mode was 5.22 t/ha, which was lower than CW: SW mode, i.e. 5.38 t/ha. This might have happened due to different initial salinity values, which affected seedling emergence rate. The emergence rate reported for 2CW: 2SW and CW: SW modes are 92 and 99%, respectively. This suggests the importance of maintaining low salinity at time of germination. Yield under CW:

SW mode (5.38 t/ha) was higher than SW: CW mode (4.01 t/ha) and mix mode (4.96 t/ha). The mix (1:1) mode performed better than SW: CW mode. The weighted salinity of irrigation water for different conjunctive use modes was 5.3 dS/m. Rainfall during the crop period was considered during estimating the weighted salinity.

Table 3. Preference order for conjunctive use practices

Conjunctive use practice	Description	Rank	Wheat yields (t/ha) by Naresh *et al*. (1993)	Wheat yields (t/ha) by Sharma *et al*. (1994)
All canal	All canal irrigations	1	5.45	6.49
2CW: 2SW	Two canal and two saline water irrigations	2	5.22	6.25
CW: SW	Canal and saline water alternate irrigation	3	5.38	6.25
Mix (1:1)	Irrigation by canal and saline water mix (1:1)	4	4.96	---
SW: CW	Saline and canal water alternate irrigation	5	4.01	6.09
2SW: 2CW	Two saline and two canal water irrigations	6	----	6.08

In case of wheat yields reported by Sharma *et al*. (1994), the highest wheat yield of 6.49 t/ha was reported, where all four irrigations were given by canal water. Yield under 2CW: 2SW mode was slightly lower (i.e. 6.25 t/ha) than canal water irrigation. The yields of CW: SW, SW: CW and 2SW: 2CW were 6.25, 6.09 and 6.08 t/ha, respectively. Field experiment was of three years, but during the first year, the 2SW: 2CW mode was not conducted. Therefore, yield data related to second year have been discussed here. The similar trends were also followed by the yield data of remaining years. It is interesting to note that yield under 2CW: 2SW mode is exactly same like CW: SW mode. Similarly, yield under 2SW: 2CW mode is almost same to SW: CW mode. This indicates that root zone salinity at critical growth stage of the crop influences the crop yield at harvest. For the remaining years, yield differences between 2CW: 2SW and CW: SW alternate as well as 2SW: 2CW and SW: CW alternate are very low. The experiment did not include treatment related to mix (1:1) mode of conjunctive use. Conjunctive use plan was implemented by Naresh et al. (1993) from pre-sowing irrigation. However, Sharma *et al.* (1994) used canal water for pre-sowing irrigation and implemented conjunctive use mode for all post-sowing irrigations only. Therefore, Sharma *et al*. (1994) reported higher wheat yields than Naresh *et al.* (1993) for the conjunctive use modes. It indicates the importance of pre-sowing irrigation by canal 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.

Long -term Sustainable Use of Saline Water

Long -term sustainable use of saline water in agriculture is needed in semi-arid and arid regions, where water scarcity and water quality both threaten the crop production and productivity. The simulations till this stage were aimed to understand the effect of individual variable on salinisation process by ignoring the variability other variables. Long-term simulations for wheat -cotton rotation for the period of six years were conducted to understand the long-term effects of saline water use particularly under Indian monsoon based agriculture. It was important to know whether long-term simulations can help in preparation of guidelines. If it is so, the long-term field experiments can be avoided to certain extent. The soil data at the farm of RBS College, Bichpuri (Agra) were adopted from Naresh et al. (1993). The soil texture is sandy loam. Thus, the soil belongs to moderately coarse category, which has clay content within 10 to 20%. Annual rainfall of the station is more than 550 mm. For moderately coarse soil with annual rainfall more than 550 mm, the saline water having EC up to 10 dS/m might be used for salinity tolerant crops as per water quality guidelines. For sensitive and semi - tolerant crops, the upper limits of EC are 3 and 8 dS/m, respectively. It is recommended that field should be kept fallow if higher salinity waters are used in low rainfall areas and SAR is more than 20. On the basis of long-term experiment on wheat- pearlmillet rotation at Agra, Gupta *et al*. (1994) reported that 90% of relative yield could be obtained if water salinity is 6.6 dS/m. In case of long term simulation for wheat- cotton rotation, the irrigation water salinity was also taken as 6.6 dS/m. Annual rainfall amounts of the station for period of six years were assumed as 820, 660, 710, 580, 650 and 735 mm. The rainfall amounts for wheat period were taken approximately as 98, 79, 85, 69, 78 and 86 mm. For cotton period values were taken as 695, 560, 602, 492, 551 and 623 mm. The annual USWB open pan evaporation values for six years were assumed as 1370, 1500, 1420, 1560, 1510, 1400 mm. The pan evaporation values for wheat crop period continuously for six years were taken as 411, 450, 425, 468, 453 and 420 mm. The values for cotton crop period were taken as 846, 926, 877, 963, 932 and 864 mm. The Atmospheric boundary was assumed at top boundary while free drainage was assumed at lower boundary. Initial condition for first wheat crop was adopted from Naresh *et al*. (1993). Pre sowing irrigation and four post sowing irrigations by saline water were given to all six wheat crops. For first, third and sixth cotton crops, pre sowing and two post sowing irrigations were given as rainfall amounts during the crop periods were above 600 mm. For remaining cotton crops, pre sowing and three post sowing irrigations were given due to insufficient rainfall during crop periods. The seasonal crop factor for wheat and cotton were assumed as 0.61 and 0.7, respectively. The data input of the UNSATCHEM model is such that it simulates unsaturated solute transport for single crop within a season. If the model is to be applied for long term simulation, it is necessary to assume that both crops have similar rooting depth and root water uptake pattern. Non -linear root water uptake was considered for wheat as well as for cotton crop. The crop rooting depth was assumed as 100 cm for both the crops. The temporal changes in soil salinity were studied using UNSATCHEM output. The average salinity and SAR values for 0-90 cm depth at wheat and cotton harvest were determined to assess sustainability of saline water use in long term under monsoon type of climate.The temporal changes in the average root zone salinity and SAR values under wheat-cotton rotation are shown in Figure 5a and b, respectively.

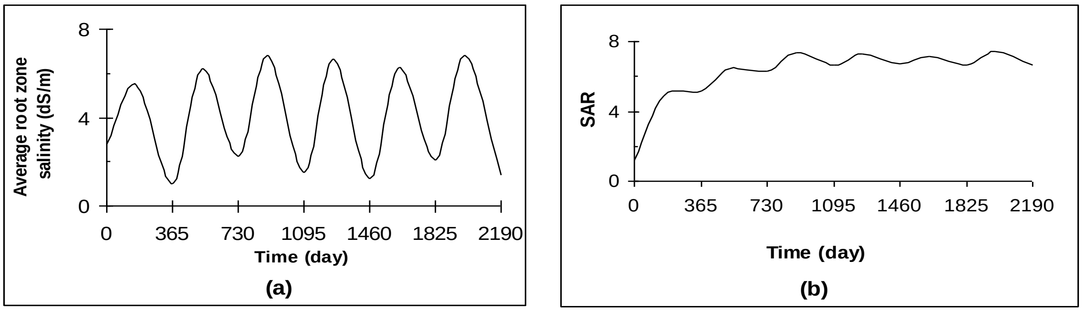

Fig. 5. Temporal changes in root zone salinity and SAR under wheat-cotton crop rotation

There is salinisation during wheat crop and desalinisation during cotton crop. Highest and lowest salinity values are observed at cotton and wheat harvest (Fig. 5a), respectively. The lowest salinity value at cotton harvest is dependent on the rainfall amount during monsoon season. The SAR has increased till the end of second year (Fig. 5b); as soil solution was reaching in equilibrium with applied saline water. Thereafter, small fluctuations in SAR values are due to seasonal variations in rainfall amounts. The Figure 5a indicates that there is no positive salinity build up at root zone in long-term. Therefore, saline water of salinity 6.6 dS/m can be used on sustainable basis on long term basis on sandy loam soil. There are different agro-climatic zones in India, where weather, groundwater quality and soil conditions vary. The long-term simulations can be effectively used to find safe salinity limits of irrigation waters for different agro-climatic zones. Such simulations can help to avoid repetitive experiments.

Conclusions

On the basis-simulated results, a linear relation is observed between the weighted average salinity of irrigation water and average root zone salinity at harvest of wheat crop. The root zone salinity values in case of higher SAR water are higher compared to low SAR water having same salinity. It may due to more precipitation of $CaCO_3$ for low SAR waters. High SAR water even with no RSC promotes sodification and gypsum application is required to reverse it. The root zone salinity decreases with decrease in Cl^-/SO_4^{--} ratio of irrigation water. This may be due to formation of complex aqueous species of SO_4^{--} with Ca^{++}, Mg^{++}, Na^+ and K^+. Similarly, root zone salinity on use of HCO_3^- rich water would be less due to precipitation of $CaCO_3$. Magnesium, carbonate and bicarbonate rich waters require application of gypsum to maintain favourable adsorbed calcium status at exchange complex. The soil texture influences the salinisation process. The results suggest that the influence of saturated water content on salinisation process is higher in comparison to saturated hydraulic conductivity of the soil. The preference order (i.e., 2CW: 2SW, CW: SW alternate, Mix (1:1), SW: CW alternate, and 2SW: 2CW), obtained on basis of simulation results considering temporal changes in root zone salinity and sensitivity of wheat crop to salinity, was validated with two sets of experimental data. Initial root zone salinity influences the wheat yields under conjunctive yields. Therefore, irrespective of conjunctive use mode, pre-sowing irrigation should preferably be given with good quality water, as it might improve germination and might ensure low salinity at root zone (at least for one month) till first post sowing irrigation at crown root initiation stage. In optimal conjunctive use planning for the wheat crop, the salinity stress should be delayed as much as possible and stress should be kept always within permissible limits. Long-term simulations based on water quality use guidelines indicate that it is possible to use the saline water in wheat - cotton crop rotation on sustainable basis. Such simulations can be used to find suitable irrigation water quality considering the sensitivity of the crop. This approach can be helpful in avoiding the repetitive experiments.

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Land Shaping Models for Waterlogged Sodic Lands in Sharda Sahayak Canal Command in UP for Enhancing Farmer's Income

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Introduction

Uttar Pradesh is blessed with good network of canals, which had certainly helped in increasing total food grain production of the state. Waterlogging is inevitable in the command of large canals. About 19 % sodic lands are under critical waterlogging and 21% area under semi-critical conditions in UP. Accumulation of salts in the root zone worsens the situation and crop growth becomes impossible. Uttar Pradesh Bhumi Sudar Nigam (UPBSN) is not selecting such areas for reclamation due to lack of matching technology for its sustainable reclamation. Long-term soil and groundwater monitoring along with project durability study and field investigations indicate that with present methodology, the sodic land reclamation is more success and sustainable in the areas of deep groundwater table. In some of the areas, soil profiles are completely improved and suitable for all types of crops. At some places in critical and semi-critical waterlogged areas, reclaimed sodic lands are reverted to B, B^+, and C types sodic lands. For this reason, for site selection, the status of groundwater level is taken into account and those areas where groundwater is within 2.0 m bgl, are not taken for reclamation. Even then in the selected sites sizable areas fall in the critical and semi-critical waterlogged belts, because most of the sodic lands are the consequent effect of waterlogging, and occur in close association. Further, due to limited ground water level data, it is not possible to delineate area at micro level. Thus, for sustainable reclamation of sodic lands in critical and semi-critical waterlogged areas, a new reclamation methodology need to be developed.

Reclaimed soils revert back to sodic conditions as the basic salts keep on accumulating in the root zone. Repeated dose of amendment is quite uneconomical. Subsurface drainage may be also quite expensive due to poor water transmission characteristics of the soil resulting in low drain spacing. Due to excessive seepage in waterlogged sodic soils in the canal command, pH reduces as one move to deeper soil profile. Land shaping and integrated farming was hypothesized as an alternative technology to traditional sodic land for successful crop production. Raised and sunken bed is one of the examples of land shaping for successful crop production in waterlogged sodic soil for small to medium land holding. Raised beds could be utilized for growing upland crops and sunken beds for water loving crops. The possible strategies ranges from alternate chemical and biological amendments to alternate land use planning such as agri-hoti- aquaculture system.

Extent of waterlogging in Uttar Pradesh

Critical and semi-critical waterlogged areas is variable in west, central and east UP plains as on post monsoon period, the highest in east UP, 31.45% and 23.07% under critical and semi-critical, respectively moderate in central UP, 25.07% and 19.65% respectively and lowest in west UP critical waterlogged 13.50%, semi-critical waterlogged 14.71%.

In UP plain as a whole, the critical waterlogged area is 21.84% and semi-critical waterlogged area is 18.94%. These data clearly indicate that intensity of soil sodicity is also related with other factors along with water logging. In the sodic dominant districts, critical and semi-critical waterlogged areas varying from 25% to 50%.

Table 1. Waterlogged areas in the Gangetic plains (post monsoon)

Zone	Geographical area (ha)	No. of hydrograph stations	Critical waterlogged area (ha)	Semi-critical waterlogged area (ha)	Total area (ha)
West UP	8.08	1074	0.87 (13.5%)	1.19 (14.7%)	2.06 (28.2%)
Central UP	4.53	738	1.13 (25.1%)	0.89 (19.7%)	2.02 (44.7%)
East UP	7.5	1361	2.36 (31.5%)	1.73 (23.1%)	4.09 (54.5%)
Total	20.1	3173	4.36 (21.9%)	3.8 (18.9%)	8.2 (40.8%)

Impact of Waterlogging

Impact of water logging is wide spread on agriculture, land use, environment and health hazards. Following major impacts are recorded in the waterlogged areas:

- Poor agriculture production, productivity and cropping intensity.
- High intensity of waste, sodic lands, fallow lands and other degraded lands.
- Dying out mango, neem, mahuwa orchards.
- Increase of ground water pollution, along with ground water alkalinity. Fluoride pollution causes fluorosis in many districts.
- More prone to growth of disease virus due to tropical humid climate, such as encephalitis, dengue, kalajar, malaria etc.

Sharda Sahayak Canal Command

Canal irrigation without proper provision of drainage has resulted in waterlogging and salinity/sodicity in canal commands. Sharda Sahayak Canal (SSC) is one of the major canal commands, which provides irrigation to 1.78 m ha in 16 districts of UP, is also encountering the similar problems. About 0.12 m ha sodic lands suffered from shallow water table conditions in Sharda Sahayak Canal Command and are not suitable for cultivation even after conventional methods of gypsum based reclamation. This has led to the diminishing water productivity; nutrients use efficiency and loss of livelihood for the farm families in this command.

To address these problems, a farming system model based on the concept of land shaping (physical land reclamation) and pond based multi-enterprise agriculture with major emphasis on aqua-culture was conceived and is being evaluated in a farmer's field near Sharda Sahayak Canal at Kashrawan village in Raibareli district of UP. The model is being standardized by considering the fact that lower layers of soil profile contain less salt compared to surface soil. While digging the pond, the good soil will come on the pond dyke surface and will be suitable for growing several crops, fruit and forest trees. Eucalyptus planted across the slope of pond and the raised beds will serve as bio-shield and bio-drainage for regulating the ground water.

Integrated Farming System Model I

Site Characteristics and Methodology: The area represents a semi-arid, sub-tropical climate characterized by hot summers and cool winter. The average annual rainfall was 880 mm; of which about 80% is received during monsoon season (July to September). The site is 110 m above the mean sea level and is situated between $26^{o}23^{'}$ N latitude to $81^{o}14^{'}$ E longitude. The soil was highly sodic with a pH_2 range of 9.84 at the 0-15 cm depth and declining to 8.50 at a depth of 120-150 cm. The sodium adsorption ratio ranged between 98.6 at surface and 17.8 at about 1.5 meter depth. The experimental site is situated about 200 m away from the north side of Sharda Sahayak canal.

Table 2. Initial soil properties of the experimental site

Depth (cm)	pH (1:2)	EC (1:2) (dS m^{-1})	SAR	Na/CO_3 ($meqL^{-1}$)
0-15	9.84	1.98	98.6	60/40
15-30	9.45	1.22	76.5	35/24
30-45	9.20	0.98	45.7	29/16
45-60	8.97	0.97	38.6	28/14
60-90	8.73	0.79	32.8	22/10
90-120	8.57	0.68	25.6	18/8
120-150	8.50	0.55	17.8	14/6

A barren one ha area where nothing was grown and lying abandoned by the farmer for many years was taken for this study. The one ha area was divided into five categories viz. 0.40 ha fish pond, 0.25 ha crops, 0.15 ha fruit crops, 0.10 ha forage crops and 0.10 ha for vegetable cultivation. The fish pond dimensions were 80 m x 50 m with inward slope of 1 m and depth of 1.75 m. The concept was that the pond could harvest maximum seepage from the canal and sustains fish production without additional water input. The excavated soil was spread over remaining 0.60 ha area thus providing the opportunity of less sodic soil at the surface. Four species of fish (Rohu 30%, Catla 25%, Mirigal 25% and Silver carp 20%) were grown in the pond with standard fish raising practices. Different field, fruit and vegetable crops were grown on 0.60 ha area.

Water table depth: The water table depth from the surface varies from 10 cm above the surface during monsoon to about 1.7 m below the surface during the summer. The groundwater fluctuation varied according to the duration of running of the canal and height of water above the soil surface in the canal.

Crop yield: Rice-wheat cultivated in 0.25 ha area yielded 4.0 and 2.7 t ha^{-1} of rice and wheat, respectively during the first year. Similarly, 15.0 and 15.4 t ha^{-1} green fodder from sorghum and berseem, respectively was obtained where nothing was produced earlier. Garlic and spinach yielded 4.5 and 25.5 t ha^{-1}, respectively. Fruit crops of banana, aonla and guava were planted on the dykes of the fish pond. Nearly 2.5 t ha^{-1} fish was harvested during first year. The B:C ratio of the system was 2.21 (Sharma *et al.*, 2008). Cultivation of crops, vegetables and fruits on the raised dykes of the pond and aqua-culture in the pond in a unified farming system will increase water productivity, nutrient use efficiency and farmer's income under waterlogged sodic soil conditions.

Raised and sunken bed

Design criteria: Raised and sunken bed is one of the examples of land shaping for successful crop production in waterlogged sodic soil for small to medium land holding. Raised beds could be utilized for growing upland crops and sunken beds for water loving crops. An experiment on 2 m wide raised beds and 7 m wide sunken beds with 0.50 m soil digging for raised and sunken beds system in waterlogged sodic soils in Sharda Sahayak Canal Command, Raebareli showed an encouraging result. Design criteria for deciding depth of sunken bed, width of raised bed and height of raised bed need to be worked out for field workers for keeping the efficacy of the system intact and cost at low level. Steady state and transient drain spacing formulas were developed for raised bed width calculation (Verma *et al*., 2016).

Raised and sunken bed system for small and marginal farmers, with limited economic resources, was planned in Sharda Sahayak Canal Command in village Kashrawan, district Raebareli with the objective to bring waterlogged sodic soils under cultivation. Most suitable crops and crop combinations were studied. Initial soil pH_2 of 0-15 cm soil depth ranged from 9.31 to 10.47 and EC_2 from 0.43 to 1.78. Two raised beds of 60 m lengths and 7 m width were constructed during the month of June 2009. Top width of raised beds was kept as 2.0 m and bottom width as 4 m. Boundary embankment width was also kept 2.0 m wide except for the boundary bunds towards south which was only 1 m wide on the top. Side slopes of raised beds and boundary bunds were kept as 1:1. Total area under raised beds, sunken beds and boundary beds was 0.36 ha (3560 m^2). Out of this area, raised beds were over an area of 1266 m^2, sunken beds of 2293 m^2. Area under boundary beds is 786 m^2. After construction of raised and sunken beds, the average pH_2 of first raised bed was observed to be 9.4 and EC_2 0.4, and second raised bed average pH_2 was 8.7 and EC_2 0.14.

Crop yield: Crop performance of vegetables crops such as bottle gourd, bitter gourd, sponge gourd, pumpkin, brinjal, tomato, coriander, spinach, okra, cabbage, garlic, onion, chilly, cowpea, colocasia, radish, mustard, dill and soya etc. were grown throughout the year. Water chestnut was grown in sunken beds. Banana ratoon was taken on boundary bunds giving satisfactory yields under partial shade conditions up to third year.

Colocasia as vegetable and turmeric as spice crop gave good yields under complete shade conditions. Sponge gourd supported on vertical bamboo frame gave the highest yield of 623.5 kg followed by bottle gourd (228.1 kg). The colocasia tuber yield was 78.4 kg along the surface drain under the shade of eucalyptus, banana, mango, and guava. Green leaves of colocasia are also favoured by the local mass and fetches good market price, it was harvested to the tune of 35.55 kg. Water chestnut yield was 64.5 kg only during *kharif*. Highest yield of papaya was recorded as 351.45 kg followed by banana (111.0 kg). Guava gave an average yield of 78.20 kg. About 2460 kg of green grass was harvested from the boundary bunds and raised beds as fodder

Farmers preferred banana ratoon under partial shade on one side of bed. The radish recorded the highest yield of 593.4 kg followed by cabbage (241.5 kg). The yields of tomato and spinach were 178.6 and 72.0 kg, respectively. Garlic and onion also gave good yields of 111.0 and 108.0 kg, respectively. The yield of banana (276.0 kg) and papaya (147.1 kg), 8.4 kg marigold and 135 gladiolas were also obtained during *rabi* 2013.

Economics: The results indicated that gross return from raised and sunken bed system during *rabi* 2012-13 and extended summer was Rs. 25,973 and during kharif 2013-14 was Rs. 36,909. Cost of inputs for rabi 2012-13 was Rs. 3281 and for kharif 2013-14 was Rs. 2,861 Similarly cost of labour was Rs. 3,210 and Rs. 3,838 during rabi 2012-13 and kharif 2013-14. Net annual gross return from the system was Rs. 62,882. Annual expenditure on account of labour charges was Rs. 7,048 and inputs were Rs. 6,142. Thus, total annual expenditure on crop production was worked out to be Rs. 13,190. The net return of the raised and sunken bed system during 2012-13 was calculated as Rs. 49,693. The benefit cost ratio (B:C) was worked out to be 3.63.

Water balance: The average water depths in canal declines continuously after rainy season due to increasing demand of water for irrigation water. The average water depths in canal were observed to be 1.10, 1.42, 0.92, 1.11, 0.73, 0.00, 0.64, 1.25, 1.71, 1.80, 1.35, 0.00 and 1.12 m during December 2012 to December 2013. Similarly, the average depth of water in surface drain were observed to be 0.49, 0.58, 0.38, 0.22, 0.27, 0.00, 0.33, 0.67, 0.56, 0.58, 0.57, 0.28 and 0.20 m for 12 months from December 2012 to December 2013. Volume of water stored in sunken bed was 87.18, 309.49, 260.09, 53.76, 0.000, 0.00, 235.39, 687.27, 569.58, 707.61, 611.71, 113.33 and 26.41 m^3 during 12 months from December 2012 to December 2013, respectively. Volumes of water stored in sunken bed were 0.42, 14.28, 51.24, 13.02, 0.00, 43.26, 55.44, 187.74, 181.02, 221.34, 167.16, 13.02 and 0.00 m3 and in sunken bed-3 64.68, 18.06, 50.40, 0.42, 0.00, 0.00, 39.90, 178.50, 185.22, 213.36, 169.68, 17.64 and 0.00 m^3 during the respective months from December 2012 to December 2013.

Salt dynamics: Total salt load in raised beds during October 2012 was 856.25 kg and May 2013 was 433.22 kg. Similarly, total salt load in sunken beds during October 2012 was 664.52 kg and during May 2013 was 1708.53 kg. Thus, there was substantial reduction in salt loads of raised bed soil profiles with the passage of time due to continuous taken crops. There was increase in salt content of sunken bed profiles indicating insufficient leaching due to shallow water table conditions and accumulation of salts drained out of the raised beds. The increase in EC_2 was always much below the threshold limit of 4 dS m^{-1}.

Integrated Farming System Model II

Study site: Study Sites and Distance from the Canal Three study sites were selected in three villages namely Lalaikheda (Jitendra Singh), Patwakheda (Kalwati Devi) and Salempur Achaka (Sher Bahadur) of Lucknow district located at 80 m, 100 m and 90 m away from the canal, respectively. The experimental sites are about 50 km away from Lucknow towards Raebarely. Water table of the area fluctuated within a range of 0.00 to 1.50 m during rainy to extreme summer. Initial soil pH of the of Jitendra Singh, Kalawati and Sher Singh's fields ranged 8.96 to 9.69, 9.47 to 9.93 and 7.49 to 7.98 and corresponding EC ranged 0.203 to 0.569, 0.368 to 1.1474 and 0.065 to 0.189 dS m^{-1}, respectively in a depth of 0 to 120 cm. The field of Sher Bahadur located at Salempur Achaka village is waterlogged only.

Two Integrated Farming System (IFS) Models were constructed under waterlogged sodic conditions and one under waterlogged conditions by hiring JCB and hydraulic tractor trolley during the month of June 2015. The width of elevated/raised beds were kept minimum fitting with field shape and boundaries to keep salt movement minimum. Levelling of elevated beds, raised beds and embankment were done using a tractor mounted levelling blade. The respective ponds area in the field of Jitendra Singh, Kalawati and Sher Bahadur were 2356, 817 and 1225 m^2 and elevated/raised field beds were 2336, 1307 and 2041 m^2, respectively. Corresponding total area of IFS models were 4692, 2114 and 3266 m^2. Average soil pH of elevated beds immediately after construction up to 1.20 soil depths ranged 9.01 to 9.30, 9.20 to 9.85 and 8.00 to 8.27 with corresponding EC range 0.188 to 0.562, 0.326 to 0.737 and 0.194 to 0.485 dSm^2, at Jitendra Singh, Kalawati and Sher Singh's field, respectively.

Soil Characteristics: Initial soil pH_2 at Lalaikheda was 9.54, 9.16, 8.91, 8.70, 8.64 and 8.64 and that of newly constructed elevated field bed 8.64, 9.22, 9.10, 9.15, 9.01 and 9.06 at soil depths of 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm, respectively. The values of soil pH_2 kept on reducing with time at respective soil depths and were observed to be only 8.50, 8.57, 8.68, 8.84, 8.96 and 9.08, respectively after the Rabi 2017. Initial soil pH at Patwakheda were 10.23, 10.47, 10.51, 10.05, 9.74 and 9.54 and that of newly constructed elevated field bed were 9.42, 9.38, 9.20, 9.50, 9.60 and 9.39 at soil depths of 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm, respectively. The values of soil pH at Patwakheda also followed the same trends and kept on reducing with time for respective soil depths and were observed to be only 8.81, 9.06, 9.16, 9.10, 9.18 and 9.20, respectively after Rabi 2017. Sub-soil sodicity is still higher at deeper depths at Patwakheda. Soil at Salempur Achaka site was not sodic and ranged 7.64 to 8.40, 8.18 to 8.27 and 7.80 to 7.89 in a soil profile of 0-120 cm initially, after construction of elevated field bed and after Rabi 2016. EC never crossed the value of 2.0 dSm^{-1}. Total salt load in newly constructed raised bed were 4000, 6960 and 4093 kg and 5232, 6356 and 2547 kg after Rabi 2017 at Lalaikheda, Patwakheda and Salempur Achaka, respectively.

Water Depth Fluctuations in Pond: Water depths in all pond remained above one meter depths only for four months (August to November). Water depths ranged 0.20 to 2.07 m, 0.10 to 2.20 m and 0.00 to 2.10 m at Lalaikheda, Patwakheda and Salempur Achaka sites, respectively. Corresponding water volumes in pond ranged 471.20 to 4876.92 m^3, 81.70 to 2042.50 m^3 and 0.00 to 2572.50 m^3. Rate of loss of water from Sher Bahadur pond has been observed to be the highest due to light texture of soil. Except for Kalawati pond, other two ponds need to be levelled in case of canal closures for a period of two months during summer season. Canal roaster may be very useful for preparing water filling plan in pond. EC of all three ponds never exceeded 0.9 -1 dSm^{-1} and pH never exceeded 8.2. Thus water EC and pH have been always favourable for fish production in ponds.

Yield of crops and economics: Maximum expenditure of Rs. 386410 occurred at the field of Jitendra Singh and he got the gross return of Rs. 610373 from 4692 m^2 area. Similarly, Kalawati spent Rs. 2835 and gross income was Rs. 9465 from 2114 m^2 area. Ser bahadur spent Rs. 11976 and gross return was Rs. 53200 from 3266 m^2 area. The B:C ratio was higher from the cultivation of fish (Verma *et al.*, 2017).

Table 3. Yield and economics of different crops

Name of farmer	Crops	Area (m)	Yield (kg)	Input cost (Rs)	Gross return (Rs)	B:C ratio
Jitender Singh	Pea	1122	230	1690	5750	3.40
	Moong	1122	80	1100	2995	2.72
	Okra	1122	600	4620	9000	1.95
	Sponge gourd	50	300	220	3000	13.64
	Pigeo pea	100	35	760	1908	2.51
	Fish	2353	6530	378020	587700	1.55
Kalawati	Wheat	818	350	3666	8300	2.26
	Rice	1200	320	3122	4960	1.59
	Fish	817	80	2677	7200	2.69
Sher Bahadur	Mentha	900	7.0	3456	11200	3.24
	Fish	1225	400	8520	42000	4.92

Conclusions

- The waterlogged sodic soil adjacent to the Sharda Sahayak canal command can be reclaimed and put to economic use by pond based farming system without application of gypsum.
- Average one-meter seepage water level in the pond could be maintained for fish production without addition of water from external source. Saline aquaculture can be promoted in a profitable way along the canal to intercept seepage which otherwise results in rise in ground-water.
- The quality of the seepage water harvested in the pond was suitable for fish production. Whatever rise in pH and EC may occur during a particular year can be taken care of by dewatering the pond once a year. The fish pond water generally contains more nutrients than canal/tubewell water. Such water when applied to crops improves productivity and economizes on the fertilizer use.
- Besides rice- wheat cropping system, vegetables and fruits can be raised in the very first year under this system, which otherwise is not possible under conventional method of land reclamation. The bi-products of banana, fish and other components can be recycled at site for generation of compost.
- The productivity of the waste land and the productive use of canal seepage water are likely to increase over the years. The benefits of this system in terms of lowering the water table may also visible in other area during the subsequent years.
- As this model involves higher initial investment in terms of digging a pond, a subsidy component would be of catalyst for large scale adoption

- The model developed suits the land holding pattern of the small and marginal farmers and has the potential to increase water, nutrient and energy use efficiency, restore and support the livelihood through the enhanced regular income and year round employment.
- However, it is not always necessary to have all the components as tried in this model. Location specific adjustment may be made to choose the components depending upon processing, value addition and market availability. Large scale adoption of this multi-enterprise agriculture model on small farm holdings will require government support during establishment phase. However, once established these practices will provide much needed livelihood security to small and marginal farmers through the enhanced input use efficiency.

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Role of Amendments and Fertilizers in Sustaining Productivity in Sodic Environment

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Introduction

Soil degradation resulting from salinity and/or sodicity is a major environmental constraint with severe impacts on agricultural productivity and sustainability, particularly in arid and semi-arid regions of the world. Salt-affected soils are characterized by excess levels of soluble salts (salinity) and/or Na^+ in the solution phase as well as on cation exchange complex (sodicity). These salts and Na^+ originate either by weathering of primary minerals (Causing primary salinity/sodicity) or from anthropogenic activities, involving inappropriate management of land and water resources (contributing to secondary salinization/sodification).

Salt-affected soils occur within the boundaries of at least 75 countries (Szabolcs, 1994). These soils also occupy more than 20% of the global irrigated area. Out of 950 m ha salt-affected soils worldwide, more than 60% are sodic soils. In India also, sodic soils constitute about 70% of 7.4 m ha of salt-affected soils (Mandal et al., 2010). In Punjab, in 1970s, there were about 7 lakh ha sodic soils but due to massive reclamation programme implemented in the state in early 80s, a large chunk of these lands have been reclaimed and brought under commercial cultivation but still 1.5 lakh ha of sodic lands remain un-reclaimed (Mandal et al. 2010), most of which are common or panchayat lands.

Soils with high levels of exchangeable sodium (Na) and low levels of total salts are called sodic soils. Sodic soils may impact plant growth by: 1) Specific toxicity to sodium sensitive plants; 2) Nutrient deficiencies or imbalances; 3) High pH; and 4) Spread of soil particles that causes poor physical condition of the soil.

Sodium Hazard

Sodium levels in soil are often reported as the sodium adsorption ratio (SAR). The SAR is determined from a water extract of a saturated soil paste. A SAR value below 13 is desirable. If the SAR is above 13, sodium can cause soil structure deterioration and water infiltration problems. In Indian subcontinent, high sodium levels in soil are expressed as ESP (exchangeable sodium percentage). An ESP of more than 15 percent is considered the threshold value for a soil classified as sodic (Table 1). This means that sodium occupies more than 15 percent of the soil's cation exchange capacity (CEC). The sensitive plants may show injury or poor growth at even lower levels of sodium.

In India, Gupta and Abrol, 1990 suggested that distinguishable pH for alkali/sodic soils should be 8.2 rather than 8.5. They also pointed out that these soils contain soluble carbonates and bicarbonates such that $Na/[Cl+SO_4] > 1$. Moreover, the value of 15 ESP to distinguish alkali soil from non-alkali soil has been considered too high in alkali smectite soil. Moreover, the threshold value for these swell-shrink clay soils (Vertisols) lies between 6-10 and thus ESP value of 8 has been observed to be more appropriate for categorizing alkali soils.

Table 1. Sodium hazard of soil based on SAR and ESP values

Classification	Sodium adsorption ratio (SAR)/ESP	Electrical conductivity (dS/m)	Soil pH	Soil physical condition
Sodic	>13/15	<4.0	>8.5	Poor
Saline-sodic	>13/15	>4.0	<8.5	Normal
Saline	<13/15	>4.0	<8.5	Normal
(dS/m = mmho/cm)				

Managing sodic and sodic-water irrigated Soils
There are usually two options for correcting sodic environment:

- Change the plant (tolerant species/variety) to suit the sodic soil environment.
- Change the soil sodic environment to suit the plant.

Often, changing the soil is the most difficult of these options.
When soils are high in sodium, the goal is to replace the sodium with calcium and then leach the sodium out of the soil profile. There are three possible approaches for doing this:

- Dissolve the limestone (calcium carbonate) or gypsum (calcium sulfate) already present in the soil.
- Add calcium to the soil.
- Add organic amendments

If free lime is present in the soil, it can be dissolved by applying sulfur or sulfuric acid. Sulfur products reduce the pH which dissolves the lime, thus freeing up the calcium. If free lime or gypsum is not present in adequate amounts then an external calcium source has to be added. The most common form of calcium used for this purpose is gypsum. After broadcasting the calcium source on the soil surface, mix it, and make sure adequate moisture is present to dissolve it. Reclaiming one acre of sodic soil to one foot requires approximately 1.7 tons of pure gypsum ($CaSO_4$-$2H_2O$) for each milli-equivalent of exchangeable sodium present per 100 grams of soil.

Once the gypsum is applied and mixed, sufficient quality water must be added to leach the displaced sodium beyond the root zone. Restoration of sodic soils is slow because soil structure, once destroyed, is slow to improve. Growing a salt-tolerant crop in the early stages of reclamation and cultivating in crop residues or manure adds organic matter which will increase water infiltration and permeability to speed up the reclamation process.

Adequate drainage is a pre-requisite for reclamation of a sodic soil and after application of gypsum, to facilitate leaching the sodium out with good quality water. Success in reclaiming non-irrigated sodic or saline-sodic soils with gypsum application may be possible on coarse textured soils that receive precipitation in excess of soil water holding capacity.

Example gypsum requirement calculation:

Your soil has a CEC of 18 milli-equivalents per 100 grams and ESP of 26, and you desire an ESP of approximately 10 following treatment.
ESP of 26% – desired ESP of 10% = ESP of 16, or 16% exchangeable Na must be replaced with calcium (Ca) to achieve the desirable ESP.
0.16 (16%) x 18 meq CEC/100g = 2.88 meq Na/100 g soil that must be replaced.
*1.7 tons $CaSO_4$ x 2.88 meq Na = 4.9 tons of gypsum.
Thus, about 5 tons of pure gypsum per acre would be required to reclaim the top 12 inches of this soil. Be sure to adjust this calculation for lower grades of gypsum and different soil depths.

**As a general rule of thumb, 1.7 tons of gypsum is required per meq of sodium.*

Reclamation of sodic soil requires removal of part or most of the exchangeable sodium, improvement of the soil physical structure and lowering of pH value. The exchangeable sodium is replaced by the more favorable calcium ions according to the exchange reactions as given below and the sodium thus exchanged is leached out of the root zone.

2 Na- X + Ca^{2+} (solution) = Ca-X + 2Na^{+} (solution) ↓
Where, 'X' is the exchange complex of the soil.

Calcium needed for this reaction can be furnished by either calcium-based amendment or calcium carbonate present in the soil whose solubility may be enhanced by application of organic amendments or acid formers. Amendments are the materials which provide Ca^{2+}or mobilize Ca^{2+} in the soil for replacing exchangeable sodium to reduce alkalinity (pH) and sodicity (ESP) of the soil. For reasonably quick results cropping must precede the application of soil amendments followed by leaching for removal of soluble salts from the soil profile.

Types of amendments
The amount and type of chemical amendments required to reclaim a sodic soil will depend upon physic-chemical properties of soil mainly pH, EC and ESP, crop tolerance to sodicity and economic condition of the farmers which will dictate desired level of replacement of exchangeable sodium. Generally, there are two types of chemical amendments:

- Soluble sources of calcium: Gypsum ($CaSO_4 . 2H_2O$), Calcium chloride ($CaCl_2$) and phospho-gypsum (an industrial bye product) and,
- Acids or acid-formers: Elemental sulphur, sulphuric acid, sulphates of iron and aluminum, pyrites and lime sulphur

The choice and effectiveness of these two types of amendments will mainly depend upon presence or absence of $CaCO_3$ in the soil. In absence of $CaCO_3$ as is the case in non-calcareous soils, only soluble sources of calcium should be used and application of acids or acid-formers is not recommended. But when soil contains calcium, both the sources may be used. Although sparingly soluble $CaCO_3$ is a potential source of calcium and is recommended for acid soil reclamation, it is not recommended for the reclamation of sodic soils because its already low solubility decreases further with increase in pH of the soil.

Calcium amendments include gypsum (hydrated calcium sulfate) and calcium chloride. Gypsum is moderately soluble in water. Calcium chloride is highly water soluble and fast acting, but it generally is too expensive for most field situations.

Acid-forming, or acidic amendments, include sulfuric acid and elemental sulfur. Sulfuric acid reacts immediately with the soil calcium carbonate to release soluble calcium for exchange with sodium. Elemental sulfur must be oxidized by soil bacteria and react with water to form sulfuric acid. The formation of sizeable amounts of sulfuric acid from elemental sulfur may take several months to several years. Calcium carbonate must be present in the soil when acid or acid-forming amendments are added.

Chemical reactions of the commonly used amendments:

a) Gypsum:

$CaSO_4 + 2NaX = CaX + Na_2SO_4$ (Leachable) ↓

Sodic soil

b) Calcium chloride:

$CaCl_2 + 2NaX = CaX + 2\ NaCl$ (Leachable) ↓

Sodic soil

c) Sulphur: The first step is a biological oxidation of elemental sulphur that is facilitated by aerobic Thiobacilli group of chemoautotrophs. In some areas with cold winters, sulphur oxidation is too slow to give satisfactory results.

$$2S + 2H_2O + 3O_2 = 2H_2SO_4$$

d) Sulphuric acid in a calcareous sodic soil:

$$H_2SO_4 + CaCO_3 = CaSO_4 + H_2O + CO_2$$

Or sulphuric acid can react with two molecules of $CaCO_3$ yielding equivalent of two soluble calcium for each equivalent of acid such as:

$$H_2SO_4 + 2CaCO_3 = CaSO_4 + Ca(HCO_3)_2$$

In practice, therefore, only 1.5 equivalents of calcium can be expected from one equivalent of acid.

e) Pyrites: Pyrites (FeS_2), like elemental sulphur first oxidizes into an acid, which in turn reacts with soil lime to yield soluble calcium:

$$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + H_2SO_4$$

$$CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2$$

$$2Na\text{-}X + CaSO_4 = Ca\text{-}X + Na_2SO_4 \downarrow$$

(Leachable)

The rate of oxidation of pyrites is slow, however, its maximum oxidation can be ensured by storing the freshly mined pyrites for a period of 15-20 days in a well aerated but covered place under moist conditions (preferably 10 % moisture). The efficiency of pyrites enhances when it is applied on the basis of its water soluble sulphur content. Best results are obtained when pyrites contain 4-6% water soluble sulphur and its pH is <3.

In some areas, cheap acidic industrial wastes may be available which can be profitably used for sodic soil improvement. Pressmud, a waste product from sugar factories, is one such material commonly used for soil improvement. It contains either lime or some gypsum depending on whether the sugar factory is adopting carbonation or a sulphitation process for the clarification of juice. It also contains variable quantities of organic matter.

Because of its high solubility in water, calcium chloride is the most readily available source of soluble calcium but it has rarely been used for reclamation because of its high cost. Similarly iron and aluminum sulphates are usually too costly and are used for any large-scale improvement of sodic soils. Large-scale use of sulphuric acid for improving sodic soils is generally not recommended because of handling and application difficulties associated with the large volumes of these acids at the field level.

Application Method

Amendments like gypsum are normally applied broadcast and then incorporated with the soil by disking or ploughing as it is more effective in the removal of exchangeable sodium than gypsum applied on the soil surface. Also mixing limited quantities of gypsum in shallower depths is more beneficial than mixing it with deeper depths. Deeper mixing exposes gypsum to react with Na_2CO_3 of the soil resulting in lesser reduction in ESP throughout the depth. This can decrease the seed germination rate and consequently the crop yield. In shallow mixing, soluble carbonates move down with the wetting front without reacting with applied gypsum.
For improving sodic soils with hardpans or dense clay subsoil layers, deep ploughing (up to 100 cm) has been found to be a useful practice. Improvements in crop yields as a result of deep ploughing occurred because of enhanced water intake rates and depth of penetration and nearly doubled the effective available water holding capacity of the sub soil layers.

Gypsum Fineness and Solubility

Since gypsum is excavated as lumps from deposit sites, it requires grinding before it can be used for sodic soil reclamation. The fineness to which gypsum must be ground is a matter of economic consideration (Choudhary and Kharche, 2015). It is often said that the finer the gypsum particles, the more effective it would be for the reclamation of sodic soils. But very fine grinding involves higher cost. Application of very finely ground gypsum resulted in high initial hydraulic conductivity of a sodic soil with free soluble carbonates but it decreased sharply with time. On the other hand, treatment with gypsum passed through 2 mm mesh and having a range of particle size distribution helped in maintaining soil permeability at higher level and for a longer period. Therefore, gypsum passed through 2 mm sieve and with a wide particle size distribution is likely to be more efficient.

In many cases, the common practice is to apply sufficient amendment to remove most of the adsorbed sodium from the top 6 to 12 inches of soil. This improves the physical condition of the surface soil in a short period of time and permits the growing of crops. Continued use of good quality irrigation water, proper irrigation methods, and cropping practices further displaces adsorbed sodium. In some cases, it may be necessary to restore the soil to greater depths to obtain adequate drainage and root penetration.

Reclaiming Sodic Dense Subsoil with Organic Amendments

Sub soil constraints due to sodicity are major limiting factors in crop production in many soils of the world particularly in Australia. In the high rainfall zone of south-west of Victoria in Australia, a survey of subsoil properties in duplex soils found that the clay subsoils were very sodic with exchangeable sodium percentages ranging from 14% to 22%. Root growth in soil layers is severely restricted and so the clay subsoil below 50–60 cm tend to remain continuously moist, as crops are unable to extract the deep subsoil water. Numerous attempts have been made to ameliorate these subsoil constraints in duplex soils. These have invariably involved deep ripping and the incorporation of high rates of gypsum in the subsoil but with little success (Clark *et al*., 2007).

A further management option for ameliorating dense clay subsoil is the deep incorporation of organic material into the subsoil layers. Gill *et al*. (2008), in a field study examined the effects of deep incorporation of organic and inorganic amendments in 30–40 cm on soil properties, plant growth and grain yield of wheat (*Triticum* *aestivum* var. Ambrook) on a Sodosol with dense sodic subsoil in Victoria, Australia. Amendments were applied at a rate of 10–20 t ha^{-1}. Deep ripping alone and deep ripping with gypsum did not significantly affect grain yields. In comparison, application of organic materials doubled biomass production and increased grain yield by 1.7 times. Organic amendment treated plots produced 60% more grains per area than the untreated control. The crop extracted over 50 mm extra water from below 40 cm soil in organic amendment-treated plots than the untreated control. Nitrogen uptake was almost doubled (403 kg ha^{-1}) in the organic amendment-treated plots than the untreated control (165 kg ha^{-1}). The improved yield with amendments was related to an increase in plant available water in the hostile subsoil, and prolonged greenness of leaves and supply of nitrogen and other nutrients. This is perhaps the key to the high grain yields from these treatments.

They proposed that a series of processes contributed to this outcome and these are outlined in Fig. 1. They all revolve around the provision of:

- a large and continuing N supply from the organic amendment that led to delayed senescence in the flag leaves involved constructing a large post-anthesis sink strength.
- access to deep subsoil water that becomes increasingly available to the wheat plants after anthesis;
- a wheat cultivar that was able to respond to the supply of these resources by producing many large ears, with many spikelets, containing competent florets that developed into kernels.

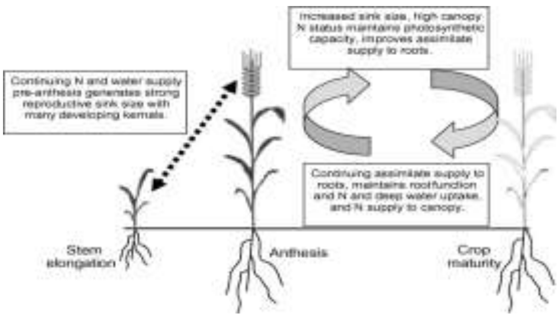

Fig. 1. Proposed scheme of the processes that resulted in delayed senescence where organic amendments were incorporated into the subsoil

Use of Amendments in Ameliorating Sodic and Saline-Sodic Irrigation Effects

Chemical Amendments

The adverse effects of irrigation with sodic/alkali waters on physico-chemical properties of soils can be mitigated by the application of Ca containing amendments such as gypsum. Unlike native sodic soils, the need for gypsum application for ameliorating the sodic irrigation effects is of the recurring nature. Application of gypsum has earlier been recommended when RSC of irrigation water exceeded 2.5 me L^{-1}. However, later researches have shown that factors such as the level of the deterioration of the soil, cropping intensity and the water requirements of the crops will ultimately decide the amount of gypsum required. Sustainable yields of crops in rice-wheat system, irrigated with alkali water (RSC > 4) are possible with occasional application of gypsum and FYM. Gypsum to supply 2.5 and 5.0 me L^{-1} to alkali irrigation water for wheat and rice, respectively, was sufficient for maintenance of higher yields. Sodic soils or soils those are previously deteriorated either due to irrigation with alkali water would require gypsum application for neutralizing both soil and irrigation water sodicity. Subsequent application of gypsum is needed on the basis of irrigation water only.

In a long-term experiment (10 years) on sugarcane, Choudhary *et al*. (2004) observed that the beneficial effect of gypsum was pronounced in increasing cane and sugar yield under sodic (30%) than under saline-sodic water irrigation (13%).

Application of gypsum with each irrigation proves better or at least equal in alleviating deleterious effects of RSC waters in rice-wheat system (Bajwa and Josan, 1989). The dissolution of gypsum directly in water through the use of gypsum beds or its application to the irrigation channels, appears economically attractive, as costs involved in powdering, bagging and proper storage before its actual use are eliminated. Dissolution of gypsum with water passing through these beds is affected by factors such as size distribution of gypsum fragments, flow velocity, salt content and chemical composition of water. It should, however, be realised that gypsum bed water quality improvement technique may not dissolve more than 8 meqL^{-1} of Ca^{2+} otherwise such an application of gypsum has better potential to improve soil's infiltration rate.

Gypsum Bed Technique

Sodic waters can alternatively be ameliorated by passing through gypsum beds in channels before they enter the field. The dissolution of gypsum in these beds mainly depends upon their dimensions, which are determined by RSC of irrigation, tube-well discharge and size distribution of gypsum fragments. Application of gypsum becomes difficult in standing crop, particularly when applied with each irrigation. Kemper *et al*. (1975) described the dissolution process by the following relationship:

$$K= (1/t_o) \ln (C_s-C_b)/C_s-C_o),$$

where K is dissolution coefficient (sec^{-1}), C_s is the calcium concentration in saturated gypsum solution (30 meq l^{-1}), C_o and C_b are the concentrations in irrigating water (at t=0) and water leaving the gypsum bed after time t_b the contact between the flowing water and the gypsum particles. The contact time (t_b) can be calculated as t_b= (h x θ)/v. Here, h is the height of gypsum bed with its porosity (θ) and v is the flow velocity of water passing through the bed.

For flowing water to pick up calcium through dissolution of gypsum, special gypsum bed has been designed (Singh et al., 1986). Calcium picked up by sodic water flowing through gypsum beds varies 3 to 5 meq l^{-1} but it seldom exceeds 8 meqL^{-1}. In a long-term experiment, Minhas *et al*. (2004) observed that while the decline in ESP was almost similar under bed and soil application of gypsum, rice responded better to the bed application treatment. Besides, this practice can help in reducing the costs in terms of grinding, bagging and storage.

Organic Amendments

It is generally accepted that additions of organic materials improve sodic soil conditions through mobilization of Ca^{2+} from $CaCO_3$ and hasten the reclamation process. Choudhary *et al*. (2011) observed that continual irrigation with sodic water resulted in the gradual increase in soil pH and exchangeable sodium percentage (ESP) in a calcareous soil. The cumulative yield loss in SW plots remained <1.5 Mg ha^{-1} for up to seven years in the case of wheat and up to nine years in the case of rice. Thereafter, SW resulted in a marked increase in pH and soil sodium saturation and an increased depression in rice and wheat grain yield (Fig. 2).

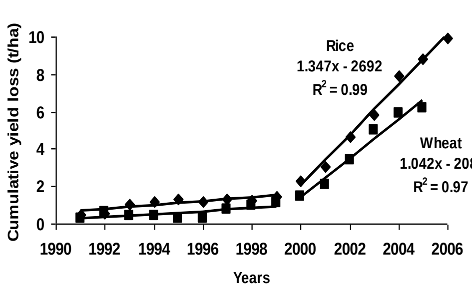

Fig. 2. Cumulative yield loss in response to sodic water irrigation compared to good quality canal water in a calcareous soil over the years (Source: Choudhary *et al*., 2011)

They conclusively found that with mobilization of Ca^{2+} from $CaCO_3$ during decomposition of organic materials such as FYM, green manuring (Sesbania aculeata), the need of gypsum required for controlling the harmful effects of sodic water irrigation can be eliminated in rice-wheat grown in calcareous soils. The application of wheat straw before rice transplanting, although was less effective than FYM and GM in increasing rice yield over SW alone treatment but was at par with GM in it residual effect on following wheat yield.

In sugarcane crop, FYM was found to be more effective under saline-sodic (38%) than under SW irrigation (23%) (Choudhary *et al*., 2004). Relative to CW treatment, there was no decline in yield up to an ESP of 12. An

ESP of 10-12 can be maintained under long-term SW irrigation through application of gypsum and FYM. Complimentary effects of these amendments in improving sugar yield were observed under sodic irrigation (12.3 t ha^{-1}). In case of saline-sodic irrigation, sugar yield under FYM treatment (10.8 t ha^{-1}) was at par with gypsum plus FYM treatment but was significantly higher than under gypsum treatment (9.0 t ha^{-1}) advocating that sustainable cane and sugar yields with good quality juice can be obtained by applying gypsum/FYM or both under sodic and only FYM under saline-sodic water irrigation.

Fertilizer Management

In the salt-affected environment there is a preponderance of nonessential elements over essential elements (nutrients). Plants must absorb the essential nutrients from a diluted source in the presence of highly concentrated nonessential nutrients in a salty environment. This requires extra energy and plants often are unable to fulfil their nutritional requirements. Excess soluble salts in the soil solution, high pH, excessive exchangeable Na and adverse soil physical properties due to long- term use of saline/sodic waters influence the transformation and availability of native and applied fertilizer nutrients.

Nitrogen: The efficiency of fertilizer N (the responses in yield per unit of applied N) in alkali soils is rather low and is controlled by the following factors: (i) The adverse effect of alkalinity/ sodicity on the transformations of soil and fertilizer N and excessive losses of N from the soil-plant system due to ammonia volatilization and denitrification, (ii) Poor plant growth due to inadequate soil reclamation and, therefore, inefficient utilization of N for grain production and, (iii) Nutritional and cationic imbalances within the plants under high soil sodicity or salinity result in poor crop response to applied fertilizers.

The major cause of low efficiency and utilization of N by rice and wheat in these soils is the extensive losses of N via NH_3 volatilization from the soil-plant system. Under high alkalinity (in the soil and flood water), NH_3 is produced.

$$NH_4^+ + HCO_3^- \rightarrow NH_3 + H_2O + CO_3^{--}$$

Which gets volatilized and lost, the extent of this depends upon soil surface evaporation, pH and NH_4^+-N concentration in the soil or flood water, cation exchange capacity of soil, depth of flood water, wind velocity and evaporation. Bhardwaj and Abrol (1978) observed that 32 to 52 per cent of the applied N was lost through volatilization in sodic soils. On flooding of the soil during rice growth, mineralization of organic N and is limited to ammonification stage due to rapid depletion of oxygen in a sodic environment. Hence NH_4^+ is the form of mineral-N that accumulates and is subjected to loss (10-60% of applied nitrogen) through volatilization (Kumar *et al*., 1995). High alkalinity and high amounts of $CaCO_3$ favour NH_3 volatilization losses in sodic soils.

Singh and Bajwa (1987) reported that volatilization losses are mainly controlled by pH of the soil and pH and alkalinity of floodwater. The reclamation of sodic soils has been found to decrease losses of volatile ammonia (Bajwa and Singh, 1992). Pre-submergence (submergence prior to planting) and N application for one week decreased the pH of alkali soils and therefore, reduced ammonia volatilization losses significantly (Kumar *et al*., 1995). Volatilization losses could also be reduced substantially if high ammonia pool resulting from rapid urea hydrolysis is reduced by the use of green or organic manures that release nitrogen slowly (Swarup, 1998).

Ammonia volatilization is also a major loss mechanism in sodic water irrigated soils. It increased with increase in EC, RSC and SAR of irrigation waters. Losses as high as 37% and 40% were observed under soils receiving irrigation waters having 15 me L^{-1} RSC and 4 dS m^{-1} EC, respectively. To decrease the N losses and increase N-use efficiency, splitting of fertilizer-N so as to match crop demands, deep incorporation, slow release N-fertilizers and application of urease inhibitors have been found successful.

Salt-affected soils are considered to be universally deficient in N and, therefore, crops greatly respond to 20-25% higher levels of N than that commonly recommended (120 kg N ha^{-1}) under normal soils (Rao and Batra, 1983). Application of 150 kg N ha^{-1}, 25% above the normal recommendation is a common recommendation for both rice and wheat crops grown in alkali soils in Punjab (Singh and Bajwa, 1987) and adjoining state of Haryana. In loamy alkali soils, a three-year study revealed that increased N doses of up to 200 kg ha^{-1} resulted in significant increase in wheat and paddy yields (Sharma *et al.,* 1998). However, in black alkali soils, wheat, paddy, cotton, and barley responded only up to 120 kg N ha^{-1}. It is evident, therefore that the crop responses to applied fertilizer N, depend upon the extent of sodicity/salinity still remaining in the soil after reclamation.

In less efficiently reclaimed soils, crops may respond to increasing levels of fertilizer N but the responses would be much less economical compared with those observed when these soils have been properly reclaimed. Under such situations adverse effects of sodicity and/or salinity are more pronounced than the beneficial nutritional effects of fertilizer N.

Under sodic water irrigated soils, the maximum yields of rice and wheat were obtained when N was applied in 3 equal splits, as basal and at 3 and 6 weeks after transplanting/sowing (Yaduvanshi and Swarup, 2005). Proper management of fertilizer N is thus necessary for better N use efficiency. Because of the adverse physical-chemical conditions, the recovery can be expected to be still lower in the salt–affected soils. Under such situation N use efficiency can be increased by integrated use of organic and inorganic sources of N (Yaduvanshi, 2001). Green manuring with Sesbania along with urea will minimize N – losses from applied Fertilizer N. Addition of FYM will help in improving the physical properties of soil, increased moisture retention and decreased nutrient losses. Following the application of N through inorganic fertilizer sources, a large pool of NH_4^+ liable to be lost through volatilization, is bound with organic forms temporarily immobilizing the ammonical N and subsequently release the organically bound N to crops during its growing season.

The composition of salts in saline and alkaline environment also influences the choice of fertilizers for crops. Bajwa and Singh (1992) observed under flooded alkaline soil conditions, urea, ammonium sulphate and ammonium chloride placed in reduced zone produced similar rice yields whereas nitrate containing fertilizers were appreciably inferior. In case of wheat, effectiveness of fertilizers containing both NH_4^+-N and NO_3^--N was similar. The reclamation of sodic soils found to decrease losses of volatile ammonia (Bajwa and Singh, 1992).

Another factor for low N levels is reduced symbiotic fixation of atmospheric nitrogen because of sensitivity of microbes to high sodicity and reduced growth of host leguminous crop plants. Rhizobium could survive and multiply in sodic soils up to pH 10.0 but the host plant is sensitive at this level of alkalinity (Rao, 1998). It is limited by the pH effect per se or due to reduced energy source caused by reduction in the growth of host plants. Losses of N can be regulated with reduction of pH of alkali through application of gypsum and soil submergence 1-week prior to crop planting.

Phosphorus: The soluble P content is generally high and is positively related with the EC and pH of the soil. High alkalinity results in the conversion of native insoluble Ca-P to soluble Na-P. Therefore water soluble P increases with soil pH in all the major benchmark series of alkali soils of the Indo-Gangetic plains. At ESP higher than 20 and at low levels of applied fertilizer P, the sorption of P by alkali soils decreases. Thus during early stages of reclamation and under conditions where farmers add lower doses of chemical amendment gypsum, the soils release sufficient P in soil solution for use by plants (Chhabra, 1985).

When sodic soils were reclaimed using amendments and growing rice under submerged conditions, Olsen's extractable P of surface soils decreased due to its movement to lower layers, and uptake by the crop (Swarup, 1998). Chhabra *et al*. (1981) observed decrease in extractable P in surface soil layers during the process of reclamation due to the immobilization of soluble Na-P through its conversion to the less soluble Ca-P. Decrease in ESP and pH of the soil upon reclamation leads to increase in sorption of soluble P.

The critical value below which crop responds to applied P varies greatly with the nature of the crop, stage of soil reclamation and initial soil test value. Rice and wheat crops grown on freshly reclaimed alkali soils (i.e. during initial 3-5 years) have not been found to respond to the application of phosphatic fertilizers. But when this surface soil layer gets depleted, rice crop having shallow root system starts responding to P fertilization. Wheat plants with a relatively deeper root system can absorb P from the lower layers also and do not respond to applied P for 3 to 5 years. In the normal non-alkali soils, depletion of extractable P by growing plants from the surface layer is compensated by mobilization of native soil P (mainly from Fe-P) as a result of water-logged (reducing) conditions maintained during rice cultivation. But in alkali soils because of their high pH, low organic matter, and dominant of Ca-P, water logging has very little role in mobilizing native soil P. Further, considering contributions from the sub-surface soil, lower doses of P should be enough to get optimum yields of rice crop in alkali soils. All phosphatic fertilizers containing water soluble P are more effective than those containing wholly or partially water insoluble P. Single superphosphate (SSP) is a better source of P than other phosphatic fertilizers as it contains some amount of Ca sulphate (Swarup, 1998).

Micronutrients

Availability of micronutrients to plants is mainly controlled by soil pH, concentration in the soil solution, organic matter content, crop species and genotypes within species, salinity level and salt composition. Due to these factors and their interactions, micronutrient availability in salt affected soils is very complex. Singh *et al*. (1992) observed that nine years of sodic irrigations caused significant decline in DTPA-extractable micronutrients. This decline was more pronounced in rice-wheat than in millet-wheat crop rotation.

Zinc: Alkali soils of the Indo-Gangetic plains contain medium to high amounts of total Zn (40 to 100 mg Zn kg^{-1} soil) which is comparable to the amount observed in the non-alkali soils of the area (Singh and Abrol, 1986). But the availability of Zn to the plants grown on alkali soils is adversely affected by high pH and P, presence of $CaCO_3$ and low organic matter. Most often alkali soils contain less than 0.6 mg DTPA-extractable Zn kg^{-1} and show acute deficiency of this element. Besides being poor in available Zn, the use efficiency and recovery of applied Zn is further adversely affected due to 85-90 per cent fixation of applied Zn by Chauhan *et al*. (1999).

The solubility of Zn in alkali soils is controlled by the solubility of $Zn(OH)_2$ and $ZnCO_3$, which are the immediate reaction products. Sadana and Bajwa (1985) found that addition of FYM, pyrites and gypsum shortened the period of predominant existence of $Zn(OH)_2$-Zn^{2+} (aq.) system which increased the solubility and thereby availability of zinc in sodic soils.

In contrast to normal soils, there is a slight improvement in the availability of native and applied Zn in sodic soils due to reduction in pH on flooding. This results primarily due to release of Zn from solid phase due to significant decrease in pH, which chiefly governs the availability of Zn in sodic soil during growth of rice. The solubility and extractability of added Zn decreased with time but increased with increase in ESP of the soil (Singh *et al*., 1987). The higher extractability at high ESP is attributed to the formation of soluble sodium zincate. Besides being an essential element, Zn also plays an ameliorative effect in alkali soils by enhancing absorption of Ca^{2+} and K^+ and thereby widening the Ca^{2+}/Na^+ and K^+/Na^+ ratios in plants. These physiological attributes interact and contribute towards increased crop yields in salt affected soils.

The fertilizer Zn requirement in sodic soils is influenced by the amount and type of an amendment and upon the degree of soil sodicity (Singh and Abrol, 1986). On addition of amendments, the extractability of added Zn decreases due to the increased adsorption of Zn on Ca saturated soil, retention of added Zn on the surface of freshly precipitated $CaCO_3$ and enhanced competition of added Ca with Zn for DTPA legends during extraction.

Rice crop, though tolerant to soil sodicity, is sensitive to Zn deficiency which may appear 15 to 21 days after transplanting in the form of brown spots on fully matured leaves causing stunted growth and ultimately severe yield reductions (Takkar and Nayyar, 1981). Therefore, application of Zn is an important requirement along with gypsum for optimum crop yields in alkali soils (Singh *et al*., 1987). In sodic soil amended with 10 to 15 t ha^{-1} of gypsum and 10 to 20 kg $ZnSO_4$ ha^{-1} was enough to meet Zn requirement of crops. In black alkali soils, applications of 50 kg ha^{-1} of $ZnSO_4$ to rice had a positive residual effect on the succeeding wheat crop (Sharma *et al*., 1998). Chhabra *et al.* (1981) observed that 4 to 5 years of continuous Zn application in a reclaimed alkali soil raised the Zn status to 1.6 mg DTPA-Zn kg^{-1} soil. At these levels, further application of $ZnSO_4$ can be deferred for the next 3 to 4 years without any loss in grain yield. The occurrence of Zn deficiency in rice crop could also be prevented by FYM and green manure due to reduction in soil pH and ESP and supply of Zn.

Among different zinc carriers, water soluble zinc sulphate is the most efficient in alleviating Zn deficiency in sodic soils (Nayyar *et al*., 1993). At equivalent Zn rates, multi micronutrient mixture including zinc has been found to be agronomically and economically inferior to zinc sulphate. Soil application of Zn has proved to be superior to foliar application.

Sodic soils are highly conducive for Zn fixation; require relatively much higher dose of Zn than normal soils to ensure adequate supply of Zn to a particular crop. The degree of sodicity also governs the optimum dose of zinc (Nayyar *et al*., 1993). Zinc applied at 5.5 to 11.2 kg/ha was sufficient to meet Zn needs of rice grown in a moderately sodic soil as compared to the need of 22.4 kg Zn/ha for optimum yield of rice in a highly sodic soil.

A new source of zinc, chelated-Zn protects soil applied Zn from fixation and improves availability and use efficiency of applied Zn. However, chelated-Zn applied @ 500g ha^{-1} in soil as recommended by manufacturers was inferior to the recommended dose of 40 kg $ZnSO_4$ ha^{-1} for rice crop (Chauhan *et al*., 1999).

Iron: Iron deficiency (Fe) is commonly observed in alkali soils on rice nurseries particularly grown on raised beds. The occurrence and deficiency of Fe is, however, small in magnitude compared to that of Zn in rice (Chauhan *et al*., 1999), because soils reclaimed by iron pyrites or organic amendments have enough Fe and submergence of soil releases large amounts of Fe. Moreover, plants grown in alkaline soil can mobilize Fe in the rhizosphere via some adaptive mechanisms (Romheld, 1987). Iron solubility is controlled by pH, $CaCO_3$, oxidation status of the soil and amount of organic matter. Therefore, soil application of $FeSO_4$ is often ineffective unless it is accompanied by changes in the oxidation state of the soil brought about by prolonged submergence and addition of easily decomposable organic matter (green manuring). Swarup (1980) showed a marked increase in the extractable Fe and Mn status of an alkali soil with submergence up to 60 days. The increase was still more when organic materials like FYM were incorporated in the soil. When rice nurseries, show iron deficiency symptoms it is always advisable to apply excess water or use green manuring. Since Fe is immobile in plants, foliar application of Fe (1-3% solution of $FeSO_4.7H_2O$) is commonly recommended.

Manganese: The solubility and availability of Mn in soil is controlled by pH and oxidation-reduction state of the soil. Singh (1970) observed that in most soils, exchangeable and active Mn was negatively related with pH and $CaCO_3$. Application of gypsum, green manuring and soil submergence lowered pH, pE and increased Mn^{2+} concentration in the equilibrium solution (Sadana and Bajwa, 1985). Deficiency of Mn is seldom a problem for wetland rice while it can become a serious limiting factor for the upland crop of rice and other upland crops grown after rice. Upon submergence, Mn gets reduced earlier than Fe and is leached to the deeper soil layers. Consequently, Mn deficiency is being increasingly observed in the wheat crop following rice in rice-wheat cropping system particularly on coarse textured soils. In a gypsum amended alkali soil, growing rice and wheat for two decades resulted in a decline in DTPA extractable Mn to 2.7 mg kg^{-1} soil and wheat responded to soil application of $MnSO_4$ application @ 50 to 100 kg ha^{-1}. Substantial leaching loss of Mn was also reported to ocure following gypsum application (Soni *et. al*., 1996). However, due to low permeability in unreclaimed/ partially reclaimed sodic soils, Mn deficiency expected to be lower due to less leaching loss than normal soils.

Due to auto-oxidation of Mn, it is very difficult to correct Mn deficiency by soil application of $MnSO_4$. Foliar application of Mn is, therefore effective and economical than soil application (Table 18). Repeated sprays (3-4 times) of 1% $MnSO_4$ solution are needed to correct deficiency of Mn in upland crops (Swarup, 1998).

Future Perspectives

Recent trends suggest that the use of sodic-water irrigated soils for crop production systems will increase in future. Therefore, an assessment of the impact such use will have on the environment and crop productivity should be made. We need to be aware, therefore, that we cannot simply evaluate the amelioration techniques used solely to reclaim soil sodicity. In fact, such an approach must consider the economic, social, and environmental aspects of any amelioration technique. It must also take into consideration several other associated components, including the cost and availability of amelioration inputs (such as water, planting material, amendments, and tillage machinery), the level to which a soil's sodicity needs to be reduced, and the depth of soil that needs to be ameliorated in order to grow crops subsequently. The quality, availability, and cost of the water required to produce crops after amelioration must also be factored in, as must the economic value of the crops grown both during and after amelioration. A holistic approach should also consider the nutrient availability status of the soil after amelioration, the long-term sustainability of an ameliorated site in terms of crop productivity as well as any changes that amelioration will be expected to cause in the market value of the land. Finally, socio-economic assessment should be made about the effect that amelioration efforts will have on the livelihoods of the farming communities owning sodic soils.

Faced with the challenges associated with sodic soil management, we believe that the time has come to consider such soils a useful resource of economic value rather than an environmental burden. Their use should therefore be considered to be an opportunity to shift from subsistence farming to progressive farming. Using amendments and fertilizers for sustainable management of soil and water induced sodicity represents an excellent opportunity to conserve the environment and make use of such initiatives.

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Improving Crop Productivity through Sustainable Use of Alkali Waters: Experiences from Punjab and Haryana

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One of the major problems confronting irrigated agriculture nowadays throughout the world is decreasing availability of good quality water. This forces many farmers in arid and semi-arid eco-systems to use poor quality ground waters for irrigation. This is of major concern in India as about 32-84 % of ground waters surveyed in the IGP are poor in quality (Minhas and Bajwa, 2001). Many farmers fail to sustain crop productivity as soil degrades due to indiscriminate use of poor quality waters. For obtaining sustainable crop production in these soils, we must ensure that salt concentration in the surface root zone soil is always maintained below the permissible limits. Continued use of poor quality waters for irrigation leads to the build-up of salinity and/or sodicity in soil and deterioration of soil physico-chemical properties resulting in reduced sustainability of crop production. However, when managed properly, poor quality waters can become a valuable resource for irrigation and sustaining crop production. Specific and efficient systems of management need to be followed to ensure a non-negative trend in productivity and economic returns in any agro-ecosystem.

Sodic waters contain higher proportions of sodium (>75% of cations) and predominance of carbonates and bicarbonates relative to calcium and magnesium. Upon irrigation with such waters, calcium gets precipitated as calcium carbonate, resulting in more saturation of sodium (Na) in soil and increase in pH and exchangeable Na percentage (ESP). Irrigation-induced sodicity in soils presents structural problems created by certain physical processes (slaking, swelling, and dispersion of clays) and specific conditions (surface crusting and hard setting) (Shainberg and Letey, 1984; Qadir and Schubert, 2002) and tillage and sowing operations. The poor soil structure and clogging of pores due to high degree of dispersion of soil results in poor infiltration of water.the effects are most apparent following rainfall or an irrigation event, which leads to stagnation of water and resultant aeration problems. The soils under sodic water irrigation, below a few centimeters of the surface remain almost dry and hard, though water may be stagnating at the surface. On drying, these soils become very hard, affecting the proliferation of roots. It also impacts seed germination and seedling emergence. The long-term use of sodic or alkali waters causes the formation of black alkali soils. Such problems affect water and air movement, plant-available water holding capacity, root penetration, seedling emergence, runoff and erosion. Waters having little of calcium (less than 2 meq l^{-1}) and high amounts of soluble carbonates and bicarbonates of NaNa cause nutritional imbalances and can also direct injury by burning of stems and leaves.

The chemical composition of sodic waters greatly varies and depends upon the kind of salts in the aquifer from which the water is drawn. The sodic waters have one or more of the following characteristics:

- Sodic waters contain higher proportion of carbonates (CO_3^{2-} + $HCO_3^{=}$) of NaNa in relation to that of other cations (Ca^{2+}, Mg^{2+}, K^+) and, anions (CO_3^{2-} + $HCO_3^{=}$) higher than (SO_4^{2-}, Cl^-, NO_3^-). The ratio of divalent to total cations is < 0.25.
- The ratio of Ca^{2+} and Mg^{2+} in sodic water depends upon the amount of calcite ($CaCO_3$) and dolomite $CaMg(CO_3)_2$, partial pressure of CO_2 (P_{CO2}) and clay fractions of the aquifer soil.
- Alkalinity of sodic waters is due to dissolved carbonates (HCO_3^- + CO_3^{2-}) and (P_{CO2})in aqueous solutions.

Alkali Irrigation Effects on Soil Physico-chemical Properties

Long-term irrigation with sodic waters results in soil condition similar to those observed in an alkali soil. The build-up of sodicity and pH increased dispersibility and structure degradation leads to poor air water transmission. The soil sodication effects are reflected in terms of poor crops stand or bare soil spots (slick spots) due to reduced seedling establishment and retardation of crop growth and yield (Bajwa *et al.*, 1993).

Salinity and Sodicity Build-up in Soil

For developing strategies for sustaining crop productivity under sodic irrigation system, information about the extent of soil sodication and its adverse impact on soil health and growth of crops is a basic need. The extent of sodicity and salinity accumulation in the soil profile is determined by SAR and residual alkalinity of irrigation water, water table depth, climatic conditions, , nature of crops grown with respect to their water uptake pattern and management practices adopted to meet leaching requirements. Under monsoonal climate of India, buildup of salt and Na occurs during irrigation to winter crops with sodic water and that too in the surface layer. Fig. 1 shows conclusively that sub-surface soil layers are little influenced even after long term irrigation with sodic/alkali waters due to low infiltration and poor leaching. The buildup of sodicity (higher exchangeable sodium percentage, ESP) in rice-wheat system (R-W) was higher than in milllet-wheat (M-W) because of high input of sodic water (Bajwa and Josan, 1989a). The waters of comparable SAR but having increasing level of electrolytes increase the level of sodication. With increasing electrolytes concentration in solution, the decrease in activity coefficient of hetero-valent ions is disproportionate. At higher ionic strength, there is always preference for the lower valency ions by the exchanger phase, which is classical response of a non-symmetrical exchange. Singh and Bhumbla (1968) observed that the salt accumulation depends to a great extent on soil texture, and in soils containing less than 10% clay, the electrical conductivity of soil saturation extract (EC_e) remains lower than that of irrigation water.

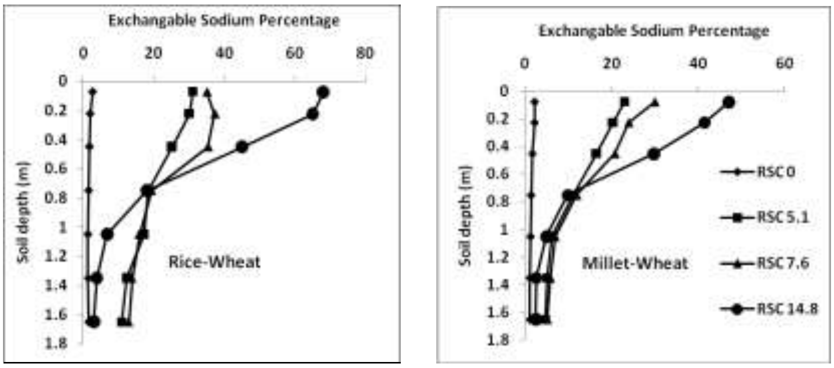

Fig. 1. Build-up of ESP in soil profile after 9 years of sodic irrigation varying in RSC level (Source: Bajwa and Josan, 1989a)

Effect of Alkali Waters on Crop Yields

Reports of several studies (Minhas and Gupta, 1992, Sharma and Minhas, 2005, Minhas *et al*., 2007, Choudhary *et al*., 2011b) suggest that the degree of sodicity hazards depends on RSC, SAR, depth of water applied, crops/cropping systems followed, soil properties, texture, $CaCO_3$, presence of hard-pan, efficiency in 'Crop—Water—Soil' health management, ground water behaviour and drainage conditions and climate.

Bhumbla and Abrol (1972) proposed that water testing less than 2.5 $meqL^{-1}$ RSC should be considered safe for irrigating field crops and those testing higher should be used after amending with gypsum. But when field is kept fallow during rainy season (kharif), underground water g RSC up to 7.5 meq l^{-1} were being used for irrigating wheat in Alwar and Jaipur district of Rajasthan (Singh and Singh, 1971) and Gurugram district of Haryana (Verma, 1973). Gupta (1980) reported that irrigation with waters having RSC of 10 meq l^{-1} can be practiced annually on sandy loam soils, provided the SAR is low when wheat crop was taken during rabi season and field was kept fallow during monsoon season which received 500-550 mm rainfall. The rainfall prevented sodicity build-up in soil to the levels that could adversely affect the wheat yields. Using sodic waters in both seasons, on the contrary, leads to faster deterioration of soils. Bajwa et al (1983) reported reduction in maize yield in a maize-wheat rotation due to build-up of sodicity of 75 cm soil profile(Y=109.36-1.948 ESP) when these crops received sodic waters (ECiw 1.15-4.5 dS m^{-1}, RSC 2 and 8 meq l^{-t}, SAR 11.6-38.5) for 5 years. Manchanda *et al*. (1985), however, found that the wheat yields started declining with each successive year and crop failed to germinate during the eighth year due to high pH (10.0) as well as high soil ESP (92) when high RSC water (RSC 10 meq l^{-1}) was continuously used on a sandy loam soil.. Thus the crop yields are not significantly reduced until sodium saturation of soil exceeded a value, known as threshold value for a given crop when Na saturation (ESP) exceeds the threshold value, the yields start declining. The decline in crop yields therefore, is determined by the sodicity of irrigation water and duration of its use.

Predicting Sodic Irrigation Effects

Effects of sodic irrigation on sodicity build-up and crop productivity have been extensively reported (Manchanda et al., 1985, Ayers and Westcot, 1985, Minhas and Gupta, 1992, Minhas and Bajwa, 2001, Choudhary et al., 2006, 2011a, Choudhary, 2017). The ability to predict the performance of different crops and cropping-systems over the years, under long-term irrigation with sodic waters can be of great significance for planning about selection of crops and cropping systems and adopting specific crop-soil-water management options so as to sustain high crop productivity.

Long-term field studies by Bajwa and Josan (1989a, 1989b) and Bajwa *et al*. (1992) showed that decline in productivity of rice-wheat, maize-wheat and cotton-wheat cropping systems was significantly related with increase in sodicity/alkalinity of water. Using best-fit quadratic relationships between adj.SAR_{iw} and crop yields, curves can be drawn for predicting 10, 25, and 50% crop yields relative to good quality water irrigation. These curves can be useful for making recommendations about the years up to which it will be possible to sustain the desired level of crop production. Based upon these data the adj.SAR_{iw} values can be predicted for sustaining 90, 75, 50% relative yields of rice-wheat, millet-wheat and cotton-wheat cropping systems irrigated with sodic water (Fig. 2). The results confirmed that when sodic waters with M^{2+}:$\sum Mn^{+}$ ratio >0.2 (or concentration of Ca^{2+} >0.2 $meqL^{-1}$) used for prolonged period, did not result in any deterioration in soil and reduction in crop yields but the waters having high SAR, RSC and divalent ratio <0.25 expectedly led to higher build-up of sodicity over the years (Fig. 3)

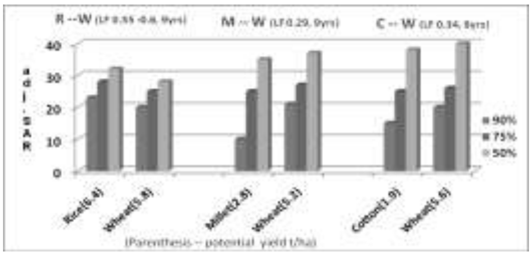

Fig. 2. Adj. SAR_{iw} for sustaining 90, 75, and 50% relative crop yields (LF : leaching fraction)
Source: Bajwa and Josan (1989a); Bajwa *et al.* (1992)

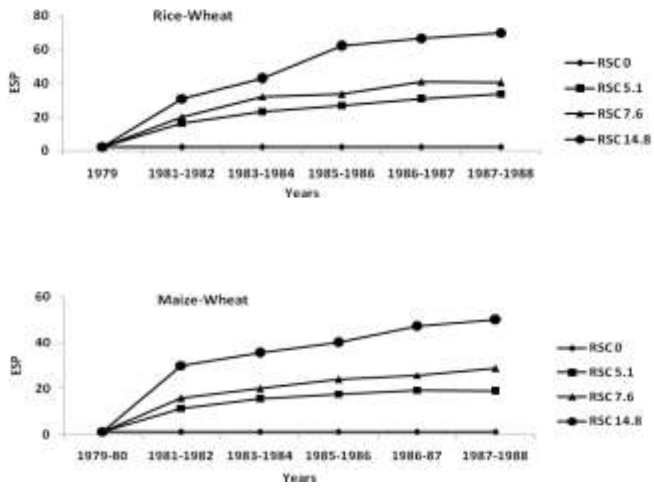

Fig. 3. Successive Changes in ESP with time in top 0-30 cm soil using irrigation water RSC ranging from 0 to 14.8
(Source: Bajwa and Josan, 1989a)

Another class of water generally referred to as saline-sodic (EC_{iw} >4, SAR>10) with high or low RSC, usually renders the soil saline, though its effect on infiltration of soils is apparent during monsoon due to sodicity build-up. At Agra and Dharwad Centres of AICRP on Saline Water, effect of irrigation waters with different combinations of SAR (5, 10, 20, 30 and 40) and salinity (EC_{iw} 6 and 12 dS m^{-1}) was studied in pearl millet-wheat and sorghum-wheat crop rotations (Minhas, 1996). Pearl millet proved sensitive to the use of saline-sodic waters compared with wheat and sorghum. The effect of SAR was pronounced at higher salinity (EC_{iw} 12 dS m^{-1}) in all the crops. If saline-sodic waters having SAR < 20 are used in the semi-arid regions with 500 mm annual rainfall, wheat or barley can be grown without any adverse effect on crop yields.

From a field experiment on cotton-wheat using sodic and saline-sodic waters for 8 years (1983-91), Bajwa *et al.* (1992) reported higher build-up of ESP under saline-sodic treatments. The decline in crops yields under sodic water (RSC 10 meq l^{-1}, EC 1.16 dS m^{-1} SAR 10.1) treatment during different years was 22 to 23% in cotton and 15 to 26% in wheat. The corresponding reduction in crop yields in high SAR saline-sodic water (RSC 11.1 meq liter $^{-1}$, EC 2.70 dS $m^{-1}$and SAR 22.4) irrigated plots was 22 to 29% in cotton and 19 to 34% in wheat. The reduction in crop yields may be attributed to the Ca-deficit in the soil solution due to higher RSC in sodic water treatment and poor aeration in the root zone soil brought about by higher SAR and ESP under saline-sodic water treatment. The build-up of ECe in the root zone under saline-sodic irrigation in this investigation, however, did not exceed the threshold levels in salinity (Maas and Hoffman, 1977) for both cotton (7.7 dS m^{-1}) and wheat (6.0 dS m^{-1}).

Sustainable Use of Alkali Waters

When waters having high residual sodium carbonate (RSC) and sodium adsorption ratio (SAR) are used for irrigation, sustainability of crop productivity is influenced by the extent of sodicity build-up in soil, sodicity tolerance of crops, maintenance of soil sodicity below permissible limits, maintenance of soil physico-chemical and biological properties for crop production, efficient management of crop-water-soil health and groundwater behaviour, etc.

Irrigation Management

Conjunctive Use: Combined use of alkali and canal waters is a good option for reducing sodicity/alaklinity hazards of irrigation water. This is particularly relevant to the areas where canal water supplies are either un-assured or inadequate and farmers often pump sodic groundwater for supplemental irrigation. For efficient use, good quality waters can be used to grow sensitive crops and sodic waters for tolerant crops. The more appropriate practice, however, can be the conjunctive use of these waters, following either of the options of (i) blending sodic and canal waters in supply network, making tailor-made water quality appropriate for each crop irrespective of the soil conditions (Minhas and Gupta, 1992), (ii) alternative use of the two water qualities (Bajwa and Josan, 1989c) depending upon availability and crop needs, and, (iii) switching these water sources according to critical stage of crop growth during the growing season. Rhoades *et al*. (1992) advocated the adoption of seasonal cyclic use, called ‘dual rotation’ strategy where non-saline non-sodic water is used for salt/sensitive crops/initial stages of tolerant crops to leach out the accumulated salts from irrigation with salty waters to previously grown tolerant crops. Sharma and Minhas (2005) stated that this strategy may work better in arid climate with very low rainfall but it is of natural occurrence in the monsoonal climate.

Blending is promising practice in areas where freshwater supplies can be made available on demand. Mixing of sodic and canal water is done in such a proportion so that final SAR/RSC is maintained below threshold limit of the crop to be grown. The proportion of blending two different water supplies (canal and sodic water) depends on the crops to be grown, extent of sodicity of water.

Alternating irrigations with good quality and sodic waters maintained the ESP at relatively lower levels and helped in sustaining good yields of rice and wheat (Table 1), sunflower and cotton. Choudhary and Ghuman, (2008) observed greater decline in seed-cotton yield (16.5% yr^{-1}) than that in wheat yield (5.9% Yr^{-1})). Compared with the SW treatment, yield of cotton and wheat were higher (93-98%) when the irrigation cycle started with CW and involved one SW (2CW:SW, CW:SW). The yields of cotton and wheat also remained higher in an irrigation cycle starting with SW followed by 2CW irrigation (SW:2CW). But with cycles (SW:CW, 2SW:CW) involving one CW, the decline in seed-cotton yield was relatively greater (18-23%) than in the wheat yield (10%) after six years. It suggests that in a cyclic strategy involving SW, pre-sowing irrigation of cotton should be performed with good-quality canal water to ensure higher yields. But if CW is not available at the time of planting cotton crop, sustainable seed-cotton yields can also be achieved even with pre-sowing irrigation with sodic water, provided the deterioration in soil properties is prevented by applying CW irrigation later (Choudhary and Ghuman, 2008). Long-term sustainability of 2CW:SW, CW:SW and SW:2CW was affirmed during the next 6 years (7-12 years) where optimum wheat and cotton yields (90-96% RY) were achieved (Choudhary, 2017). This trend was also confirmed by sustainable yield index (SYI) values after 6 and 12 years. The SYI ranged from 0.55-0.57 for cotton and 0.81-0.83 for wheat in 2CW:SW, CW:SW and SW:2CW treatments after 12 years, respectively. The SYI values were higher by 0.06-0.11 for cotton and 0.10-0.15 for wheat compared with that of CW:2SW, SW:CW and 2SW:CW treatments. It suggests that although pre-sowing irrigation to cotton should be given always with good quality CW for ensuring better germination of cotton, sustainable seed-cotton yield can also be obtained even with occasional pre-sowing irrigation with SW followed by 2CW (SW:2CW). This treatment mimics situations where availability of CW is not assured at the time of sowing. It is due to lower build-up of ESP (ESP<10 in the 0-0.30 m soil layer) in this treatment (similar to that observed in 2CW:SW) controlled the precipitation of Ca^{2+} as $CaCO_3$. These results are of considerable agronomic significance when canal water supplies progressively decrease from the head reach to the tail reach in a canal command (Tyagi, 2003) and may not be available at the time of sowing of a crop. The proposed strategy offers the additional advantage of integrated water resources management by using low quality water for soil reclamation while saving better-quality water for producing high-value crops.

Generally winter crops like wheat and sunflower can be grown reasonably well even with pre-sowing irrigation using SW. These crops respond to the total proportion of SW used rather than the order of SW and CW applied in a cyclic strategy (Choudhary *et al*., 2006; Choudhary and Ghuman, 2008).

Table 1. Effect of cyclic use of sodic and canal water on yields (Mg ha^{-1}) of various crops and cropping systems

Irrigation treatments	Rice-wheat[a]		Cotton-wheat[b]		Cottn-sunflower[c]
	Rice	Wheat	Cotton	Wheat	Sunflower
Canal water (CW)	6.78	5.43	1.32	5.20	3.28
Sodic water (SW)	4.17	3.08	0.95	4.43	2.55
2CW:SW	6.67	5.22	1.26	5.10	2.99
CW:SW	6.30	5.72	1.21	4.95	2.88
CW:2SW	5.72	4.85	1.15	4.70	2.67
SW:2CW	-	-	1.22	4.82	3.01
SW:CW	-	-	1.08	4.70	2.80
2SW:CW	-	-	1.02	4.75	2.69
LSD (p=0.05)	0.60	0.50	0.18	0.21	0.22

[a]1981-1985; [b&c] 1996-2002; RSC of sodic water >5meq L^{-1}

(Source: Bajwa and Josan, 1989c; Choudhary et al., 2006; Choudhary and Ghuman, 2008)

Higher proportions of SW used in cyclic option can also lower the quality of the harvested product. Reduction in potato grade and weight loss during storage and,smaller seeds and lower oil content in the case of sunflower was observed (Chauhan *et al*., 2007). In onion, the proportion of 'A' grade bulbs was higher in 1TW:1AW cyclic mode; at par with good quality water (TW) irrigation (Chauhan and Kaledhonkar, 2018). The proportion of lower grade bulbs (C grade) and weight loss during storage were higher under AW irrigation and the treatments with more number of AW irrigations in a cyclic mode. Chauhan and Kaledhonkar (2018) also reported higher water use efficiency (WUE) of about 560 kg/ha-cm in 1TW:1AW and TW treatments than mixing treatment of 2TW and 1AW (540 kg/ha-cm) and AW treatment (240 kg/ha-cm).

Irrigation Intervals: A general recommendation under sodic soil conditions is to apply light and frequent irrigation for overcoming the effects of poor hydraulic properties of soils. Under arid conditions, higher transpiration rates from wetter soils due to frequent saline irrigations may lead to increased soil solution salt concentration (1.5 to 2.0 folds) adjacent to growing roots, thus disapproving the case for a higher irrigation frequency. In a long-term study, Bajwa *et al*. (1993) reported that crop responses to shorter irrigation intervals under involving sodic and saline-sodic waters depended upon the season in which crop was grown and its relative salt and Na tolerance.

Irrigation Methods: The distribution of water and salts vary with the method of irrigation. The surface irrigation methods such as border strips check basins and furrow are the oldest and most commonly practiced in India. However, these irrigation methods generally result in excessive irrigation and non-uniformity in water application. Consequently the on-farm irrigation efficiency is low (50-60%).

High energy pressurized irrigation methods such as sprinkler and drip are typically more efficient as the quantity of water to be applied can be adequately controlled. Application of highly saline (EC = 12 dS m^{-1}) water through sprinkler is detrimental for pearl-millet and cotton whereas it can be safely used for wheat and barley. Water use efficiency, although decreased with salinity, was higher when applied by using the sprinkler than by surface. Saline water use through sprinklers, however, may cause leaf burning and toxicity when used in some sensitive crops.

The distribution of salt and water in the root zone vary with method of irrigation. Ideally, the method should create and maintain a favorable salt and water regimes in the root zone soil so that water is readily available to plants without affecting crop growth and yield.

Surface irrigation and irrigation in furrows generally result in excessive losses of water and thus, are less efficient (40-60%). High energy pressurized irrigation methods such as sprinkler and drip are typically more efficient (> 90% efficiency) as these methods can adequately control quantity of water to be applied unlike surface irrigation systems. Sprinklers distribute water uniformly on undulating soils and those with variable infiltration rates. Compared with surface irrigation methods, sprinklers also increase the efficiency of salt leaching (Minhas and Gupta, 1992). However saline/sodic water applied through sprinklers, may cause leaf burn due to excess salt accumulation on leaves. This is particularly true for sensitive crops that exhibit high rates of foliar salt absorption during dry summer period having high evaporative demand.

The drip irrigation has revolutionized the production of some high value crops. As regular and frequent water supply is possible with drip irrigation, it has been observed to enhance the threshold limits of their salt tolerance by modifying the pattern of salt distribution and crop yields. This resulted in superiority in water use efficiency and yield, as well as size and quality of vegetables. Rajak *et al.* (2006) observed that crops perform better under drip irrigation as opposed to other methods because a higher soil moisture and lower soil salinity is maintained near the drip emitter where root density is high. Unlike in sprinkler irrigated conditions, it also avoids leaf wetting and injury to plants. Drip irrigated crops have also been found to show higher water uptake by their roots resulting in higher water use efficiency and yield of vegetables. While using sodic waters for irrigating tomatoes, Choudhary *et al*. (2010) observed that while irrigating tomato crop with sodic waters high in bicarbonates, effects on soil physical and chemical properties can be severe in furrow than in drip-irrigation. On the other hand, better soil moisture conditions and lesser deterioration in soil properties when irrigated with medium and high RSC water under drip irrigation can lead to higher tomato yields than under furrow irrigation (Fig. 4).

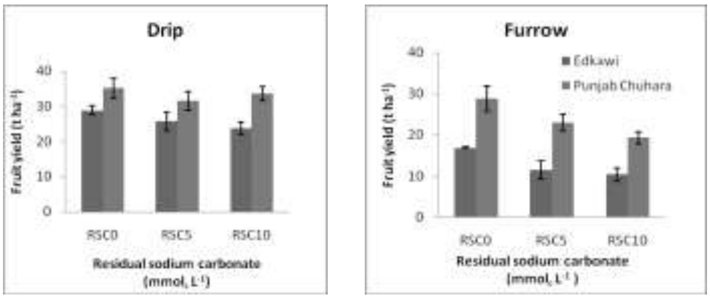

Fig. 8. Tomato fruit yields (t ha^{-1}) as influenced by RSC of irrigation water under drip and furrow irrigation (after three years in 2003-04).
(Source: Choudhary *et al*., 2010)

Higher soil and water sodicity in general, leads to reduced fruit quality. Nevertheless, better fruit quality can be maintained in drip-irrigated tomatoes at higher RSC. The other advantage with drip system using saline/sodic water application is that it avoids leaf injury to plants as with sprinklers and maintains optimum conditions for water uptake by their roots.

Leaching Requirement

Another recommendation is the application of excessive water to meet the leaching requirement (LR) and maintain a desirable salt balance in the soil having adequate drainage. The concept of LR for achieving salt balance holds good for the situations of no or very low rains. But it is of natural occurrence in monsoonal type climate where rains are concentrated in 2-3 months.

In general, leaching requirement increases with salinity of water supply and sensitivity of the crop for salinity. However, 30-50% higher salinity build up even in light textured soil was observed when 50% extra saline water (EC_{iw} = 3.2 dS m^{-1} and RSC = 4 me L^{-1}) was applied to meet the leaching requirement in rice-wheat and maize-wheat systems. The general strategy to use more efficiently the monsoon rainwater to take care of LR and to maintain low salt build up in the root zone soil seems to be more helpful.

Crop and Cultivar Selection

Several reports on the use of poor quality waters for crop production show that selection of suitable crops and their varieties capable of producing high yields and economic returns under varying levels of soil Na saturation is a fundamental factor for achieving sustainable high agricultural productivity under sodic irrigation system. This is mainly because crops differ in tolerance to soil salinity and sodicity/alkalinity (Maas and Hoffman, 1977, Minhas and Gupta, 1992**),** which may form the basis of selection of crops for growing on soils irrigated with varying levels of sodicity in water.

Rice and wheat are the crops most commonly recommended for growing in salt-affected soils during reclamation process as both these crops can tolerate higher levels of salinity and sodicity. However, rice is not recommended to be grown with saline and sodic waters as rice and other high water requiring crops need large number of irrigations (24-28) that can appreciably increase salt load and Na build-up in the soils and hasten the degradation of the soils. So under poor quality water irrigation, low water requiring crops that are tolerant or semi-tolerant to the salts should be raised.

Most of the high yielding crop varieties can give high productivity in alkali soils up to pH 9.1. Beyond this, only the salt tolerant cultivars produce economical yields. Central Soil Salinity Research Institute, Karnal has developed salt tolerant cultivars of rice (CSR 23, CSR 27, CSR 36) and a basmati cultivar (CSR 30), wheat (KRL1-4, KRL19, KRL 210) and mustard (CS 52, CS 54). All these tolerate high levels of salinity up to ECe of 7-10 dS m^{-1} and high levels of alkalinity (pH_2 9.3 -10). At Kanpur, screening of rice, wheat and mustard cutlivars in sodic soil was carried out under sodic condition (Soil pH 9.3, ESP 45.3) (AICRP Annual Report, 2016-17). In case of rice, the maximum yield 43.1 q ha^{-1} of rice was recorded from variety CSR 36 followed by CSR 23 (40.7 q ha^{-1}) and CSR 27 (38.2 q ha-1). The minimum yield 21.89 q ha^{-1} was obtained from CSR 30. For wheat, the maximum yield 35.4 q ha^{-1} of wheat was recorded from variety KRL 210 followed by KRL 213 (34.3 q ha-1) and PBW 343 (32.8 q ha-1) while the minimum yield 26.9 q ha^{-1} was obtained from WH-147. Among different varieties of mustard screened, the maximum yield 16.20 q ha^{-1} of mustard was recorded from variety CS 56 followed by CS 54 (14.6 q ha^{-1}) and CS 52 (13.3 q ha-1) with the minimum yield of 10.46 q ha^{-1} from Urvasi. However, it is pertinent to mention that all these screening studies were conducted on a native sodic soil irrigated with good quality water.

Choudhary *et al*. (1996) reported that tolerant wheat genotype had penetrative root system and higher spike number in a unit area than the sensitive ones. The response of wheat cultivar PBW 343 to sodicity (RSC) of irrigation water was influenced by the number of irrigations and amount of rainfall in a year (Fig. 9). Subsequently, Choudhary *et al*. (2012) concluded that that cultivar PBW 343 should be preferred over other wheat cultivars (PBW 550 and PBW 502) to obtain acceptable yield levels without any loss in grain quality in soils irrigated with sodic waters containing RSC > 5 $meqL^{-1}$.

Major problems occur due to nutritional imbalance in the soil-plant system as a result of severe reduction in Ca concentration (below 2 $meqL^{-1}$) in soil solution (Rhoades *et al*., 1992) with increase in alkalinity and Na saturation in soil. Sodicity tolerance of crop plants also depends upon the ability of plant-roots to exclude Na and absorb nutritionally adequate amounts of Ca (otherwise deficient under sodic soil environment). Crops having higher tolerance to soil Na saturation have also been reported to maintain relatively higher Ca/Na and lower Na/K ratios in shoots (Choudhary *et al*., 1996) by restricting Na absorption.

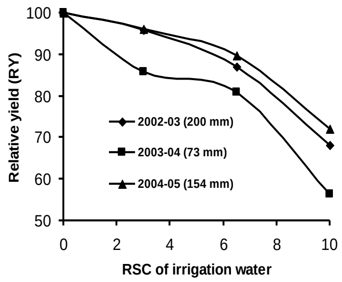

Fig. 9. Influence of rainfall on response of 'PBW 343' to RSC of irrigation water in different years (Source: Choudhary *et al*., 2007)

Growth and yield of three cotton cultivars were adversely affected by long-term irrigation with sodic waters having RSC of 5, 10 and 15 me L^{-1} (Choudhary *et al*., 2001). Compared with CW treatment, relative seed-cotton yield under ESP of 56.2 was 69% in F-846, 49% in LD-327 and only 29% in F-505. The cultivar F-846 produced heavier bolls than the other two cultivars due to irrigation with higher RSC levels. The harmful effects of high RSC waters on fibre quality (2.5 % span length, micronaire value and bundle strength) observed in F-505 and

LD-327 at an ESP of 56.2 in the soil were not observed in case of F-846. Recently, among Bt cotton hybrids, RCH 134 was observed to perform better than MRC 6301 and MRC 6304 (Choudhary *et al*., 2012b).

Policy Issues

Following policies issues should be framed and adopted by various stakeholders in order to sustain healthy agro-ecosystem while using saline/sodic waters for irrigation:

- Policy on water quality monitoring network
- Modifications in surface water delivery schedules
- Subsidies on amendments
- Promoting conjunctive Use
- Promotion of micro irrigation techniques
- Participatory planning
- Capacity building

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Bio-saline Agriculture with Medicinal and Aromatic Plants for Salt Affected Conditions to Enhance Farmers' Income

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Introduction

Some salts are always present in soil but excess accumulation in root zone causes a variety of harmful effects on soil properties and growth of plants. It is estimated that about 20% of the global irrigated lands suffer from waterlogging and salinity to varying extents. In addition, salinity also affects a significant proportion of lands in rainfed arid to semi-arid areas. Projections shows that global food demand is likely to double, in the foreseeable future, which will pose a huge challenge to produce adequate food without impairing the land and environmental sustainability (Tilman *et al.*, 2002). Despite substantial improvements in food availability, malnutrition and poverty are still rampant in many parts of Africa and Asia. High consumption of energy-rich foods also results in diabetes and heart problems and at the same time nutrition transition characterized by the simplification of diets can further accentuate the problem in the form of reduced intake of functionally healthy plant foods. Consequently, people have become more health conscious than before and looking for adequate access to health protective food products. This has given impetus to the global trade in 'medicinal and aromatic plants' (MAPs) (Johns and Eyzaguirre, 2006). MAPs can be defined as 'plants used not only medicinally *sensustricto* but also in the fields of condiments, food and cosmetics' (Schippmann *et al.*, 2002).

People have gathered plant and animal origin products for medicinal, cosmetic or cultural uses since pre-historic times. Millions of people in developing countries still derive a significant part of their subsistence needs and income by gathering the plant and animal products. In many cases, such MAPs also play a major role in local and distant trade and their demand continues to increase with the evolving of human and commercial needs. Unfortunately, over-exploitation of certain MAPs ascribed to strong demands has reached to critical levels. Accordingly, it is argued that such medicinally important wild species need to be brought into cultivation to address the interrelated objectives of commercial production and conservation while lessening the pressure on natural populations (Schippmann *et al.*, 2002). In spite of the pressing need to increase cultivation area of MAPs, it is also to be remembered that prime agricultural lands and fresh water are depleting at an accelerated rate. The competition from other sectors of economy (*e.g.*, housing, industry etc.) for land use is such that unabated urbanization could usurp nearly 2% of the highly productive global croplands by 2030 (d'Amour *et al.,* 2017). In this backdrop, the future plans to extend the cultivated area under MAPs should depend on harnessing the potential of marginal lands suffering from constraints such as salinity or sodicity and fresh water scarcity. Available evidence suggests that MAPs can be successfully grown in marginally productive salt-affected soils (SAS) often irrigated with poor quality saline and alkali waters. It is pertinent to mention that salt stress may not always prove an insurmountable challenge for crop production. This is especially true for lands suffering from minor to moderate constraints which can easily be overcome by adopting the feasible salinity management techniques. For instance, a study by Wicke *et al.* (2011) reported that as much as 85% of the total global salt-affected area (1128 M ha) has only slight to moderate limitations implying that precise mapping of such salt-affected pockets of agricultural relevance on country and regional scales followed by technological interventions can significantly enhance their economic value. In this chapter, thereforean attempt has been made to organize the available information for sustainably utilizing the poor quality water for the commercial production of MAPs.

Global use and trade of MAPs

MAPs have been always playing important role in healthcare needs and economic wellbeing of rural communities across the world. Health care of a vast majority of people in developing countries is still dependent on traditional medicines. Of late, developed world has also developed manifold interest in MAPs as a safe and effective option for preventive health care. The growing interest in MAPs can be explained by consistently rising costs of prescription drugs, development of potentially novel plant-based products and the public concerns on the side effects of synthetic drugs (Hoareau and DaSilva, 1999). It is estimated that currently nearly 50% of the North American and European population regularly uses some form of traditional and alternative medicine which is as high as 80% in several developing countries (Bodeker and Kronenberg, 2002). In addition to the traditional use in medicine, diverse industrial uses of MAPs are increasingly coming to fore. Some of the notable applications include essential oils, pharmaceuticals, dyes and colorants, cosmetics and biocides. About 3000 plant species are used to extract essential oils and approximately 10% of them are currently traded globally. Plant-derived extracts and compounds are used either as ingredients or starting materials in the production of over 25% of the pharmaceutical drugs. Terms 'herbal medicine' and 'botanical drugs' specifically refer to the plant-based extracts, teas and tinctures produced from MAPs in health care. A large variety of MAPs are also being marketed as 'nutraceuticals' *i.e.*, dietary supplements with potential health benefits. Increasing public awareness about the adverse health and environmental impacts of synthetic colours and dyes has generated huge interest in natural plant extracts. In European Union, for example, imports of natural dyes have steadily increased with a concomitant decrease in the imports of synthetic dyes. Newer applications as ingredients in personal care and cosmetic products are increasingly adding value to the global MAP trade. Plant-derived oils, waxes, essential oils, oleoresins and colorants are being used in the manufacture of premium cosmaceuticals. The socio-economic importance of MAPs remains incomplete without mention of their conventional use as herbal insecticides and pesticides. Plant-derived insecticides have been used for more than 2000 years in countries like India and Egypt (Lubbe and Verpoorte, 2011). During the recent past, MAPs have acquired the status of commercial crops even in highly developed countries such as United States where farmers have gradually switched over to the commercial cultivation of MAPs (Craker, 2007). The medicinal properties and uses of selected salt tolerant MAPs are furnished in Table 1.

Table 1. Medicinal properties of selected salt tolerant MAPs

Species	Salt tolerance	Medicinal uses
Lemon grass *Cymbopogon flexuosus*	Tolerates soil pH up to 9.5 and salinity up to 10 dS m^{-1}. Irrigation with saline water (~4 dS m^{-1}) improves growth and herbage yield.	Leaf oil is bactericidal and insect repellent. Citral, main constituent of the oil, is used to manufacture Vitamin A tablets.
Palmarosa *Cymbopogon martini*	Performs well in saline soils (EC_e8-12 dSm^{-1}) and responds favourably to saline irrigation (EC_{IW} up to 16 dS m^{-1}).	Leaf oil is antiseptic, antiviral, bactericide, and hydrating. Oil is rich in natural antioxidant geraniol.
Indian Aloe *Aloe vera*	A xerophytic plant with moderate tolerance to drought and salinity.	Aloe improves physical strength, potency, liver functioning and gives relief from cough, fever and burns.
Ratanjot *Jatropha curcas*	Can be successfully grown in highly sodic soils (pH 10.2 and ESP 80) using auger-hole planting technique.	Kernel oil rich in linoleic acid is purgative and is used for skin problem and to soothe pain caused by rheumatism.
Bhringraj *Eclipta alba*	Plants have wide ecological adaptation; performs well in partially reclaimed sodic lands. Seed germination is not affected by moderate salinity.	Promotes digestion, purifies blood and promotes blood formation, enhances memory and acts as an anti-aging agent. It checks hair loss and stimulates hair growth.
Liquoorice *Glycyrrhiza glabra*	A salt tolerant species. After continued cropping with liquoorice, saline soils may revert back to normal condition.	Roots are sweet and soothing, detoxify the liver, act as a strong anti-inflammatory agent and are used in conditions such as arthritis and mouth ulcers.
Sacred basil *Ocimum sanctum*	Moderately salt tolerant, performs well in saline and sodic soils with EC_e up to 8 dS m^{-1}, pH 9.2 and ESP 45.	Leaf oil shows anti-bacterial, anti-inflammatory and insecticidal properties. It is used to cure cough, cold, fever and bronchitis. It improves digestive functions, strengthens heart and purifies blood.
Indian Ginseng *Withania somnifera*	Moderately salt tolerant, can be grown successfully on alkali soil (pH ~9.5), calcareous soils and can be irrigated with saline water (EC_{IW} up to EC 12 dS m^{-1}).	Roots contain withanolideswhich exhibits excellent antioxidant, anti-inflammatory, immune-modulating and anti-stress properties.
Neem *Azadirachta indica*	A hardy tree, it grows well in degraded lands. It tolerates moderately calcareous soils, soil pH up to 9.8 and soluble salts up to 0.45%.	Kernel oil, and the bark and leaf extracts are used to treat leprosy, intestinal helminthiasis, respiratory disorders and constipation. Oil is used to treat skin infections. Twigs are used as toothbrush to keep the teeth and gums healthy.
Arjun *Terminalia arjuna*	Grows successfully in saline (EC_e 10 dS m^{-1}) and alkali (pH around 9.5) soils.Older plantations can gradually ameliorate the alkali lands.	Tree bark is highly valued as a cardiac tonic and is recommended for treating heart related illnesses. Powdered bark is used for alleviating angina and other cardiovascular problems.

Bael *Aegle marmelos*	Tolerates saline (EC_e 6-7 dS m^{-1}), sodic (pH 9-10) and dry conditions.	Unripe fruit is astringent and digestive, and used to cure diarrhea and dysentery. Sharbat prepared from ripe fruits is cooling and effective in digestive ailments. Leaf extract controls blood sugar level.
Karanj *Pongamia pinnata*	Tolerates moderately calcareous, dry, sodic and saline soils.	Leaf infusion relieves rheumatism and leaf decoction is a remedy for cough. Fresh stem bark is applied to reduce the enlargement of the spleen. It is astringent and taken internally to relieve bleeding heamorrhoids.

Plant response to salinity

Saline and sodic soils having excess soluble salts and exchangeable sodium, respectively, are collectively referred to as salt-affected soils (SAS). In some cases, both soluble salts and exchangeable sodium may be present resulting in saline-sodic conditions. Abundance of soluble salts, mainly consisting of the chlorides and sulphates of Na^+, Ca^{2+} and Mg^{2+}, raises the saturation extract electrical conductivity (EC_e) of soils (≥ 4 dS m^{-1}) which in turn leads to the reduced water availability and specific ion toxicities in plants. High exchangeable sodium percentage (ESP >15) in sodic soils deteriorates the soil structure, impedes the water and air flows, reduces water holding capacity and hampers the root penetration. Plants exposed to salinity stress initially suffer from osmotic stress and the roots fail to extract sufficient water for metabolic requirements even when water is present in sufficient amounts. This condition is referred to as the 'water-deficit effect' of salinity. Depending on the plant species, osmotic stress may last for few days to weeks or even months. Subsequently, salt ions (Na^+ and Cl^-) enter inside the plants and lead to a variety of physiological abnormalities. This is called the 'salt-specific' effect of salinity. Various effects of salinity stress on the growth and development in MAPs, and the possible remedial measures to overcome the salt-induced damage are briefly discussed under the following heads:

Seed germination: Elevated salt levels hamper the seed germination and seedling emergence by lowering the soil osmotic potential, retarding water uptake by seeds and by causing injury to the seed embryo (Zekri, 1991). NaCl-induced salinity considerably decreased seed germination and early seedling growth in *Withaniasomnifera* (Jaleel*et al*., 2008) and*Perillafrutescens* (Zhang *et al*., 2012) plants. As with other crops, marked inter-generic differences are noted for salt-inhibited seed germination in MAPs. For example, application of NaCl water (0-10 dS m^{-1}) did not significantly reduce seed germination percentage in basil (*Ocimumbasilicum* L.) and rocket (*Eruca sativa* L.) but led to substantial reductions in parsley (*Petroselinumhortense*Hoffm.) (Miceli *et al*., 2003). Similarly, isabgol seeds showed almost complete germination when treated with using 5000 ppm saline solution (Dagar *et al*., 2006).

Plant establishment and survival: Salinity induced growth reduction in MAPs varies with the species/genotype, growth stage and the environmental conditions. Salinity suppresses the shoot growth by arresting leaf initiation and expansion and the growth of internodes. While initial reductions in growth may occur due to osmotic stress, tissue Na^+ and Cl^- concentrations shortly attain toxic levels and further debilitate the plant growth. Some species may be susceptible to excess Na^+ while others to Cl^-. Under certain conditions, both Na^+ and Cl^- may be equally injurious and may act synergistically to hamper the plant growth. Saline irrigation reduced the biomass and foliage oil yield in peppermint (*Mentha × piperita* L.), pennyroyal (*Menthapulegium* L.) and apple mint *(MenthasuaveolensEhrh.*) (Aziz *et al*., 2008).In pennyroyal, 25 mMNaCl caused concurrent reductions in growth and tissue hydration in the first 15 days of salinity exposure suggesting that osmotic stress was the main cause of growth reduction (Oueslati *et al*., 2010). Similarly, NaCl (1500 ppm) treated *Thymus vulgaris* L. plants showed significant decrease in stem length, branching and fresh and dry plant mass (El-Din *et al*., 2009). In certain species, low-to-moderate salinity often improves the plant growth. In sea fennel (*Crithmummaritimum*), for example, 50 mMNaCl had a growth promoting effect but plants succumbed at 200 mMNaCl. Plants treated with 50 mMNaCl had higher root length and leaf number and thus higher biomass. While leaf hydration did not change, Na^+ and Cl^- accumulation in shoots suggested their probable role in osmotic adjustment (Amor *et al*., 2005). In chamomile (*Matricariachamomila*) plants, branching, flowers production, peduncle length and flower head diameter progressively decreased with increasing salinity (Razmjoo *et al*., 2008). In clary sage (*Salvia sclarea*L.), plant growth reduced by over 40% at 75 mMNaCl probably due to both osmotic and salt-specific effects (Taarit *et al*., 2011). Among bael

(*Aeglemarmelos* Correa) cultivars, NB-5 was found to be salt tolerant, while NB-9 and CB-2 performed poorly after prolonged exposure to salinity (Singh *et al*., 2016).

Physiological relations: Salt stress drastically alters the physiology of crop plants. The effects are manifested as membrane injury, solute leakage, altered leaf water relations, loss of leaf pigments, reduced stomatal conductance and photosynthesis. Stress conditions result in the disintegration of plasmalemma and lipid membranes in the plant cells. These alterations enhance the cell permeability and solute leakage. Irrigation with80 mMNaClsignificantly enhanced lipid peroxidation in *Phyllanthusamarus* (Jaleel *et al*., 2007b) and *Catharanthusroseus* L. plants (Jaleel *et al*., 2007a). Increasing NaCl content in irrigation water (0-160 mM) enhanced the oxidative stress and lipid peroxidation in *Artemisia annua* L. plants (Qureshi *et al*., 2005). In certain MAPs, moderate salt stress may enhance the activities of anti-oxidant enzymes to scavenge the reactive oxygen species (ROS) and thereby protecting the plants from their adverse effects. Sea fennel (*Crithmummaritimum*) plants had higher levels of antioxidant enzymes like superoxide dismutase, catalase and peroxidase, especially in shoots at 50 mMNaCl than control (Amor *et al*., 2005). While salinity retards water uptake by the plant roots, actively growing leaves continue to transpire resulting in reduced relative water content and leaf dehydration. Reductions in leaf and cell hydration alter the water balance of plants and account for the initial reductions in plant growth under saline conditions. Saline irrigation (EC_{iW} 8 dS m^{-1}) markedly altered the plant water balance in cumin (*Cuminumcyminum*L.) with effects being more pronounced at the flowering than at the vegetative stage (Garg *et al*., 2002). In *Crithmummaritimum* (Sea fennel), leaf water relations were unaffected by salinity (Amor *et al*., 2005).

Salt stress hastens the loss of leaf chlorophyll pigments giving the plants a pale look. Unabated loss of chlorophyll results in severe leaf chlorosis impairing the ability of leaves to produce sufficient assimilates for the plant growth. *Withaniasomnifera* plants exhibited lower leaf chlorophyll contents when irrigated with 40 mMNaCl (Jaleel *et al*., 2008). Salinity induced oxidative stress damaged the photosynthetic apparatus resulting in the loss of chlorophyll, decline in photosynthesis, biomass production and artemisinin biosynthesis in *Artemisia annua* L. plants (Qureshi *et al*., 2005). In leaves, chlorophyll remains bound to the cell membranes suggesting that salt-induced damage to the membranes will also affect the stability of chlorophyll molecules. The loss of leaf chlorophyll in salinized plants thus largely results due to damage to the cell membranes. Reduced chlorophyll levels in salt stressed plants may be ascribed to the alterations in enzymatic activities as excessive Na^+ and Cl^- ions impair the functions of nearly all the important enzymes. In order to cope up with osmotic stress, salinized plants tend to reduce the stomatal conductance to arrest the water loss from leaves which may also decrease the photosynthesis. In peppermint (*Menhtapiperita*) and lemon verbena (*Lipiacitriodora*) plants, net photosynthetic rate was least affected up to 2.8 dS m^{-1} but considerably dropped at 5.6 dS m^{-1} and above salinity levels (Tabatabaie and Nazari, 2007). Some plants may endure high salinity without showing any appreciable reductions in carbon assimilation: net photosynthesis and transpiration rates were unaffected by the increasing NaCl levels in *A. majus* L. (Ashraf *et al*., 2004).

Biochemical responses: Under salt stress, plants tend to accumulate osmo-protectants and antioxidant enzymes to overcome the osmotic and oxidative stresses. Proline is one of the major metabolites in the plants under stress conditions. Proline content mostly increases in salt stressed plants where it could act as an osmoprotectant and/or a storage source of N. Salt tolerant and salt sensitive genotypes vary with each other in proline accumulation in saline soils. Shoot proline content markedly increased in saline irrigated *A. majus* plants (Ashraf *et al*., 2004). Continued accumulation of ROS such as superoxide radical (O_2^-), hydrogen peroxide (H_2O_2) and hydroxyl radicals (HO^-) induces the formation of lipid radicals which cause damage to the cell membranes. ROS up-regulate the enzymatic antioxidant system in plants. The main antioxidant enzyme is superoxide dismutase (SOD). It is a metallo-protein that catalyzes the conversion of superoxide radical into hydrogen peroxide. There are several SOD isozymes: Mn-SOD, Cu/Zn-SOD and Fe-SOD. To avoid hydrogen peroxide accumulation, a compound even more damaging than the superoxide radical, two enzymes, catalase (CAT) and ascorbate peroxidase (APX) detoxify this compound and yield water and oxygen (Arbona *et al*., 2003). Exposure of *Withaniasomnifera* Dunal plants to 40 mMNaCl caused changes in the activities of antioxidant enzymes like SOD, CAT, peroxidase (POX) and polyphenol oxidase (PPO). Triadimefon (5 ppm) application partially mitigated salt stress by upregulating the antioxidant activities (Jaleel *et al*., 2008). Antioxidant enzymes SOD, POX and CAT were upregulated by salt stress in *Phyllanthusamarus* (Jaleel *et al*., 2007b) and *Catharanthusroseus* (L.) plants (Jaleel *et al*., 2007a). Salt treated *Menthapulegium* L. plants showed appreciable changes in the activity of antioxidant enzymes (Oueslati *et al*., 2010). Severe reduction in plant growth in sea fennel at 200 mMNaCl was attributed to diminished efficiencies of SOD, CAT and POX (Amor *et al*., 2005).

Mineral nutrition: Plant growth and productivity is adversely affected by salt-induced nutritional disorders resulting from ionic imbalances, competitive uptake and transport or partitioning within the plant. In saline soils, Na^+ and Cl^- ions reduce K^+ and NO_3^- uptake. An increase in Cl^- uptake is often accompanied by a decrease in shoot- NO_3^- levels. Similar to N, interactions between salinity and P nutrition are also very complex and depend on factors such as plant species or cultivar, growth stage, level of salinity and the soil concentration of P. For enduring the salinity stress, plants need to maintain adequate K^+ levels. In contrast, under saline conditions, higher levels of Na^+ repress K^+ absorption by the roots. Similar to N, P and K, most of other macro and micro-nutrients are deficient in saline soils (Grattan and Grieve, 1999). In certain cases, nutrient toxicities may also prove a growth limiting factor in salt-affected soils. For example, boron toxicity is a major concern in most of the arid saline areas (Nicholaichuk *et al*., 1988). Salt stress led to increased Na^+ levels and a concomitant decrease in K^+ in different plant parts of *Menthapulegium* L. (Oueslati *et al*., 2010). K^+, Ca^{2+} and Mg^{2+} levels significantly declined in shoots of salinized (200 mMNaCl) *Crithmummaritimum*plants (Amor *et al*., 2005). Saline irrigated (75 mMNaCl) clary sage (*Salvia sclarea*L.) plants showed restricted uptake of K^+ and higher uptake of Na^+ ions (Taarit *et al*., 2011). While both Na^+ and $Cl^−$ increased in shoots and roots, K^+ and Ca^{2+} consistently decreased with increasing salinity in *Ammimajus* L. plants (Ashraf *et al*., 2004).

Salt tolerance of medicinal and aromatic crops

The indigenous system of using wild plants for treating mental and physical sufferings of humanity thrives on naturally occurring floral diversity referred as medicinal plants. Till now more than 250000 plant species have been identified and of which over 7000 species are used by different ethnic communities in our country. One–third of these are trees and equal numbers are herbs including grasses while remaining one-third are shrubs and climbers. The information on salinity and sodicity tolerance limits of some medicinal and aromatic crops is compiled in table 2. Assessment on salt tolerance of medicinal and aromatic crops by some researchers (Patra and Singh, 1995; Dagar et al. 2004; Tomar and Minhas 2004a & b) has shown promise for cultivation of some medicinal and aromatic plants on degraded salt affected soils and irrigation with poor quality water.

Table 2. Salinity and sodicity tolerance of different medicinal and aromatic plants

Crops	Salinity tolerance (EC dS m^{-1})		Sodicity tolerance	
Aromatic Crops	Soil EC_e	Irrigation water	Soil (pH_s)	ESP
Palmarosa	9-12	14-16	9.5	55
Lemon grass	8-10	7-8	9.0	50
Citronella	4-5	5-6	8.5	25
Jamrosa	10-12	9-10	10.0	45
Vetiver	9-10	10-11	9.5	55
Marigold	4-5	5-6	8.8	40
Medicinal plants				
German Chamomile.	10-12	8-10	9.5	--
Isabgol	7-8	11-12	9.5	--
Periwinkle	6-8	8-10	10.0	--
Rye for ergot of rye	10-12	12-15	9.6	--
Egyptian Henbane	7-8	8-10	8.9	--
Artemisia	8-10	8-10	8.4	--
Sowa/Dill	8-9	6-8	8.6	--
Vasaka	--	8-10	--	--
Aloe	8-10	10-12	8.4	--
Kair	18-20	15-18	8.6	--
Euphorbia	12-14	10-12	8.8	--
Jamalghota	6-8	6-8	8.7	--
Tulsi	--	8-10	8.6	--
Senna	9-10	10-12	8.7	--
Chanrasura/Halim	10-12	15-17	8.6	--
Satavari	7-8	10-12	8.2	--
Aswagandha	8-10	10-12	8.4	--
Mentha	4-5	4-5	8.6	--

Observations of different researchers indicated that in general medicinal and aromatic plants are comparatively more tolerant to salinity than sodicity. Very useful information on cultivation of certain medicinal and aromatic crops under saline environment has been compiled by (Patra and Singh, 1995; Tomar and Minhas, 2002 a & b). Dagar et al. (2004 and 2005) have demonstrated that medicinal and aromatic crops as Isabgol, Periwinkle, Tulsi, Aloe, Vasaka, Jatropha and different aromatic grasses like Palmarosa, Lemon grass and Vetiver can be successfully grown on salt affected soils and irrigation with saline water (10-12 dS m^{-1}). Threshold limits of soil salinity for Periwinkle and German chamomile is 10 and 12 dS m^{-1} as against the less tolerant medicinal plants like Egyptian henbane, Tulsi and Mentha. Isabgol can tolerate about 8-9 dS m^{-1} of salinity. Results from micro-plot studies using irrigation water of salinity 8.0 dSsm^{-1} did not show any adverse impacts on grain or straw yield of this crop. Senna and garden cress have also shown good promise for cultivation under saline conditions. Field studies on salinity tolerance of these crops have indicated that yield and quality of these two species was not affected adversely when irrigated respectively with 10 and 17 dS m^{-1} salinity water. Reports also indicated that salinity or sodicity of soils or irrigation water did not have any adverse effect on their oil yield or quality. Moreover, there are reports that quality with respect to active principle components improves under salt stress. Lodha (2005) also reported higher sennosides content in Senna and garden cress oil content and quality under salt stress.A brief account of net return as shown below in Table 2 revealed that the vetiver cultivated in alkali (sodic) soils of pH 9.0 and 10.0 gave net return of Rs. 20,480 and Rs. 13,427 /ha, respectively.Low oil yield in salt stressed peppermint and apple mint were attributed to salinity induced reductions in plant biomass (Aziz *et al*., 2008). Saline irrigation (0.39- 9.38 dS m^{-1}) caused significant decrease in flower head diameter and pigment (total flavonoids and carotenoids) contents in *Calendula officinalis* L. (Khalid and da Silva, 2010). Salinity suppressed fresh and dry flower weights and essential oil production in chamomile (Razmjoo*et al*., 2008). NaCl induced salinity (25 mM) significantly reduced essential oil yield in clary sage (Taarit *et al*., 2011). Irrigation with high RSC water leads to yield reduction in palmarosa (Singh *et al*., 1994a) and Java citronella (Singh *et al*., 1994b). Saline irrigation (4, 8, 12 and 16 dSm^{-1}) had no significant effect on oil yield, chemical composition and apigenin content in chamomile suggesting that it could be a profitable crop in salt-affected soils (Baghalian *et al*., 2008).Increasing salt concentrations in irrigation water caused a significant reduction in fresh and dry weights of shoots and roots and seed yield in Bishop's weed (Ashraf *et al*., 2004).

Sometimes moderate salinity may prove beneficial. It is beyond doubt that salt concentrations above the critical threshold adversely impact plant growth in most of the cultivated crops. However, under certain conditions, moderate levels of salinity indeed enhance the growth and productivity of some crops. In salinized pennyroyal plants, foliage oil yield was higher than control implying that oil synthesis was insensitive to salt stress (Aziz *et al*., 2008). Essential oil percentage increased with increasing salinity in *Thymus vulgaris* L. and the highest essential oil yield was obtained with the application of 4500 ppm NaCl (El-Din *et al*., 2009). Saline irrigated *Calendula officinalis* L. plants had higher essential oil content and a high concentration of main oil constituents (α-cadinol, γ- and Δ-cadinene) than control (Khalid and da Silva, 2010). In lemon grass, application of 50 mMNaCl stimulated plant growth and essential oil yield. Furthermore, biosynthesis of oxygenated monoterpenes was stimulated in response to 50, 100 and 150 mMNaCl (Khadhri*et al*., 2011). Mild salinity stress may augment essential oil production and quality by positively affecting certain aroma constituents in parsley (Petropoulos *et al*., 2009).

Table 3. Yield (root and oil) and economic return from vetiver in sodic soil

Soil	pH	EC (dS/m)	Yield (kg/ha)		Net return (Rs./ha)
			Root	Oil	
I	9.0	2.5	27.2	16.3	20,480
II	10.0	2.6	19.9	11.3	13,427

The results from field experiments involving varieties of two aromatic grasses viz. palmarosa and lemongrass grown on sodic soil indicated that in some cases herb yield reduced due to high sodicity but since the oil content under stress condition was higher, the oil yield was not considerably affected as compared to normal soil. It was further observed that active ingredient in palmarosa (geraniol) and lemongrass (citral) also increased under sodic conditions compared to normal soils (Table 3).

Table 4. Yield (herb and oil) and quality of oil of varieties of aromatic grasses under sodic and normal soil

Yield/yield attributes	Palmarosa		Lemongrass	
	PRC-1	RRL B77	Pragati	Jor lab L 2
Yield (t/ha) herb of 3 cuts	38.5 (47.4)	39.3 (52.5)	29.0 (35.9)	30.9 (37.6)
Oil content (%)	0.75 (0.63)	0.65 (0.57)	0.65 (0.52)	0.64 (0.52)
Oil yield (kg/ha)	288.8 (298.6)	255.4 (299.2)	188.5 (186.2)	197.8 (195.5)
Geraniol/citral (%)	90.0 (89.2)	88.5 (87.5)	85.0 (76.0)	89.2 (76.2)

Figures in parentheses give the corresponding values under normal soil. *Source: Patra et al. (1997)*

Kumar et al. (2003) reported that oil yield of aromatic grass palmarosa increased significantly by 24.5 percent at ESP 55 over ESP 16 (control). Further increase in ESP upto 85 decreased the oil yield by 36.5, 57.5 and 71.8 percent, respectively over yield obtained under ESP 55 (Table 5).

Table 5. Effect of ESP levels on oil yield of palmarosa (sum of 5 cuts)

ESP levels	Oil yield (g/pot)
16 (control)	2.45
55	2.88
65	1.84
75	1.16
85	0.77
CD (5%)	0.025

Aromatic grass vetiver has been reported to withstand soil sodicity (pH 9.0) and periodic water logging without adverse effect on yield and quality of oil (Singh *et al.*, 1987). It is clear from the data in Table 6 that significant reduction took place in both root (16.91) and oil (17.0%) yield at pH 9.5 over control (pH 7.5).

Table 6. Influence of soil pH on root and oil yield of vetiver

Soil pH	Oil content	Yield	
		Root (g/pot)	Oil (ml/plant)
7.5 (control)	0.045	172.8	0.78
8.0	0.046	181.2	0.85
8.5	0.045	161.3	0.74
9.0	0.045	159.8	0.72
9.5	0.045	143.5	0.63
10.0	0.046	109.1	0.50
10.5	0.046	91.9	0.42
11.0	0.046	66.7	0.31
CD (5%)	-	15.3	0.14

Source: Anwar *et al.,* (1996).

It is documented that *Tagetesminuta* (African marigold) was grown on soils of ESP 45 without reduction in yield of herb as well as oil. Moreover the dihydrotagetone content in *Tagetesminuta* oil increased considerably due to sodicity (Table 7).

Table 7. Effect of ESP on the herb and oil yield and dihydrotagetonecontent inessential oil of Tagetesminuta

Soil ESP levels	Herb yield (kg/plant)	Oil yield (ml/plant)	Dihydrotagetone (%)
1.2	25.7	0.18	22.1
6	41.6	0.27	24.7
16	34.6	0.25	30.4
24	33.6	0.25	31.5
45	28.8	0.21	33.2
CD (5%)	3.6	0.025	-

Source: Prasad *et al*. (2002)

Similarly Prasad *et al*. (1997) also reported that oil content increased in palmarosa due to sodicity. Sodicity also improved the oil composition as geranyl acetate in the oil of palmarosa increased with increase in soil ESP from 5 to 65 (Table 8).

Table 8. Effect of ESP on oil content and its composition in palmarosa oil

ESP	Oil content (%)	Oil composition	
		Geraniol	Geranyl acetate (%)
5 (control)	0.4	79.4	10.0
16	0.4	78.5	10.5
35	0.5	76.3	12.2
48	0.6	75.1	13.7
65	0.4	78.1	14.9

Results of the experiments conducted at CSSRI farm at Hisar indicated that medicinal plants like IsabgolTulsi and aloe produced equivalent yield with saline irrigation water compared to canal irrigation water (Table 9). Similarly aromatic plants also produced good yield with saline irrigation water alone or alternate use of saline and canal water irrigation (Table 10).

Table 9. Yield of some medicinal plants with saline water irrigation

Crops	Botanical name	Saline Water	Canal Water	CW/SW	$LSD_{0.05}$
Isabgol, (unhusked grain yield, t/ha)	*Plantagoovata*	1.014	1.059	1.091	NS
Periwinkle, (flower yield t/ha)	*Catharanthus roseus*	0.12	1.15	0.18	0.69
Tulsi, (dry wt. of shoot, t/ha)	*Ocimmum sanctum*	0.91	1.06	0.93	NS
Aloe, (fresh wt./plant, kg)	*Aloe barbadensis*	5.56	3.18	2.59	-

Table 10. Biomass of some aromatic plants with saline water irrigation

Crops	Dry weight of shoot biomass (t/ha)			$LSD_{0.05}$
	SW	CW	CW/SW	
Palmarosa,	24.3	34.0	29.1	4.8
Lemon grass	14.0	19.2	15.1	2.1
Vetiver	7.26	9.47	9.38	1.73

Uses of salt tolerant medicinal and aromatic crops

The information on drugs or aroma yielding plants and their efficiency in medicines is available and updated regularly in many authentic sources as Indian Pharmaceutical Codex, British Pharmaceutical Codex, United States Pharmaceutical Codex and National Formulary *etc*. The drugs extracted from medicinal and aromatic plants have been found successful in controlling serious diseases as cancerous tumors, HIV, hypertension, rheumatoid arthritis, digestive disorders, used as contraceptives and treatment of many other ailments. Extracts of different medicinal and aromatic crops are used in pharmaceutical, food, flavor and cosmetic industries. However, some of the medicinal and other important specific uses of salt tolerant medicinal and aromatic crop species compiled from literature are presented in Table 11. The economics of these crops in comparison to other cultivated conventional crops needs to be assessed in addition to availability of the local market for sale of the produce that can boost their cultivation.

Reclamation of salt affected soils

Several studies have established that cultivation of medicinal plant as Isabgol and aromatic grasses like Palmarosa, Lemon grass and Vetiver can reduce pH, EC, ESP and Na of salt affected soils (Table 12 and 13). In case of aromatic grasses the reclamation process occurs through improvement of physico-chemical properties of sodic soils due to extensive growth of roots which increase permeability of soil.

Table 11. Medicinal uses of different medicinal and aromatic plants

Crop/species	Medicinal Uses
Aromatic crops	
Palmarosa (*Cymbopogonmartinii*)	Oil contains geraniol, and emit rose like aroma used in perfumes, tobacco, soaps, medicines
Lemon grass (*Cymbopogonflexuosus*)	Contains citral used in vitamin-A, other edible recepies, perfumery, cosmetics
Citronella ((*Cymbopogonnardus*)	Oil has mosquito repellant characteristics, also used in cosmetics and perfumery
Vetiver (*Vetiveriazizanioides* Linn.)	oil from roots used in perfumery, cosmetics and flavouring sherbets
Medicinal plants	
German Chamomile (*Matricariachamomilla* L.).	Flowers yield essential oil used as expectorant, sedative, perfumery, gastric stimulant
Isabgol (*Plantagoovata*Forsk.)	Mucilage present in husk helps in cure of various intestinal, blood and cough ailments
Periwinkle (*Catharanthusroseus*)	All parts are used for treatment of tumors, menorrhagia, leukemia and antibacterial uses
Rye for ergot (*Clavicepspurpurea*)	Dried sclerotium used in contraction of uterus and bladder, controls bleeding. Ergotamine used for migraine
Satavar (*Asparagus racemosus*)	Roots rich source of minerals and other chemicals used for gas and lever, leucoria and as tonic
Aswagandha (*Withaniasomnifera*)	Alkaloids are anti-cancer, anti-sleeplessness and immune system motivators
E. henbane (*Hyoscyamusmuticus*).	Tropane and hyscine are used in treatment of cold, cough, lever pain and apoplexy
Sowa/Dill (*Anethumgraveolens*)	Essential oil is given to children for flatulence, seeds are used as carminative and stomachic
Vasaka (*Adathodavasica*)	Bark and leaves extract has antiviral activity, used in cold, cough, bronchitis, rheumatic pain etc.
Aloe (*Aloe barbadensis*)	Extract is cathartic, used in lever, spleen, piles, rectal, menstrual and constipation problems
Kair (*Capparisdeciduas*)	Fruit used in cardiac problems, bark used in cough and asthma. Fruits are used as pickles.
Mint (*Menthacitrata*)	Mint oil has great industrial value and also used in flavors of candies, anta-acids and other fresheners
Euphorbia (*Euphorbia antisyphilitica*)	Extract antisyphlatic and is a potential petro-crop
Jamalghota (*Jatrophacarcus* Linn.)	Extract used in toothache, diarrhea, skin infections
Tulsi (*Ocimum sanctum* Linn.)	Leaves stimulants, anti-cough, yield essential oil
Senna (*Cassia angustifolia*)	Leaves and fruits laxative, vermifuge, purgative
Chandrasura (*Lepidium sativa*)	Oil is rubifacient/antinflamatory and galactogogic

Table 12. Ameliorative effects of different aromatic grasses on salt affected soils

Crop	Soil pH (1:2.5)		Soil EC (dSm^{-1})		ESP		Authors
	Initial	Harvest	Initial	Harvest	Initial	Harvest	
Palmarosa (2yrs)	10.62	9.40	4.80	0.64	93.0	43.8	Prasad *et al.,* 1995
Lemongrass	9.80	8.95	1.25	1.35	60.0	52.8	Patra et *al.,* 2002
Vetiver	10.50	9.50	--	--	82.0	--	Anwar *et al.,* 1996
Vetiver	9.50	9.00	--	--	56.5	38.7	Anwar *et al.,* 1996
Isabgol	10.00	9.70	1.25	0.81	60.0	48.4	Patra e*t al.,* 2002

As a result of decomposition of roots, CO_2 may be evolved which resulted in solubilisation of native $CaCO_3$. This process takes place much effectively in the fields of vetiver which has the ability to withstand even under water logged conditions in sodic soils. A marked decrease in the ESP of soils and changes in Na and pH after harvesting of vetiver has proved the ameliorative potential of this crops on such soils (Table 13).

German chamomile could also help in ameliorating the sodic soils through higher update of sodium a especially harmful cation. It is reported that this crop absorbed sodium to the extent of 66 meqNa/100 g of dry matter and improve alkali soils through ion uptake.

Table 13. ESP and Na of sodic soil before planting and after harvesting of vetiver

Before planting			After harvest of crop		
ESP	pH (1:2.5)	Na (meq/L)	ESP	pH (1:2.5)	Na (meq/L)
10	8.0	87.6	9	7.5	83.6
15	8.5	89.9	14	8.0	86.8
30	9.0	108.9	28	8.3	100.1
50	9.5	122.5	35	9.0	114.1
65	10.0	125.4	42	9.3	118.6
80	10.5	135.9	50	9.5	132.1
85	11.0	152.5	61	9.6	147.6

Conclusion and future perspective

The inherent capability of a particular genotype to sustain relatively high salt levels has been observed in several MAPs. Such salt tolerant genotypes and their diverse germplasm maintain adequate growth under salt stress. Suyin 1 variety of peril (*Perillafrutescens*) was observed to be more salt tolerant thanZiye 10. Similarly Malaysian accessions of *Andrographis paniculata* (11261 and 11265) grew well in saline (EC_{iw} 5 dS m^{-1}) irrigation with no adverse effect on phytochemical content. It is desirable that diverse germplasm lines available in different MAPs should be screened for identifying the superior salt tolerant genotypes for use as commercial cultivars and/or parents in genetic improvement programs. Ranking of cultivars for salt tolerance may benefit the prospective growers in selecting a high yielding salt tolerant cultivar. Pre-sowing irrigation with fresh water may considerably lessen the anticipated damage to seeds by leaching the soluble salts to lower depths. In MAPs amenable to grafting, identification of salt excluder rootstocks should be prioritized. In certain cases, seed priming with GA_3 can significantly improve the seed germination and seedling establishment.Available evidence suggests that salt tolerant MAPs can easily be grown in such areas with the aid of improved planting, irrigation and other management techniques. In fact, perennial MAP plantations can lead to substantial improvements in soil quality of salt-affected lands in the long run.

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Modeling for Conjunctive Use Irrigation Planning in Sodic Groundwater Areas for Sustainability of Rice-wheat Rotation in Haryana

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Introduction

In arid and semi-arid parts of north and north-western India, use of poor quality groundwaters for irrigation in wheat based crop rotations is a common practice. The shortage of water in these areas is so acute that there seems no other way except harnessing the available poor quality groundwaters. The use of poor quality waters in India ranges from 32-84 percent of total groundwater development (Minhas and Gupta, 1992). In the poor quality water areas, the extent of saline, sodic and saline-sodic waters are approximately 20, 37 and 43 percent, respectively (Yadav and Kumar, 1995). Poor quality sodic water zones occur in Uttar Pradesh, Haryana, Punjab and Rajasthan. Sodic water occupies 25 and 21 percent in Punjab and Haryana, respectively. AICRP on Saline Water, Central Soil Salinity Research Institute, Karnal, Haryana Agricultural University, Hisar and Punjab Agricultural University, Ludhiana jointly developed and recommended guidelines for use of saline and sodic waters for crop production under Indian monsoon type of climate (Gupta *et al.*, 1994).

Solute transport in the soil as a result of sodic water irrigation is reactive transport and it is controlled by cation exchange capacity and hydraulic conductivity of the soil. A linear relationship exists between cation exchange capacity (CEC) and clay percentage while the hydraulic conductivity has an exponential relationship with clay percentage. Both properties vary spatially and an ESP (Exchangeable Sodium Percentage) development in the topsoil layer as a result of sodic water irrigation is not influenced by spatial variability of these soil properties. However, irrigation water quality and its temporal variability can influence ESP development (Kaledhonkar *et al.,* 2001, 2006; Kaledhonkar and Keshari, 2006a, 2006b). Temporal variability in irrigation water quality might occur due to alternate use of sodic and canal water or due to occurrence of rains. Though ESP is not influenced by spatial variability in soil properties, adsorption of sodium ions is directly proportional to CEC of the soil. Thus, soil with higher CEC may have higher sodium ions at soil exchange complex compared to soil with lower CEC at the same ESP value (Kaledhonkar, 2003). Soils having different CEC values might show different desorption behaviour on application of canal water or occurrence of rains. There is need to understand these behaviours for making/ improving guidelines on sodic water irrigation.

The joint guidelines (Gupta *et al.*, 1994) for use of saline and sodic waters for *kharif* fallow/ *rabi* crop rotation provided limits of SAR and RSC of irrigation water, considering soil textural group and annual rainfall of the region. In this research existing guidelines for use of sodic waters were further investigated through UNSATCHEM modeling. Improved guidelines were verified with published and field data. Sustainability of rice-wheat rotation under conjunctive use of sodic groundwater and canal water, in Assandh and Nissang blocks of Karnal district, was assessed with help of the improved guidelines.

Haryana state is a part of the Indo-Gangetic plain, which consists of alluvial deposits from the Himalayas. The soils are of medium texture and homogeneous. The climate in the area is semi- arid, continental subtropical characterized by long hot summers and cool winters without substantial night frost. The mean annual precipitation and potential evapotranspiration (PET) in the state vary from 300 to 1000 mm and from 1200 to 1650 mm, respectively. The state has saucer shape topography with depression of inland basin between Indus and Ganges basin. Rainfall amount decreases, PET increases and groundwater quality deteriorates in the state from the northeast to southwest direction towards the inland basin. In between fresh groundwater area of northeast and saline groundwater area of southwest, there are patches of sodic groundwaters. The state receives canal water from Western Yamuna Canal (WYC) system and Bhakra canal system. As state is under intensive agriculture and canal water supply is limited, use of groundwater for irrigation is common. The use of sodic and saline waters for irrigation in the areas enhances the soil salinisation and sodification.

Understanding the Soil Variability

Data on the soil properties such as textual class, soil moisture retention characteristic, cation exchange capacity, saturated hydraulic conductivity, bulk density, etc. from different places in the commands of the

Bhakra Canal system and Western Yamuna Canal system in Haryana were collected from Sood (1969) and Sharma (1972). The sandy loam is dominant textural class in the area. Therefore, data relating to sandy loam class from 27 samples were pooled together irrespective of location, and used in further analysis. The data of CEC expressed in mmol$_c$/kg followed log normal distribution with mean ($\mu_{ln(CEC)}$) and standard deviation ($\sigma_{ln(CEC)}$) as 4.25 and 0.28, respectively. Data of saturated hydraulic conductivity (Ks) in cm/day also followed lognormal distribution with mean ($\mu_{ln(Ks)}$) and standard deviation ($\sigma_{ln(Ks)}$) as 4.02 and 0.52, respectively. The statistical properties of CEC and Ks were used to prepare three soils with combinations of CEC and Ks as mentioned in Table 1. The three soils, considered for analysis, represented the possible variability in sandy loam textural class within the region.

Table 1. Properties of different sandy loam soils

Soil	CEC (mmol$_c$/kg)		Ks (cm/day)	
A	$\mu_{ln(CEC)}+\sigma_{ln(CEC)}$	93.18	$\mu_{ln(Ks)}+\sigma_{ln(Ks)}$	33.37
B	$\mu_{ln(CEC)}$	70.11	$\mu_{ln(Ks)}$	55.91
C	$\mu_{ln(CEC)}-\sigma_{ln(CEC)}$	52.74	$\mu_{ln(Ks)}-\sigma_{ln(Ks)}$	93.18

In irrigation water quality guidelines, Gupta *et al.* (1994) defined moderately coarse group of soils as soils with 10-20% clay. Sandy loam textural class mainly belongs to this group. Safe limits for RSC and SAR of irrigation water for moderately coarse soils are 5-7 and <15, respectively. These limits pertain to *kharif* fallow/*rabi* crop rotation when annual rainfall is 350-550 mm. These guidelines are of general type. It would be interesting to study how the irrigation water quality safe limits vary with variability in soil properties within a textural class and variability in rainfall amount.

UNSATCHEM Modeling to Improve Guidelines

The one-dimensional variably saturated flow and multi-component transport model; UNSATCHEM (Simunek *et al*., 1996), was employed for simulations to find the safe water quality limits, for soils in Table 1, considering variability in rainfall/canal amount and consequent variability in sodic groundwater use for irrigation. The model required soil hydraulic properties in terms of soil water retention and hydraulic conductivity parameters (Van Genuchten, 1980). Though variability in CEC and Ks was considered by selecting three soils as given in Table 1, variability of soil water retention parameters such as volumetric saturated water content (θ_s), residual water content (θ_r), α and η was ignored. The average values of these parameters for sandy loam soil class were determined by analyzing an array of (h,θ_{mean}) by the RETC model (Van Genuchten *et al.,* 1991). The θ_{mean} represents the geometric mean of θ values determined from n individual pF curves by following equation.

$$\theta_{mean} = \exp\{(\sum_{i=1,n} \ln\theta)/n\}$$

The geometrically averaged soil water retention parameters θ_s, θ_r, α and η were equal to 0.43, 0.0, 0.033 and 1.31, respectively. The bulk density and Gapon selectivity coefficient were assumed as 1.5 g/cc and 0.35 mol$_c^{-0.5}$/l$^{-0.5}$, respectively.

The model was calibrated and validated by Kaledhonkar *et al*. (2001) for sodic water use experiment on summer moong crop conducted by Dhaliwal (1992). It was also calibrated and validated by Kaledhonkar and Keshari (2003, 2006b) for saline water use experiment on wheat crop conducted by Naresh *et al.* (1993). The calibrated and validated UNSATCHEM model was used for further simulations. The simulations were planned considering sodic water guidelines (Gupta *et al*., 1994), which suggested upper limit of SAR as 15 (mmol$_c$/l)$^{0.5}$ and range of RSC as 5.0-7.5 mmol$_c$/l, for irrigation water use in fallow *kharif* and *rabi* crop rotation on moderately coarse soils with 10-20% clay. These water quality limits were applicable for *kharif* fallow/ *rabi* crop rotation when annual rainfall remained 350-550 mm. As *kharif* fallow/ *rabi* crop rotation required one year, simulation period was taken as one year, starting from pre-sowing of wheat crop to end of monsoon season, for all simulations. As per guidelines, *kharif* season was kept fallow to promote desodification process and wheat crop was assumed during *rabi* season. For each soil given in Table 1, three simulations were done with three levels of rainfall amount i.e., 350, 450 and 550 mm, respectively. Thus total 27 simulations were done. Daily potential soil evaporation and irrigation by sodic water were considered as input at soil surface during simulation. Pre-sowing irrigation and four post-sowing irrigations, for wheat crop, were applied by sodic water. Total irrigation amount was 38 cm. The rainfall during wheat period was assumed as 7 cm. The rainfall events and their amounts, during remaining part of the year, were adjusted to have annual rainfall amounts equal to 350, 450 and 550 mm as required for different simulations. The weather data of Hisar meteorological station in south- western region of Haryana were selected considering its annual rainfall of 420 mm, which was in the range of rainfall selected for simulations. The class A pan evaporation for Hisar station was 2150 mm for period from November 1985 to October 1986. The sowing and harvesting dates of wheat crop were assumed as 10^{th} November 1985 to 20^{th} April 1986. The daily pan data were analyzed to determine reference evapotranspiration during wheat period using CROPWAT model (Smith *et al.*, 1999) and soil evaporation for remaining period (Feddes *et al.*, 1974; Singh, 1983). The average annual class A pan evaporation for Hisar station was 2136 mm and variability in class A pan evaporation data was ignored during simulations. The period November 1985- October 1986 was randomly selected. It was ensured that rainfall of a particular year (i.e. 390 cm) was within the decided range of rainfall (i.e. 350- 550 mm). Penman Monteith method was used to estimate reference evapotranspiration as suggested by Tyagi *et al.* (2000). Evapotranspiration requirement for different growth stages of wheat crop was determined by using crop coefficients such as 0.35, 0.44, 0.84, 1.11, 1.07 and 0.59, respectively (Smith *et al*., 1999).

Initial concentrations of dissolved Ca^{++}, Mg^{++}, Na^{+} K^{+}, HCO_3^{-}, SO_4^{--}, and Cl^{-} were taken as 3.15, 1.55, 1.2, 0.1, 1.6, 2.9 and 1.5 $mmol_c/l$, respectively for all three soils. The corresponding initial adsorbed concentrations of Ca^{++}, Mg^{++}, Na^{+} and K^{+} were determined as 0.66, 0.32, 0.0025 and 0.0124 times the CEC for all soils. These ratios were determined from the field data of Dhaliwal (1992) that were used in calibration and validation of the UNSATCHEM model. Initially soils were assumed as non-sodic. The Gapon selectivity coefficient was assumed as 0.35 $mol_c^{-0.5}/l^{-0.5}$ for all soils (Poonia et al., 1990). Free drainage was assumed at lower boundary. The CO_2 concentration ($cm^3\ cm^{-3}$) was assumed to increase linearly from 0.00033 at the soil surface to 0.0006 at 30 cm depth. It reduced to 0.0004 (at 32 cm) and remained constant up to 50 cm. Below, a constant concentration of 0.0002 $cm^3\ cm^{-3}$ was assumed considering some trapped air in sub layers. The assumption related to CO_2 concentration was based on the presence of the organic matter in the soil due to root activity. A time invariant CO_2 concentration was prescribed depth wise during the simulations.

The quality parameters such as RSC and SAR of sodic irrigation waters during simulations were selected according to irrigation water quality guidelines of Gupta *et al*. (1994). These parameters were worked out by adjusting the concentrations of different ions. As per guidelines, range of RSC of sodic water should be between 5 to 7 $mmol_c/l$ for moderately coarse soil. Therefore an average value of 6 was selected as suitable (safe). During the simulation, SAR value of sodic irrigation water was considered as suitable (safe) under *rabi* wheat- *kharif* fallow crop rotation provided average ESP for 0-30 cm soil layer at the end of simulation period (i.e. at the end of monsoon) remained less than 3. The same value of SAR is referred as threshold SAR for sodic irrigation water. It was assumed that sodification would take place due to sodic water application during wheat crop, while rainfall during monsoon season (fallow period) would help in desodification. The ESP value of 3 is sufficient enough to assume the soil as non-sodic. Hira *et al*. (1980) reported that wheat root growth was unaffected and also wheat yields were not affected significantly when ESP did not exceed 30.5. Wheat plants were reported to tolerate this degree of sodium saturation without yield reduction (Pearson, 1960). The ESP value of 3 (10% of threshold ESP value) was much lesser than threshold value 30.5.

Thus, keeping RSC of sodic water at 6, the threshold value of SAR was determined for each soil (in Table 1) through different repetitive simulations. Temporal changes in 0-30 cm ESP values on application of sodic water having RSC =6 $mmol_c/l$ and SAR=10 $mmolc^{0.5}/l^{0.5}$ for soil A under wheat-fallow crop rotation are shown in Fig. 1. It was appropriate to select 0-30 cm depth as maximum ESP on application of sodic water was observed in topsoil layers (Kaledhonkar, 2003). Also yield and fibre quality of cotton cultivars under sustained sodic water irrigation under semi-arid condition were predicted on the basis of ESP development in topsoil layers by Choudhary *et al*. (2001). The ESP increased during wheat crop period with use of sodic water for pre-sowing irrigation as well as for four post-sowing irrigation on 2^{nd}, 32^{nd}, 61^{st}, 76^{th} and 112^{th} day, respectively. The sowing and harvesting of wheat crop was done on 10^{th} and 161^{st} day. The rainfall before and after harvest, with total amount of 35 cm, reduced the ESP. The average ESP (0-30 cm) at the end of monsoon season (simulation period) was 5.33, which was higher than 3. Temporal changes in ESP as result of sodic waters of different SAR such as 7, 6, and 5 $mmolc^{0.5}/l^{0.5}$ but RSC as 6 $mmol_c/l$ are shown in Fig. 1.

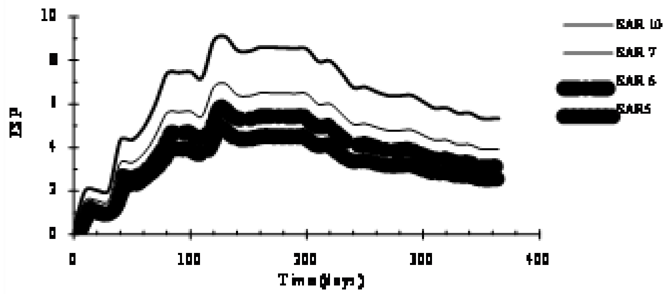

Fig. 1. Temporal changes in ESP (0-30 cm) for wheat-fallow crop rotation

The average ESP (0-30 cm) values at end of monsoon season for these waters were 3.93, 3.45 and 2.87, respectively. In case of sodic water with RSC=6 $mmol_c/l$ and SAR=5 $mmolc^{0.5}/l^{0.5}$, the average ESP (0-30 cm) at end of monsoon was less than 3. Therefore, it was considered as safe sodic water for soil A under wheat-fallow crop rotation and SAR 5 was treated as threshold SAR for soil A. Similarly threshold SAR values (at RSC=6) for soil A for 45 cm and 55 cm annual rainfall amounts were 6 and 7 $mmolc^{0.5}/l^{0.5}$, respectively. The threshold SAR values of sodic waters having constant RSC=6 $mmol_c/l$ were 6, 10.5 and 12 $mmolc^{0.5}/l^{0.5}$ for soil B and 7, 13 and 15.5 $mmolc^{0.5}/l^{0.5}$ for soil C at annual rainfall amounts of 35, 45 and 55cm, respectively. The threshold SAR and cation exchange capacity values are plotted in Fig. 2.

Effects of cation exchange capacity and rainfall amounts on sodification were analyzed further to develop set of curves/ equations to determine threshold limits of sodic water quality parameters on the basis of soil properties and proportion of sodic and fresh water. At constant annual rainfall, threshold SAR value decreased with increase in cation exchange capacity. However, it increased with increase in rainfall amount at constant cation exchange capacity. The Fig. 2 also suggested that sodic waters of higher SAR could be used for soils with low cation exchange capacity values and the effect of rainfall would be more significant for such soils. As soils with low cation exchange capacity adsorbed less Na^+ ions at same ESP, desodification might be much quicker in case of such soils. The threshold SAR values, and ratios of sodic and rainfall water at constant cation exchange capacity are plotted in Fig. 3. The ratios were determined from the applied amounts of sodic waters during wheat crop and rainfall amounts during wheat and fallow period. The threshold SAR value of sodic water decreased with increase in ratio of sodic and rainfall water (or reduction of fresh water availability). The equation y=mx+c was fitted to three lines in Fig. 3 and results are given in Table 2.

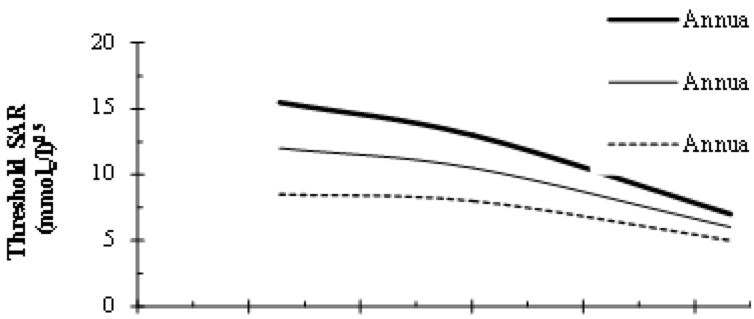

Fig. 2. Threshold SAR of sodic water with RSC=6 for wheat-fallow crop rotation

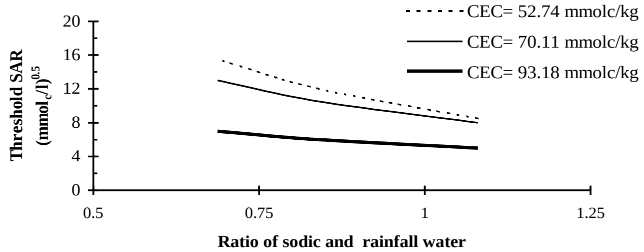

Fig. 3. Safe SAR of sodic water with RSC=6 for different annual rainfall amounts

Table 2. Equations for determining the safe SAR values

Soil	CEC ($mmol_c/kg$)	Equation	Regression coefficient
A	93.18	Y = (-5.010*X)+10.354	0.99
B	70.11	Y = (-12.525*X)+21.386	0.99
C	52.74	Y = (-17.535*X)+ 27.24	0.99

Y means safe SAR; X means ratio of sodic and rainfall water (fresh water)

The threshold SAR values for soil A, B and C could be determined by simply putting the ratio of sodic water and rainfall amount in the equations in Table 2. The amount of sodic water required in any crop rotation could be approximately estimated from evapotranspiration requirements of different crops and availability of fresh water. Available canal water might be added to rainfall amount to get total amount of fresh water available for desodification. These equations clearly indicated that threshold SAR of sodic water should be reduced with increase in amount of sodic water to make its use safe. Water quality guidelines by Gupta *et al*. (1994) gave general hints for use of sodic water. However, equations developed in this study provided the threshold SAR at constant RSC of 6 on the basis of cation exchange capacity and ratio of sodic and fresh water, which could be determined on the basis of proposed crop rotation. These curves/ equations are very easy to use and require easily available information. As cation exchange capacity has linear relationship with clay percentage, it can be approximately estimated from clay percentage alone. For the sandy loam soils, having cation exchange capacity values other than those mentioned in Fig.3, parallel lines might be drawn to existing lines by interpolation. Similar type of analysis could be carried for other textural classes to find threshold SAR value based on soil properties.

Verification Improved Guidelines

Verification of curves in Fig.3 was done with help of published field data (Sharma and Mondal, 1981). The average CEC value for soils under consideration was taken as 8.5 $mmol_c/100g$ approximately. The ratio of sodic water amount to fresh (canal and rainwater) water amount, in case of rice-wheat crop rotation, was worked out as 1 (Table 3).

Table 3. Estimation of ratio of sodic water and canal water

Details	Depth of water (cm)
Paddy water requirement	120
Wheat water requirement	40
Annual water requirement	160
Rainfall amount	60
Canal water	20
Total fresh water used	80
Sodic groundwater used	80
Ratio of sodic water and fresh water	1.00
Threshold SAR as per curve	6.56

Using ratio of sodic and fresh water utilization alongwith average cation exchange capacity value of 85 meq/kg, threshold SAR value was estimated as 6.56. The threshold SAR for CEC of 93 meq/kg, considering ratio of sodic and fresh water as 1, was 5.34 while it was 8.86 for 70.11 meq/kg with same ratio. Threshold SAR for CEC of 85 meq/kg, with ratio of 1, was estimated as 6.56 $(mmol_c/l)^{0.5}$ by interpolation. It indicated that there would be reduction in yield, if SAR of groundwater exceeded this threshold value. This assumption was verified with farmers' views about crop performance for 24 cases reported by Sharma and Mondal (1981). The details of groundwater quality, soil EC_e, Soil ESP, prediction about crop performance and farmers' reactions are given in Table 4. It was found that predictions made with the help of curves were very much satisfactory.

Table 4. Verification of guidelines with published data of Sharma and Mondal (1981)

Ground water EC dS/cm	SAR	RSC	Threshold SAR	Soil EC_e	ESP	Safe or not	Yield reduction Prediction	Farmers' reaction about yield
2.62	23.5	10.8	6.56	10.8	64.1	No	Severe	Very poor
2.19	16.4	10.6	6.56	4.5	42	No	Severe	Very poor
2.62	20.5	9.5	6.56	15.0	81	No	Severe	Very poor
1.83	14.4	8.0	6.56	14.8	67.2	No	Severe	Very poor
1.71	11.5	7.0	6.56	6.8	41.2	No	Slight	Fair
1.52	14.1	7.3	6.56	7.0	53.8	No	Severe	Poor
1.34	10.5	7.2	6.56	8.2	57.2	No	Slight	Poor (wheat), Fair (Rice)
0.98	6.7	6.0	6.56	3.7	19.6	Yes	Normal Yield	Good
1.83	8.9	4.3	6.56	2.4	18.9	No	Slight	Good
0.57	2.8	2.8	6.56	1.4	6.2	Yes	Normal Yield	Good
2.61	17.6	5.7	6.56	18.4	67.2	No	Severe	Very poor
3.54	18.7	4.7	6.56	8.3	56.5	No	Severe	Poor
2.14	18.3	4.9	6.56	6.5	50.6	No	Severe	Poor (wheat), Fair (Rice)
2.15	15.7	6.1	6.56	13.5	73.7	No	Severe	Very poor
2.07	17.5	9.0	6.56	11.3	73.3	No	Severe	Very poor
1.22	6.5	5.1	6.56	2.9	25.4	Yes	Normal Yield	good
1.28	9.9	5.0	6.56	4.1	35.4	No	Slight	Fair (Wheat), Good (Rice)
1.18	7.5	5.6	6.56	3.1	19	Yes	Normal Yield	Good
0.85	8	6.3	6.56	1.6	21	No	Slight	Good
1.10	6.5	6.4	6.56	2.1	23.5	Yes	Normal Yield	Good
1.10	6.5	6.0	6.56	1.7	15.3	Yes	Normal Yield	Good
1.15	12.5	8.6	6.56	4.1	35.9	No	Severe	Fair (Wheat), Good (Rice)
2.68	20.9	8.0	6.56	5.8	59.5	No	Severe	Poor (wheat), Fair (Rice)
0.73	2.5	2.8	6.56	1.0	7.3	Yes	Normal Yield	Good

Sustainability of Rice-Wheat Rotation in Sodic Water Blocks

The curves were further used to assess the sustainability of rice-wheat rotation in villages of Assandh and Nissang blocks of Karnal district. Groundwater samples from irrigation tubewells from different villages of these two blocks, ranging from 3 to 14 tubewells per village depending on the area of village, were randomly collected. Soil and water samples were collected and analyzed (Singh, 2005). As RSC was constant at 6 during the simulations, hence more importance was given to SAR data. There were variations in RSC values also and RSC values were not always close to 6. Minimum values of RSC ranged from 0 to 2.7 with average of 0.45 while maximum values ranged from 0 to 18.10 with average of 5.76. Minimum values of SAR ranged from 0.26 to 9.64 with average of 2.58 while maximum values ranged from 1.4 to 19.86 with average of 8.18. On the basis of ratio of sodic and fresh water (canal and rain water) utilization for rice-wheat crop rotation and average soil cation exchange capacity, a threshold SAR value of groundwater was estimated for each village. Yield reduction was expected, if SAR of the groundwater was greater than its threshold value. With this assumption, a village was considered as safe under prevalent conjunctive water use of sodic and fresh water, if minimum and maximum values of groundwater SAR range were below threshold value. If minimum value was below the threshold but maximum value was higher than threshold, the village was considered under marginal category. The village was treated as unsafe provided both minimum and maximum values of SAR range were higher than threshold value. With these assumptions, safe, marginal and unsafe villages were explored and maps indicating those villages were prepared for Assandh and Nissang blocks of Karnal district.

Analysis to assess the sustainability of rice-wheat rotation in villages of Assandh and Nissang blocks of Karnal district revealed that both blocks had areas under safe and marginal zone villages. The areas under marginal zone villages were considerable. The Assandh block had few villages under unsafe category, but there was no village under this category in Nissang block. The change of crop rotation is required in unsafe category villages in Assandh block for sustainability of crop production while villages under marginal zone need cautious approach. It means that farmers in unsafe and marginal zones must change the rice-wheat crop rotation to reduce the use of sodic water. There is need to find a substitute to rice crop, which may require less water.

Conclusions

Existing irrigation water quality guidelines for use of sodic waters are for kharif fallow and rabi crop rotation and are of general type. The guidelines were further investigated through UNSATCHEM modeling to prepare set of curves for sandy loam class, which could be used to determine threshold SAR value (at constant RSC of 6 meq/l) of sodic water considering soil properties and, ratio of sodic and fresh water utilization in crop production. The curves could be used to assess the sustainability of conjunctive water use policy in sodic groundwater areas or to prepare conjunctive water use plan of sodic and fresh water (canal and rainwater) under any crop rotation. The use of amendments can be minimized by sodic water irrigation planning by this approach. Similar type of curves could be easily developed for other textural classes. The improved guidelines are more flexible and it would be possible to consider individual soil and exact amounts sodic and fresh water being utilized in the crop production and quality parameters of irrigation waters. Also it would be possible to work out threshold SAR of groundwater respective of conjunctive water use mode. Therefore, these guidelines could be effectively used for better planning of conjunctive water use of sodic and canal (fresh) water.

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Use of Models in Water Management under Climate Change Scenarios

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Introduction

Water is the most precious natural resource and a vital component of a socio-ecological system. India is supporting an increasingly large population with decreasing per capita water availability. Availability of freshwater water resources is of particular interest for supporting agrarian economy in a country like India. Global climate change is expected to alter regional hydrological condition, affecting regional water resources availability. A small perturbation in the magnitude and/or frequency of precipitation can result in significant impacts on regional water resources, and the frequency of drought or flood events. With increase in total rainfall and high intensity rainfall events, occurrence of flood incidence is likely to increase under the changing climate scenarios. At the same time, increased evapotranspiration demand and/or decreased precipitation may result in severe and widespread drought by late half of this century (Dai, 2013). Sea level rise due to climate change is likely to increase the salinity problem along the coastal regions. Changes in regional water availability due to climatic changes will affect agricultural water productivity, hydropower generation, flood control, municipal and industrial water supply, and fish and wildlife management (Minville *et al.*, 2008). Improved understanding of climatic causes of hydrological variability is of paramount importance for developing adaptation strategies for sustainable development and management of water resources.

Climate Change and Climatic Variability

The term "climate change" refers to a persistent, and sometimes irreversible, shift in the long-term statistics of climate variables in a specific region or the entire globe. Increase in the atmospheric concentrations of greenhouse gases appears to be the predominant cause of recent climate change. Climate variability is the way climate fluctuates yearly above or below a long-term average value. The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) estimated that the global atmospheric concentration of CO_2 increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005, and the most conservative projection (following the emission scenario SRES B1) of atmospheric CO_2 concentration by 2100 is at about 600 ppm. The CO_2 induced climate change, which has already started to impact different sectors around the globe, is expected to become more evident in future decades with far-reaching impact in many sectors.

The Couple Model Intercomparison Project Phase-5 (CMIP5) -based model ensemble, based on new-emission scenarios termed as representative concentration pathways (RCPs), projects a warming of 1.5, 2.4, 2.8 and 4.3°C increase in temperature under the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios respectively, for 2080s (2071-2100) compared to 1961-1990 baseline (Chaturvedi et al., 2012). There is a consistent warming trend over the country in short, mid as well as long-term scenarios. All-India annual mean temperature increases by 1.70–2.02°C by 2030s under different RCP scenarios and by about 1.95 –4.78°C by 2080s, relative to the pre-industrial base of 1880s (1861-1900). Precipitation is projected to increase almost all over India except for a few regions in short-term projections (2030s). CMIP5-based ensemble projects an all-India precipitation increase of 6, 10, 9, and 14% increase under the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios respectively, for 2080s compared to the 1961-1990 baseline. All-India annual precipitation increases by 1.2–2.4% by 2030s under different RCP scenarios and by 3.5–11.3% by 2080s, relative to the pre-industrial base. Similarly, analysis based on MIROC-ESMCHEM projections for RCP 4.5 suggests a consistent positive trend in frequency of extreme precipitation days (e.g. > 40 mm/day) for decades 2060s and beyond (Chaturvedi *et al*., 2012).

Modeling Climate Change Impact on Water Resources

The quantitative assessment of the impact of climate change on water resources availability and its management requires knowledge of climate, hydrological and water management models, and particularly the relationships between each of them.Hydrologic models provide a framework to conceptualize and investigate the relationship between climate, human activities and water resources. Hydrologic models driven by climatic data obtained either from GCM outputs through statistical downscaling techniques, or from high resolution regional climate models; or from hypothetical scenarios are often used in the assessment of climate change impact on hydrology and water availability at the basin or watershed scale (Fig. 1).

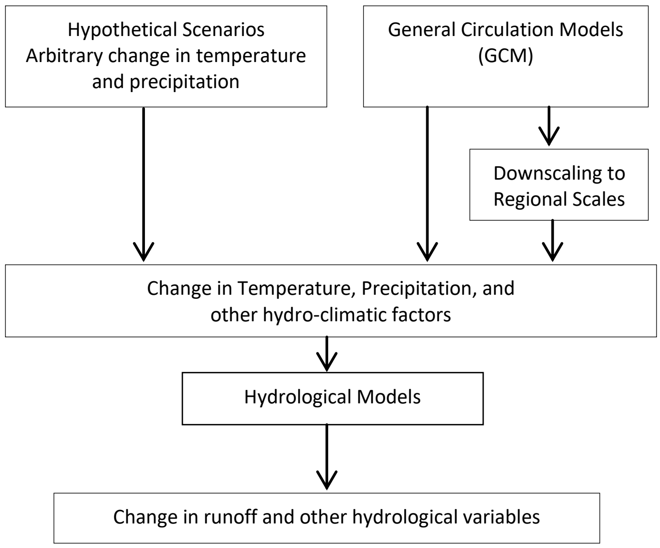

Fig. 1. Methodology for Climate Change Impact Assessment on Hydrology and Water Resources

Global Climate Models (GCMs) are the primary tools to simulate multi-decadal climate dynamics and to generate and understand global climate change projections under different future emission scenarios. However, these models have a coarse spatial resolution (typically a few hundred kilometres) and suffer from substantial systematic biases when compared with observations. These models perform reasonably well in simulating climatic variables at larger spatial scale, but poorly at the smaller space and time scales relevant to regional impact analyses (Grotch and MacCarcken, 1991).Therefore, they are unable to provide actionable information at the regional and local spatial scales required in impact and adaptation studies. Given the limitation of GCMs and downscaling methods, hypothetical scenarios are preferred by several researchers (Xu, 2000; Islam *et al.*, 2012a). Hypothetical scenarios are constructed by simply perturbing an historical record for a particular climate variable by an arbitrary amount, covering a reasonable range of possibilities. Islam *et al.* (2012a) considered a range of climate change scenarios with ± 10 to 30% changes in rainfall and 0 to 4°C changes in air temperature from the measured baseline climate (1980–1990). Simulation results using Precipitation Runoff Modeling System (PRMS) showed that the changes in temperature had a relatively lesser effect on the magnitude of annual and seasonal stream flow as compared with rainfall changes in the basin. A 10% decrease in rainfall resulted in a 23% decrease in annual stream flow, whereas a 4°C rise in temperature resulted in an 11% decrease in annual streamflow (Fig. 2a). A 10% decrease inrainfall resulted in 25, 12, and 21% decreases in streamflow during monsoon, pre-monsoon, and post-monsoon seasons, respectively, and a 4°C increase in temperature resulted in 12, 3, and 11% decreases in streamflow during the same seasons. The combined effect of changes in rainfall and temperature showed changes in the mean annual streamflow in the range of −33 to 62% (Fig. 2b). A 4°C rise in temperature coupled with a 30% increase in rainfall resulted in 62, 73, 39, 52, and 30% increases in annual, monsoon, pre-monsoon, post-monsoon, and winter season streamflow, respectively. Similarly, a temperature rise of 4°C and a 10% decrease in rainfall resulted in 33, 35, 15, 32, and 21% decreases in annual, monsoon, premonsoon, post-monsoon, and winter season streamflow, respectively. The greater effect of rainfall changes on streamflow compared to temperature change may be due to sub-humid climatic conditions in the basin with lower part of basin being located in the coastal region.

Though the GCMs are the preferred option for deriving climate change scenarios, there is considerable uncertainty associated with the GCM simulations due to uncertainty in greenhouse gasses (GHG) emission, uncertainty in global GHG cycles usually simulated “offline”, and uncertainty in GCM response to a particular forcing associated with model structure, parameterization, and spatial resolution (Anderssonet al., 2006). Different GCMs produces significantly different outputs for some regions, posing the problem of GCM selection for impact assessment studies. Since each climate model has its own uncertainty, use of climate change scenarios from more than one GCM is suggested for dealing with the uncertainty linked with climate projections. Use of multi-model projections allows consideration of uncertainty by providing a range of possible changes of future streamflow and water resources availability. To reduce the uncertainty associated with individual GCM projections, climate change projections from multiple GCMs and/or ensemble of multiple GCMs and emission scenarios is generally preferred (Islam et al., 2012b, 2012c; Vandana et al., 2018).

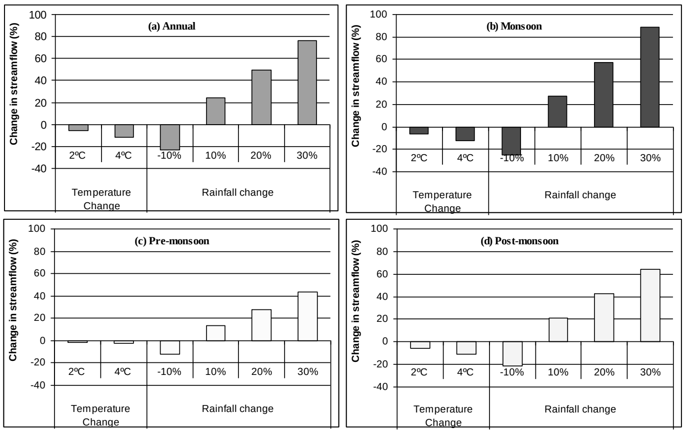

Fig. 2a. Response of Streamflow to Potential Rainfall and Temperature Changes (Adopted from Islam et al., 2012a).

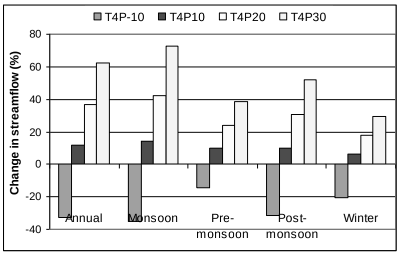

Fig. 2b. Response of Streamflow to Combined Effect of Rainfall and Temperature Changes (Source: Islam *et al.*, 2012a).

Modeling Downscaling Approaches

Planners/ decision makers' needs climate information at the national to local scale to address the risk posed by projected climate changes and developing suitable adaptation plans. Further, GCM outputs involve a great deal of biases that, if not corrected, can lead to significant errors in impact assessments. In order to derive climate projections at local or regional scales that decision makers' desire,spatial downscaling and bias correction of GCM outputs are necessary. Spatial downscaling refers to the methods used to derive finer-resolution spatial climate information from coarser-resolution GCM output, e.g., 500 kilometers grid cell GCM output to a 20 kilometers resolution, or even a specific location. Temporal downscaling refers to the derivation of fine-scale temporal information from coarser-scale temporal GCM output (e.g., daily rainfall sequences from monthly or seasonal rainfall amounts). A number of downscaling approaches have been developed to convert large-scale data to local-scale data. The simplest approach to downscale from global climate model scale to finer scale is to interpolate GCM outputs from nearest grid boxes using some form of interpolation procedure such as Inverse Distance Interpolation (Brumbelow and Georgakakos, 2007) followed by temporal downscaling to convert monthly parameter values to the daily values using different stochastic weather generates such as WGEN (Richardson, 1981), LARS-WG (Semenov and Barrow, 1997). Other downscaling approaches include dynamic downscaling, and statistical downscaling. The dynamical downscaling approach consists of using regional climate models (RCMs) to resolve physical equations of atmospheric regional dynamics (Wood *et al.*, 2004). However, this approach is computationally expensive, restricting their use for many applications. RCM biases can be introduced by incorrect boundary conditions provided by reanalysis data or by a GCM, and by systematic model errors, such as the errors resulting from the imperfect parameterization of some climate processes (Teutschbein and Seibert, 2012). Therefore, post-processing of RCM outputs (such as bias correction) is normally a prerequisite step of most climate change impact studies.

The statistical downscaling approach is based on statistical relationships between large-scale GCM features and local-scale climatic variables (such as precipitation or temperature).It involves the establishment of empirical relationships between historical and/or current large-scale atmospheric and local climate variables. Once a relationship has been determined and validated, future atmospheric variables that GCMs project are used to predict future local climate variables. Statistical downscaling can produce site-specific climate projections, which RCMs cannot provide since they are computationally limited to a 20–50 kilometers spatial resolution. Statistical downscaling methods (SDMs) are quite flexible and computationally less expensive. However, this approach relies on the critical assumption that the relationship between present largescale circulation and local climate remains valid under different forcing conditions of possible future climates (Zorita and von Storch, 1999).

Several bias correction methods ranging from simple scaling to sophisticated distribution mapping have been developed in the last decade (Teutschbein and Seibert, 2012). The delta change method is the most commonly used method for generating future climate scenarios. In this method, the differences between (or the ratio of) the control and future climate simulations are applied to historical observations by simply adding (or multiplying) the change factor to daily observed data. This method does not consider variability or change in time series behavior in the future. The hybrid-delta method, on the other hand, considers inter-annual variability for each month (Islam *et al.*, 2012b, 2012c; Vandana *et al.*, 2018). This method applies different scaling factor to each month of the historic time series based on where it falls in the probability distribution of monthly values (Vandana et al., 2018).

Modeling Climate Change Impact on Irrigation Water Demand

Irrigation water demand is likely to be affected under the projected climate change scenarios due to changes in rainfall, temperature and the evaporative demand. Several studies have showed that the effect of rising temperature on evapotranspiration is moderated by elevated CO_2 concentrations (Martin *et al.*, 1989; Islam *et al.*, 2012b, 2012c), and thereby ETo demand may not rise significantly. Simulation study conducted using meteorological data of Varanasi (Latitude: 25.2628° N, Longitude: 82.9919° E, and Altitude: 80.71m) also demonstrated similar results (Priya *et al.*, 2014). They used FAO-56 Penman–Monteith method was used to estimate ETo, and the combined effect of temperature and elevated CO_2 levels was studied by varying the temperature from 1°C to 5°C, and the CO_2 level from 330 ppm to 660 ppm. Every degree centigrade rise in mean temperature resulted in increase in reference ETo by about 0.1 mm day^{-1} (2.3% increase with respect to baseline) annually. There is a decrease in reference evapotranspiration with increases in CO_2 concentration (Fig. 3), due to decrease in stomatal conductance and increase in stomatal resistance with increase in CO_2 concentration. There is about 6% decrease in annual ETo demand with doubling (660 ppm) of CO_2 concentration, temperature remaining constant. Simulating the combined effect of temperature and elevated CO_2 showed that the effect of about 1.0 °C rise in temperature is offset by increase in CO_2 levels upto 495 ppm, and 2.5 °C rise in temperature is offset by increase in CO_2 levels upto 660 ppm (Fig. 3). These results demonstrates that the crop water demand may not rise significantly under the climate change scenarios because of the moderating effect of rising CO_2 concentration on evapotranspiration demand.

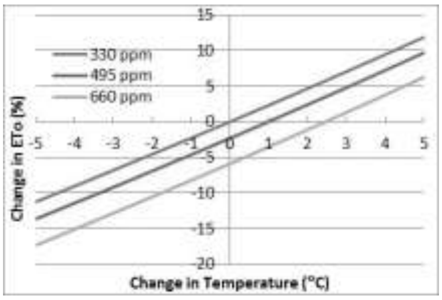

Fig. 3. Effect of Changes in Temperature and CO_2 Concentration on Reference evapotranspiration (Source: Priya *et al.*, 2014)

Adaptation to Climate Change

Climate change is expected to produce water stresses in several parts of the country and thereby affecting crop production. Substantial adaptation efforts will be neededto ensure adequate supply and efficient utilization of available water resources. The supply and demand management measures either meant at conserving ,enhancing, or improving the water supply may be capable of alleviating suchimpacts to a certain extent. The greatest potentialfor short-term adaptation is in demand management and more efficient and integrated management of surface and groundwater supplies. Adoption of drip or micro-irrigation, rainwater harvesting, recharging groundwater, encouraging water saving techniques such as water recycling, and reducing losses in canal systems could form some of the adaptation options. Participatory integrated watershedmanagement approaches covering biophysical and socio-economic interventionshave shown rich dividends for ensuring resilience to climate change. Managed aquifer storage is one of the adaptation options to improve water availability and address region-specific changes in precipitation distribution and increased evaporation rates (Shah, 2009). Under the National Initiative on Climate Resilient Agriculture (NICRA), a network project of the Indian Council of Agricultural Research, different interventions like in situ moisture conservation, biomass mulching, water harvesting and recycling for supplemental irrigation, improved drainage in flood prone areas, conservation tillage where appropriate, artificial ground water recharge, and water-savingirrigation methods have been implemented under the technology demonstration component of NICRA in the vulnerable districts of India to enhance the resilience of Indian agriculture to climate change and climate variability. Though many adaptation options are generic, activities with an explicit focus on adaptation and climate change will also be required. Options to address increasing water scarcity through better co-management of water at the watershed, aquifer, and river basin level need many water-stressed areas. The major challenge, however, remains in proper planning and effective implementations of different developmental programs and schemes at the local level. A combined bottom-up participatory process and top-down modeling tools could be helpful to identify, prioritize, and assess the adaptation options for developing locally relevant climate change adaptation measures.

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Application of Hyperspectral Imaging for Appraisal and Characterization of Salt Affected Soils-Practical

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Soil salinization and alkalizations are common land degradations in arid and semi-arid regions of Haryana affecting productivity and socio-economic status of poor and marginal farmers. Frequent use of poor quality (saline/sodic) of ground waters for irrigation have aggravated secondary salt enrichment in soil profiles impeding water and nutrient movement and reduced productivity.The increase in concentrations of four chemical groups namely carbonates, halides, sulphates and borates (Klein and Hurlbut, 1999) by the use of poor quality irrigation watercauses major soil degradation such as dispersion ofsoil, reduction of pore volume, crust formation, low hydraulic conductivity and distortion of structure (Agassi *et al*., 1981; De Jong, 1994; Metternicht and Zinck, 2003), leading to yield reduction of crop (FAO, 1988).Traditional methods of soil salinity characterization involves tedious processesandemphasizes the analysis of saturation extract parameters such as the determinations of EC_e, pH_s, Na^+, K^+, Mg^{++}, Ca^{++}, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-}(Shepherd and Walsh, 2002).Besides,aerial photography and electromagnetic methods (Everitt et al., 1988; Rhoades and Miyamoto, 1990; Mougenot *et al*., 1993) were used successfully to identify saline soils with high concentration of surface salts and the significant presence of cationsand anions such as Na^+, K^+, Mg^{2+}, Ca^{2+}, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-} (Baumgardner et al., 1985). Such methodology often lacks in following difficulties:

1. The presence of salts is often undetected, at its low to moderate concentrations at surface.
2. The physical boundaries separating saline areas of different degrees are fuzzy.
3. The salinization that occurs at lower depths the soil profile, also remain undetected by optical sensors.
4. Natural salt minerals are also associated with many trace elements often trapped in crystal lattices during crystallisation. It changes the reflectance properties of minerals (Hunt and Salisbury, 1970, 1971) and causes errors in the experimental models.

Remote sensing data stored in discrete spectral bands are potential for mapping and monitoring salt affected soils in visible and infrared regions (Metternichtand Zinck, 2003). Indian Remote Sensing ResopuceSAT data (imageries) are quite efficient in the detection of surface salt encrustations in severely salt affected areas. Other areas such as moderate to slightly salt affected soils that showed mixed pixels of soil, water, scattered crop and salts are difficult to segregate and needs adequate ground truth studies for delineation. Digital image processing of satellite data using unsupervised and supervised classification methods, are commonly done using spectral indices for vegetation, water and salt supported by principal component analysis of multiple bands. Such methodology though used widely for natural resource inventories but showed low accuracy for salt affected soils due to close reflectance between sands and salts, a common coexistence found in the Gangetic alluvial and sandy plain of arid/semiarid regions. Besides, high absorption from surface water stagnations limits the detection of salt affected areas apparently due to low permeability at surface and sub-surface depths. Such incidence is common in canal irrigated regions, where waterlogging occurs due to restricted drainage from thick and impermeable layers of calcium carbonates (calcretes), located at a depth (1 m) below the surface. Further, the atmospheric effect on the quality of data received from a remote platform is also a major concern in optical remote sensing. Through automated atmospheric corrections, though major errors are removed, it also caused changes in the data quality deviating from the real time acquisition. Such methodology also lacks in the detection of high salt concentration at sub-surface depths in irrigated regions showing high water table depth (<2.5 m). The data used in microwave region are capable in detection of salty layer in sub-surface depths. The remote sensing data in thermal region have showed its potentiality in assessing salty and waterlogged soils with high water table depths at sub-surface regions (Verma *et al*., 1994).

The level of precision of diffuse reflectance spectroscopy technique increases at hyperspectral region. The "hyper" in hyperspectral means "over" as in "too many" and refers to the large number of measured wavelength bands. Hyperspectral images are spectrally over-determined, which means that they provide ample spectral information to identify spectrally unique materials. Hyperspectral imagery provides the potential for more accurate and detailed information extraction than possible with any other type of remotely sensed data.Typical spectral signatures of salts have been successfully identified and reported in the VNIR-SWIR region (Hunt *et al.*, 1971, 1972; Gaffey, 1987; Crowley, 1991; Drake, 1995; Farifteh *et al.*, 2004; Farifteh *et al*., 2007; Farifteh *et al*., 2008). Such studies also reported the variations in the characteristic signatures with respect to the nature and composition of salt minerals. Hyper-spectral data often stored in large number of discrete bands facilitates in preparing the databases of natural resources with minimum interferences from atmosphere and clearly segregates reflectance from mineral and organic components, salts and water, cropped and bare soil surfaces. The mineralogy of salts in multiple forms during dry and wet seasons can also been measured with adequate accuracies using standard salt profiles data. Unlike optical remote sensing data, which is stored in bands with a range of wavelengths, the hyperspectral data are stored in large discrete bands for target source objects such as salts thus highlighting nature and concentrations in specific wavelength region. Unlike traditional practices of laboratory soil characterization of salts, high temporal resolutions of remote sensing data often produced equally competent results showing seasonal variability and easy characterization of non-destructive concretionary soil materials such as calcium carbonate and calcium sulfates. Often halite, calcite and magnetite are easy to detect by such techniques compared to the laboratory methods.

Difference between Broad and Narrow-band Data

Most broad band data mainly multispectral imagers (*e.g*., Landsat, SPOT, AVHRR) measure radiation reflected from a surface at a few wide, separated wavelength bands (Fig. 1). Most hyperspectral imagers (narrow band data), on the other hand, measure reflected radiation at a series of narrow and contiguous wavelength bands. When we look at a spectrum for one pixel in a hyperspectral image, it looks very much like a spectrum that would be measured in a spectroscopy laboratory. This type of detailed pixel spectrum can provide much more information about the surface than a multispectral pixel spectrum.

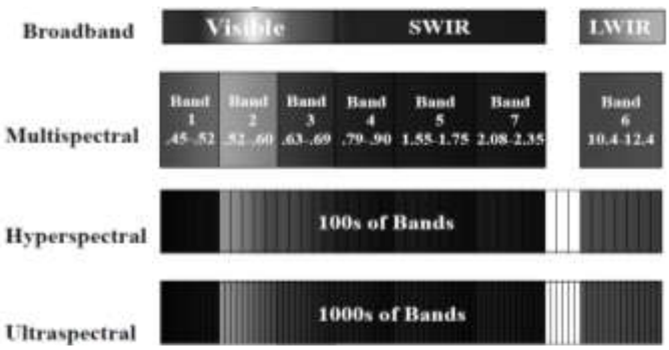

Fig.1. Spectral comparison between narrow and broad-band data

Although most hyperspectral sensors measure hundreds of wavelengths, itis not the number of measured wavelengths that defines a sensor ashyperspectral. Rather it is the narrowness andcontiguous nature of themeasurements. For example, a sensor that measured only 20 bands could beconsidered hyperspectral if those bands were contiguous and, say, 10 nm wide. Ifa sensor measured 20 wavelength bands that were, say, 100 nm wide, or thatwere separated by non-measured wavelength ranges, the sensor would no longerbe considered hyperspectral.

Concept in Hyperspectral Remote Sensing (HRS)

Hyperspectralimagery is typicallycollected (and represented)as a data cube with spatialinformation collected in theX-Y plane, and spectralinformation represented inthe Z-direction. The conceptof hyperspectral imagery is shown in Fig. 2. Hyperspectral data (or spectra) can be thoughtof as points in an n-dimensionalscatterplot. Thedata for a given pixelcorresponds to a spectralreflectance for that givenpixel. The distribution of thehyperspectral data in n-spacecan be used toestimate the number ofspectral endmembers andtheir pure spectralsignatures and to helpunderstand the spectral characteristics of the materials which make up thatsignature.

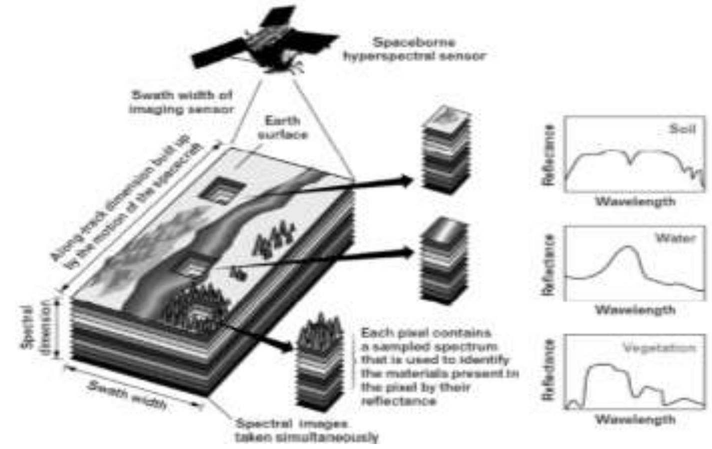

Fig. 2. The concept of hyperspectral imagery
Image measurements are made at many narrow contiguous wave length bands, resulting in a complete spectrum for each pixel

Reflectance is the percentage of the light hitting a material that is then reflected by that material (as opposed to being absorbed or transmitted). A reflectance spectrum shows the reflectance of a material measured across a range of wavelengths (Fig. 3). Some materials will reflect certain wavelengths of light, while other materials will absorb the same wavelengths. These patterns of reflectance and absorption across wavelengths can uniquely identify certain materials.

Spectral Libraries

Soil salinity/alkalinity measurement using spectroscopy (*e.g.*vis–NIR, mid-IR) requires the calibration of the spectra to soil salinity/alkalinityrelated parameter using multivariate statistics or machine-learning algorithms. The calibrations can be derived using existing large spectral libraries (ESLs) (*e.g.*ViscarraRossel and Webster, 2012; Shepherd and Walsh, 2002; Stevens *et al*., 2013) or using new site-specific libraries developed with local soil samples (LSLs). Using an ESL to predict parameters incurs no immediate cost, but it is likely that the predictions at the local site (farm or field scales) will be biased (Clairotte *et al.*, 2016; Guerrero *et al.*, 2014). Using an LSL will produce more accurate (unbiased) predictions but will incur a cost because soil needs to be analysed in the laboratory to derive the local model. Significant investment has been made in developing large regional, country, and global spectral libraries (Shepherd and Walsh, 2002; Brown *et al.*, 2006; ViscarraRossel *et al*., 2016), and there will be value in using these for developing site-specific calibrations.Development of spectral library can reduce analytical cost and improve the financial viability of soil spectroscopy.

Saxena *et al*. (2005) prepared soil reflectance library of soils of India in the electromagnetic spectral region of 350 nm to 2500 nm using ASD spectroradiometer. The spectral library contains reflectance spectra measured under laboratory conditions of 128 soils samples collected from different physiographic and agro-ecological regions of the country. The spectral plot of five soils having different soil characteristics are shown in Fig. 3.

Methodology of Soil Salinity Characterization and Mapping using HRS

The complexity of salinization processes, spatial and temporal variability makes soil salinity mapping a difficult proposition. Severely SAS can be easily detected due to high reflectance from salt crust on soil surface, whereas, detection of low and medium SAS is difficult due to intricate association of salt, soil, water and vegetation. An attempt has been made by CSSRI to characterize such SAS using HRS data. A methodology was developed, integrating HRS data with limited ground truth and further quantifying through statistical modeling. The variability of salinity and sodicity attributes such as EC_e, Na^+, Cl^-, CO_3^{2-} and HCO_3^- (me L^{-1}) of the saturated soil extract were related quantitatively (r^2=>90%) by HRS data. The spectral regions of 1400, 1900 and 2200 nm showed prominent peak due to the changes in soil salinity. At 1900 nm prominent shifting facilitated in establishing a significant correlation with salt concentration. The proposed methodology was found useful for delineating SASfrom the space platform (Fig. 4).

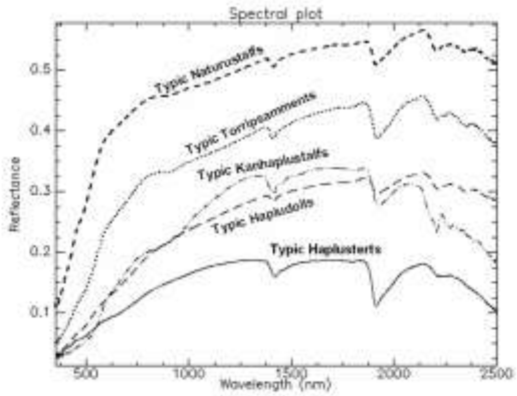

Fig. 3. Spectral reflectance characteristics of some selected soils of India

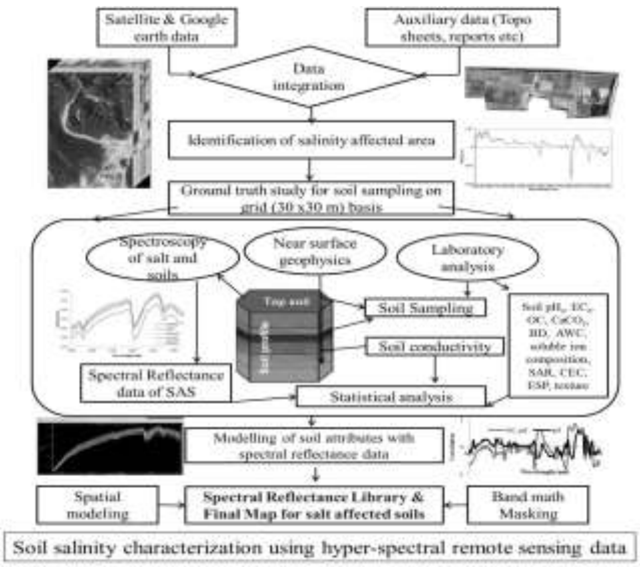

Fig. 4. Methodology for characterizing SAS using spectral data (Barman *et al*., 2017)

Prediction of SAS Properties based on Soil Reflectance Data (Case Study)

Soil reflectance data have been successfully used to predict different soilproperties by several workers (Shephered and Walsh, 2002; Farifteh *et al*., 2004, 2006, 2007, 2008; Wang *et al*., 2012; Srivastava *et al.*, 2017). In a laboratory study (CSSRI, 2016-17), spectral properties of main salt types (chloride, sulphate and carbonate of sodium) with soil salinity (0% to 10%) levels (in weight basis)from thealluvial soil of Haryana, India were examined using VNIR.The results indicated that thespectral regions of 1400, 1900 and 2200 nm were highly sensitive to changes in salinity. Thereflectance values of Na_2SO_4 and Na_2CO_3 were higher in the wavelength from 1300 to 2450 nm than control (Fig. 5a) due to thedevelopment of sodicity by the replacement of calcium and magnesium by sodium cation which resultedinexpansion of soil colloids and less retention of moisture in air-dried soil samples.But due to high hygroscopicity of NaCl, reflectance value was decreased than other over the wavelength domain and there was the mixture effect of reflectance in thecase of amixture of these three salts of sodium.There was a shifting of higher wavelengths at 1900 nm with increase in salt concentration (Fig. 5b).Higher coefficient of determination with low RMSE for all salinity related parameters was obtained during calibrations of PLS regression model (Table 1). Square root transformation of saturated extract potassium (R^2=0.90, RMSE= 0.24), calcium (R^2=0.90, RMSE= 0.75) and magnesium (R^2=0.92, RMSE= 0.74) were well calibrated in Partial Least Square Regression (PLSR) model due to existence of variation from lower to higher value among the samples, suggesting that there was replacement of above cations by sodium ions. The coefficient of determination was recorded more than 0.93 for four anions and among them, square root transformation of saturated extract carbonate (R^2=0.96, RMSE= 1.03) and bicarbonate (R^2=0.97, RMSE= 0.96) were fitted well in the calibration set. Saturated extract pH (R^2=0.93, RMSE= 0.23), EC_e (R^2=0.88, RMSE= 9.68) and SAR (R^2=0.95, RMSE= 1.31) were also in good agreement of calibration sets of PLSR model. PLS regression coefficients (B) values for EC_e, pH_s and SAR against wavelength help us to find out the sensitive bands.Comparatively higher absoluteB values at wavebands 470, 1400, 2020 and 2190 nm for pH_s, 1400, 1890, 1930 and 2180 nm for $EC_e$and 460,1400, 1910, 2180, 2340 and 2430 for saturated extract SAR pointed out that these bands are carrying more soil salinity and sodicity relatedinformation.The efficacy of the calibrated PLSR model when applied to a validation set of soil samples correctly predicted more than 87% variability in EC_e and other salinity and sodicity related attributes including saturated extract K^+, Na^+, Cl^-, CO_3^{2-} and HCO_3^-.

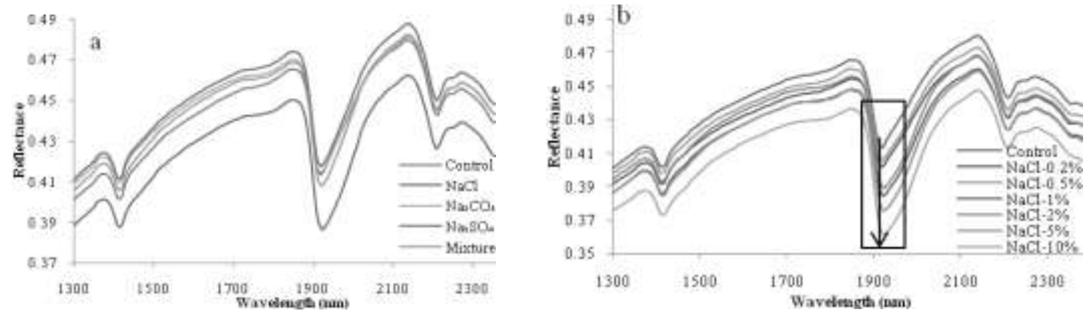

Fig. 5. Effects of (a) salt types (averaged spectra from six levels of salt contents) and (b) change of reflectance with different levels of NaCl contents on air-dried soil reflectance spectra

Table 1. Summary statistics of the hyperspectral partial least-square regression (PLSR) model

Soil parameters*	No. of Factors	Calibration set			Validation set				
		N	R^2	RMSE	N	SD*	R^2	RMSE	RPD
EC_e (mS m^{-1})	3	98	0.88	9.68	50	28.86	0.87	10.49	2.75
pH_s	7	98	0.93	0.23	50	0.87	0.89	0.29	3.00
SE Cl^- (meq L^{-1})	5	98	0.93	2.73	49	10.70	0.92	3.00	3.57
SE HCO_3^- (meq L^{-1})	6	98	0.97	0.96	49	5.84	0.93	1.51	3.87
SE CO_3^{2-} (meq L^{-1})	5	98	0.96	1.03	48	5.11	0.95	1.28	3.99
SE SO_4^{2-} (meq L^{-1})	11	98	0.94	1.06	41	4.27	0.77	2.25	1.90
SE Na^+ (meq L^{-1})	4	98	0.88	4.39	50	12.93	0.86	4.88	2.65
SE K^+ (meq L^{-1})	6	98	0.90	0.24	50	0.76	0.87	0.28	2.71
SE Ca^{2+} (meq L^{-1})	9	98	0.90	0.75	49	2.41	0.79	1.06	2.27
SE Mg^{2+} (meq L^{-1})	11	98	0.92	0.74	50	2.65	0.85	1.08	2.45
SAR ([meq $L^{-1}]^{0.5}$)	7	98	0.95	1.31	50	5.78	0.92	1.63	3.55

**Square root transformation was applied on all soil parameters except pH_s (no transformation)*

Conclusions

Predictive models to estimate SAS related parameters are empirical nature and have limited applicability beyond the area of development. Identified spectral band can be used for the development of sensors that can be mounted on the variable rate applicator and will be able to indicate the status of SAS and other surface soil properties.With the growing interest on high resolution hyperspectral satellite data applicability; our findings regarding rapid assessment of soil salinity and sodicity through hyperspectral models are encouraging as it might assist in real-timeprecise monitoring of salinity over the spatiotemporal context and also helps to improve spectral library; facilitating the farmers to manage salinization and alkalinization more effectively and efficiently. Further calibration/validation of these site specific hyperspectral models with respect to large field investigation is needed in SAS of India.

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Decision Support System for Enhancing Crop Productivity in Irrigated Saline Environments

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Introduction

Head-tail productivitygap in watercourses and distributaries in the Western Yamuna Canal (WYC) command in Haryana is expanding due to stiff competition from other sectors,inadequate and inequitable distribution of canal supply to farms,in-efficient on-farm water management practices, in-effectiveconjunctive use of marginal to poor quality groundwater, and limited investment capacity of marginal and small farmers.In order to reduce the productivity gapin the command, a holistic approach with modern tools, information systems, and modellingwas appliedto map spatial variability of irrigation water availability and its quality, and socio-economic conditions for targeting canal reach specific problems. In this study, a user friendly modern tool such as DSS program was developed throughthe four developmentstages from data collection, data processing, modelling to scenario evaluation and rankingwhich was programmed using MS Visual C#.NET programming language.The developed DSS program was validated from 52 field demonstration data and was applied for predicting crop yield loss of *rabi*cropsfromthe prevailing six saline environmentsand for generating suitable BMPs for minimizing yield loss.The DSS program and knowledge was transferred to state line departments, KVKs, WUA members and progressive farmersof Haryana. The lecture deals with modern tools, information system, development, validation and application of a DSS program for ensuring better distribution of canal water to farms, efficient irrigation scheduling and effective conjunctive use with poor quality groundwater for minimizing productivitygap in saline environments.

Decision Support System

The introduction of information systems based decisionsupport system (DSS) tools for monitoring and controlling canal operations and water delivery to farms is necessary to improve water management not only at the operational level but also at the farm level.Poor management of water supply in primary, secondary and tertiary canal network is identified as an important component of underperformance of an irrigation system. It was suggested that computer based DSS could assist in making better management decisions for improving performance. Therefore, the adequate emphasis must be given on software componentof the irrigation project. Four levels of DSS tools-management information system, knowledge based system, expert system and decision support system are usedfordecision making in irrigation management. Management information system (MIS)is a computerized management tool for information storage and retrieval for irrigation managers and innovative farmers for efficientirrigation management in irrigation schemes.It helps engineers, agriculturalists, and irrigation managers at the project level and higher to understand water needs at the farm level and to develop operation schedules, operating procedures and timely maintenance to maximize the benefits of irrigation. Whereas knowledge-based system (KS) is a computer program that reasons and uses knowledge to solve complex problems. The knowledge is acquired and represented using various knowledge representation techniques rules, frames and scripts. The advantages offered by such system are documentation of knowledge, intelligent decision making, self learning, reasoning and explanation. These systems are based on the methods and techniques of Artificial Intelligence and comprise of three core components ofknowledge base, acquisition mechanisms, and inference mechanisms.

Expert system (ES) is a computer program that is designed to emulate the logic and reasoning processes that an expert would use to solve a problem in the irrigation domain using artificial intelligence technology.Expert knowledge required for intelligent decision-making is notnecessarily and entirely contained by a conventional program which makes it unsuitable for strategic decision-making. An expert system tends to behave as human experts in decision-making and is highly interactive. It has the ability to capture human decision-making expertise and represent this expertise as a series of rules and facts. Decision support system (DSS) is aninformation system which provides a framework for integrating database management system, modelmanagement system, decision rules for ranking, and graphical user interface in order to resolve semi-structured problem for improving decisionmaking processes in irrigation systems. A properly designed DSS is intended to help decision makers to compile useful information from a combination of data, documents, personal knowledge or models to identify and solve problems and make logical decisions. An ideal DSS performs selected cognitive decision-making functions and are based on intelligent agent's technologies forintelligent decision support systems.These systems facilitate the decision-making of irrigation managers to accomplish the water management tasks that are required to be achieved.

Modern tools provide effective and reliable techniques for obtaining accurate spatial data on crops and crop conditions, water demand, actual water use (evapotranspiration), allocation and distribution of canal water, salt-affected soils, and crop yield to address the problem of spatial variability of land and water productivity at command scale in saline environments. These tools include satellite remote sensing, GPS (global positioning system) based field survey, GIS (geographic information system), CropWat model and IDSS (Irrigation DSS).

Decision Tools in Irrigation Management

Advances in remote sensing, GIS and modelling have offered a novel way for obtaining accurate spatial data on salt-affected soils, cropping pattern, crop water demand, canal water allocation and delivery, actual crop water use, crop yield and water productivity in saline environments. The development of irrigationmanagement is the optimization of irrigation water which requires proper irrigation scheduling with conjunctive use of poor quality waters based on crop water requirements of different crops sown over an area during that particular season. In real life situations, limited water resources, water quality and multiple objectives can often complicate the task of decisionmaking, especially when the objectives are demanding and conflicting. A DSS tool helps the decision makers by considering all the objectives and then evaluating options to identify an optimal solution that best solves a complex problem. A DSS tool helps to collect, organize and process information, and then to translate the results into management plans that are comprehensive and justifiable. DSS recommendations are based on scientific data and modelling and can account for multiple objectives, cause/effect relationships, risks and reliability, economicaland environmental aspects whereas conventional decision processes have difficulty aggregating all these considerations.

DSS has many useful applications in water resources and irrigation planning and management as irrigation managers or stakeholdershave diverse goals ofhydraulic, economic, environmental, and ecological interests. The decision making becomes difficult in achieving numerous and often conflicting objectives, such as ensuring adequate irrigation water supply, minimizing waterlogging and salinity, managing costs, maintaining adequate water quality, controlling floods, minimizing energy use, and providing environmental flow. A DSS can be used to develop sound water management plans, adaptable water supply rules, conjunctive use planning and multi-sector policies. Many irrigation, municipalities and water authorities often derive their water supplies from several sources, which may include reservoirs, rivers, groundwater wells or combinations of these sources. To identify the best combination of canal supply in the long term or to determine the most effective way of managing existing canal systems, decision-makers need a lot of information to account for all the hydrologic, hydraulic, water quality, economic and environmental relationships within the system and DSS applications can be very helpful.

Components of Decision Support System

A DSS has five major components (Fig. 1) as follows:
(i) Database (ii) Models (iii) Scenarios/decision tools (iv) User interface and (v) User

In a DSS, the database plays an important role as it contains geographical and non-geographical data with attributes in a well organize manner. Models are the set of analysis tools and operate on a particular set of data under the supervision of user and generate corresponding decision options for desired queries. Scenarios are used to work out possible scenarios for a given situation. The user interacts with data and models through graphical user interface. This interface links the user, the data, scenarios and the models together. A user interacts with the DSS through a computer, directly or indirectly, wherever it is located.

Development of a Stand alone DSS Program for Enhancing Productivity in Western Yamuna Canal Command

The Western Yamuna Canal System in Haryana, designed as a protective irrigation system (water allowance 2.4-3.01 cusecs per 1000 acres with 62% irrigation intensity), is one of the oldest canal systems in the country having CCA of 10,840 km^2 and was selected on the basis of run-of-the river barrage scheme, large mismatch between water demand-supply, large extent of poor quality groundwater in the command, declining and rising water table zones, severe soil salinization and waterlogging, inadequate drainage infrastructure, arid to semi-arid climate, diverse cropping systems and moderate socio-economic conditions in comparison with other canal commands. The WYC command is located between 280 20' 14'' and 300 29' 32'' N latitude, and 75° 48’ 20'' and 77° 34' 42'' E longitude with elevation ranging from 212.0 m to 355.2 m(Fig. 2). The WYC canal system takes off from the river Yamuna at Hathnikund barrage across the river Yamuna, and often suffers from shortage and uncertainty of canal supply during rabi season despite assured water transfer from Bhakra canal system through NBK link canal. The command is spread in 2205 villages covering 5 districts in full (Karnal, Panipat, Sonipat, Rohtak and Jhajjar) and 7 districts in part (Yamunanagar, Kurukshetra, Jind, Hisar, Bhiwani, Rewari and Gurgaon) and is divided into 8 water service circles (Jagadhri, Karnal, Sonipat, Delhi, Jind, Rohtak, Jhajjar, and Bhiwani). Butana and Jhajjar distributaries were selected for field demonstration and DSS validation.

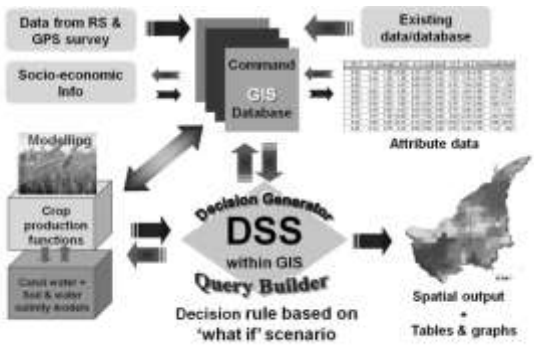

Fig. 1. A framework and components of a DSS in GIS environment

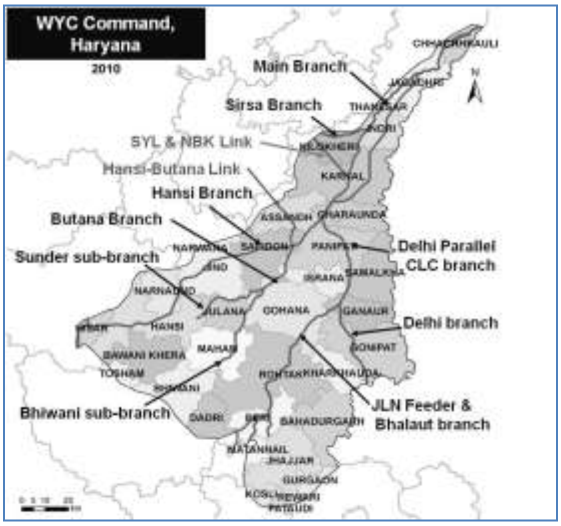

Fig. 2. Canal network in the Western Yamuna Canal (WYC) command in Haryana

Development of an *Irri-agro Informatics* Geodatabase

Since a spatial database on bio-physical and socio-economic resources was the first requirement for characterizationof the WYC command, twelve secondary source maps and data acquired (Table 1) were digitized in ArcGIS 9.3 environment andthe attribute information was added tothe respective spatial features and layers. Thus, an *Irri-agro Informatics* Geodatabase of the WYC command was developed using GIS, remote sensing and GPS tools and techniques and is comprised of canal network and system characteristics and inflow data, shallow and deep groundwater quality, salt-affected soils, soil texture, rainfall, waterlogging, contours, geology, land use, cropping system, rail and road infrastructure, socio-economic data, canal water users’ association data, satellite data derived current land use, and digital cadastral maps of four villages. The geodatabase has been periodically updated with current season data and information extracted from remote sensing imageries on new link canals, distributaries, minor canals and watercourses, and extension of existing canals and roads. Multi-date Resourcesat-1 LISS-3and 4 data (Table 2) were processed and geo-referenced to extract the new canals to the database. Land use maps of the Butana distributary command and WYC Command of the last *rabi* season was generated from Resourcesat-1 LISS-3 and 4 data, respectively using digital image interpretation and analysis techniques of ERDAS Imagine 9.3.0.The primary data of command resources for gap filling was collected from the study area through DGPS ground surveys and PRA exercise.

Table 1. Secondary sources maps and data collected for Geodatabase

Data	Scale	Data product	Publicationyear	Source
OSM series topo maps	1:50,000	Digital Vector	1997	Survey of India
Canal network	1:50,000	Map	1996	Irrigation Dept, Haryana
Soil salinity	1:500,000	do	1996	CSSRI/ NBSSLUP
GW quality	1:500,000	do	2006	CGWB/Agriculture Dept
Waterlogging	1:500,000	do	2005	CSSRI/ NRSC
Land use	1:250,000	do	2005	Agriculture Dept/NRSC
Soils	1:500,000	do	1996	NBSSLUP
Roads	1:250,000	do	2010	B&R, PWD
Rainfall	1:500,000	do	2005	IMD/CSSRI
Socio-economic	Village	Digital	2001	Census Haryana
Canal discharge	Point	Sheet	2011	Irrigation Department

Table 2. Details of satellite datacollected for every wheat crop calendar

Scene Date	Resolution (m)	Wheat crop calendar
10 October	23.5	Beginning of Rabi crop season
27 November	23.5	Timely sowing: 10-25 Nov Late sowing: 1-10 Dec
3 March	23.5& 5	Wheat in peak greenness stage; other crops in flowering/senescence
20 April	23.5	Wheat harvested/ late harvesting
1 May & 15 June	23.5	Surface salt encrustation

Characterization and Identification of Areas of Low Productivity

The geodatabase, updated periodically with the current crop, inflow and remote sensing data, has characterized the bio-physical resources at entire command, district, tehsil, distributary, village, watercourse and farm levels. The command characteristics are 3 levels in canal network (main canal to watercourses) with system and inflow characteristics; 4 rainfall departure classes (excess, normal, deficient and scanty) during 2006-13; 6 rainfall zones - 18.6% area (<500 mm), 51.6% (500-600 mm), 17.3% (600-700 mm), 8.8% (700-800 mm), 1.6% (800-900 mm), 2.1% (>900 mm); 5 groundwater (GW) quality classes- good (38.3% area), marginal (15.2%), saline (5.3%), sodic (4.2%) and saline-sodic (37%); two salt-affected soils (SAS)- saline (4.0%), and sodic (14.5%); four soil texture classes- sand (2.4%), loamy sand (6%), sandy loam (78.6%), and loam (13%); and five cropping systems (rice-wheat, bajra-wheat/mustard, sorghum-wheat, cotton-wheat, and sugarcane-wheat). The geodatabase has also delineated district-wise area of low productivity in the command adopting a GIS protocol using data of canal supply, GW quality, SAS and NDVI. About 7.24% of the WYC command was affected with low productivity (988.9 sq km) in Rohtak, Jind and Sonipat districts. The low productivity area may increase substantially during deficient rainfall years. Two distributaries - Butana distributary in Sonipat and Rohtak districts, and Jhajjar distributary in Rohtak and Jhajjar districts within the low productivity areas were selected for analyzing production constraints. This has helped to assess resource constraints in order to predict the crop yield loss at farm level in saline environment using crop-water-salinity yield response model.

Modelling

Water driven crop growth models of varying complexity are necessary for simulating grain yield, water productivity and rootzone salt dynamics of different crops under varying saline and non-saline irrigation regimes. These models are the appropriate tools to understand crop yield and productivity and salt dynamics trends under future climate and irrigation water supply scenarios. The AquaCrop, SWAP and CROPWAT models were calibrated and validated for simulating grain yield, water productivity and salt dynamics for four wheat varieties (KRL-19, KRL-1-4; KRL-210 and HD-2894), and four irrigation water salinity regimes (1.5, 4, 8 and 12 dSm^{-1}) from three year experiment data from *Rabi* 2009-10 to 2011-12. The accuracy of model prediction was evaluated by estimating model efficiency (ME), index of agreement (d) and coefficient of determination (R^2) comparing between the observed and the model simulated results. However, AquaCrop model predictions were the best for the grain yield, and relatively inferior for water productivity for all wheat varieties and salinity levels. Overall, the grain yield and biomass predictions by AquaCrop model for salt tolerant wheat varieties under irrigated saline regimes were obserevd to be better than the salt non-tolerant variety HD-2894. Further, the validated model was linked with CROPWAT and climate generator ClimGen to estimate the irrigation water requirement to obtain yields of wheat under full, deficit irrigation and rainfed conditions. These models were integrated in DSS program to estimate the future crop water requirement for sustainable yield under various resources scenarios.

DSS Program for Enhancing Productivity in Irrigated Saline Environment

A standalone window based DSS program was developed in MS C#.NET by integrating database, key modules, crop-water-salinity-yield module, AquaCrop and SWAP to generate and evaluate the BMPs for various resource scenarios in saline environment for enhancing productivity. The developed DSS application consists of six main modules- *Crop Water Demand*, *Canal Supply*, *Groundwater*, *Irrigation Scheduling*, *Modelling*, and *BMPs based Strategies,* and three supporting modules- *Database*, *Farmer*'s *Services* and *Help.* These main modules were validated, debugged and integrated into the main user interface. The *Database module* displays the eight thematic data of the *Irri-agro Informatics Database* for assessing the saline scenarios/constraints at watercourse and farm level. The *Crop Water Demand* module computes the crop ET from daily weather data for 2001-2013 using Penman-Monteith method and weekly Kc. The irrigation demand at watercourse outlet is thus computed from aggregation of water demand of various crops after subtracting effective rainfall and capillary water, and adding conveyance and application loss. The *Canal Supply* module computes the canal supply and irrigation gap to meet full crop water demand whereas the *Groundwater* module computes the groundwater share and quality. In *Irrigation Scheduling* module, irrigation schedules to maximize/ optimize yield are generated for wheat and other crops from one of four options- canal supply or fresh groundwater in direct or conjunctive mode, deficit irrigation or allowed threshold water stress, effective conjunctive mode with poor quality waters, and both water and salinity stresses.

Scenario development and evaluation in saline environments

In *Modelling*, crop yield response module for prevailing six saline environments in the WYC command namely, *Surface water stagnation,Waterlogging*, *Soil salinity*, *Soil sodicity*, *Saline/sodic water irrigation*, and *Deficit irrigation* was developed to predict the crop yield loss in order to recommend innovative best management practices (BMPs) for minimizing yield loss. The module was validated from the field data. In *Surface water stagnation* and *waterlogging* sub-modules, the crop yield loss for five crops (wheat, barley, mustard, pearlmillet and pigeon pea) was predicted for different short-term water stagnation periods and waterlogging and subsequently, suitable BMP recommendations were suggested for minimizing crop yield. The short-term water stagnation and waterlogging conditions were resulted due to sodic nature of soils, excessive irrigation, seepage from distributaries, minors, and watercourses, and heavy winter rains, due to rise of water table and drainage congestion. These sub-modules have helped in minimizing crop yield loss.

In *Soil Salinity* sub-module, relative crop yield loss was predicted for various rootzone salinities at different growth stages for five crops (wheat, barley, mustard, pearlmillet and pigeon pea). The suitable BMP for four salinity ranges (ECe< 4, 4-8, 8-12 and >12 dSm^{-1}) were recommended, respectively, for minimizing yield loss. Since soil ECe was mainly used in crop production function for saline conditions, the soil EC_2 was converted to soil ECe for predicting the yield loss. Whereas in *Soil Sodicity* sub-module, relative crop yield loss was predicted for different rootzone exchangeable sodium percentage (ESP) values for 6 *rabi* and *kharif* crops. The suitable

BMPs for three ESP ranges (< 20, 20-50 and > 50%) were recommended, respectively, for minimizing yield loss. Since soil ESP was used crop production function for sodic conditions, the soil SAR, pHs and pH_2 were converted to soil ESP for predicting crop yield loss. The gypsum requirement (GR) was computed using Schoonover's formula and standard GR graph. The GR was also converted to equivalent amount of other chemical amendments required to reclaim sodic soils, if gypsum availability is reduced drastically in future.

In *Saline/sodic water irrigation* sub-module, water quality was assessed and the permissible limit of water salinity (ECiw) for different agro-climatic zones was identified. The relative crop yield loss was predicted for different irrigation water salinities for five crops (wheat, barley, mustard, pearlmillet and pigeon pea). The suitable BMP recommendations were suggested, respectively, for minimizing yield loss. In *Deficit Irrigation* sub-module, phenological growth stages for eight crops- wheat, barley, mustard, cotton, sunflower, sorghum, pearlmillet and pigeon pea were assessed and suitable irrigation strategy for different number of irrigations to be applied was suggested. The relative crop yield loss was predicted for five crops using three methods- tested production functions, Jensen's model and Stewart's model. The suitable BMP recommendations for different crops were suggested, respectively, for minimizing yield loss. AquaCrop and SWAP models were integrated under Modelling menu to estimate the crop yield under varying soil and water salinities, foliar potassium fertilization and salt deposition. These models can be used wherever possible to simulaterootzone salinity build-up and crop productivity, but these models require a large number of site specific parameters. In *BMP strategies*sub-module, several BMP based strategies for controlling water stagnation, waterlogging, soil salinity and sodicity, sodic/saline water irrigation and deficit irrigation were generated and the detailed information on each BMP are provided for understanding quantitative impact of such BMPs. The *Farmer's Services* module provides information on various facilities and services to farmers that would be useful on soil and water testing facilities, salt tolerant crops and varieties, high yielding crops and varieties, toll free phone number available in Agriculture Department, KVKs, CADA and irrigation department, input suppliers, and list of BMP interventions in saline environment.The *Help module* providesall the necessary steps that are required to run the DSS program and its individual module. In order to cater the demand of canal water users' association members and progressive farmers, Hindi version of DSS program and crop yield response module was redeveloped and tested to popularize its use among stakeholders as well as in state line departments.

Validation and Application of DSS program

The DSS program was validated from field demonstration data of wheat crop conducted at 52 farmers' fields in mid and tail reaches of Butana distributary and Jhajjar distributary in saline environment which were selected on the basis of prevailing twin problems of soil salinity and waterlogging, varying canal duty, length and inflow capacity. DSS generated best management practices (BMPs) demonstrated were high yielding varieties (HD-2967, 2891, 2894 and DBW-17) and salt tolerant varieties (KRL-1-4, KRL-210, and KRL-19), optimum irrigation scheduling, effective conjunctive use of moderate saline, SAR saline and high RSC sodic groundwater, zero tillage, laser land leveling and line sowing for three years during 2010-11, 2011-12 and 2012-13. The wheat yield increased ranging from 17 to 33% in saline environment and improved the income of marginal and small farmers by Rs. 13,490-25,700 per hectare. The validation of the program has infused confidence in stakeholders on DSS generated solutions for quick adoption.The DSS program was applied to Butana distributary and Jhajjar distributary for testing and the results obtained were found to be reasonably good for enhancing crop yield by 15-20%. The upscaling of DSS program is continued to Agriculture Department, CADAand KVKs of Haryanaas well as to other canal commands. The users' feedback on DSS application has been quite satisfactory.

Transfer of DSS Knowledge to Stakeholders

Since stakeholder's servicing is the important activity for transfer of DSS knowledge to stakeholders, the DSSknowledge was transferred to 1194 stakeholders from canal water users' associations and farmers from 8 districts (Karnal, Panipat, Sonipat, Jind, Rohtak, Jhajjar Rewari and, Bhiwani) through customized trainings and interactive workshops on DSS generated BMP interventions for growing bumper crop yield under deficit water supply, use of marginal and poor quality ground water, varying soil salinity and waterlogging, and poor land levelling conditions. Similarly, 121 district officers/engineers from Command Area Development Authority, Agriculture Department, Irrigation Department, KVKs and Regional Research Stations of CCS Haryana Agricultural University, Hisar, and NGOs from 12 districts within the WYC Command in Haryana were imparted knowledge on DSS program and its application through hands-on trainings, field days, and workshops for generating BMPs for enhancing productivity in saline environment. Further hands-on trainings and backstopping to users at site/online for DSS deployment and for generating BMP based interventions for enhancing crop yield are providedto popularize the DSS program.

Conclusion

A DSS toolfor WYC command is useful for assessingwater resource constraints at farm level for predicting crop yield in six saline environments and for generating BMPs for enhancing productivity. This helpsin arriving right decision with recommended BMPs under various constraints for optimizingcropyield with less water or in saline environment. It isbeing refined and tested to accommodate more scenarios. The DSS program and knowledgecan betransferred to stakeholders through hands-oncapacity building trainings and technical support for its effective use. Further, the DSSprogram can be upscaled/outscaled to the other similar canal irrigation projects in the country for enhancing the productivity.

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Optimizing Irrigation and Planting Schedule of Salt Tolerant Rice and Wheat varieties for Higher System and Water Productivity

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Introduction

Rice and wheat are the staple food crops, which have become the integral part of human diet of 800 million people in South-East Asia. The system is fundamental to employment, income and livelihood for 700 million populations in India. The rice-wheat cropping system fulfills 80% of the food requirement of 60% of the nutrition requirement of Indian population (Timsina and Connor, 2001). This system occupies 12.3 m ha in north India, of which 10 m ha is in the Indo-Gangetic Plains (IGP), covering 75% of the wheat area. In IGP soil sodicity is very common and reclamation with gypsum is very expensive that deters small and marginal farmers to use gypsum. In these circumstances the use of salt tolerant varieties of rice and wheat can be a boon for small and marginal farmers. Both rice and wheat are considered as reclaiming crops and since its inception CSSRI has developed 6 rice and 4 wheat salt tolerant varieties. Among salt tolerant rice varieties, CSR 30 which is of basmati nature is presently grown on an area of about 3 lakh hectares specially in reclaimed sodic and normal soils as well. Due to very high water requirement of rice the problem of water scarcity is coming up and threatening the most intensive irrigated rice–wheat growing areas. Groundwater tables have fallen in the major rice-growing countries. In the Indian states of Punjab, Haryana, Gujarat, Tamil Nadu, Rajasthan, Maharashtra, and Karnataka, it is falling at 0.5–2 m per year (Singh and Singh, 2002; Tuong and Bouman, 2003). In a recent study, jointly carried out by NASA and the German Aerospace Center (DLR), satellite data showed a groundwater table decline rate of 0.33 m per year in northwestern India (Rodell *et al.,* 2009). The study estimated that over a period of 6 years (from August 2002 to October 2008), there was a net loss of 109 km^3 of groundwater in northern India, double the capacity of India's largest surface reservoir (Rodell *et al.,* 2009). The decline in the water table is mainly because of the heavy use of groundwater for irrigation as evidenced from intensive groundwater development (tubewells) during the past decades. In India, the number of groundwater structures (dug wells and tubewells) increased from 3.9 million in 1950–1951 to more than 20 million in 2000 and they currently extract 185–210 km^3 $year^{-1}$ of groundwater (Kumar and Ladha, 2011). The present scenario clearly highlights the need for efficient water management technologies especially for rice in rice-wheat cropping system which requires more than 170 cm water. Similarly salt tolerant wheat varieties KRL-210 and KRL-213 has shown promise in reclaimed sodic soils compared to conventional varieties of the region. Agronomic requirements of traditional varieties may differ from salt tolerant varieties of rice and wheat. In this backdrop, the present study was conducted to standardize irrigation water requirement of salt tolerant rice and wheat varieties in relation to different dates of sowing on a reclaimed sodic soils.

In rice crop treatments consisted of three irrigation schedules (continuous submergence(CS)/ Farmers practice (FP), 3 days after disappearance of ponded water (DAD) and 5 DAD and four dates of transplanting (21 June, 1 July, 11 July and 21 July) in strip plot design with three replications. One month old seedlings were transplanted in all the treatments. Differential irrigation schedules were imposed after one month of transplanting. Results of three year pooled data indicated that different irrigation schedules, CS/FP (3.40 tha^{-1}), 3 DAD (3.29 tha^{-1}) and 5 DAD (3.35 tha^{-1}) did not influenced rice grain yield significantly, however differences in rice grain yield were statistically significant with respect to different dates of transplanting. No interaction between irrigation schedules and dates of transplanting was observed. Maximum grain yield was recorded when transplanting was done on 1 July (3.60 t ha^{-1}) followed by 21 June (3.47 t ha^{-1}). Transplanting of basmati CSR-30 after 1 July resulted in 11.9 and 13.1% reduction in grain yield with every 10 days delay, respectively (Table 1). Irrigation scheduling at 5 DAD and 3 DAD saved 32.5 and 19.8 % of irrigation water compared to CS. Mean irrigation water used varied between 84.7 to 112.4 cm for different irrigation schedules and 82.2 to 120.4 cm for different dates of transplanting. Higher irrigation water productivity was observed in 3 and 5 DAD schedules than continuous submergence/FP across the dates of transplanting (Fig. 1). The mean irrigation water productivity was 0.522, 0.483 and 0.438 kg m^{-3} in 5 DAD, 3 DAD and continuous submergence schedules, respectively. It was observed that 3 DAD and 5 DAD schedules could only be imposed after one month of transplanting and some hair cracks were noticed in 5 DAD schedule which were filled with the help of adjoining soil to avoid leaching of water. Data on lodging was recorded at harvest and it was observed that the lodging was positively correlated with quantum of irrigation water applied. Across the dates of transplanting the lodging was lowest in 5 DAD (5.16%) and highest in continuous submergence schedule (14.2%). Observation on panicle initiation and maturity indicated that both were hastened by 23 and 24 days, respectively, by transplanting rice seedlings on 21 July than 21 June.

Table 1. Grain yield of basmati CSR-30 with different dates of transplanting and irrigation schedules (3 year pooled data)

Date of transplanting/ Irrigation schedules	Grain yield (t/ha)			
	CS/FP	3DAD	5DAD	Mean
21 June	3.43	3.45	3.54	3.47a
1 July	3.69	3.48	3.63	3.60a
11 July	3.36	3.06	3.10	3.17b
21 July	3.10	3.17	3.12	3.13b
Mean	3.40	3.29	3.35	-
$LSD_{0.05}$	IS: NS DoT: 0.21 Interaction: NS			

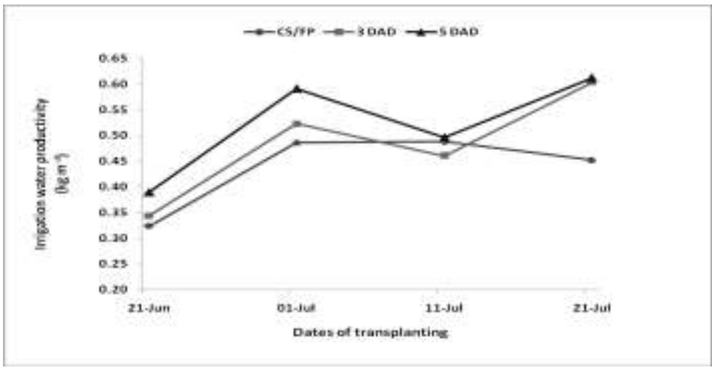

Fig. 1. IWP of basmati CSR-30 transplanted on different dates and irrigation schedules (3 year pooled data)

Salt tolerant wheat varieties KRL-210 and KRL-213 were grown under three irrigation schedules (IW/CPE =1.0, 0.8 and 0.6) with four dates of sowing (10 Nov., 20 Nov., 30 Nov. and 10 Dec.). Across date of sowing and variety the numerically higher grain yield was recorded when irrigation was scheduled at IW/CPE = 1.0 (6.03 tha^{-1}) followed by 0.8 (5.75 tha^{-1}) and 0.6 (5.57 tha^{-1}) ratio. Over irrigation schedules and variety the highest grain yield was recorded when sowing was done on 10 November (6.48 tha^{-1}) which was statistically at par with 20 November sowing (6.10 tha^{-1}) and significantly higher than 30 November (5.60 tha^{-1}) and 10 December sowing (4.95 tha^{-1}). Perusal of the table 2 indicated that both KRL-210 (6.76 tha^{-1}) and KRL-213 (6.88 tha^{-1}) yielded higher when sowing was done on 20 November and irrigation was scheduled at IW/CPE = 1.0; however, under water stress treatments (IW/CPE = 0.8 and 0.6), grain yield in both the varieties was higher when sowing was done on 10 November. Irrigation water productivity (IWP) increased with decreased irrigation frequency, however, IWP decreased linearly with delay in date of sowing from 10 November to 10 December and statistically similar in KRL-210 and KRL-213 (Fig. 2).

Table 2. Grain yield of salt tolerant wheat varieties grown at different dates of sowing and irrigation schedules

Date of sowing	Irrigation schedule (IW/CPE)							
	KRL 210				KRL 213			
	1.0	0.80	0.60	Mean	1.0	0.80	0.60	Mean
10 November	6.46	6.36	6.45	6.42a	6.50	6.65	6.48	6.54a
20 November	6.76	6.16	5.20	6.04ab	6.88	5.99	5.57	6.15a
30 November	5.82	5.48	5.73	5.68b	5.68	5.37	5.53	5.52b
10 December	4.83	5.11	4.57	4.84c	5.30	4.85	5.03	5.06c
Mean	5.97	5.78	5.49	5.74	6.09	5.71	5.65	5.82
$LSD_{0.05}$	IS=NS; DoS: 0.42; Variety: NS; IS×DoS×Variety=NS							

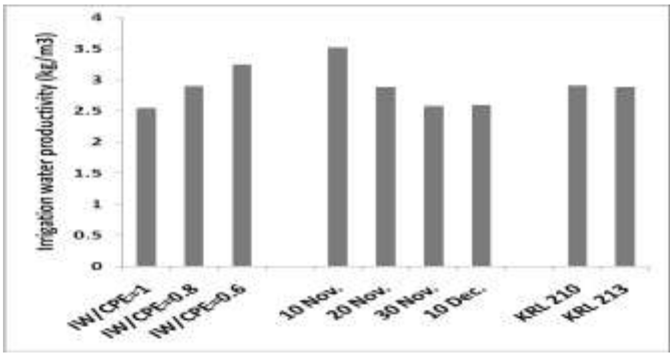

Fig. 2. Irrigation water productivity of salt tolerant wheat varieties

Conclusions

- Rice may be transplanted on 1st July (3.63 t/ha) to realize higher yield and IWP (0.591 kg/m^3) by following 5 DAD after 1 month of transplanting.
- Wheat can be sown on 20 November (6.82 t/ha) with irrigation schedule of IW/CPE=1.0 to realize maximum yield.

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Role of Recharge in Improving Groundwater Availability and Quality in Poor Quality Areas

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Introduction

The groundwater systems are the planet's largest freshwater resources and have storage capacity far more than all man-made surface reservoirs. This key component of the water cycle is the major source of drinking water and agricultural and industrial supplies in many parts of the world. About 70 percent of irrigation and 85 percent of drinking water requirements of India are met from groundwater sources. India has built more than its share of the world's dams but 1150 km^3 of its rainwater runoff still goes to the seas annually in the form of "rejected recharge" (INCID, 1999). The rivers and rivulets of the Indian sub-continent are mainly monsoon fed with 80 to 90 percent run-off occurring during the monsoon. Harnessing of excess monsoon runoff to create additional ground water storage can not only increase the availability of water to meet the growing demands, but also will help in controlling damages from floods.

Groundwater has played a vital role in stabilizing Indian agriculture, but its indiscriminate use is resulting in fast depletion and degradation of this key natural resource. Un-regulated development of groundwater has resulted in alarming decline of water tables in about one seventh (15 %) of country's geographical area accompanied by degradation of its quality at several locations. Kamra et al (2010) reported that north-western states of Haryana, Punjab, Uttar Pradesh and Gujarat account for 27 percent of country's 839 over-exploited groundwater blocks where groundwater pumping is more than the annual natural recharge.

The sustainability of agriculture in north- western Indian states, in particular in highly productive, water intensive and widely prevalent rice- wheat system in Haryana and Punjab, is getting threatened due to alarming decline of water table, increase in pumping cost and deterioration in groundwater quality. The major cause of rapid groundwater decline is the paddy crop which consumes extremely high quantities of fresh water (approx. 3000 litres for producing 1 Kg of rice). The rate of groundwater decline can be slowed down either by replacing high water demanding crop like rice with the crops having less water requirement or by enhancing groundwater recharge through surface spreading and recharge well techniques (Kamra *et al.*, 2013). It helps in utilizing flood water that 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 areas having problems of fluoride contamination, groundwater recharge can help in improving water quality by dilution.

Natural and Artificial Groundwater Recharge

Natural recharge is how groundwater is formed as the difference between water inputs into the soil (precipitation and infiltration from streams, lakes, or other natural water bodies) and outputs (evapo-transpiration plus runoff). Natural recharge occurs seasonally in temperate climates, but much less frequently in arid and semi- arid regions. This can be enhanced by management of aquifer recharge and optimizing the storage capacity of the aquifers through interventions which have been used for centuries: simple check bunds in gullies to complex diversion and infiltration structures, as well as injection wells. To combat water demand variability resulting from persistent droughts and climatic change, more widespread and socially sustainable groundwater recharging systems are needed.

The artificial recharge to ground water aims at augmentation of ground water reservoir by modifying the natural movement of surface water utilizing appropriate engineering structures. Artificial recharge techniques normally address to the following issues:

(i) To enhance the sustainable yield in areas where over-development has depleted the aquifer.
(ii) Conservation and storage of excess surface water for future requirements, since these requirements often change within a season or a period.
(iii) To improve the quality of existing ground water through dilution.

The guiding principles in framing the perspective GR recharge plan of any region are:

- Availability of non- committed surplus monsoon runoff in space and time.
- Identification of suitable hydro- geological environment and sites for creating sub-surface reservoir through cost effective artificial recharge techniques.

The water availability in a basin is a time dependant variable of the rainfall, evaporation, natural recharge from precipitation and runoff loss. The number of rainy days and maximum one- day rainfall would qualitatively indicate how effectively the rainfall could be used for ground water recharge. The flow of water in moisture form to groundwater is governed by the infiltration and transmission characteristics of different lithological layers between land and aquifer zone(s). Beyond these technical issues, the institutional, social and financial concerns and availability of technical expertise to construct, operate, monitor and maintain the recharge structures determine the success or failure of a scheme.

Artificial ground-water recharge is accomplished by two basic methods: spreading and injection through wells. The most widely used technique is spreading, in which water is commonly diverted from a stream or released from reservoirs to shallow basins or trenches. Injection recharge is used in localities where there are zones of so low vertical permeability between the surface and the water table that movement of water in deeper layers is slow or negligible. 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; Malik *et al*., 2004). The most notable for north-western states include CGWB studies on well injection and induced recharge in Ghaggar river basin in Haryana, well injection and subsurface dykes in Mehsana and Kutch districts of Gujarat, 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 Uttar Pradesh and a regional IWMI study on diversion of 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 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). Kamra *et al*. (2006) and Malik *et al.* (2004) clearly indicated better social viability of individual farmer based small recharge structures in fresh and marginally saline groundwater regions of Haryana.

Groundwater Recharge Tubewells

Haryana and Punjab have similar topographical and hydro- geological situations, both comprising of high yielding fresh water aquifers where rice- wheat cropping is practiced and saline groundwater regions where aquifers of relatively poor transmission characteristics occur. The number of private shallow tube wells has increased twenty fold to about 0.75 million in Haryana and forty times to 1.4 million in Punjab over the last four decades. These two states have semi- arid climate with annual rainfall of 450- 800 mm, about 85 percent usually occurring between June and September. About two- third and one- third areas of Haryana and Punjab are underlain with saline ground water, a major part by high residual sodium carbonate (RSC) waters. In both states, there is a constant rise of water levels in the saline areas and a decline in the fresh water areas. The water table depth in most fresh groundwater districts of Haryana and Punjab has fallen below 15-20 m and still deeper at 28.8 m and 41.1 m in Kurukshetra and Mahendragarh districts in Haryana.

Under Farmers' Participatory Action Research Project (FPARP) of Ministry of Water Resources (GOI), research funds were provided to 38 ICAR institutes and state agricultural universities to demonstrate water conservation technologies in farmers' fields. FPARP was operational at CSSRI, Karnal and its Regional Research Stations at Bharuch (Gujarat) and Lucknow (Uttar Pradesh) from March 2008- Nov. 2010. Under this project, groundwater recharge structures were implemented and evaluated in 53 farmers' fields including 34 in six districts of Haryana, 5in one district of Punjab, 3 in one district of UP and 12 in one district of Gujarat (Table 1).

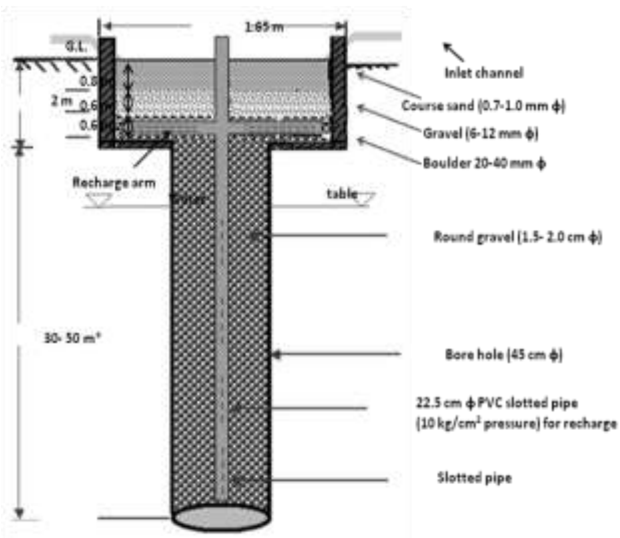
The watertable depth in most selected sites in four states varies between 10- 30 m and has been falling @ 20- 60 cm every year. Despite semi-arid climate at selected sites, there are depressional areas where water accumulates during rainy season and can be recharged to groundwater. About one third sites of Haryana and all sites of Punjab have high groundwater salinity and residual sodium carbonate (RSC) problems. Groundwater in Unnao district has high fluoride concentration that is adversely affecting the health of the people and livestock.

Table 1. Distribution of groundwater recharge structures installed in different states

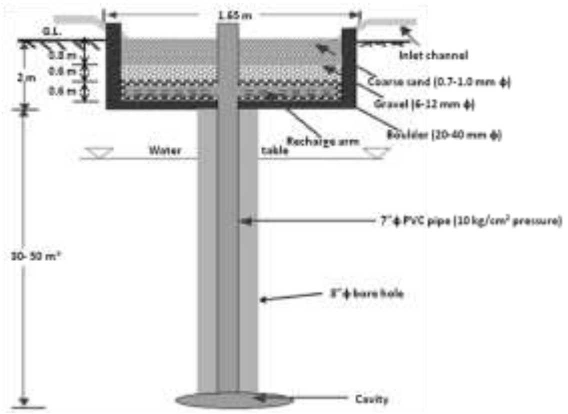
States/District	Technology/intervention	No. of sites
Haryana		33
Karnal, Kaithal, Jind, Kurukshetra, Yamunanagar, Sonipat	Recharge shaft	21
	Recharge cavity	08
	Other (abandoned cavity, dry cavity)	04
Punjab		05
Patiala	Recharge shaft	05
Uttar Pradesh		03
Unnao	Recharge cavity	03
Gujarat		12
Bharuch	Recharge well	12
Total		53

The design features of these structures involving passing of excess rain and canal water under gravity to suitable aquifer after filtration were provided by Kamra (2013) who reported these to be highly effective. Selection of recharge structures of different designs, depths and costs was based on hydro- geological investigations and quantum of potential runoff water available at specific locations. Brief features of 3 structures (recharge shaft, recharge cavity, and recharge wells) are presented below:

(i) Recharge shaft and r**echarge cavity** type small structures were designed and developed for enhancing groundwater recharge using rain and surplus canal water and saving crop of low lying area from submergence during extreme and untimely rain. The design feature of developed recharge shaft and recharge cavity are given bellow (in picture) which were demonstrated and evaluated at farmers fields in Haryana and Punjab at 43 locations. The recharge shaft consists of a bore hole of 45 cm ϕ and varying depths filled with gravel pack of 1.5 – 2.0 cm ϕ 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 ϕ 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 was decided based on the criterion to provide 10- 15 m cumulative sand layers for recharge.



(a) Recharge shaft



(b) Recharge cavity

Fig. 1. Design features of (a) recharge shaft and (b) recharge cavities installed in Haryana, Punjab and Uttar Pradesh

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. It is constructed by drilling a bore hole until a sandy layer is found below a clay layer. A blind PVC casing pipe is drilled into the clay layer and sand is pumped out until a stable cavity is developed below the clay layer. The developed techniques are fast and do not requires land for surface ponding. They also serve as small vertical drainage systems and save the cropped from submergence due to heavy rain.

(ii) Recharge Wells (12 sites) installed in Bharuch district of Gujarat, the recharge wells are similar to recharge shaft except that boreholes of different sizes (17.5- 40 cm ϕ) and filter chambers of different shapes have made at different sites. Placement of 12.5 cm ϕ PVC pipes and 8-20 mm ϕ pebbles in the bore hole was facilitated through air compressor; pebbles were not used in 2 sites having rocky substratum. Brief features and cost of recharge technologies are summarized in Table 2. At current prices, the cost of groundwater recharge structure installed at 30- 45 m is likely to be Rs. 60000- 100,000.

Table 2. Features of demonstrated recharge structures and interventions

Structure	Depth (m)	Thickness of sandy layers (m)	Cost (Rs.) 2009 prices
Recharge Shaft	30- 46	10- 18	35000- 48000
Recharge cavity	40- 55	NA	35000- 45000
Recharge cavity cum strainer well	50	25	55000- 58000
Recharge well	25- 45	15- 18	22000- 31000

Recharge Filters: The clogging of the vertical sand filters consisting of layers of coarse sand, gravel and boulders, was found to be a major constraint in the performance of developed recharge structures. Even if the farmer is ready to clean it, there are practical problems in cleaning of clogged sediments during high rainfall events. Without cleaning of deposited clogged material from upper sand layer of recharge filter, the recharge rates are reduced drastically, sometimes virtually to zero rates if sediment load in runoff water to be recharged is high.

CSSRI team made (and is still making) research efforts to improve effectiveness of sand based filtration unit for harnessing the maximum benefits of individual farmer based recharge structures. In this direction, size and thickness of sand, gravel and boulder layers were optimized through a series of field and lab studies, which indicated the thickness of upper sand layer to be the primary factor influencing clogging. The size of gravel in the middle layer also influences effectiveness of sand as a filter. After a series of studies, top sand layer (0.7-1.0mm Ø, 75 cm thickness), gravel (8-20 mm Ø, 30 cm minimum thickness) and boulders (20-40 mm Ø and 30 cm minimum thickness) were found effective for sand based vertical filter (Kumar *et al.*, 2012).

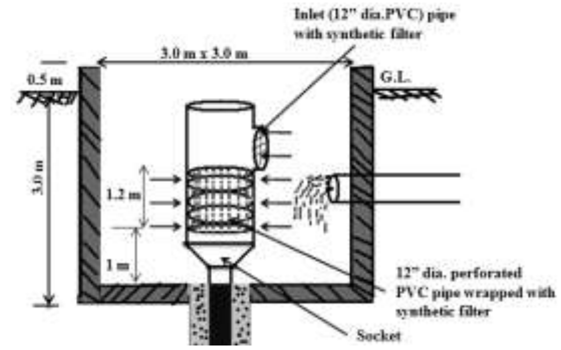
Similar studies were conducted with partial success on effectiveness of different radial and biological filters to entrap the sediment load of excess canal/rain water before recharging to groundwater. The radial filters involve replacement of sand, gravel and boulders by concentric larger size pipes of PVC or other materials around the well pipe and having perforations all along its length and wrapped with same or different material as on the well pipe. The inflow movement of water to recharge well in radial filters is in horizontal direction from outer filter pipes to inner well pipe. Practical problems, encountered about stable positioning and theft/ pilferage of such light weight radial filters, restrict their extensive use.

Out of 4 grass species evaluated as biological filters to be created around recharge structures, to improve effectiveness of existing vertical sand filters, it was found that 50 per cent sediments could be retained within five meter strip of *Saccharum munja* grass. To improve the effectiveness of vertical sand filter, farmers themselves also introduced minor modifications like one farmer in village Sawant (Karnal) significantly improved recharge rate by connecting an additional radial pipe to well pipe above the sand layer and wrapping the opening with synthetic cloth filter.

A view of clogging of sand based vertical filtering unit of well type drainage cum recharge structure

Modification in vertical sand based filtering unit of well type drainage cum recharge structure at farmer's field

Modification in vertical sand based filtering unit of well type drainage cum recharge structure at farmer's field



Developed new design of filter for well type drainage cum recharge structure

Fig. 2. Design and clogging in different recharge filters

A new filter design for recharge structures has also been developed by CSSRI and tested in farmers' fields. For this recharge filter, the filter chamber remains same as in 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. Another inlet pipe is connected with a T-Joint above the perforated portion to increase surface area to enhance recharge rate. 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 modification done at farmer's field and new design developed are shown below through pictorial presentation.

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Above design of recharge filter and much larger recharge chambers have been implemented in conjunction with village ponds to facilitate augmentation of groundwater through 9 " Ø recharge cavities at 2 locations (village Kutba and village Nirmana) in Muzaffarnagar district (UP) during 2016. Similar designed filters have considerable scope for implementing recharge projects just adjoining to surface drains, instead of inside the drain due to clear advantage of better cleaning of recharge filters.

Keeping the observed experience on the performance of recharge structures in Haryana and Punjab, it is recommended to prefer recharge cavities of minimum 7- 9 inch Ø over recharge shafts, where ever possible. Pumping of water from recharge cavities by using 2" size motor immediately after monsoon season helps in cleaning the whole system and in particular very fine suspended particles, if any, deposited in the cavity during the rains.

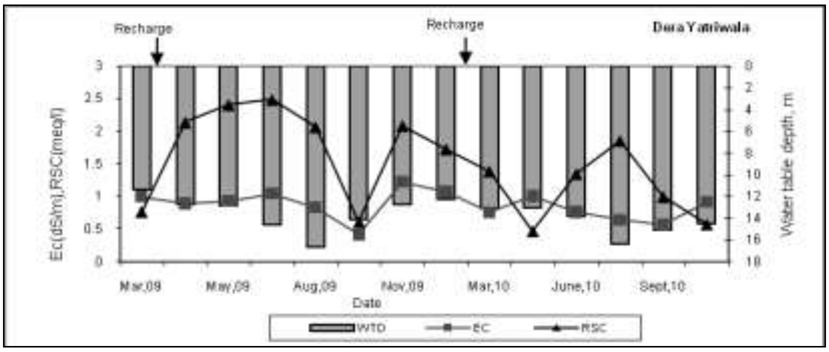
The observations in a farmer's field in Karnal district during heavy rains of August 2012 clearly indicated a recharge structure to be essential for saving maize crop from adverse effect of prolonged water submergence. Improved designs of recharge structures and recharge filters, including less costly smaller structures for small and marginal farmers, are highly desirable which will require basic studies on the governing mechanisms of natural recharge under different land uses and through well injection techniques.

Impact of Recharge Tubewells

Individual farmers can construct recharge structures at any low lying location where runoff gets accumulated and adversely affects the production of rice during monsoon rains and of wheat during occasional winter rains. There are encouraging results on the effectiveness of recharge shaft and recharge cavities to replenish groundwater and improve its quality. Depth to groundwater and EC, pH and RSC of groundwater were determined periodically to assess the impact of recharge structures. The temporal changes in depth, EC and RSC or pH of groundwater at 2 representative sites in Haryana and Punjab are presented in Fig. 3. 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 results of 2 rainy seasons during the project period indicate these structures to be highly effective in augmentation of groundwater and improving its quality.

- The proposed individual farmer based groundwater recharge structures have simple design and have better chances of success and adoption than the bigger and much costlier recharge schemes due to scope of maintenance of recharge filters by farmers themselves. The capital investment cost of the recharge structures has been worked out @ Rs. 3.5 to Rs. 2.1/ m^3 recharge water for locations collecting runoff from 12- 20 ha area.

- The recharge structures, with intake rate of 4-6 litre/ sec, have proved highly effective in augmenting groundwater, improving its quality and enhancing farmers' income by saving of submerged crops. The recharging of water resulted in 0.6- 3.3 m and 0.3 to 3.2 m rise in water table at different sites in Haryana and Punjab during rainy seasons of 2009 and 2010 respectively. The corresponding reduction in salinity and RSC of groundwater ranged from 0.2- 2.4 and 0.1- 0.8 dS/m and 0- 6.6 and 0- 8.3 respectively. The payback period of 30- 45 m deep recharge structures installed in Haryana and Punjab and costing Rs. 30000- 50000 (2009 prices), has been estimated to be 1- 2 years only.



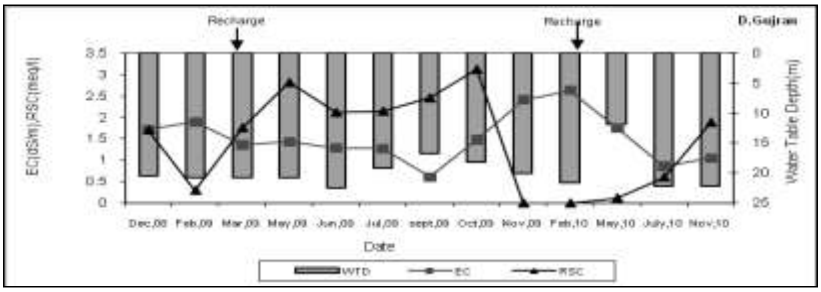


Fig. 3. Temporal changes in depth, EC and RSC or pH of groundwater at two representative sites

- In addition to augmentation of groundwater, recharge structures also bring about notable improvement in groundwater quality. The improvement in salinity and RSC of groundwater at different selected sites in Haryana, Punjab and Gujarat ranged from 0.2- 2.4 and 0.1- 0.8 dS/m and 0- 6.6 and 0- 8.3 respectively during 2009 and 2010. The temporal changes in groundwater quality due to recharge interventions at selected sites during these two years are presented in Table 3.

- The recharge wells in Gujarat also resulted in prolonged availability and improvement in quality of groundwater that facilitated increase in income of Rs. 30000- 75000/ha in mango, papaya and banana plantations. Further, recharge of excess canal water through recharge wells at 3 sites in Unnao district of UP reduced fluoride concentration of groundwater from 2.0 ppm to 1.2 ppm, i.e. below prescribed limit of 1.5 ppm for drinking water.

Table 3. Improvement in groundwater quality with recharge interventions at selected sites

State/Village	EC (dS/m)			RSC		
Haryana	May/ June	July/ August	October/ November	May/ June	July/ August	October/ November
2009						
a) Nabiabad (Karnal)	1.9	1.1	0.5	6.0	2.4	0.2
b) Paju Kalan (Jind)	1.2	0.9	0.5	5.6	3.4	0.6
c) Dussain (Kaithal)	1.4	1.1	0.5	6.7	3.9	2.1
2010						
a) Newal Khurdh (Karnal)	1.3	0.7	1.1	3.7	2.3	1.0
b) Paju Kalan (Sonipat)	1.7	0.6	1.5	4.4	0.7	2.1
c) Dussain (Kaithal)	1.0	0.8	1.1	6.9	3.4	2.6
Punjab						
2009 : Jodhpur (Patiala)	2.0	1.7	1.1	7.1	3.4	3.2
2010: Budhmor (Patiala)	1.3	1.1	1.1	4.8	3.0	3.1
Gujarat						
2009: Borebhete (Bharuch)	1.9	0.3	0.6	-	-	-

- The clogging of the recharge filter has been observed to be a major constraint in the performance of recharge structures. Farmers need to be trained to clean the deposited sediments on the sand layer of recharge filter after every recharge event and replaced with new or washed sand to maintain optimal water intake. Mechanisms for farmers' involvement and marginal sharing of cost of recharge structures need to be developed. Field and lab studies are in process to devise improved designs of recharge filters to minimize clogging problem. Thickness of upper sand layer of recharge filter has been found to be a primary factor influencing clogging, while size of gravel in the middle layer also controls effectiveness of sand as a filter.

Conclusions

Over the past two years, CSSRI has successfully installed individual farmer based groundwater recharge structures at 52 sites in Haryana, Punjab, Uttar Pradesh and Gujarat under Ministry of Water Resources (GOI) funded FPARP. These structures are based on well injection techniques and involve passing of excess rain and canal water under gravity through tubewell type recharge structures to suitable aquifer sandy zones after filtration through a recharge filter. These structures are successful at any low lying location where runoff gets accumulated and adversely affects the production of rice and wheat during heavy rains.

The groundwater recharge structures are simple in design keeping individual farmer's needs in mind. These systems have better chances of success and large scale adoption than the bigger and much costlier recharge schemes due to scope of maintenance of recharge filters by farmers themselves. The recharge structures have proven highly effective in augmenting groundwater, improving its quality and enhancing water productivity and farmers' income. The structures helped in reducing flood volumes through recharge to save transplanted rice in the lowest 1-2 ha area at certain sites in Haryana and Punjab resulting in net saving of more than 25000/ from rice only. Similarly the recharge wells in Gujarat also resulted in prolonged availability and improvement in quality of groundwater that facilitated increase in income of Rs. 30000- 75000/ha in mango, papaya and banana plantations. Based on results of two rainy season, it seems that payback period of 30- 45 m deep recharge structures, costing Rs. 30000- 50000 is 1- 2 years only. Groundwater recharge structures also provide impressive perceptible benefits like improvement in salinity, alkalinity and fluoride concentration at selected sites in four states, which have high scope to reduce drinking water hazards of such contaminated waters on the health of human beings and livestock as well as on crop production.

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Resource Conservation Technologies for Increasing Crop Productivity under Rice–wheat Cropping System

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Introduction

The Indo-Gangetic plains (IGP) are of great importance for the food security of India. It extends over 1600 km with a width of 320 km, including the arid and semi-arid environments in Rajasthan and Punjab and the humid and per humid deltaic plains in west Bengal (Shankaranarayana, 1982). During the green revolution period in the early 1960s, production increased through area expansion and intensification of the rice–wheat system. Driving forces included suitable thermal regimes for rice and wheat cultivation, development of short-duration, nitrogen responsive cultivars, expansion of irrigation and an ever increasing demand for food from the rising population. The rice–wheat, covering an area of 10 m ha is a major cropping system in the IGP. These two crops together contribute more than 70% of total cereal production in India from an area of around 25 mha under wheat and about 40 mha under rice. The small states of Punjab and Haryana contribute 20% to the total national grain production and 50 and 85% of the government procurement of rice and wheat, respectively (Singh, 2000). A decline in land productivity, particularly of the rice-wheat system, has been observed over the past few years in the northern and north western IGP despite the application of optimum levels of inputs under assured irrigation (Paroda, 1997).

It was owing due to, the indiscriminate use, or rather misuse, of natural resources, especially water, has led to the pollution and depletion of ground water resources (Nayar and Gill 1994). Intensive tillage and residue burning has led to depletion of soil organic carbon resulting in decreased soil fertility and reduced factor productivity (Yadav, 1998). It indicates that the RW system, especially residue burning, intensive tillage and injudicious use of water resources, has weakened the natural resource base. Evidence, is now appearing that continued intensification of input use since the adoption of green revolution technologies has provided lower marginal returns (Ladha *et al.,* 2000). In addition, inappropriate use of applied inputs and over exploitation of the natural resource base, land and water, are leading to degradation in the form of salinization, drop in the ground water table, physical and chemical deterioration of the soil and pest problems (Bye lee, 1992 and Murgai *et al.,* 2001). Reicosky, 2008 reported that tillage or soil preparation has been an integral part of traditional production.

Tillage is also a principal agent resulting in soil perturbation and subsequent modification of the soil structure with soil degradation. Intensive tillage can adversely affect soil structure and cause excessive breakdown of aggregates increasing soil erodibility. Intensive tillage causes soil degradation through carbon loss and tillage-induced greenhouse gas emissions, mainly CO_2, that impact productive capacity and environmental quality. Improved tillage management techniques have shown that scientific agriculture can also be a solution to environmental issues in general and, specifically to mitigating the green house effect (Lal et al., 1998). Improved agricultural practices such as direct seeding or conservation tillage have the potential to sequester more carbon in the soil than farming emits through land use and fossil fuel combustion. Thus, a combination of the economic and carbon related environmental benefits of enhanced soil management through reduced labor requirements, time savings, reduced machinery and fuel saving with direct seeding has universal appeal. In recent years, due to continuous energy crisis and increasing fertilizers prices, interest has aroused in the age-old practices of green manuring. Issues of great concern associated with this practice are the sustainability of soil productivity. Indiscriminate use of high analysis chemical fertilizers results in the deficiency of nutrients other than the ones applied and causes decline in the organic carbon content (Singh et al., 1999). Kumar and Prasad (2008) also, revealed that when green manure is applied along with chemical fertilizers for efficient growth of crop, decline in organic carbon is arrested and the gap between potential and actual yield also narrows down to a large extent. Green manuring of legume shrubs has for long been known to sustain the crop productivity. The benefits of green manuring of different materials under rice-wheat cropping system have been reported by several workers (Prasad *et al*., 1995, Bhandari *et al*., 1992, Hundal *et al*., 1992, Singh *et al*., 1999, Yadvinder Singh *et al*., 1991). Therefore, to achieve sustainable or higher productivity, efforts must be focused on reversing the trend in natural resource degradation. Moreover, due to rising prices of inputs, it is imperative to develop technologies which save on inputs to increase the profit margins of the farmers. Hence, the study was design in such a way that how to integrate the recourses to arrive at optimal tillage, water in rice-wheat system to economize energy, labors, time and ultimately the cost of cultivation. Consequently, there is now great concern about the future potential for productivity growth and long term sustainability of the irrigated rice-wheat system of the IGP. Ideally, crop residue management practices should be selected to enhance crop yield with minimal adverse effects on the environment. Thus, the major challenge is to continue to look the technological innovations, socio-economic adjustments, and policy reforms for sustained increases in productivity and production of the rice-wheat systems.

Effects of Tillage and Crop Residue Management practices on crop productivity

The results have shown in Table 1, 2 reveals that continuous rice-wheat cropping sequence in light textured soils has weakened the natural resources base. A long-term experiment was initiated to address some of the problems faced by the farmers in managing the natural resources for increasing the rice-wheat productivity at Central Soil Salinity Research Institute, Karnal. The aim was enhancing water, nutrient, and energy use efficiency by ensuring soil health and quality. Nine adaptable resource conservation practices were compared with the conventional practice of rice-wheat cultivation.

(a) Wheat grain yield: Wheat sowing in 50% reduce tillage with rice residue incorporation produced highest grain yield (5.43 t ha^{-1}) compared to conventional (4.73 t ha^{-1}) and 50% reduced tillage (5.18 t ha^{-1}).

Table 1. Effect of surface and mini sprinkler method on wheat yield (Cv. HD 2967), irrigation water requirement, water productivity, saving of water and electricity during 2015-2016.

RCTs	T_1	T_2	T_3	T_4
Mode of irrigation	Surface T_1	Surface T_7	Mini Sprinkler T_8	Mini Sprinkler T_9
Irrigation criteria	Growth stages	Growth stages	(Previous 7 days CPE)	(Previous 7 days CPE)
Grain yields (t ha^{-1})	4.73	4.89	5.18	5.29
Total crop productivity (t ha^{-1})	12.43	11.82	10.77	10.74
Total irrigation water (ha-cm)	28.0	23.0	18.53	18.53
Total irrigation water (m^3ha^{-1})	2800	2200	1853	1853
Crop water productivity (kgm^{-3})	4.44	5.37	5.81	5.79
Grain water productivity (kgm^{-3})	1.79	2.22	2.24	2.28
Irrigation water saving (%)	-	21.43	33.82	33.82
Electricity saving (%)	-	27.77	8.15	8.15
NUE ($kgkg^{-1}$ nitrogen)	31.53	32.6	69.07	70.53
Physiological observation	yellowness-water stagnated after irrigation and rainfall	Greenness No stagnation	Greenness No stagnation	Greenness No stagnation
Rainfall received = 46.2 mm and Pan evaporation=257.1 mm during November 2015 to March 2016 , CPE= cumulative pan evaporation of 7 days used for irrigation through mini sprinkler system , CD (0.05) =0.32 and NUE= nitrogen use efficiency				

T_1: Conventional wheat sowing; T_2: Wheat sowing in Zero tillage with100 % rice mulch / DSR without wheat residue; T_3: Wheat sowing in Zero tillage with 100 % rice mulch/DSR without wheat residue; T_4: Wheat sowing in Zero tillage with 100 % rice mulch /DSR with wheat residue incorporation.

- Crop residue incorporation resulted ~14.80 % additional grain yield for wheat under 50% reduce tillage practice.
- Conventional tillage with crop residue incorporation yielded 12.26% higher grain yield in comparison to conventional wheat sowing without crop residue. This may be due to optimum hydrothermal regime under residue incorporation treatments, facilitated better seed germination and crop growth as compared to no- residue treatments.

(b) Rice yield:

- Highest grain yield of rice (7.44 t ha^{-1}) was recorded in conventional transplanted rice with wheat residue incorporation followed by conventional transplanting (7.16 t ha^{-1}) without crop residue.
- Crop residue incorporation in transplanted rice resulted ~3.46 % higher additional grain yield.
- In DSR with crop residue grain yield was 6.84 t ha^{-1} which is 4.91% higher as comparison to DSR without crop residue.

Effects of irrigation methods on rice-wheat crop productivity

Wheat and rice productivity under mini sprinkler irrigation shown in table 1 and 2, reveals that wheat crop during 2015-16 in rabi season and rice in kharif season 2016 under mini sprinkler irrigation observed the following results:

Wheat (2015-16)

- Sprinkler irrigation system in wheat crop saved 33.82 % more water over the surface irrigation method.
- Wheat in Zero tillage with 100% rice straw mulch produced highest wheat grain yield (4.89 t ha^{-1}) under surface irrigation but in sprinkler irrigation produced 5.29 t ha^{-1} where wheat was sown in zero tillage with 100% rice straw mulch.
- Electricity consumption saving in wheat crop was 8.15% when irrigation was given through mini sprinkler irrigation method in comparison to surface irrigation method with conventional wheat sowing.
- Highest nitrogen use efficiency 70.53 kg kg^{-1} nitrogen observed in mini sprinkler fertigation method and saved 50% nitrogen of recommended (75kgN and 162 kg urea) in wheat as compared to conventional surface irrigation.

Rice (2016)

- Mini sprinkler irrigation in DSR produced grain yield of 6.68 t ha^{-1} with 50% reduced tillage. This method saved 55 % of irrigation water and 28.11% electricity consumption.
- DSR with 50% reduce tillage under surface irrigation method saved 31 % irrigation water in comparison to conventional rice.
- Mini sprinkler fertigation in rice saved 27% nitrogen (40 kg) and increases nitrogen use efficiency maximum up to 60.7 kg kg^{-1} nitrogen as compared to conventional rice.

Rice grain yield under different crop establishment technologies

Conventional rice transplanting

The results showed in table 2 indicated that rice in kharif 2016 produced highest grain yield (7.44 t ha^{-1}) recorded in Conventional with wheat residue incorporation followed by conventional transplanting (7.16 t ha^{-1}) without crop residue. Crop residue incorporation in transplanted rice resulted ~3.46 % higher additional grain yield. Wheat residue in rice season and rice residue in wheat season, in-situ incorporation increased the rice grain yield by 7.44 t ha^{-1} with 3.91% higher yield even under conventional transplanted rice. Residue incorporation in transplanted rice produced significantly higher grain yield 7.44 t ha^{-1} than the non-residue treated (7.16 t ha^{-1}) under conventional tillage. Maximum rice yield was obtained in conventional rice transplanting by conventional transplanting with wheat residue incorporation.

Direct seeded rice in reduced and zero tillage condition

DSR in reduced tillage: Data given in Table 1 shows that in direct seeded rice (DSR) technique grain yield obtained up to 6.8 t/ha. In DSR erratic results were obtained due to relatively high weed population. Further, rice productivity affected by tillage intensities and crop residue added continuously.

Rice grain yields in year 2016 under DSR technique was 4.47% lower than that of transplanted rice. However, in 2016 rice grain yield improved with the reduction of 4.47% under DSR, due to effective weed control measures relatively. Rice grain yield increased, under residue management both in transplanted and direct seeded rice (DSR). In DSR with crop residue grain yield was 6.84 t/ha, which was 4.91% higher in comparison to DSR without crop residue. DSR with wheat residue incorporation yielded 6.84 t ha^{-1} which was 3.79% higher in comparison with DSR without wheat residue incorporation treatment (6.52 t ha^{-1}).

DSR in zero tillage: Direct seeded rice in zero tillage with anchors yielded 6.76 t ha^{-1}, which was 4.91 % higher than DSR in zero tillage without crop residue retention. This was because of better weed control in DSR with residue retention. Transplanted rice grains were totally infected by false smut disease, while there was no infection in DSR. It might be due to higher relative humidity in transplanted rice.

Table 2. Effect of surface and mini sprinkler irrigation method on hybrid rice yield (Arize 6129), irrigation water requirement, water productivity, saving of water and electricity during 2016

RCTs	T_1	T_2	T_3	T_4
Mode of irrigation	Surface T1	Surface T7	Mini –Sprinkler T8	Mini –Sprinkler T9
Irrigation criteria	1DADPW	Small soil cracks with surface dryness	(CPE) Alternate day	(CPE) Alternate day
Grain yields (t ha^{-1})	7.16	6.84	6.59	6.51
Total crop productivity (t ha^{-1})	15.28	13.47	12.96	13.58
Total irrigation water (ha-cm)	72.5	50.0	32.58	32.58
Total irrigation water (m^3/ha^{-1})	7250	5000	3258	3258
Crop water productivity (kg m^{-3})	2.11	2.69	3.98	4.17
Grain water productivity (kgm^{-3})	0.99	1.37	2.02	1.99
Irrigation water saving (%)	-	31.03	55.06	55.06
Electricity saving (%)	-	31.03	28.10	28.10
NUE (kg kg^{-1} nitrogen)	47.87	45.6	59.10	59.18
Rainfall received = 544.5 mm and Pan evaporation = 483.7 mm during June, 2016 to September 2016, CPE= cumulative pan evaporation criteria used for irrigation through mini sprinkler system, CD (0.05) = 0.35 (grain yield) and NUE= Nitrogen use efficiency				
T_1: Conventional rice transplanting; T_2: DSR without wheat residue /wheat in Zero tillage with100 % rice mulch; T_3: DSR without wheat residue /wheat in Zero tillage with 100 % rice mulch; T_4: DSR with wheat residue incorporation /wheat in Zero tillage with 100 % rice mulch				

Effects of tillage and crop residue on soil health

Effects of tillage on soil health: Zero tillage treatment along with residue retention had a positive impact on the enhancement of mean weight diameter, geometric mean diameter and aggregate stability and soil organic carbon, which are considered to be a good indicator of soil health. From the study, it is concluded that alternative cultivation methods (zero/reduced tillage, residue retention/ incorporation) could improve the soil physical health for long-term sustainable production system and be a useful method to increase the amount of organic carbon in soil and it may reduces its emission into the atmosphere. Soil under zero tillage had 17.61% and 35.45% higher amount of total water stable aggregates than reduced tillage and conventional tillage, respectively (Fig. 1).

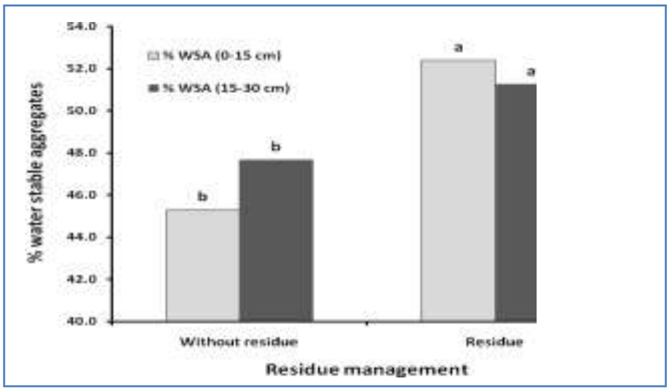

Fig. 1. Effect of residue management on water stable aggregates in surface (0-15cm) and sub-surface (15-30 cm) soil depth

Effects of crop residue management on soil health: Residue management caused a significant increment (15.65 and 7.53%) in total water stable aggregates under surface soil and sub surface soil, respectively (Fig.1).Water stable macro aggregates were found to be in relatively higher proportion than water stable micro aggregates in both 0-15 cm and 15-30 cm soil depths. Direct seeded rice coupled with zero tillage and residue retention had the highest aggregate associated carbon (11.57 g kg^{-1} soil aggregate) in surface (0-15 cm) soil layer and retained 12.2% lesser aggregated carbon in sub–surface (15-30 cm) depth, while comparing with conventional tillage. On an average, (silt+clay) sized particle contained 11.08% carbon out of the total aggregate associated carbon.

Constraints of tillage and residue management techniques in rice– wheat cropping system

Rice Crop: Rice seed germination and plant population could not maintained properly, resulting lower yield because of improper placement of seed into the furrow by zero tillage seed drill machine in zero tillage with wheat residue retention treatment in comparison with conventional tillage and zero tillage without residue. Rice and wheat crop harvesting manually in reduced tillage, conventional tillage, and in zero tillage with residue retention created problem of harvesting and collecting and tying of produced in bundles and their threshing. Residue incorporation/retention with conventional, reduced and zero tillage created problem during harvesting and threshing of both the rice and wheat crops.

Wheat Crop: Yellowness in wheat crop observed in conventional and reduce tillage (with and without rice residue incorporation) after first and 2^{nd} irrigation .It was due to water lodging as soil wetting condition maintained prolonged in high tilled conventional and reduced tillage techniques in comparison to zero tillage with and without rice residue, as in zero tillage irrigation water dry up at fast rate in comparison to conventional and reduce tillage. Conventional tillage and in reduce tillage soil disturbed before sowing and as and when irrigated, water dispersed the soil particles and settled in macrospores resulted restricted percolation and so water remains in soil for prolonged periods created water lodging and developed wheat yellowness .Such yellowness was not noticed in zero tillage techniques. Even than wheat irrigated with sprinkler not observed such yellowness.

Mini sprinkler system and their problems

Wheat Crop: Wheat crop faced the problem of crop lodging at the time of grain filling and dough stage. Wheat crop during flowering, irrigation with mini sprinkler created the problem of grain setting as crop during grain filling stage watering with the help of mini sprinkler ,water collected in the spikes and became heavier and ultimately lodged resulted into reduction in grain size and number of grains per spike and reduced the grain yields relatively. Root growth in sprinkler were not deeper and higher with looser soil condition, where soil water and air relationship might be favorable, but plants standing with poor soil support , as soil after surface irrigation became compacted and plant roots and soil relation becomes tight ,such situation not prevailed under sprinkler irrigation system. Wheat grains became whitish in colour with sprinkler irrigation but in surface irrigation, they remain reddish in colors of original one.

Conclusion

Zero tillage in wheat with and without rice residue crop is promising and sustainable. Rice straw either incorporation or retention (stables/mulch) both method are promising and economic for high wheat productivity. DSR method with wheat residue incorporation is a better option with higher water productivity. Sprinkler irrigation in wheat with zero tillage and rice residue mulch is economically feasible option for increasing water productivity and NUE. Mini sprinkler irrigation method in rice with DSR crop establishment technique is feasible option for increasing water productivity and NUE. Drip irrigation method is feasible under zero tillage wheat sowing with 100% rice residue mulch, using Turbo seed drill machine for wheat seed sowing. Drip irrigation method saved irrigation water and nitrogen in fertigation. In rice crop drip irrigation method is feasible under reduced tillage with saving of irrigation water.

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Practical Methods for Determination of Soil Physical Properties of Salt Affected Soils

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Introduction

Saline irrigation water contains dissolved substances known as salts. In much of the arid and semi-arid regions, most of the salts present in irrigation water are chlorides, sulfates, carbonates, and bicarbonates of calcium magnesium, sodium, and potassium. While salinity can improve soil structure, it can also negatively affect plant growth and crop yields.

Sodicity refers specifically to the amount of sodium present in irrigation water. Irrigating with water that has excess amounts of sodium can adversely impact soil structure, making plant growth difficult. Highly saline and sodic water qualities can cause problems for irrigation, depending on the type and amount of salts present, the soil type being irrigated, the specific plant species and growth stage, and the amount of water able to pass through the root zone.

Effects of Salinity on Plant Growth

Salinity becomes a problem when enough salts accumulate in the root zone to negatively affect plant growth. Excess salts in the root zone hinder plant roots from withdrawing water from surrounding soil. Although the water is not held tighter to the soil in saline environments, the presence of salt in the water causes plants to exert more energy extracting water from the **soil.** The main point is that excess salinity in soil water can decrease plant available water and cause plant stress.

Effects of Salinity on Soil Physical Properties

Soil water salinity can affect soil physical properties by causing fine particles to bind together into aggregates. This process is known as flocculation and is beneficial in terms of soil aeration, root penetration, and root growth. Although increasing soil solution salinity has a positive effect on soil aggregation and stabilization, at high levels salinity can have negative and potentially lethal effects on plants. As a result, salinity cannot be increased to maintain soil structure without considering potential impacts on plant health.

Effects of Sodium and Sodicity on Soil Physical Properties

Sodium has the opposite effect of salinity on soils. The primary physical processes associated with high sodium concentrations are soil dispersion and clay platelet and aggregate swelling. The forces that bind clay particles together are disrupted when too many large sodium ions come between them. When this separation occurs, the clay particles expand, causing swelling and soil dispersion.

Soil dispersion causes clay particles to plug soil pores, resulting in reduced soil permeability. When soil is repeatedly wetted and dried and clay dispersion occurs, it then reforms and solidifies into almost cement-like soil with little or no structure. The three main problems caused by sodium-induced dispersion are reduced infiltration, reduced hydraulic conductivity, and surface crusting.

Salts that contribute to salinity, such as calcium and magnesium, do not have this effect because they are smaller and tend to cluster closer to clay particles. Calcium and magnesium will generally keep soil flocculated because they compete for the same spaces as sodium to bind to clay particles. Increased amounts of calcium and magnesium can reduce the amount of sodium-induced dispersion.

Infiltration: Soil dispersion hardens soil and blocks water infiltration, making it difficult for plants to establish and grow. The major implications associated with decreased infiltration due to sodium-induced dispersion include reduced plant available water and increased runoff and soil erosion.

Hydraulic Conductivity: Soil dispersion not only reduces the amount of water entering the soil, but also affects hydraulic conductivity of soil. Hydraulic conductivity refers to the rate at which water flows through soil. For instance, soils with well-defined structure will contain a large number of macropores, cracks, and fissures which allow for relatively rapid flow of water through the soil. When sodium-induced soil dispersion causes loss of soil structure, the hydraulic conductivity is also reduced.

If water cannot pass through the soil, then the upper layer can become swollen and water logged. This results in anaerobic soils which can reduce or prevent plant growth and decrease organic matter decomposition rates. The decrease in decomposition causes soils to become infertile, black alkali soils.

Surface Crusting: Surface crusting is a characteristic of sodium affected soils. The primary causes of surface crusting are 1) physical dispersion caused by impact of raindrops or irrigation water, and 2) chemical dispersion, which depends on the ratio of salinity and sodicity of the applied water.

Surface crusting due to rainfall is greatly enhanced by sodium induced clay dispersion. When clay particles disperse within soil water, they plug macropores in surface soil by two means. First, they block avenues for water and roots to move through the soil. Second, they form cement like surface layer when the soil dries. The hardened upper layer, or surface crust, restricts water infiltration and plant emergence.

Relationship between Salinity and Sodicity and Soil Physical Properties (EC/SAR): The relationship between soil salinity and its flocculating effects and sodicity and its dispersive effects influence whether or not soil will stay aggregated or become dispersed under various salinity and sodicity combinations. As irrigation water with low salinity is applied to the soil by irrigation or rainfall, this water flows into the spaces between clay particles (micropores).

More than fifty years of research have been conducted to determine the relationship between salinity (EC) and sodicity (SAR) of irrigation water and its affects on soil physical properties. This relationship is now understood well enough to make accurate predictions of how specific soils will behave when irrigated water containing different levels of salts and sodium. The main concerns related to the relationship between salinity and sodicity of irrigation water are the effects on soil infiltration rates and hydraulic conductivities.

Practical methods for determination of soil physical properties

The problem of evaluating soil physical conditions has been separated into components and they are discussed under the headings of mechanical impedance, aeration, soil water, and soil temperature. These are logical ultimate aspects; but, for practical work on alkali soils, measuring methods are needed that yield immediate results having more or less direct diagnostic significance.

Soil in terms of physical properties, i. e., intrinsic qualities of soil that can be expressed in standard units and that have values which are substantially independent of the method of measurement. Infiltration rate, permeability, bulk density, pore-size distribution, aggregation, and modulus of rupture appear to be such properties. Experience indicates that the physical status of any given soil is not static. There is a range of variation of physical status that is related to productivity, and this is reflected in corresponding ranges in the values of pertinent physical properties.

Saturation Percentage (SP): From the Weight of a Known Volume of Paste Remarks By this method, the saturation percentage is calculated from the weight of a known volume of saturated soil paste. It is assumed that the soil particles have a density of 2.65 gm./cm.“, and that the liquid phase has a density of 1.00 gm./cm.“.

Apparatus:

1. Balance, accurate to 0.1 gm.
2. A cup of known volume. This measurement can be combined with the soil-paste resistance measurement using the same loading of the Bureau of Soils electrode cup.

Procedure: Determine the volume and weight of the cup. Fill the cup with saturated soil paste, jarring it during filling to exclude air, and strike off level with the top. Weigh and subtract the cup weight to get the net weight of the paste.

Calculations

Sp **=** 100 (2.65V-- W) / 2.65(W-V)

Where SP: Saturation percentage; Y : volume of saturated soil paste, in cm. 3 : a constant; and W : net weight of V cm. 3 of saturated soil paste, gm.

Calculations are simplified by the use of a table or graph relating values of W and SP for a given value of V.

(Source: Wilcox (1951); Agriculture hand book 60.

Hydraulic Conductivity of Soil Cores: Thin-walled cylinders or cans may be pressed into the soil in the field to obtain samples of soil of substantially undisturbed structure. More often, soil cores are obtained in metal sleeves that fit into a sampling tube, and, after the samples have been taken, the sleeves serve as the core retainers. Power-driven machines are available for taking undisturbed cores of 4 and 6 inch diameter. Such cores are encased in the field for transportation and subsequent water-flow measurements. Various casing methods have been used, such as painting the core with wax or plastic cement before and after wrapping in cloth.

Procedure: In the laboratory, the cores are mounted vertically and supported on a porous outflow surface such as sand or filter paper and metal screen. A shallow depth of water is usually maintained over the soil surface by a siphon tube from a constant-level reservoir. Flow tests should be conducted with water of the same quality as that which occurs in the field. If discharge rates are low, care must be taken to avoid errors arising from evaporation of the percolate. If possible, flow tests should be conducted at or near constant temperature.

Where desirable, especially for long cores, manometers can be attached at various points along the core. These should be installed at transition zones between horizons or at textural discontinuities

Calculations

Water flow takes place in accordance with the equation : Q/t = kA (dH/dl) ,

*Where Q is the volume of water passing through the core in time **(t)**, A **is** the area of the core, and **k is** the average hydraulic conductivity in the soil interval **(dL),** over which there is a hydraulic head difference of dH.*

Solving for k gives k = QdL /At dH.

Hydraulic conductivity (k) will be in centimeters per hour if t is expressed in hours, Q in cm.3, A in cm^2, and dH and dL are both in the same units.

Source: Bower and Peterson (1950)) Kelley and coworkers (1948), Marsh and Swarner (1949)) and Richards (1952).

Infiltration rate and infiltration test

Infiltration: Water-movement rates attainable in soil under field conditions relate directly to irrigation, leaching, and drainage of saline and alkali soils. Infiltration is the process by which water on the ground surface enters the soil .Infiltration refers to the downward entry of water into soils and the term “Infiltration rate” has special technical significance in soils work. Infiltration rate in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation. The infiltration rate is the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm) of the water layer that can enter the soil in one hour. An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the soil surface will take one hour to infiltrate. In dry soil, water infiltrates rapidly. This is called the initial infiltration rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate. This is called the basic infiltration rate (Table 1). The infiltration rate is measured under field conditions. The cylinder method of Musgrave (1935) is probably the most versatile of the various methods available. A guard ring is needed if lateral spreading is excessive. It is most often measured in millimetres per hour or inches per hour. On the soil surface rather than in the soil profile, ponded water is subject to increased evaporation, which leads to decreased water available for plant growth. A high infiltration rate is generally desirable for plant growth and the environment. The infiltration rate is the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm) of the water layer that can enter the soil in one hour. An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the soil surface will take one hour to infiltrate. In dry soil, water infiltrates rapidly. This is called the initial infiltration rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate. This is called the basic infiltration rate (Table 1). The infiltration rate depends on soil texture (the size of the soil particles) and soil structure (the arrangement of the soil particles) and is a useful way of categorizing soils from an irrigation point of view. The most common method to measure the infiltration rate is by a field test using a cylinder or ring infiltrometer.

Table 1. Basic infiltration rates for various soil types

Soil Type	Basic infiltration rate (mm/hour)
Sand	<30
Sandy loam	20-30
Loam	10-20
Clay loam	5-10
Clay	1-5

Field Infiltration Test

Equipments: Shovel/hoe, hammer (2 kg), Watch or clock, 5.0 litre bucket, Timber (75 x 75 x 400), Hessian (300 x 300) or jute cloth, 100 litre water, Ring infiltrometer of 30 cm diameter and 60 cm diameter. Instead of the outer cylinder a bund could be made to prevent lateral water flow, Measuring rod graduated in mm (300 mm ruler)

Method
The following steps required to test the infiltration rate of soil:

Step 1: Hammer the 30 cm diameter ring at least 15 cm into the soil. Use the timber to protect the ring from damage during hammering. Keep the side of the ring vertical and drive the measuring rod into the soil so that approximately 12 cm is left above the ground.
Step 2: Hammer the 60 cm ring into the soil or construct an earth bund around the 30 cm ring to the same height as the ring and place the hessian inside the infiltrometer to protect the soil surface when pouring in the water.
Step 3: Start the test by pouring water into the ring until the depth is approximately 70-100 mm. At the same time, add water to the space between the two rings or the ring and the bund to the same depth. Do this quickly.
The water in the bund or within the two rings is to prevent a lateral spread of water from the infiltrometer.
Step 4: Record the clock time when the test begins and note the water level on the measuring rod.
Step 5: After 1-2 minutes, record the drop in water level in the inner ring on the measuring rod and add water to bring the level back to approximately the original level at the start of the test. Record the water level. Maintain the water level outside the ring similar to that inside.
Step 6: Continue the test until the drop in water level is the same over the same time interval. Take readings frequently (e.g. every 1-2 minutes) at the beginning of the test, but extend the interval between readings as the time goes on (e.g. every 20-30 minutes).

Precautions to be taken during infiltration testing

- Water having the same quality as that which will be used for irrigation or leaching must be used for infiltration tests in the field; otherwise the results may be misleading.
- The length of time the tests should be conducted and the depth of water to be applied depend upon the purpose of the test and the kind of information that is sought.

- If it is a matter of appraising an irrigation problem, the depth corresponding to one irrigation may be sufficient; but, if information on infiltration for planning a leaching operation is needed, it may be desirable to apply the full depth of leaching water to a test plot.
- It often happens that subsurface drainage is sufficiently restricted to cause the infiltration rate to decrease considerably with time. It should be kept in mind, therefore, that although small area tests will give useful information on soil changes during leaching, the infiltration values thus obtained will apply to large areas only if under drainage is not limiting.
- Experience indicates that the infiltration rate of a given soil can be high or low, depending on physical status and management history. Infiltration rate is often critically influenced by surface soil conditions, but subsurface layers also are sometimes limiting.
- Water distribution in the profile and depth of water applied are modifying factors. The infiltration rate can be undesirably high or undesirably low.
- It is the low end of the range that may be a critical limiting factor in the agricultural use of alkali soils. It is difficult to specify a boundary limit between satisfactory and unsatisfactory infiltration rates at the low end of the range, because so many factors are involved, including the patience and skill of the farmer. However, if the infiltration rate is less than 0.25 cm./hr. (0.1 in./hr.) special water-management problems are involved that may make an irrigation enterprise unprofitable for average operators.

Bulk density of soil: The bulk density (apparent density) of soil is the mass of soil per unit volume, and the porosity of soil is the fraction of the soil volume not occupied by soil particles. Bodman (1942) has discussed soil density in connection with water content and porosity relationships. For a certain range of moisture contents with soils that are comparatively free of gravel and stones, it is possible to press into the soil a thin-walled tube having a suitable cutting edge. The soil is then smoothed at each end of the tube and oven-dried at 105” C.

The bulk density is the mass of soil contained in the tube divided by the volume of the tube. The bulk density of most soils ranges from 1.0 gm. cm^{-3} for clays, to 1.8 gm. cm^{-3} for sands. Veihmeyer and Hendrickson (1946) found that plant roots were unable to penetrate a gravelly loam soil when the bulk density exceeded a value of around 1.8 gm. cm^{-3}. Also, when the bulk density of medium- to fine-textured sub soils exceeds about 1.7 gm. cm^{-3}, hydraulic conductivity values will be so low that drainage difficulties can be anticipated.

Apparatus: Balance, drying oven, moisture, boxes, and core sampler. The latter can be anything from an elaborate power-driven machine to a short section of thin-walled brass tubing with an internal closely fitting ring of clock spring soldered in place to form the cutting lip.

Procedure: Details of procedure will depend on the type of core sampler and soil conditions. Usually a flat soil surface, either horizontal or vertical, is prepared at the desired depth, and the core sampler is pressed or driven into the soil. Care should be taken to see that no compaction occurs during the process, so that a known volume of soil having field structure is obtained. The oven-dry weight of the sample is then determined.

Calculations

Bulk density (d_b) = (wt. of oven-dry soil core) / (field volume of sample). Bulk density is expressed as pounds per cubic foot or grams per cubic centimeter. For practical purposes, the latter is equal numerically to apparent specific gravity or volume weight.

Particle density: The mass per unit volume of soil particles, usually expressed in grams per cubic centimetre.

Apparatus: Balance, vacuum desiccator, and pycnometers.

Procedure:
Weigh a pycnometer when filled with air (va), when filled with water (Ww) , when partially filled with an oven-dried sample of soil (Ws,), and when completely filled with soil and water (Wsw). To exclude air, pycnometers containing the soil with enough water to cover should be subjected to several pressure reductions in a vacuum desiccator and then allowed to stand for a number of hours under reduced pressure before completely filling with water for weighing Wsw. The particle density (dp) of the soil in gm. cm^{-3}, is then given by the formula:

$dp = dw (Ws-Wa)/(Ww+Ws-Wa-Wsw)$

where dw, is the density of the water in gm. $cm.^{-3}$.

Slightly different and perhaps better values will be obtained for dp if a nonpolar liquid such as kerosene, xylene, or acetylene tetrachloride is used for the displacing liquid. The particle density of many soils averages around 2.65 gm. cm^{-3}

Porosity: The porosity of soil is the fraction of the soil space not occupied by soil particles. The porosity (n) may be calculated from the formula:

$$n= (dp-db) /dp,$$

if the bulk density (db) and the particle density (dp,) are known. Solutions of this equation may be found graphically by use of the nomograms given at the right of

Aggregation and Stability of Structure

The arrangement of soil particles into crumbs or aggregates that are more or less water stable is an important aspect of soil structure. Alkali soils often have a dense, blocky, single-grain structure, are hard to till when dry, and have low hydraulic conductivity when wet. This is generally because the aggregates and also the pores of such soils are not stable. The aggregates slake down in water, and the pores become filled with fine particles. Several methods have been proposed for measuring the water stability of soil aggregates, the most common being the wet-sieving method proposed by Yoder (1936). Soils that are low in organic matter and contain appreciable amounts of exchangeable sodium seldom contain aggregates of larger sizes and for that reason measuring procedures adapted for the smaller aggregates.

Wet sieving method: The method in brief consists of placing a sample of soil on a nest of sieves that is oscillated vertically under water. The amount of soil remaining on the individual screens is determined, and aggregation is expressed as the mean weight-diameter of the aggregates and primary particles. After weighing, the aggregate separates are combined and dispersed and washed through the nest of sieves. The resulting separates make it possible to correct the previous separates of aggregates for primary particles and to calculate the aggregation index. This is a single value index of the aggregation of a soil.

Apparatus: Yoder-type wet-sieving apparatus, sieve holders, 4 sets of 5-inch sieves with 2-, l-, 0.5-, O-25-, and O.lO-mm. openings (corresponding to United States Screens Nos. 10, 18, 35, 60, and 140)) drying oven, moisture cans, balance Pyrex watch glasses, and 6-in. diameter porcelain funnel.

Procedure

- Collect the soil sample with spade or garden trowel, preferably when the soil is moist, avoiding excessive compaction or fragmentation of soil.
- Dry the sample slowly and, when sufficiently friable, pass it gently through an 8-mm. sieve and air-dry. If the soil is stony, pass the sample through a 4mm. sieve and discard all primary material greater than 4 mm in size.
- Mix the soil and take sub samples in accordance with ethod 1. Make determinations in duplicate on 40- to 60-gm. subsamples. Weigh the subsamples to the closest 0.1 gm. and determine the moisture content by drying a separate subsample at 105” C.
- Install the nests of sieves in the water slowly and at a moderate angle to avoid entrapping air bubbles below the sieves. Adjust the mechanism so that the top sieve makes contact with the water surface when the oscillation mechanism is at the top of its stroke.
- Distribute the sample on the top sieve so that wetting occurs by capillarity and wait 5 to 10 min. after the soil surface appears wet to insure saturation of the aggregates.
- Oscillate the sieves for 30 min. with a stroke of 3.8 cm. and a frequency of 30 cycles per minute, keeping soil submerged at all times. Some attention may be required during the first few minutes of operation, in order to prevent water from spilling over the top sieve, and later, to prevent the top sieve from rising above water level.
- Remove the sieves from the water and drain for a few minutes in an inclined position. Remove excess water from the bottom of the screens with absorbent tissue and place the sieves on watch glasses.
- Dry in a circulating oven at not higher than 75” C. because high temperatures cause some soils to adhere.
- Then remove the soil from the sieves, dry at 105”, and weigh.

- In order to determine how much of the soil retained on the individual sieves represents aggregates and how much is gravel and sand, the oven-dried soil taken from the five sieves is dispersed and washed through the sieves with a stream of water.
- The oven-dry weight of the primary particles remaining on each sieve is then determined.

Calculations

- The amount of soil remaining on each sieve is expressed as percentage of the total sample.
- Prepare a saline and alkali soils 125 graph, plotting the accumulated percentage of soil remaining on each sieve as ordinate against the upper limit of each fraction in millimeters as the abscissa, and measure the area shown by the curve connecting these points and by the ordinate and the abscissa.
- If 1 mm. (sieve size) represents 1 unit of the abscissa and 10 percent a unit on the ordinate, a square unit will represent 0.1 mm. mean weight-diameter of the aggregates of the sample.
- Multiplying the number of square units of the area by 0.1 gives the mean weight-diameter of the entire sample, including the material that has been washed through the smallest sieve.

Water stable aggregates increased with crop residue incorporation /anchors/mulching. Crop residue increased the soil organic carbon, resulted formation of sol aggregates and indicates better soil health. This is the significance of crop residue management for soil health improvement quantitatively.

Results: The results from the wet sieving of the dispersed sample are plotted and calculated in the same way. The difference between the mean weight-diameters of the original and the dispersed samples gives the aggregation index.

Remarks: The water container in which the sieve nest is oscillated can be of any desired size or shape, providing its area is at least 1.6 times the area of the sieves. The temperature of the water should be in the range 20 to 24° C and the water should not be excessively saline. Fresh water should be used for each set of determinations. Rubber bands cut from old inner tubes are convenient for holding loosely fitting sieves together.

Soil Crust

Soil crust meaning: Soils that have low stability of structure disperse and slake when they are wetted by rain or irrigation water and may develop a hard crust as the soil surface dries. This crust presents a serious barrier for emerging seedlings, and with some crops often is the main cause of a poor stand

Crust formation: Structural soil crusts are relatively thin, dense, somewhat continuous layers of non-aggregated soil particles on the surface of tilled and exposed soils. Structural crusts develop when a sealed-over soil surface dries out after rainfall or irrigation. Water droplets striking soil aggregates and water flowing across soil breaks aggregates into individual soil particles. Fine soil particles wash, settle into and block surface pores causing the soil surface to seal over and preventing water from soaking into the soil. As muddy soil surface dries out, it crusts over. Factors influencing development of hard surface crusts appear to be high exchangeable sodium, low organic matter, puddling, and wetting the soil to zero tension, which occurs in the field with rain or irrigation. Crust prevention would, therefore, involve removal of exchangeable sodium, addition of organic matter, and care to avoid puddling during tillage and other operations. Where possible, the placement of the seed line somewhat above the water level in a furrow is desirable so that the soil above the seed will be wetted with water at appreciable tensions, thus lessening the tendency for soil aggregates at the surface to disintegrate.

Procedure: The procedure for measuring the modulus of rupture of soil (Method 43) was developed for appraising the hardness of soil crusts, since a satisfactory measuring method is essential in developing and testing soil treatments for lessening soil crusting.

Measuring soil crusts: Crust air-dry rupture resistance can be measured by taking a dry piece of the crust about ½ inch on edge and applying a force on the edge until the crust breaks. Generally, more force is required for crusts that are thick and have high clay content. A penetrometer to measure the penetration resistance of the crust can be used. Crust thickness can also be measured.

Nano Reclaimants and Fertilizers for Enhancing Input Use Efficiency in Salt Affected Soils

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Introduction

Crop lands in world are set to face excessive stress for matching food production with population growth. Added to it is the increased frequency of natural calamities and climate driven changes. A large extent of marginally productive salt affected lands and waters in India and world presents opportunity for bolstering food security via remediation and use for productive agriculture. The remediation of these lands opens window for improving biological functioning and enhancing net productivity of soil.Salt-affected lands cover large areas in the world spanning from irrigated Indo-Gangetic plain to the great Hungarian plain, Australia, Israel, China, Russia and United States of America. The salt laden soils in these areas are not only unsuitable for crop production but are also environmentally vulnerable to further degradation, sometimes irreversible.

Presence of salts in the soil and water, including surface water and groundwater, pose threat to productivity of soil. Excessive salts in the soil are harmful to plant growth, and restrict uptake of water and nutrients by plants. Several problems such as poor porosity, high sodium concentration, water logging, and other hydraulic constraints in the soil make these lands unproductive. Such chemically and physically deteriorated land area reflecting sodicity, salinity, waterlogging, and soil acidity has been estimated to be 29.17 mha in India (Sharma *et al*., 2004; Maji *et al*., 2008; NAAS, 2010). In India, 6.73 Mha area is salt affected soils (saline, sodic and saline-sodic) (Mandal *et al*., 2010). Morethan 1.37 Mha area of sodic land in Indo-Gangetic region alone.

There are two broad classes of salt affected soils, saline and sodic. Saline soils have neutral salts, mostly Cl^- and SO_4^{2-}. HCO_3^- may be present but CO_3^{2-} is mostly absent, while sodic soils are capable of alkaline hydrolysis and there is preponderance of HCO_3^- and CO_3^{2-} of sodium. The presence of excessive amounts of Na cations (predominantly in sodic conditions) leads to clay soils becoming solid and impenetrable. Soil sodicity is intrinsically caused by a feed-back loop. Sodium transport takes place via the water fluxes through the soil pores and thus highly depends on the local porous structure. On the other hand, the Na cations bind to the clay minerals and this greatly affects the swelling and shrinking behavior of the soil. Clay swelling and dispersion are the key processes making sodic soils unsuitable for agriculture (Bhardwaj *et al*., 2008). Sodicity is difficult to treat and only viable remedy has so far been the use of gypsum. Salinity in soil poses threat to germination of seeds, and non-availability of water to plants for growth, if germination takes place. Such adverse conditions make the salt affected soils unviable for agriculture. Besides decreasing productivity of land, these conditions also affect soil physical and chemical conditions threatening agro-ecological balance. Changes in soil biotic forms due to presence of salts, soil erosion due to increased dispersibility, flooding of land, deterioration of structures due to interactions with salts, low ground water recharge and threat to human and animal health are some other consequences in regions having salt affected lands.

Nanotechnology as an emerging science will play a greater role for managing these salt affected marginal lands. Nanotechnology can be effectivelydirected towards understanding and creating improved materials, and in exploiting their Nano-properties for managing these lands. Nanotechnology has not left agricultural sector untouched and promises to revolutionize the agriculture sector with new tools for molecular treatment of plant diseases, rapid detection of diseases, and enhancing the ability of plant to absorb nutrients, thus increasing soil fertility and crop production. The potential of nanotechnology is yet to be fully exploited in salt affected land management, and agriculture, yet if once realized it is likely to bring a sea change in agricultural production and productivity.

Nanotechnology is the study of the properties of materials and structures of the size smaller than several hundreds of nano-meter (nm). A nanometer (nm) is one-billionth of a meter. Nanotechnology is a science that deals with objects of nanometer size (1-100 nm) for at least one dimension. The unique properties of nano-materials differ substantially from bulk materials. Nano-materials with one or more external dimensions, or an internal structure, at a nanoscale could exhibit novel characteristics compared to the same material at a larger scale. Nano-particles (NPs) have predominant surface effects (Fiorani, 2005) for the high proportion of the atoms located on their surface that lead to an increase in their reactivity. Some of the examples of natural nano-particles are soil colloids, humic organic matter, and black carbon. Incidental nano-particles are largely either of anthropogenic (from grinding of minerals, wear of metal or mineral surfaces, combustion) or pyrogenic (smoke from fires) origin. Engineered nano- particles (ENPs) are particles that are produced by man because of specific nano-technological properties. A large number of nano particles (NPs) are present in the soil environment.

Nano Opportunities for Managing Salt Affected Soils

Nanotechnology based initiatives in developing reclaimants for salt affected soils have perceivable advantages. Nanoparticles become more reactive for geometrical reasons as the proportion of surface atoms increase which enhances the bonding possibilities. Bringing reclaimants to nano scale might enhance their reactivity. Sodic lands can be effectively reclaimed by adding gypsum ($CaSO_4.2H_2O$) in large quantities. Usual rates of application of gypsum for reclamation of top30 cm of soil may range from 10-20 t ha^{-1}.Application at this rate may increase the input cost for a marginal farmer. Gypsum is also less available these days due to other more lucrative uses in housing industry. It is also inefficient material due to its solubility which is only 0.25%. So far, there is no proposed alternative to gypsum except agro-industrial byproducts, such as phospho-gypsum, which has fluoride (drinking water pollutant) and radioactive elements associated with it.

Nanotechnology can play an important role in developing reclaimants which are more efficient and readily manufacturable. Reactive nanoparticles encapsulated in carrier polymeric materials would enhance reclamation efficiency by utilizing the nano-properties of reactive materials along with clay binding properties of carrier materials. Sodicity develops by an intrinsically caused feedback loop wherein Na transport takes place via the water flux through soil pores. HereNa attaches itself to clay micelle, causes swelling and dispersion, and destroys porous structure. For effective reclamation, Na displaced by Ca requires removal via same pore structure which is no more available. Polymeric carriers in Nano-reclaimants can enhance soil stability and hydraulic characteristics via clay binding processes (Bhardwaj *et al*., 2007, 2009, 2010) and enhance Na removal. Nano scale gypsum particles encapsulated in soil binding polymers would thus enhance reclamation efficiency (Na ion neutralized per unit reclaimant used). Polymer part in the nano–complexes will contribute towards clay binding and thus will improve soil stability and hydraulic characteristics. Improvement in these particles will hasten removal of soluble sodium salts (formed after reaction with gypsum and nano particles) via stable capillary pores upon drainage.

This two pronged approach should increase reclamation efficiency manifold. Similarly other materials whose efficiency can be enhanced using nanotechnology for salt affected land reclamation include Sulphur, naturally occurring carbon and zeolite substrates in nano-scale will provide altogether new materials, with abundant availability, for salt affected land reclamation. The carbon and zeolite nano-particles with polymer carrier can act as exchange sites for binding Na+ and thus reduce the adverse effects like clay swelling and dispersion. The local availability of suitable nanoparticles from materials such as biochar (anaerobic burn of plant materials such as crop residues such as rice straw which are unsuitable for animal feed) will boost marginally productive sodic land reclamation at an exponential scale.

For optimal growth and development, cultivated plants require balanced presence of water and dissolved minerals (salts) in their rhizosphere. Some of the most produced and widely used crops such as cereals (rice, maize), forages (clover) or vegetable crops (potatoes, tomatoes) usually require irrigation practices, but are relatively susceptible to excessive concentration of salts either dissolved in irrigation water or present in soil solution. In majority of cultivated plants, yields start declining even at relatively low salinity in irrigation water (EC_w>0.8 dSm^{-1}) or soil (EC_{se}>1 dSm^{-1} in saturated soil extracts. Salt stress is one of the most widespread abiotic constraints in food production. Itmay also result in the negative ecological, social and economic outcomes. However, recent advances in technologies like nanotechnology may be used to investigate the increasing salt tolerance in cultivated plants and that could be one of the most promising and effective strategies for food production in salt-affected environments.

In the current ties, a pressing need exists to elucidate the basic properties of nano-particles and different processes that govern their fate in the salt-affected soils and their bioavailability. This understanding will help us to reap the benefit of nanotechnology without producing adverse ecological consequences. Determination of the bioavailability of nano-particles in soil is required. If nano-materials are not bioavailable, they are not likely to have impacts. The extent and mechanisms of NPs uptake by plants in soil and subsequent translocation remain to be precisely determined. Characterizing intracellular transformation is also necessary to assess bioavailability. Research efforts need to focus on understanding responses to nano-material inputs on agroecology and biogeochemical processes at relevant environmental concentrations and forms. Assessing these processes and effects requires developing methods and perhaps new instrumentation capable of quantifying nano materials in environmental matrices and in organisms. A broader range of species needs to be investigated for nano-particles impacts.

There is a need for measurements of the stability of NPs, and their long-term fate. The measurements need to focus on particle concentration and surface characteristics. Development of increasingly more sensitive analytical equipment should provide means by which to analyze quantitatively the nano-particle stability in aqueous environments. Limited information is available on natural nanoparticle formation and their stability in the soil systems. The conditions and geo/soil variables that promote their formation or control their stability are not known.This is an area that requires concentrated research efforts. The issues related to nanoparticles role in affecting or controlling the extent and rates of soil processes and reactions and overall nutrients and contaminants mobility need to be considered seriously. Studies are required with different types of engineered nanoparticles to provide evidence and measure in a more rigorous manner in relation to the effects of a variety of soil variables, in addition to soil solution pH and ionic strength. Studies are needed to determine the roles and contributions of these processes to the overall mobility of nutrients and salts in terrestrial systems.

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Efficient Utilization of Wastewater for Irrigation

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Introduction

Growing urbanization coupled with industrialization has been placing immense pressure on the dwindling fresh water resources and producing huge quantities of wastewaters. Agriculture is the single largest user which consumes about 70% of the total fresh water abstraction. Each year to feed world's population 7130 km^3 of water are currently used, it is estimated that without further improvements in water productivity or major shifts in production patterns, the amount of water consumed in agriculture will increase to 12000-135000 km^3 in 2050 (de Fraiture *et al*., 2005; Molden *et al*., 2007).

Besides agriculture, domestic and industries uses about 15% of available water resources in India. By 2050, the share of these two sectors is expected to increase by 30% and the market forces will lead to reallocation of water resources from agriculture to urban sectors. According to an estimate by the Central Public Health Engineering Organization, about 70 to 80% of these water supplies turn into wastewater. Further, as per the UNESCO and WWAP (2006) estimates (Van-Rooijen et al., 2009), the industrial water use productivity (IWP, in billion constant 1995 US$ per m^3) of India is just 3.42 (i.e. the lowest and 1/3 rd of that for USA) as compared to 119.62 for Japan and 93.66 for Republic of Korea. To substantiate this, as per the CPCB (1990-2001) estimates, of the total 40 BCM of annual water consumption by Indian industry, about 31 BCM is discharged as wastewater. With increased use of water by municipalities and industries, larger volume of wastewater will be generated in coming years and fresh water availability for agriculture will reduce drastically.

To assimilate huge quantities of wastewaters is beyond the capacity of natural systems. Wastewater contains salts, pathogens, heavy metals and other pollutants, which impair quality of natural resources, contaminate food chain and pose serious threat to human and animal health. Soils also have limited capacity to absorb toxic contaminants without impairing their productivity and quality. Once introduced into the soil environment, these pollutants are difficult to remove and may find their way to ground water where pollution before certain limit is irreversible. Thus, wastewater discharge into the surface or ground water bodies without treatment results into de terioration of quality of these valuable natural resources on permanent basis. Presently, discharge of untreated domestic wastewater is a single major cause of land and water pollution in India.

To overcome this problem, worldwide, water reuse is becoming an increasingly common component of water resource planning as the costs of wastewater disposal rise and opportunities for conventional water supply development dwindle. Under fresh water scarcity conditions, wastewater is being increasingly used as a valuable source of irrigation and plant nutrient in the peri-urban agricultural areas of the developing world for supporting livelihoods of poor farmers. Even in high rainfall countries like Japan, whose mean annual precipitation of 1,714 millimeters (mm), urban wastewater reuse is common due to high population density in some regions, which suffer from water shortages (Ogoshi *et al*. 2001). In developing countries like India, the problems associated with wastewater reuse arises from its lack of treatment, whereas in developed world, recycling projects do not take off even when wastewater is treated to tertiary level, due to a number of reasons like the "yuck factor", high cost of supply, higher salinity than normal river water and lack of information and trust in the authorities.

The challenge thus is to find such low-cost, low-tech, user friendly methods, which on one hand avoid threatening our substantial wastewater dependent livelihoods and on the other hand protect degradation of our valuable natural resources. Hence, for planned, strategic, safe and sustainable use of wastewaters there seems to be a need for such policy decisions and coherent programs, encompassing low-cost decentralized waste water treatment technologies, bio-filters, efficient microbial strains, and organic / inorganic amendments, appropriate crops/ cropping systems, cultivation of remunerative non-edible crops and modern sewage water application methods, that can address following vital issues for devising appropriate site-specific and waste water-specific strategies:

1. **Reduction of toxic contaminants in wastewater at source:** The industrial effluent must be treated at source and strict guidelines should be formulated and implemented for the disposal of the industrial effluents.
2. **Setting up of wastewater use guidelines:** There are two primary constraints w.r.t. the adoption of any set of guidelines: firstly infrastructure, operation and maintenance, and the associated investment and recurring costs that are required to handle or treat wastewater to the quality levels stipulated in the guidelines, and secondly regulatory enforcement to ensure compliance with required practice on the part of water authorities/ those discharging wastewater and/ those handling and using wastewater.

To minimize health hazards to the stake holders, wastewater should be treated at least to secondary level prior to its use for irrigation particularly for crops, which are consumed after cooking. World Health Organization formulated some guidelines which regulates wastewater irrigation based upon number of nematodes and faecal coliforms for restricted crops (like industrial cotton, sisal, sunflower etc.; not intended for direct human consumption) and unrestricted uses (crops for direct human consumption like vegetable). For restricted irrigation, wastewater should not have more than one viable human intestinal nematode egg per litre, whereas for unrestricted irrigation in addition to the above criteria, faecal coliform bacteria per hundred millilitres should not exceed 1000. The WHO guidelines are in fact difficult to follow in true practical sense. Hence developing and applying pragmatic guidelines based on *managed risk* or *acceptable risk* instead of *'no risk'* criteria must be the approach adopted.

Besides this, guidelines for untreated wastewater, where sufficient treatment of wastewater, is not feasible should also be formulated.

3. Crop restrictions protect the health of consumers when water of sufficient quality is not available for unrestricted irrigation. However, crop restriction does not provide protection to the farm workers and their families where low-quality effluents are used in irrigation or where wastewater is used indirectly, i.e. through contaminated surface waters (Blumenthal *et al.,* 2000). Crop restriction is therefore not an adequate single control measure, but should be considered as part of an integrated system of control. Along with guidelines, some of the easily adaptable and low cost practices which can be recommended include information on hygiene, wearing of shoes while working with wastewater, regular treatment of farmers and their families with anti-helmintic drugs to prevent worm infection, growing of crops on ridges or raised beds to minimize the contact with wastewater, the removal of outermost two leaves in cabbage, repeated washings, sun drying for 3 to 4 hours of vegetables and harvesting of Egyptian clover and sorghum 5- 10 cm above ground have been found to be quite effective in reducing the pathogen load to a great extent (Minhas *et al.*, 2006).

Crop restriction has been used effectively in Mexico, Peru and Chile (Blumenthal *et al.,* 2000). In Chile when implemented with a general hygiene education programme the use of crop restriction reduced the transmission of cholera from the consumption of raw vegetables by 90% (Monreal, 1993). However, crop restriction is feasible only under following conditions:

- Where a law-abiding society or strong law enforcement exists
- Where a public body controls allocation of the wastes and has the legal authority to enforce those crop restrictions
- Where adequate demand for the crops allowed under crop restrictions exists and where they fetch a reasonable price, and
- Where there is little market pressure in favour of the excluded crops

4. Types of crops that farmers can raise are affected by the wastewater quality and the prevailing climatic conditions. In arid and semiarid regions, high evaporation rates cause wastewater to be more saline and thus calls for the cultivation of salt tolerant crops and varieties. As many fodder crops are salt tolerant therefore use of wastewater for fodder production in urban and peri-urban areas, particularly having urban demand for dairy products, may be encouraged. However, the health of the livestock fed on the wastewater irrigated fodder may be seriously impaired (as currently in Hyderabad) and the quality of milk may be affected with the consequent transference of the danger to the humans. Similarly, many varieties of fish are sensitive to the changes in the water quality (Buechler and Devi, 2002).

5. **Fertilizer application:** Wastewater is a rich source of plant nutrients, therefore soils irrigated with wastewater are enriched in nutrients. Therefore, doses of fertilizers to be applied should be adjusted according to the nutrient contents in wastewater, amount of wastewater to be applied and crop nutrient requirement. Soil testing should also be carried on regular basis to check imbalanced nutrition or soil sickness.

6. **Irrigation management**

a) **Conjunctive water use**: Practically, except presence of high organic load, there is no difference in wastewater irrigation and saline water irrigation. Therefore, guidelines formulated for saline water use may also be considered while dealing with wastewater. Strategies involving dilution principal like conjunctive use in cyclic mode with fresh water sources may be adopted to overcome many problems associated with wastewater use.
b) **Application Methods:** Spray/sprinkler irrigation methods are associated with the highest potential salt, pathogens and other pollutant deposits on crop surfaces. Further, bacteria and viruses can be transmitted through aerosols to the nearby communities. Where spray/sprinkler irrigation is used with wastewater it may be necessary to set up a buffer zone, e.g. 50–100 m from houses and roads, to prevent health impacts on local communities (Mara and Cairncross, 1989). Also, farm workers and their families are at the highest risk when furrow or flood irrigation techniques are used. This is especially true when protective clothing is not worn and earth is moved by hand (Blumenthal *et al.,* 2000). To reduce pathogen load, contact between the edible parts of the plant and the contaminated irrigation water should be minimum. If the effluent is transported through pipes and delivered into individual furrows by means of gated pipes, risk to irrigators may be minimized.

Besides this, localized irrigation techniques e.g. bubbler, drip, trickle (though expensive) may offer the maximum health protection to the farm workers and result in comparatively lower crop contamination (Armon *et al.*, 2002; Solomon *et al.,* 2002). Pescod (1992) concluded that, as opposed to the surface and sprinkler methods of irrigation, drip irrigation is the safest irrigation method for using wastewater. However, clogging of emitters is the main problem in the operation of the drip systems, which can't be avoided completely (Tajrishi *et al.*, 1994). The performance and clogging of the emitters depends on the quality of the wastewater mainly total suspended solids. Tertiary treatment and chlorination have been found to be an effective way to reduce clogging caused by bacteria and algae (Capra and Scicolone, 2007). Filtering also reduces clogging by preventing the suspended particles in water from entering the drip irrigation system. In India, mostly gravel media filter, screen and disk filters have been used to clean the water for drip irrigation system. However, gravel media and disk filters have been investigated to be superior to the screen filters. Studies carried at IARI, New Delhi revealed that combination of media and disc filter used in cauliflower proved better than media filter or disc filter used alone in terms of filtration efficiency, discharge rate and reduction in total coliforms and *E. coli* population (Tripathi *et al.*, 2011). Placing drip laterals at 30 cm also assisted in reduction of *E. coli* population present at soil surface.

Low-cost drip irrigation techniques like bucket drip kits have shown a high potential for use and adoption in low-income countries. Studies done in Ghana using bucket drip kits showed higher reduction in contamination (up to 6 log units) especially during the dry season (Keraita *et al.*, 2007) as compared to the often cited 2–4 log units (WHO, 2006).

c) **No irrigation before harvest**: Stopping irrigation 1–2 weeks before harvest can effectively reduce crop contamination. However, this is difficult to implement because many vegetables (especially leafy vegetables) need watering up to the point of harvest to increase their market value. This technique may be possible for some fodder crops that do not have to be harvested at the peak of their freshness (Blumenthal *et al.,* 2000).

7. Alternate land uses

a) **High rate transpiring plantations**: Under the situations where land has already been contaminated and food crops are not permitted; alternate land uses like establishment of manmade forests with high economic value and having high rate transpiring trees like sisal, mahogany, Eucalyptus, poplar, bamboo, neem, shisham etc. for non-edible products like fuel and timber and developing green belts around the cities can be another approach to overcome health hazards. Such plants can transpire water higher than the potential evapo-transpiration from the soil matrix alone. Although water use could be as high as 2500 mm annually in 6 year old Eucalyptus plantation, the exact amount of water and nutrients taken up depend upon climate and vigour (Minhas *et al*., 2015; Rockwood *et al.*, 1996; Rockwood *et al.*, 2004). Eucalyptus can also reduce N and P leaching up to 75% where sewage effluents are applied. Under such systems, the quality of groundwater has also been observed to be not affected by effluent applications and the heavy metals in soil have also been observed to be low. However, to avoid heavy metal accumulation in soil, the loading rate equivalent to crop removal has often been suggested (Rockwood *et al.*, 2004). Biochemical oxygen demand removal efficiency of tree plantations has also been observed to be 80.0 to 94.3% (Thawale *et al.*, 2006). Hence, based on varying water demand in different seasons, area to be brought under high rate transpiration systems may be evolved.

b) **Agro-forestry**: Wastewater-irrigated agro-forestry could also be a potential strategy to dispose-off urban wastewater and rehabilitate wastelands. The benefits of agro-forestry include reduced irrigation requirements, and therefore reduced exposure of farmers to wastewater. Furthermore, an agro-forestry system can increase income from the produce substantially. In the peri-urban areas of Hubli, Karnataka, important tree species chosen for such a system are sapota, guava, coconut, mango, areca nut and teak and the field crops grown include irrigated groundnut in the dry season and sorghum in the *kharif* season. However, vigorous incidence of weeds like *Parthenium hysterophorus* and insect pests due to, in general, low uses of pesticides in agro-forestry systems are some of the main constraint to agro-forestry. Besides this, early dropping of fruit from trees and the softening of fruit while still growing (Bradford *et al.*, 2003) are some other problems associated with such systems.

c) **Selection of crops as per toxic constituents of wastewater**: Crops vary in terms of tolerance to heavy metal concentration in soil. They also differ in terms of metal affinities and accumulation of assimilated heavy metals in different plant parts. Thus crops should be selected in such a way that they can tolerate the given toxic constituents of wastewater and accumulate in plant part which is of least importance or not consumed.

8. **Phyto-remediation:** This may involve different phyto-remediation approaches such as phyto-degradation, rhizofiltration, phyto-stabilizaiton and phyto-volatization. In this respect, initial success has been possible with the use of species such as *Tilaspi caerulescens* for Zn and Cd. *Brassica oleracea* and *B. juncea* have also shown potential to remove toxic ions. Hyper-accumulator plants like *Thlaspi*, *Brassica* etc. are grown on contaminated sites and harvest is later disposed-off at safer locations. In developing countries, even contaminated sites, which exist to the proximity of urban agglomerations and are the means of livelihood for the poor cannot be spared for such non-economic interventions. Under such situations, a viable and remunerative option could be the cultivation of crops with non-edible part as economic, like cut flowers, aromatic grasses etc., which will also prevent the entry of pollutant in the food chain (Lal *et al.*, 2008; Lal *et al.*, 2008a). Soil amendments like chelators (EDTA, HEDTA, DTPA etc.) and organic acids (citric, oxalic etc.) have also been attempted to enhance the phyto-extractibility of metals, thus assisting their hyper-accumulation capabilities.

9. **Bio-remediation:** In different treatment processes, the most important aspect is reduction of pollutant load by involving microbes. Bioremediation, which refers to the use of lower organisms (bacteria, fungi and algae) is more feasible for treating aquatic system. They degrade organic matter and bring down BOD and COD levels. Even after secondary treatment, N, P and heavy metals are still present in wastewater and can be removed in tertiary treatment with microorganisms. Novel biological approaches, based on microbial nitrogen cycle, can be exploited to remove N from wastewater (Zhu *et al.*, 2007). Microbes have the potential to concentrate metals from the surrounding and can also transform one form to another.

However, bioremediation has its own limitations. The main limitation is the ability of the microbes to adequately attack everything that is released into the environment. Although immobilized microbial cells offer considerable potential for varied applications but suffer from poor cell retention. At times, when pure bio-sorptive metal removal is not feasible, application of a judicious consortium of growing metal resistant cells can ensure better uptake of metals after physical adsorption. However, sensitivity of living cells to extremes of pH or high metal concentration is the major constraint. Based on various morphological, physiological and biochemical tests, microbial cultures identified as *Enterobacter intermedius* and *Alcaligenes cupidus* and *Aspergillus flavus* have been found to be the most efficient for reducing BOD, COD and coliform counts. Laboratory experiments conducted at CSSRI, Karnal for bioremediation of heavy metals through microorganisms found substantial removal of lead and cadmium from liquid medium by fungal cultures (*Aspergillus awamorii*, *Trichoderma viride* and *P. chryosporium*) (Annual Report 2007-08, CSSRI, Karnal).

Predator bacteriophages can also play an important role in reducing coliforms and pathogens in the wastewater.

10. **Use of chemical amendments:** The use of sewage and industrial effluents has been observed to enhance the available metal status of agricultural soils by 2-100 times (Minhas and Samra, 2004). Most of the accumulations of these metals are observed in the surface soil itself and the contents were negatively related with soil pH and positively with organic carbon and clay content of soils. Increasing soil pH by using lime and other amendments can render the metals in unavailable form. Similarly, tillage operation and enhanced aeration of soil may reduce solubility of metal in oxidized form thus making it less available for plant uptake. Application of phosphate, kaolin/zeolite and Fe-Al oxides to soils also reduces availability of toxic constituents.

11. **Use of bio-adsorbents:** Other viable low-cost, low-tech removal methods can be a variety of lignacious biomass like activated charcoal, press mud, rice husk and sawdust which have the ability to strongly reduce the prevalence of metals in the wastewater based on sorption principles (Anderson *et al*., 2014).

12. **Treatment systems:** Wastewater treatment cost increases with treatment level. The treatment efficiency of conventional type is limited only to remove organic and microbial pollution at satisfactory level while removal efficiency for nutrients, dissolved solids and heavy metals is poor. Land based systems like waste stabilization ponds are considered to be the best especially in the arid and semiarid regions as the treatment cost is comparatively lower, provided land is available at reasonable prices.

An alternate to tertiary treatment with conventional municipal treatment (non land based systems) can be the use of floating aquatic plants in constructed wetland configurations. The constructed wetlands are engineered systems designed and constructed to utilize natural processes involving wetland vegetation, soils and the associated microbial assemblages to assist in treating wastewaters. Constructed wetlands are driven by natural energies, have lower construction, maintenance and operation costs, have no sludge disposal problems and can be maintained by untrained personnel (Morari and Giardini, 2009). It has been estimated that the cost of treating domestic sewage through a constructed wetland technology is at least half (i.e. about Rs. 20 per kilo-liter) that for a conventional wastewater treatment system. Because of low operating costs, the systems are well suited to the needs of the small communities.

13. **Construction of weirs:** Natural remediation efficiency of the river system aided by the construction of irrigation infrastructure, particularly weirs improves water quality as evidenced by reduced helminthes egg and *E. coli* concentrations, lower biochemical oxygen demand and higher dissolved oxygen down the stream (Ensink *et al.*, 2010). The treatment efficiency of the above system has been observed to be comparable to that of a well designed waste stabilization pond system (Mara 1997). These improvements have been mainly attributed to a set of different remediation processes: principally sedimentation, dilution, aeration, natural die-off and exposure to UV-light.

14. Research should be promoted in areas like nanotechnology to find out ways and means to build cheaper wastewater management plants. Here also, the approach should be to re-use the treated water for agriculture instead of letting it go into the rivers and streams.

15. With issues of climate change, increases in urban population and increased demand for water from competing sectors, more emphasis should be given on wastewater recycling to complement the existing water resources (Mekala *et al.*, 2008).

16. Indigenous technical knowledge (ITK), local knowledge'' and "Traditional Knowledge should be properly documented for safe and sustainable wastewater use.

17. Socio-economic studies: Socio-economic characteristics as caste, class, ethnicity, gender and land tenure influence the type of wastewater-dependent livelihood activities. Therefore, socio-economic survey should be carried to collect the relevant data for the formulation of the practical policies.

Policy Guidelines

- Data on wastewater generated and extent of treatment must be collected so that wastewater is duly incorporated as a component of water management programme.
- To treat whole of the wastewater generated seems financially infeasible particularly in developing countries. Therefore, appropriate strategies using crop selection, suitable planting methods, cultivating non-edible remunerative crops and reducing wastewater exposure to the cultivators should be chalked out for the use of untreated or partially treated wastewater in agriculture.
- Industry should be encouraged to decrease amount of water used, reuse chemicals and treat effluent at source. The industries adopting control measures and having zero liquid discharge should be suitably rewarded. Constructing industrial complexes and collecting each type of industry together to make common treatment plant minimizing cost of construction and O&M cost should be promoted. This will create a new market for the waste of each industry to reach zero exhaust system. Introduction of tax incentives can hasten technology investments that enable companies to meet the more stringent effluent standards. In other cases Polluter pay's principal should be strictly followed.
- Under any circumstances, industrial effluents should not be allowed to mix with domestic wastewater.
- Quality of wastewater before use in agriculture should be regularly monitored. Similarly, groundwater quality and soil health should also be tested on regular basis.
- Depending upon the quantity and quality of the wastewater available for use, appropriate combination of wood trees, fruit trees, fodder, industrial crops and cereals should be formulated. Wastewater use in public park, golf course, green belts and tree plantation should be promoted. In Tunisia, a country known for better use of wastewater, main crops irrigated with treated wastewater are: fruit trees including citrus, grapes, olives, peaches, pears, apples, pomegranates, etc. (28.5% by area); fodder including alfalfa, sorghum, clover, etc. (45.3%); industrial crops such as sugar beet (3.8%); and cereals (22.4%).
- Farmers using wastewater should be identified and issue wastewater use permit. They should be encouraged to take crops with non-edible economic parts like flower, aromatic grasses and tree plantation. It must be ensured not to take crops like vegetables which are eaten raw. Same should be applied to grazing animals or milking on the field irrigated with wastewater. Farmers may be adequately compensated for the land value damage and difference in margin obtained from crops cultivated as asked and high value crops which would have otherwise been taken. Suitable charges should be fixed for supply of wastewater, which can be used for wastewater treatment.
- Land irrigated with wastewater use should be allotted for longer tenures so that farmers can make permanent structures and improved methods of irrigation required for wastewater use. Insecurity of tenure may prevent farmers from taking steps to minimize their exposure, such as buying shoes, gloves or medicine.
- Farmers should be encouraged to adopt modern methods of irrigation like drip. Combinations of emitter size, placements and filtration units need to be found for wastewater of different qualities for its better management.
- Farmers should be made aware to use fresh water for washing the produce before taking to the market. Consumers should also resort to sufficient washing and cooking to reduce pathogen load.
- Promote decentralized, affordable treatment systems: Waste stabilization ponds and chemically enhanced primary treatment with sand filters are two examples of methods that have proven efficient in protecting public health, while being less costly than traditional mechanical, secondary treatment plants. Wetland technology should be adopted in smaller areas. Macrophytes should be exploited to remove toxic metals.
- Efficient strains of microbes for wastewater remediation should be searched out and applied at field scale.
- Similarly more research needs to be conducted to find remunerative crops with non-edible economic part to avoid food chain contamination and better phyto-remediation of polluted sites.
- Interdisciplinary research: Research needs to be participatory, and account for farmers' concerns, perceptions, and practices, if the research results are to be implemented in a sustainable manner. Both socio-economic and bio-chemico-physical data must be collected through field surveys, water, soil and plant sampling and analysis, group discussions, interviews with users, researchers and policy makers.
- Increased funding may be provided for research to design efficient, cost-effective, and sustainable natural wastewater treatment systems that conserve nutrients while effectively removing pathogens and other pollutants.

- Regular health checks and administration of antihelmintic drugs should be held in families working with wastewater.
- Regular awareness campaign should be carried to educate the farmers, consumers and policy makers about wastewater issues and impacts.

For effective and sustainable management of wastewater short, medium and long term planning involving economic niche and users' perceptions, comparative advantages and disadvantages of wastewater irrigation needs to be formulated. The short term objectives are to minimize wastewater exposure (using crop selection, methods of irrigation etc.) and provide therapeutic medical care for irrigators. In the long term, wastewater treatment to at least primary level using settling basins or facultative lagoons must be the norm. Lowering the cost is essential if efforts to treat wastewater are to be effective.

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Gypsum Requirement for Reclaiming Alkali Soils and Waters for Crop Production - Practical

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Alkali soils are characterized by high pH (>8.2), exchangeable sodium per cent (>15) and variable electrical conductivity. Soils have low pore spaces, and difficulty to water entry and poor infiltration and prone to waterlogging, impedance aeration, deflocculating of soil particles resulting in a degradation of soil structure and formation of hard crust on the surface layer hinders seedling emergence and poor plant establishment. Further, high soil pH adversely affects the availability of several important plant nutrients (nitrogen, zinc and iron), toxicity of specific ion effect root injury and hindered plant metabolic activity (bicarbonate and carbonate). Hence, such unfavorable soil conditions for crop establishment hinder the economic return of the growers (Chhabra, 2004). Diagnosing the nature, extent, spatial distribution and management of alkali land is imperative for planning and executions of rehabilitation programs and sustain agricultural productivity, securing livelihood for farming communities and sustaining food buffer-stock of the country. Whereas, alkali water synonymously called as 'RSC (residual sodium carbonate)' affected water usually carry excess of bicarbonate and/or carbonate ions compared to calcium and magnesium. Depending on the soil properties usually irrigation water having RSC <2.5 me L^{-1} recommended as safe for crop and less chances to alkalinity development in soil. Further, a range between 2.5-5.0 me L^{-1} categorized as medium hazard to develop alkalinity whereas, RSC >5.0 me L^{-1} need to neutralization before irrigation (Gupta, 2010). Prolonged use of alkali water leads to soil sodification, loss of the crop productivity and increase in cost of crop production. Both cereals crop appears with huge losses of yields and income because of spikelet sterility caused by high RSC water irrigation (unfilled grains). The problem is likely to further aggravated with expected changes specially increase in temperature, erratic behavior of rainfall. The increase in temperature will raise evapotranspiration (ET) requirement of the crops and thus more salt-load in case of sodic water irrigation. Therefore, the ecological and economical resilience of farm productivity and agriculture in alkaline environment are threatened. It result into low economic status and many farmers have been forced to switch over to different occupation to secure livelihood security.

Philosophy of Gypsum Technology

Gypsum recommendations are developed with an assumption that one equivalent of a calcium will displace an equivalent of either sodium or magnesium on the soil exchange sites (Schoonover, 1952; Bhargava, 2003). A known weight of soil is shaken with a relatively large volume of nearly saturated gypsum solution. The loss of Ca in solution (used for replacing Na from exchange complex) is taken as a direct measure of the gypsum requirement of the soil. Gypsum is being the cheapest and easily available, and easy to handle- so it is most commonly used as amendment. Reclamation with inorganic amendment is relativity faster. The quantity of gypsum ($CaSO_4$. $2H_2O$) required to be applied to reclaimed a alkali soil depends on the factors like degree of sodium saturation, texture, degree of improvement desired, crop intended to be grown, quality and quantity of irrigation water.

$$\text{Soil-2Na}^{+} + CaSO_4 = \text{Soil-Ca}^{2+} + Na_2SO_4$$

Laboratory Procedure of Gypsum Requirement of Alkali Soil

Reagents

- Saturated calcium sulphate solution: About 5.0 g of pure $CaSO_4$ $2H_2O$ taken in one litre of distilled water shaken mechanically for 10 minutes and filtered.
- Sodium hydroxide buffer (4*N*): 160.0 g of pure sodium hydroxide dissolved in 800 ml of distilled water and volume make up in 1000 ml volumetric flask.
- Ammonium perpurate (Murexide) indicator: Mix 0.2 g of ammonium perpurate in 40 g of K_2SO_4 with pestle and mortar and store it dark colour bottle.
- 0.01 *N* calcium chloride solution: 0.50 g of AR grade calcium carbonate taken in little excess of AR HCl (about 10 ml of 3 *N* HCl) and the solution made up to one litre with distilled water.
- Standard versenate (EDTA) solution (0.01 *N*). 2.0 g of EDTA and 0.05 g $MgCl_2$ (AR) dissolved in water and diluted to 1 litre. This solution is to be standardized against 0.01 *N* calcium chloride.

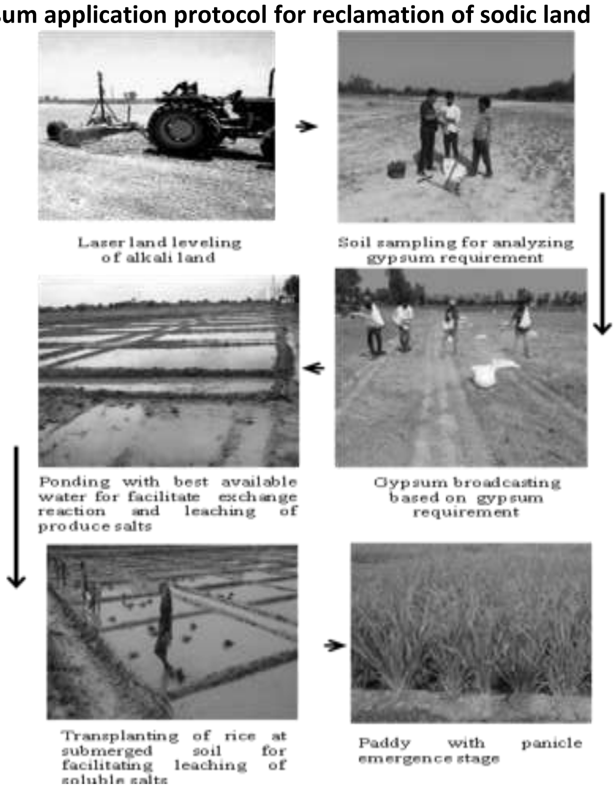
Procedure

- Five gram of soil is placed in a 250 ml conical flask to which 100 ml of the saturated $CaSO_4.\ 2H_2O$ solution is poured in shaken for 5 minutes and filtered (Whatman No. 1).
- After rejecting first few ml, 5 ml of the extract is pipetted into a 100 ml flush or porcelain dish and diluted to about 25 ml with distilled water. Five ml of NaOH buffer and 25 mg of ammonium perpurate are added and titrated with the standard EDTA solution until the colour changes from orange red to purple.
- Similarly 5 ml of the saturated $CaSO_4.\ 2H_2O$ solution is titrated separately (blank).

Interpretation

Weight of the soil= 5 g (say)
Volume of saturated gypsum solution added= 100 ml
(Volume of saturated gypsum solution/ filtrate taken for titration= 5 ml)
Volume of 0.01*N* EDTA solution used for titrating standard gypsum solution= A ml
Concentration of Ca in Standard gypsum solution=
[(A× Normality of EDTA×1000)/volume of aliquot]= S me L^{-1}
Volume of 0.01*N* EDTA solution used for soil filtrate = B ml
Concentration of Ca in soil filtrate=
[(B × Normality of EDTA×1000)/volume of aliquot]= T me L^{-1}
Total me of Ca remained in soil after addition of 100 ml of gypsum solution=
[(S-T) × 100/1000]= 0.1× (S-T) me
So, for 5 gm soil = 0.1× (S-T) me
For 100 gm soil = [0.1× (S-T) × 100]/ 5 me = 2(S-T) me/100g
Thus, 1 kg soil contain= [20 × 20 × (S-T)] mg Ca= 400 × (S-T) mg Ca
For 2.24×10^6 kg soil = [400 × (S-T) × 2.24×10^6] / 10^6 kg Ca
= 896 × (S-T) kg Ca
Molecular Weight of gypsum = 172
Now, 40 kg Ca = 172 kg of gypsum
So, 896 × (S-T) kg Ca is obtained from=
[172 × 896 × (S-T)]/(40 × 1000) tons of gypsum
= 3.85 × (S-T) tons ha^{-1}

Schematic diagram of gypsum application protocol for reclamation of sodic land



Ready Reckoner of Gypsum Technology

Some time determination of gypsum requirement is not feasible due to inadequate laboratory facility and limitation of time or other. A good and acceptable relationships between $pH_{1:2}$ (soil and water) and gypsum requirement for a large number of alkai soils in Indo-Gangetic Plain are worked out to address this problem. One added advantage of these relationships that it is devolved for three distinct categories (light, medium and heavy textured soil) of alkali soils (Fig. 1). By interpretation of $pH_{1:2}$ the approximate gypsum requirement can be work out of alkali soil (Bhargava, 2003).

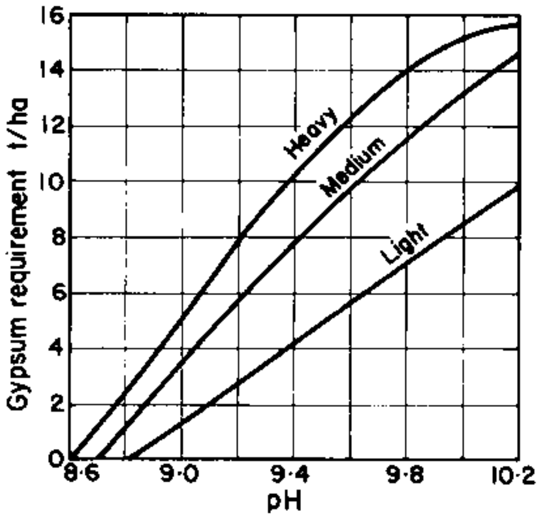


Fig. 1. Relationship between $pH_{1:2}$ and gypsum requirement of alkali soil

Determination of Residual Sodium Carbonate (RSC) for Irrigation Water

This is an important character for assessing the suitability of irrigation water in consideration of likely alkalinity hazards. Alkalinity build-up in soils depends on the amount of carbonates and bicarbonates ions present in the irrigation water. Groundwater with excessive carbonate/ bicarbonate contents leads to the precipitation of calcium and magnesium as their corresponding carbonates and resulting high alkalinity build-up in soils. Excess of sodium bicarbonate and carbonate is considered to be harmful to the physical properties of the soil, as it causes dissolution of organic matter in the soil which in turn leaves a black-brown stain on the soil surface on drying. Moreover, high alkalinity in irrigation water leads to disperse soil structure following by reducing soil infiltration and hydraulic conductivity.

Clay-Ca + $CO_3^{2-}{}_{(iw)}$ + $Na^+{}_{(iw)}$ ---> Clay- Na^+ + $CaCO_3$ (ppt.)
Clay- Na^+ results in increase in ESP, high ESP causes high pH.
RSC is calculated from the analysis data for carbonates, bicarbonates and calcium plus magnesium in the following manner.
RSC (me L^{-1}) = $[(CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})]$
Where, concentrations of ions are in me L^{-1}.

Determination of Calcium + Magnesium by Versenate (EDTA) Method

Principle
The method is based on the fact that calcium, magnesium and a number of other ions form stable complexes with Versene (ethylene di-amine tetra-acid di-sodium salt) at different pH. Some elements like Sn, Cu, Zn, Fe, Mn may interfere in the determination of calcium and magnesium. Usually the quantities of interfering ions are negligible in irrigation waters and soil extract.
A known volume of the solution is titrated with standard versenate 0.01 *N* solution using murexide (ammonium purpurate) indicator in the presence of NaOH solution. The end point is a change of colour from orange red to purple at pH = 12.0, when the whole of calcium forms a complex with EDTA. Beyond pH 10.0 magnesium is not bound strongly to EDTA.

Reagents

- EDTA or Versenate solution (0.01 *N*): See in calcium determination.
- NH_4Cl-NH_4OH buffer solution: Dissolve 67.5 g of pure ammonium chloride in 570 ml of ammonia solution and made to one litre and adjust to pH 10.0 with ammonia or HCl.
- Erichrome black-T indicator (EBT): Mix 0.5 g of the indicator with 100.0 g of potassium sulphate and store it.

Method

- Take 5 ml of the sample in the conical flask and dilute it with DW and add 5-10 drops NH_4Cl-NH_4OH buffer solution.
- Add a pinch of the EBT indicator and titrate it with 0.01 *N* EDTA till the colour gradually changes from wine red to blue green. Record the reading and designate as R.

Calculations

If N_1 and V_1 normality and volume of aliquot taken and N_2 and V_2 are the normality and volume of EDTA used respectively, then.

$N_1V_1 = N_2V_2$

Or, $N1 = \frac{N2V2}{V1} = \frac{(volume\ of\ EDTA\ used\ \times Normality\ of\ EDTA)}{aliquot\ taken\ (ml)}$

Here N_1 = Normality = equivalents of Ca^{2+} + Mg^{2+} present in one litre of aliquot.

Hence, milliequivalents of Ca^{2+} + Mg^{2+}per Litre (me L^{-1}):

$=\frac{(volume\ of\ EDTA\ used\ \times 0.01 \times 1000)}{aliquot\ taken\ (ml)} = \frac{(R \times 0.01 \times 1000)}{5} = R \times 2$

Determination of Carbonate and Bicarbonate

Principle

Carbonate and bicarbonate in a water/ soil extract can be determined by titrating the sample against standard acid using phenolphthalein and methyl orange or methyl red as end point indicators, respectively. When the colour of phenolphthalein is discharged, indicates half the neutralization of carbonate. At this stage methyl red indicator is added and the titration has been continued. When the colour changes from yellow to rose red, it is the end point for the complete neutralization of bicarbonate. The following equations illustrate these changes:

$2Na_2CO_3 + H_2SO_4$ ----> $2NaHCO_3 + Na_2SO_4$
pink colorless

$2NaHCO_3 + H_2SO_4$ ----> $Na_2SO_4 + 2H_2O + 2CO_2$
yellow rose red

Reagents

- Standard Sulphuric acid (0.01 *N*): First prepare 1 *N* acid by taking approx 28 ml. of concentrated H_2SO_4 (36 *N*) and dilute to one liter with distilled water and make it to 0.01 *N* by diluting it 100 times and then standardized it by 0.01 *N* sodium carbonate solution.
- Methyl red indicator (0.5%): Dissolve 0.5 gram dry methyl orange powder in 100 ml. of 95% ethanol.
- Phenolphthalein **indicator (0.25%)**: Dissolve 0.25 gram of pure phenolphthalein powder in 100 ml. of 60% ethanol.

Method

- Pipette 5 ml. of water extract in a conical flask and dilute it with approx 10 ml of DW and add 2 drops of phenolphthalein. Appearance of pink colour indicates the presence of carbonates.
- If carbonate is present, add 0.01 *N* sulphuric acid from a burette till the solution becomes colorless.
- Record this reading and designate it as Y. Add a few drops of methyl red indicator in the same solution and continue the titration till the colour changes from yellow to rose red and record this reading also and designate it as Z.

Calculations

If N_1 and V_1 normality and volume of aliquot taken and N_2 and V_2 are the normality and volume of sulphuric acid used respectively, then

$N_1V_1 = N_2V_2$

or

$$N1 = \frac{N2V2}{V1} = \frac{(volume\ of\ acid\ used \times Normality\ of\ acid)}{aliquot\ taken\ (ml)}$$

$$= \frac{(2Y \times 0.01)}{aliquot\ taken\ (ml)}$$

Here N_1 = Normality = equivalents of CO_3^{2-} present in one litre of aliquot.

Hence, milliequivalents of CO_3^{2-} per Litre (me L^{-1}):

$$= \frac{(2Y \times 0.01 \times 1000)}{5}$$

$= 2Y \times 2 = 4Y$

Similarly,

milliequivalents of HCO_3^- per Litre (me L^{-1}):

$$= \frac{(Z-2Y) \times Normality of\ acid \times 1000)}{aliquot\ taken\ (ml)}$$

$$= \frac{(Z-2Y) \times 0.01 \times 1000)}{5}$$

$= (Z-2Y) \times 2$

Ready Reckoner for Neutralization of Alkali Water

The quantity of gypsum (~70% pure) for neutralization of each me L^{-1} of RSC is 86 kg ha^{-1} per 1000 m^3 of water. The need for gypsum application for ameliorating the sodicity effects is of the recurring nature.

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Commercial Vegetable Production in Protected Structure in Saline Environment for Livelihood Security

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Introduction

The availability of fresh water for agricultural use is declining in many areas of world due to increasing water needs of industries and municipalities. Thus agriculture faces challenges of using low quality waste water and saline water for crop production. Many studies indicate that these water resources traditionally classified as unsuitable for irrigation can be used successfully to grow crops without long-term hazardous consequences to crops and soils if proper management strategies are established. These strategies include adopting advanced irrigation technology, selection of salt tolerant crops, leaching of salts below the crop root zone.

Water scarcity is becoming one of the major limiting factor for sustainable agriculture in the semi arid regions of the world. In India the entire arid and semi-arid regions have been characterised by low rainfall and has the problem either of water scarcity or poor quality groundwater. The use of saline/alkali ground water posses a major threat to plant growth and health, which is mostly observed in semiarid parts (Minhas and Bajwa, 2001). In India, the regions identified for poor quality water are major parts of Rajasthan, Gujarat, Haryana, North western UP and South western Punjab. Poor quality water constitutes 32-84 % of ground water surveyed in different parts of India is either saline or alkali (Minhas, 1996).

Saline water upto 11 dS/m has been used successfully for commercial irrigation for a number of crops globally (Rhodes *et al*., 1992). However, in order to assure maximum yield form crops irrigated with saline water, it is necessary to develop special management techniques. Presently drip irrigation is widely regarded as the most promising irrigation system to use saline water. Several factors contribute to the good results obtained with saline water irrigation using drip irrigation under protected structures. I) less water use results in less salt deposited on the beds, ii) avoidance of leaf burn, iii) high frequency drip irrigation prevents the soil from drying out between irrigations, thereby avoiding peaks in salt concentration and concomitant high osmotic potentials and iv) salts are continuously leached out from the wetted section and accumulate at the wetting front away from the active root zone.

Due to diversity in climatic conditions ranging from extreme temperate to extreme tropical. The majority of cultivation practices for vegetables occur in open conditions but there is vast scope for protected cultivation of commercial vegetables in hills as well as in plains. India is a leading country in area and production after China in many crops in the world but vegetable production is much lower than the present requirement to feed the people of India. The main reason is adoption of traditional cultivation technology which results in low productivity. Also there is lack of good management practices for biotic and abiotic stresses. There are different ways to revive from this situation. Bringing additional area under vegetable cultivation to feed the burgeoning population, use of hybrid seeds and adoption of improved agro-techniques to enhance the vegetable production. Another approach is cultivation of commercial vegetables under protected environment. The majority of parts of northern plains including hilly area have fertile lands which is suitable for vegetable production but extreme temperature ranging from 0-48^0 celsius during winter and summer, renders the year round production of vegetables. Protected agriculture, which includes polyhouse, shade nets, poly tunnels, polymulch etc protects the agricultural crops from extreme weather conditions and provides the suitable environment inside these structures. (Negi *et al*., 2013). Greenhouse/polyhouse/net houses are suitable under these diverse climates for year round and off season vegetable production.

Evaluation of farm friendly cultivation technology for production of high value vegetable crops during summer and sustaining vegetable production system during freezing winters can be well achieved by protected cultivation technology (Kanwar and Akbar, 2011).

Vegetables are recognized as health food globally and play important role in overcoming micronutrient deficiencies and providing opportunities of higher farm income. The world-wide production of vegetables has tremendously gone up during the last two decades and the value of global trade in vegetables exceeds that of cereals. India is the second largest producer of vegetables in world next to China. India's share of the world vegetable market is around 14%. During 2014-15 the vegetable crops in India occupy only 2.8 % of the total cultivated land producing 169.47 mt of vegetables annually from a cropped area of 9.52 mha. In Haryana vegetable production was 5.5 lakh tonnes from 373.17 thousand ha of land (NHB, 2015). According to statistics release by Ministry of Agiculture, there has been 13.5% increase in are and 13.4% increase in production during 1996 to 2010. However, vegetable production is much less than the requirement if balanced diet is provided to every individual. There are different ways and means to achieve thus target, e.g., bringing additional area under vegetable crops using hybrid seeds, use of improved agro-techniques and another potential approach is perfection and promotion of protected cultivation of vegetables. Vegetables are generally sensitive to environmental extremes and thus high temperature and limited soil moisture are the major causes of low yields and will be further magnified by climate change.

Protected Cultivation

Protected cultivation practices can be defined as cropping techniques in which the microclimate surrounding the plants is controlled partially or fully as per the requirement of plant species grown during growth period. Protected cultivation also known as controlled environment agriculture (CEA) is highly productive, saving of water and conservation of land and environment friendly (Jensen, 2002). Protected cultivation is considered as a recent and innovative plasticulture intervention for the cultivation of high value crops. The cultivation of high value crops under climate controlled conditions has been found to be more remunerative as it makes product in a season when it is not possible in the open condition.

The green house is generally covered by transparent or translucent material such as glass or plastic. The green house covered with plastic sheet is termed as polyhouse. Growing of tomato, capsicum, cucumber using cost effective polyhouses provides an alternative for raising crop in the off season. This also ensures to meet year round supply of fresh produce with more efficient utilization of resources. (Sharma *et al*., 2009). New features added to these structures have cut down the requirement of water and energy in such cultivation through novel means like micro irrigation-cum-fertilization (fertigation) and rainwater harvesting.

Present status vis-à-vis global and National Scenarios

The idea of growing plants in environmentally controlled areas has existed since Roman times. The Roman Emperor Tiberius (42 to 37 BC) daily ate cucumber grown through artificial methods. In the 16th century, European explorers brought back exotic plants acquired in the course of their travels. Many tropical plants could not survive in the cold climates results in the creation of greenhouses. Later, with the advent of plastics during World War II , a new phase in green house technology emerged. At present nearly 90% of the greenhouses are being constructed utilizing UV stabilized polythene sheets as the glazing material.

Principles of Greenhouse Cultivation

The greenhouse cultivation is based upon the principle called as greenhouse effect. Actually, greenhouse is a structure made with the transparent covering materials that transmit the solar energy inside the structure. This energy absorbed by the vegetable crops and objects inside the house releasing light of long wave length. Finally the light gets trapped inside increasing the inside temperature. This rise in temperature in polyhouse is responsible for growing vegetables during winter, however, during summer increase in temperature can be managed by the natural ventilation.

Why Protected Cultivation

The open field production of vegetables encounter with many production constraints like heavy rain, thunderstorms, excessive solar radiation, temperature and humidity levels (Max *et al*., 2009), high insect pest infestation and fungal diseases. Environment is the most determinate factor in vegetable crops. Protected cultivation is being used to control the adverse environmental effect on vegetable crops. Protected cultivation is the sustainable approach toward the vegetable production under adverse climatic conditions. Besides, from protection to adverse climatic condition, the vegetable under protected production yield high quality vegetable in terms of shape, size and colors. The production of vegetables is higher than the open field condition due to congenial microclimate inside which results in better price of the produce.

The protected cultivation comprises different devices and technologies viz., windbreaks, drip irrigation, mulching. He modified natural environment inside the polyhouse will prolong the harvest period, increase the yield, quality improvement and keeps the frequent availability of the commodities for a longer period.

Suitable crops for protected cultivation

High value, short duration and small size vegetable crops are mostly suitable under protected cultivation. In India, sweet pepper, tomato, green chilli, egg plant and cucumber are being produced. Cabbage, cauliflower, tomato, brinjal, capsicum, pea and coriander can be successfully grown under protected cultivation structures.

Response of Individual crops to protected cultivation

Tomato requires a relatively cool, dry climate for high yield and premium quality (Nicola *et al*., 2009). In the open field condition, when the temperature falls below 10° Celsius, causes the pollen bursting and less fertilization and less fruit yield while the high temperature results in premature fruit drop, badly damaged mis-shaped fruits (Singh *et al*., 2015). These These problems can be overcome with the temperature maintained inside the protected structure. Issac (2015) revealed that coriander establishes and grow well with higher biomass production in naturally ventilated polyhouse.

Singh *et al*. (2007) reported that low cost naturally ventilated green house were most suitable and economical for year round cucumber production in northern plains of India. Sweet pepper can be successfully grown under zero energy naturally ventilated green house conditions. Capsicum is most extensively grown vegetable under green houses and gives higher returns. Kumar and Singh (2015) reported that with the development of parthenocarpic hybrids in brinjal, it is possible to grow it under protected structures.

Salinity stress

Salinity is an environmental stress that mits growth and development in plants. The response of plants to excess NaCl is complex and involves changes in their morphology, physiology and metabolism. Translocation of salts into roots and shoots is a outcome of the transpirational flux required to maintain the water status of the plant and unregulated transpiration may cause toxic levels of ion accumulation in the shoot. The response of plants to high salinity may vary with different growth stages. This has been shown in egg plant (Chartzoulakis and Loupassaki, 1997). Young seedlings and plants at the flowering stage seem to be more sensitive than mature stages. Salt tolerance of plants can be grouped in three categories, exclusion of salts (Achilea *et al*., 2002); compartmentation of salt (Adams, 1988) and biomass distribution of plant shoots and roots (Adams, 1991). NaCl (common salt) can interfere with plant growth. By applying nutrients like potassium and calcium these affects can be minimized.

Response of sweet pepper under polyhouse and open field condition

Sweet pepper (*Capsicum annum* L.) is one of the important vegetable crop which require mild climate for its growth and development. The fruits are harvested either at green mature stage or colouring stage having great demand in big cities and other urban areas of the country and fetch very high price. Prevailing night low temperature, energy, high rainfall, frost, waterlogging, higher relative humidity and cold winds are limiting factors for growing sweet pepper under open field conditions. To make its cultivation successful, polyhouses, poly-tunnels, plastic mulching are most suitable solutions (Chandra *et al*., 2000; Singh *et al*., 2010).

In addition these structures facilitate the utilization of nutrients from soil for longer duration (Singh 2005). Results of the study conducted by Singh *et al*., 2011 showed that maximum crop duration (270 days) was recorded in sweet pepper under polyhouse conditions along with fruit diameter (6.91cm), maximum no. of fruits/plant (47), highest individual fruit weight (62.17 g), yield (17.48 kg/m^2) followed by poly-tunnel and plastic mulching treatments. The above observations wer recorded minimum under open field conditions (Table 1).

Table 1. Effect of different protected and open field conditions on sweet pepper

Sweet pepper variety	Total crop period (days)	Fruit diameter (cm)	Fruits/plant (No.)	Fruit wt/fruit (g)	Fruit yield (kg/m^2)
Protected condition					
Polyhouse	270	6.90	47	62.16	17.48
Poly-tunnel	180	4.49	41	45.64	11.34
Poly-mulching	150	4.03	37	41.74	9.43
Mean	200	5.14	42	49.85	12.75
Open field condition	117	3.05	33	40.20	5.90
CD (P=0.05)	28.53	0.89	2.33	0.75	2.17

(Source: Singh et al., 2011)

Protected cultivation improves water productivity due to reduction in the ET and increased production. Soil and water salinity in the arid regions are continuously increasing (Rus *et al*., 2000). Due to scarcity of non-saline water, use of recycled waste water/desalinized water is often used in agriculture. However, there are serious limitations to the continuous use of poor quality water for agriculture especially for cultivation of crops in greenhouses. The continuous use of saline water in greenhouses grown crops results in build-up of soil salinity in the root zone that may be detrimental to growth and yield (Flowers, 1999).

There are very few reports on the effects of salts on greenhouse pepper (Sonneveld and Van der Burg, 1991; De Kreij, 1999). Although pepper plants have been reported to be moderately sensitive (Mass and Hoffman, 1977; Pasternak and Malach, 1994) to very sensitive to saline water but greenhouse grown bell pepper has been reported to be sensitive (Chartzoulakis and Klapaki, 2000; Navarro *et al*., 2002) or moderately sensitive to salinity (Ayers and Westcot, 1985; Rhodes *et al*., 1992) due to adverse effect of high salt concentration on stomatal conductance and net photosynthesis (Gunes *et al*., 1996; De Pascle *et al*., 2003; Lycoskoufis *et al*., 2005). Despite its varied sensitivity to salinity, bell pepper is often cultivated in greenhouses by using saline water. In Cyprus, Papadopoulos (1998) obtained a yield of 79 t/ha of greenhouse grown bell pepper using saline water with an EC of 3.1 dS/m. Rubio et al (2010) reported decreased above ground biomass and marketable fruit yield from the saline water treatment (4.6 dS/m) when compared to control (2.6 dS/m) and increased water use efficiency by reducing the frequency f per day irrigation from eight to one.

Patil *et al*. (2014) reported that soil EC was significantly influenced by the quality of water. Saline water use resulted in significantly higher soil EC compared to non-saline water consistently throughoput the crop growth period. The soil EC values varied from 1.157 to 1.661 dS/m in non-saline water treatment and from 1.632 to 2.808 dS/m in saline water treatment. The differences in soil EC values were narrower during the initial stages and considerably widened during the later stages of the crop growth. Patil et al (2014) also reported that irrigation with saline water resulted in fresh fruits of superior quality parameters (total sugar – 6.556%; TSS-1.80%) in pepper.

Effect of irrigation water quality on bell pepper fruit yield

Patil *et al*., 2014 reported that fruit yield of greenhouse grown bell pepper was inversely proportional to the salinity of irrigation water. The fruit yield was drastically reduced by irrigation with saline water. Saline water (3.5 dS/m) irrigation caused s drop in the fresh fruit yield by 72% as compared to irrigation with non-saline water (0.5 dS/m). The lower fruit yield obtained by using saline water was mainly due to build up of soil salinity, since water quality exhibited an overriding effect on soil EC, saline water use resulted in significantly higher EC compared to non-saline water consistently throughout the crop growth period. There was a steady increase in soil EC throughout the crop growth period in saline water treatment well above the threshold value of 1.5 dS/m. The increase in soil salinity in the root zone beyond the tolerance capacity of the crop might have resulted in substantial reduction in the yield of fruits. Lower yield in saline water treatment could also be due to significantly higher crop canopy temperatures. De Pascale *et al*. (2003) attributed lower pepper yield at higher salinity level to reduced vegetative growth associated with marked inhibition of photosynthesis (Bethke and Drew, 1992; Chartzoulakis and Klapaki, 2000) and decreased biomass production (Ben-Gal *et al*., 2008) Reduced growth and yield of bell pepper due to due to salinity was attributed to reduced water content in leaves caused by poor osmotic adjustment (Navarro *et al*., 2002), osmotic effect and increased Na+ and Cl- in the leaves (Lycoskoufis *et al*., 2005) and decreased transpiration (Ben-Gal *et al*., 2008).

Fruit Yield of Capsicum, Green Chilli and Tomato in Naturally Ventilated Polyhouse under Saline Enviroment

Capsicum

During 2015-16, with initial low production of capsicum fruits, significantly highest fruit yield of capsicum (63.1 t/ha) was obtained with BAW which was at par with the fruit yield obtained at EC_{iw} 6, 8 and 4 dS/m (62.2, 58.2 and 52.3 t/ha) respectively while during 2016-17, there was no much variation in fruit yield at different salinity treatments though the highest fruit yield (49.9 t/ha) was obtained with BAW while during 2007-18, the fruit yield was significantly highest with EC_{iw} 2 dS/m (41.8 t/ha) over all other irrigation salinity treatments including BAW (36.9 t/ha) and this might be due to more number of fruits/plant. The average fruit yield was highest with BAW (49.97 t/ha) followed by EC_{iw} 2 dS/m (45.1 t/ha) and EC_{iw} 6 dS/m (44.8 t/ha) and lowest fruit yield (33.0 t/ha) was obtained at EC_{iw} 10 dS/m which was 33.8 percent lower as compared to BAW at the highest salinity of irrigation water. This might be due to high concentration of Na+ ion in the soil solution which modify the ratio of Na+/K+ . Increase of cations and their salts in particular NaCl leads to an increase in the osmotic potential that can precisely cut off or reduce the ingress of water to the roots of plants (Boris *et al*., 2016).

Chilli

During 2015-16, production of chilli fruits, differ non-significantly with all saline treatments though the highest fruit yield (48.6 t/ha) was obtained at EC_{iw} 6 dS/m and lowest fruit yield (36.1 t/ha) was recorded with BAW while during 2016-17, significantly highest fruit yield (47.7 t/ha) was obtained at EC_{iw} 6 dS/m which was at par with fruit yield obtained at EC_{iw} 4 dS/m. Lowest fruit yield (27.5 t/ha) was obtained at EC_{iw} 10 dS/m while during 2017-18 the fruit yield was significantly higher (39.2 t/ha) with BAW irrigation over other saline irrigation treatments except yield at EC_{iw} 2 dS/m. At highest salinity of irrigation water (EC_{iw} 10 dS/m) the fruit yield (15.5 t/ha) was reduced by 60 percent as compared to BAW during third year of cropping cycle which might be due to increased salinity in the crop root zone due to continous irrigation for three years. This clearly showed that continuous use of even higher salinity cause a reduction of 60% at the end of three year. The average fruit yield showed that highest fruit yield (41.8 t/ha) was obtained at EC_{iw} 4 dS/m ha) followed by EC_{iw} 6 dS/m (40.7 t/ha) and lowest fruit yield (29.6 t/ha) was obtained at EC_{iw} 10 dS/m which was only 16 percent lower as compared to BAW irrigation. This shows the better salinity tolerance of chilli grown under naturally ventilated polyhouse structures.

Tomato

During 2015-16, fruit yield of tomato differ significantly and highest (116.3 t/ha) was obtained at EC_{iw} 6 dS/m which was at par with the fruit yield (110.9, 100 and 111.1 t/ha) obtained at EC_{iw} 4, 8, 10 dS/m respectively and significantly lowest fruit yield of tomato was recorded at EC_{iw} 2 dS/m while during second year, significantly highest fruit yield (114.0 t/ha) was obtained at EC_{iw} 10 dS/m as compared to all other salinity levels including BAW irrigation. Lowest fruit yield (67.1 t/ha) was obtained with BAW irrigation while during 2017-18 significant difference was found in the tomato fruit yield and it was highest (149.0 t/ha) at EC_{iw} 4 dS/m which was at par with the fruit yield obtained at EC_{iw} 6 dS/m over other saline irrigations. At highest salinity of irrigation water (EC_{iw} 10 dS/m) the fruit yield (138.6 t/ha) was higher than BAW irrigation 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. 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. 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.

Advantages of Protected Vegetable Cultivation

Protected vegetable production can reduce the amount of water and chemicals used in production of high value vegetables compared to open field conditions. The comparative advantages are:

1. Year round production of vegetables.
2. Adverse climate for production of vegetables can be overcome by different systems of protected cultivation.
3. Multiple cropping on the same piece of land is possible.
4. Off season production of vegetables to get better return to growers.

5. Use of protected vegetable cultivation can increase production as well as productivity per unit area of land, water, energy and labour. It supports the production of high quality and clean products.
6. Vegetable cultivation is possible in area where it is not possible in open conditions such as high altitudes, deserts, salt affected conditions.
7. The potential of polyhouse production technology to meet the demand of producing good nutrition and healthy foods and quality vegetables free from pesticides can be fully exploited.
8. Management and control of insect-pest, diseases and weeds is easier.

Conclusion

The study conducted on evaluation of commercial vegetable crops using saline water for irrigation revealed that these vegetables could be grown under naturally ventilated polyhouse using saline water for irrigation. Though the fruit yield reduced with saline water in comparision to good water but has yield advantage over open field condition. The protected cultivated cultivation could be the only one alternative to control the environment for sustainable production of vegetables crops.

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NRM and Varietal Interventions to Address Sustainability Issues in Salt Affected Agro-ecosystems of Ghaghar Basin: Experiences from Farmer FIRST Programme

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Introduction

The Farmer FIRST (Farm, Innovations, Resources, Science and Technology) Programme was initiated in October 2016 by Indian Council of Agricultural Research (ICAR), New Delhi to move beyond the production and productivity, to privilege the smallholder agriculture and complex, diverse and risk prone realities of majority of the farmers. It seeks to provide a platform to farmers and scientists for creating linkages, enriching knowledge and integrating technological options in holistic approach as per the ground realities and available resources including natural to specific agro-ecological environments.

In past, the knowledge and innovations of the farmers were not valued much and their presence was relegated at most as a participant but not as a partner in the experimentations. The wisdom available with the farmers was also not channelized so much to derive suitable options for different production systems. The participation of multiple stakeholders was also not taken up in perspective for technology development, integration and adoption. Now the situation has changed drastically and this necessitated new approach for project development involving innovation and technology development with the strong partnership of the farmers for developing location specific, demand driven and farmer friendly technological options.

Farmer FIRSTprovides an opportunity for the researchers, extension professionals and farmers to work together and find appropriate ways through assessing different solutions. In this approach, the farmers have been kept in a centric role for research problem identification, prioritization and conduct of experiments and its management in farmers' conditions. During the production process, farmers often evolve new ideas and provide feedback to further improve their cultivation practices and natural resource management activities.

Farmer FIRSToffers an opportunity to create synergy of formal and informal knowledge systems where technologies developed by scientific institutions are taken on farmers' field to scale-up, make necessary refinement according to location specific stressors and vulnerability. Farmer FIRST can be applied not only at household level but also at village and community level as community experimentation.

Components of Farmer FIRST Programme

1. Enhancing Farmer–Scientist Interface:
2. Technology Assemblage, Application and Feedback
3. Partnership and Institution Building
4. Content Mobilization

Following this concept, Farmer FIRST Programme (FFP) entitled *"Empowering farmers through selective interventions in salt affected agroecosystems of Ghaghar Plains"* was initiated at ICAR-Central Soil Salinity Research Institute, Karnal.

Five villages namely Mundri, Geong, Kathwar, SampliKheri and BhainiMajra in Kaithal district of Haryana state were purposefully selected to accomplish the targeted objectives. The degradation of natural resource base over a period of time and loss of social-ecological resilience has increased risks manifold in the vicinity of targeted site, and as a result farmers' dependency on external resources has increased manifold.The proposed agro-ecosystem represents Ghaghar plains and is dominated by rice-wheat cropping system. Sodic soils (pH>8.2) with high clay content and high residual alkalinity in irrigation water (RSC>2.5meL^{-1}) are the characteristic features of the region. During the heavy downpour, water-logging is a common feature in the area and thus increases cropping system's vulnerability to a great extent.

About 96% of the crop waterdemand is fulfilled byunderground water resources. In addition, the underground water is of poor quality with high residual alkalinity. Continuous irrigation with sodic water results in a rise in soil alkalinity/sodicity, thus, adversely affecting the soil physical properties (low permeability and poor infiltration rate) adversely affecting crop yields to a greater extent.Furthermore, in spite of significant technological breakthroughs to productively utilize salt-affected soil and water resources, farmers in the area still show poor adaptive capacity due to several socio-economic, ecological and technological factors which limit the scope for sustainable adaptations against multiple stressors.

Technological Gaps, Research Problems Identification and Prioritization

Focused group discussion and transcend walk were held with the famers to diagnose their socio-economic and agro-ecological stressors vis-a-vis general, agriculture and livestock related problems (Table 1). Majority of the farmers have farm holding less than <2 ha, growing two crops in a year under irrigated conditions. Most of the soils are medium to heavy textured sandy loam (normal to sodic soils).

Table 1. Gist of module-wise problem identified in adopted villages

	Category	Problem
i)	General	− Water drainage: Chocking of drains with dung. − General cleanliness/sanitation/waterlogging in common areas. − Requirement of RO system for drinking purpose.
ii)	Agriculture	− Poor quality water (RSC) − 40-50% area is sodic soil − Awareness regarding soil and water testing, balanced fertilization, IPM, Govt. policies − Reproductive sterility (*Ukasa*) in rice cultivated in highly sodic soils − Herbicide resistance particularly *Phalaris minor* in wheat − Non-availability of good quality seed − Spurios pesticides − Labour scarcity during crucial time − Provision of compensation for climatic hazards
iii)	Livestock	− Prolaps, Mastitis, Repetitive breeding, Fever, Cold, Haemorrhagic Septicaemia, Foot & Mouth Disease

The agriculture and livestock based technological modules were finalized and the location specific technological interventions were prioritized to experiment upon in the marginal salt affected environments. The conceptual framework depicting interrelationship of stressors and technological interventions was prepared for enhancing their farm productivity, profitability and livelihood security.

Technology Assemblage, Application and Feedback

1. Delineation and assessment of salt affected soils and irrigation water quality

Grid based (0.5 x 0.5 km) soil sampling along with GPS location was done collecting 354 samples from 0-15 cm depth and 283 water samples in the adopted villages. The spatial variability was estimated using geo-statistics tool in ArcGIS 9.2 for windows. Spatial variability in terms of soil sodicity, water quality and soil fertility status were mapped (1:50,000 scale) by ordinary Kriging interpolation method based on spherical model.

1.1. Extent and distribution of salt affected soils: About 40.1% of area is affected with sodicity having soil pH_s>8.2. Out of total area, village-wise sodicity was observed to be in the order of Sampli Kheri>Kathwar> Bhaini Majra> Geong> Mundri. Soil salinity is not a major problem in the area though initiated due to indiscriminate use of irrigation water. Only 2.5% of the total area is affected by salinity (EC>4 dS/m); encountered in 3.4% area of Mundri and 4.1% area of Kathwar village.

1.2. Water quality status: Residual alkalinity in irrigation water dominated by bicarbonates of sodium results in buildup of soil sodicity to levels limiting land and crop productivity.Only 5.7% of the total area is having RSC<2.5 meq/l, threshold value defining the critical limit for safe use of underground water for irrigating purpose. Majority (43.6%) of the area is having underground water having RSC values ranging between 4.5-5.5 meq/l, being maximum in Bhaini Majra (84%) followed by Geong (65.5%) and Kathwar (44.5%).

Out of total 3247 ha area, only 10.1% area was found where good quality underground water is available for irrigation purpose while 90% area was confirmed with residual alkalinity of variable nature.Poor quality irrigation waters is a major problem in all the adopted villages affecting crop and land productivity to a greater extent and was found in the order of Geong> Kathwar> Bhaini Majra> Sampli Kheri> Mundri. Maximum (30.1%) good quality water was found in Mundri village. In Geong, 59.5% area is affected with alkali waters while 40.5% area is dominated by highly alkali waters. Majority of the area in Kathwar (91%) and BhainiMajra (84.1%) is confined to alkali waters.

2. Mapping and characterization of soil fertility status using GIS technique

Out of total 3247 ha area, nitrogen was deficient (< 250 kg N/ha) in whole of arable area while 27.1% area belongs to deficient organic carbon (<0.4%) status. There was no deficiency of phosphorus (<10 kg P/ha) in the study area; 24.9% area belonging to medium (10-20 kg P/ha) and 75% to high (>20 kg P/ha) category. Similarly, 100% soil was found high in available K status (>110 kg K/ha).

Zinc deficiency was identified as one of the major problem; 38.2% area belonging to low (<0.6 ppm Zn) category, 50.8% medium (0.6-1.2 ppm Zn) and 10.9% area sufficient (1.2-2.4 ppm Zn) in range. About 87.2% area was high in available iron (>18 ppm Fe) while rest being under sufficiency range (9-10 ppm Fe). Half of the samples were deficient in available zinc (<0.6 ppm). B deficiency (<0.5 ppm) was prevalent in about 87% of the tested soil samples. Manganese (≥3.5 ppm Mn) and copper (≥0.4 ppm Cu) was found in sufficient to high range in tested soil samples though the ratio was 25:75 and 40:60 respectively. B was found to be deficient (<0.5 ppm B) in 90% of the area.

3. Managing localized water stagnation and improving ground water quality by harvesting excess rain water into aquifer through drainage-cum-recharge structure

The average ground water level in Kaithal block during the last 10 years (2005-2015) has gone down by more than twice (-1.33 m/year) in last 10 years compared to 40 years average data (-0.61 m/year); owing to excessive pumping for water requirements of predominant rice-wheat cropping system. A total of six recharge strictures, 2 with radial type filtration and 4 with integrate filtration unit have been installed in adopted villages for augmenting ground water, improving its quality (reduction in salinity, alkalinity) through recharge of excess water and enhancing farmers income by saving submerged rice during the period of intense rains.

Point observations through periodic monitoring (case study for Kathwar-1) indicated rise in ground water table (upto 1 m) during monsoon (July-September 2017) beneath the recharge structure and improvement in ground water quality with concomitant reduction in residual alkalinity in irrigation water (RSC: 1.5-2.5 meq/l).

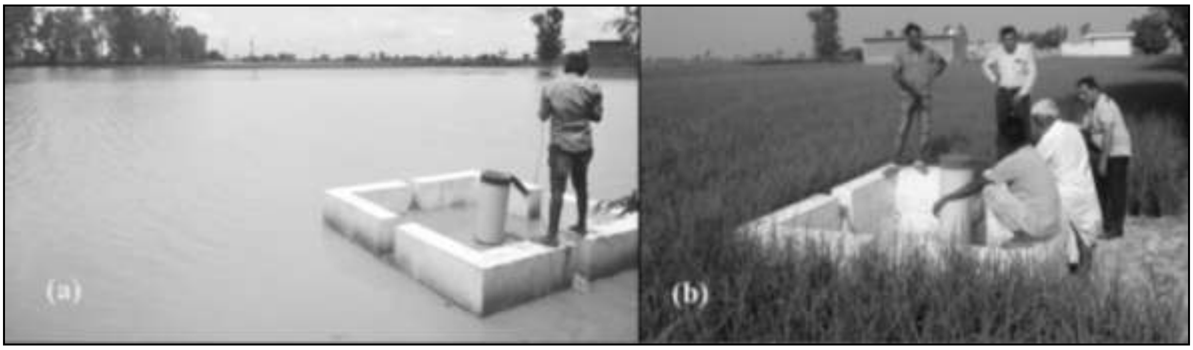

Fig. 1 (a). Flood condition due to heavy downpour on 29 June 2017
(b). Crop condition on 27 August 2017 after receding of flood water by drainage-cum-recharge.

Heavy downpour during the last week of June 2017 (150 mm on a single day) during the last week of June 2017 immediately after rice transplantation resulted in complete crop submergence (Fig. 1a). The installed structure reduced flood volumes through drainage-cum-recharge structure and saved transplanted rice crop (Fig. 1b) in lowest 5 ha area, though low to modest impact was also clearly visible in the surrounding areas.

4. Crop/Varietal diversification for sustainable yield under sodic environments

Rice-wheat cropping monoculture is most dominant one in the study domain of District Kaithal. Heavy textured sodic soils (pH>8.2) with high RSC irrigation water (RSC>2.5meq/l) are the characteristic features of the region. Through focused group discussion and transcend walk with the famers it was diagnosed that non-availability of good quality seed of improved varieties and lack of knowledge about the salt tolerant varieties is one of the major concerns limiting crop production in this region. Central Soil Salinity Research Institute, Karnal has developed salt tolerant cereal varieties (Wheat: KRL 210 and Rice: Basmati CSR 30) which can provide a viable option for sustaining crop yields in salt affected environments (sodic soils with poor quality irrigation water). A total of 309 varietal intervention was demonstrated among small and marginal farmers in adopted villages having sodic soils (pH>8.2) and high residual alkalinity in irrigation water (RSC>2.5meq/l).

4.1 Adaptation of wheat variety KRL 210 vs HD 2967 in Salt Affected agro ecosystem

Wheat variety HD 2967 is highly adapted cultivar in the region. To showcase the adaptation of salt tolerant wheat variety KRL 210 under salt affected agro-ecosystems, a total of 126 demonstrations were conducted under technology-generation trials, keeping the plot size of 4000 m^2 i.e. large plot trials (LPT).Varietal demonstrations of wheat variety KRL 210 conducted in farmers' participatory mode revealed an overall yield advantage of 4.4% with KRL 210 compared to HD 2967 (most cultivated variety) in the area.

Under normal conditions (pH_2< 8.0), HD 2967 attaining 5.4 t/ha grain yield significantly out yielded KRL 210 with yield difference of 0.11 t/ha. There was non-significant differences in wheat yield for both the varieties at sodicity stresses ranging between pH_2~8.0 to 8.5. With further increase in sodicity stress beyond soil pH_2>8.5, yield superiority of KRL 210 was observed compared to HD 2967. Interesting trends was observed at higher sodicity gradients at which KRL 210 outclassed HD 2967. Significant yield difference of 0.33 t/ha being the highest for KRL 210 at sodicity stress ranging between pH_2~9.0 to 9.25.

Test of significane for grouped technology adoption trials conducted with poor quality water (RSC water) indicated non-significant differences in grain yield for the demonstared (KRL 210) and traditional (HD 2967) variety for crop irrgated with RSC waters having residual alkalinity upto 4 meq/l though HD 2967 found numerically supeior. As the irrigation water quality deteriorating (increasing gradient of RSC) superiority of KRL 210 can be seen in comparison to farmer practices.With the increase in residual alkalinity in irrigation water (RSC>4 meq/l), KRL 210 significanlty outyielded HD 2967 attaining pooled genetic gain of 0.13 t/ha at RSC ranging between 4-5 meq/l to 0.34 t/ha at RSC >7 meq/l.

Confidence of interval of regression coefficient for sodicity indicated lesser yield reduction with KRL 210 for each unit increase in soil pH and RSC in comparison to HD 2967.

4.2 Adaptation of rice variety CSR 30 Basmati vs Pusa 1121 in Salt Affected agroecosystem

ICAR-Central Soil Salinity Research Institute, Karnal, developed the first ever salt tolerant rice variety basmati CSR 30 in 2001. Because of its high profitability, excellent aroma and cooking quality it is adored by the farmers, traders and consumers alike. Farmers prefer to grow basmati CSR 30 in areas dominated by soil sodicity and where irrigation water is of poor quality (high RSC waters). Indian Agricultural Research Institute developed extra-long slender fine grain basmati rice named Pusa Basmati 1121 in the year 2003. The farmers pointed out that there happens to be a sharp decline in grain yield of Pusa 1121 with increased levels of soil sodicity and deteriorating water quality. No doubt, it has higher yield potential in comparison to basmati CSR 30 but the salt tolerance limit of Pusa 1121 is not well defined.

Technological demonstrations on varietal component carried out on 183 small and marginal farmers' fields (Fig. 3) indicated that Pusa 1121 gave significantly higher mean grain yield in comparison to CSR 30 upto moderate sodicity (pH_2<9.25). It is interesting to note that inter-varietal differences between Pusa 1121 and basmati CSR 30 narrowed down for mean grain yield at higher gradients of sodicity.Both the cultivated varieties were found at par with each other at soil pH_2~9.25-9.50. With further increase in soil sodicity (pH_2>9.5), basmati CSR 30 gave numerically higher yield in comparison to Pusa 1121 though the difference in yield was found to be non-significant.

Varietal adaptation trials in relation to poor quality RSC waters indicated that the superiority of Pusa 1121 over the Basmati CSR 30 kept on decreasing with the increase in residual alkalinity. It is pertinent to note that basmati CSR 30 numarically edged over Pusa 1121 with a genetic gain of 0.11 t/ha when irrigated with RSC water of >7.0, indicating the relatively better response of basmati CSR 30 ubder stress environments.Stress conditions in terms of residual alkalinity in irrigation water (RSC) has lesser impact on yield reduction in rice compared to its impact soil sodicity (pH).

5. Herbicide based weed management in wheat

Phalaris minor in wheat is a noxious weed difficult to control. It has developed high degree of herbicide resistance owing to faulty management practices. Farmers' survey indicated that majority (68%) of the farmers are using more than the recommended dose (X) of herbicides for the control of grassy weed particularly *Phalaris minor* in wheat. Half of the farmers are applying double than recommended dose (2X) while 4% are even using three times (3X) of the recommended dose. Only 5% of the respondents are applying the recommended rate of water (300 litres/ha) while 1.5% are using the spray nozzles recommended for herbicide application in achieving better herbicide efficacy.

Majority (92%) of the farmers are using clodinafop followed by pinoxadem (8%) for controlling grassy weeds. About 84% farmers are applying metsulfuron for controlling broadleaf weeds (BLWs) while 16% are of the opinion that broadleaf infestation is not a serious problem to control with herbicides. One-fifth of the farmers are using sulfosulfuron for controlling mixed weed flora (grassy and BLWs) in their fields. Almost all the farmers criticized the spurious quality of pesticides influencing the desired herbicide efficiency. One-third of the farmers are mixing different group herbicides without giving due consideration to herbicide compatibility.

Field demonstration conducted over 30 locations in farmers' participatory mode revealed that improved technological intervention including pre-emergence application of pendimethalin @ 2 lt/acre followed by post-emergence application of recommended herbicide (clodinafop/pinoxaden) resulted in better weed control efficiency at 30-35 DAS and 115-120 DAS and 4132 kg/ha mean wheat yield as against the 3888 kg/ha under farmer's practice (2-3 times higher dose of recommended herbicides) excelling by 6.24 per cent in mean wheat yield over the later.

6. Management strategies for reclamation of sodic soils and neutralization of residual alkalinity in irrigation waters

Continuous use of poor quality (sodic) ground water results in buildup of higher proportion of exchangeable sodium ions in the root zone causing soil sodicity to levels limiting land and crop productivity. The sodicity hazards can be mitigated by neutralization of the RSC in irrigation water with chemical/organic materials (gypsum, pressmud) while aiming at preventing build-up of salt load in soil-water system as well as minimizing their adverse effects on crop growth. Complementary effects of applying reclamative/neutralization ameliorants (gypsum or pressmud) either individually or in combination proven their effectiveness in sustainable use of poor quality waters for rice cultivated on sodic soils. Integrated use of gypsum (soil pH based) and pressmud (5 t/ha) resulted in 15.4% yield advantage while presssmud alone @ 10 t/ha gave 14.9% yield superiority over the control (unamended). Yield advantage was relatively more at soil pH_2>8.5 in comparison to what was obtained under lower pH soils.

7. Diversifying rice-wheat system through vegetables for sustainable yield under sodic environments

Continuous rice-wheat monoculture has led to decline in water table, deteriorating water quality, soil health and environmental issues vis-à-vis related problems of soil sodicity limiting crop and land productivity. Exploring bio-economic feasibility through vegetable/horticultural crops will help in increasing the farm profitability and diversify the prevalent exhaustive system.

Diversifying rice-wheat cropping system by including short duration pea (KashiAgeti) and okra (KashiKranti) in place of wheat resulted in 24.4 t/ha of wheat equivalent yield (WEY) with production efficiency (PE) of 81.7 kg/ha/day and net returns (NR) of 3.0 lac/ha in comparison to 15.3 t/ha WEY, 57.5 kg/ha/day PE and 1.97 lac/ha NR obtained under traditional rice-wheat cropping system.

8. SALINITY EXPERT: Mobile enabled Decision Support System for Sodic Agro-ecosystems

Mobile apps offer an efficient means of resource sharing among the farmers while disseminating technologies to the target farmer clientele quickly and efficiently. This will definitely help bridge the knowledge divide between the researchers and the farmers to enable the latter to ensure sustainable crop production using latest technologies.

'Salinity Expert' is an ICT-based initiative towards 'Digital India' with aim to fast track the dissemination of doable salinity management technologies to the farmers. It seeks to provide the farmers and other stakeholders pertinent .information supplemented with pictorial illustrations for reviving the productivity of salt-affected lands. This is a user friendly innovative digital tool compatible with android mobileoperating systems. The App can be freely downloaded from the Google Play Store.The entire information in the 'Salinity Expert' app is available in Hindi language with focused approach targeting salinity management and related practices. The App has been designed in such a manner that only one-time internet connection is required to download it. However, query handler requires internet connectivity to be functional on real time basis.

The main features of the App include static as well as dynamic platforms including:

- Login ID (Aadhar/Mobile) enabled GPS-based digitization of Soil Health Cards (SHCs) including farmers' basic information, soil fertility and water quality status and analysis.
- Methodology to be adopted while taking soil and irrigation water samples for laboratory analysis.
- Package of practices for rice, wheat and mustard crops grown under salty environments right from sowing to harvesting.
- Estimated gypsum requirement considering inherent soil sodicity (pH) and residual alkalinity in irrigation water (RSC) and their concomitant effects on crop yields (yield predictions).
- User friendly query handler to raise queries either as text messages or in graphic/recorded form. The queries then will be attended by the administrator via message sorting, short message service, email etc.
- Updated agro-advisories and information pertaining to training programmes and other important events.
- Digitization of soil fertility status and water quality maps of study domain under 'Farmer FIRST' project.

Conclusions

External farming technologies offered to small and marginal farmers living in complex and fragile agroecosystems are based on general recommendations. Farmer FIRST provides us holistic opportunity tointegrate formal and informal knowledge networks where technologies developed by scientific institutions are taken up in farmers' participatory mode to scale-up (bottom-up approach), compliment need based refinement and validate to enhance farmers' adaptations against various agro-ecological stressors. Adaptive knowledge co-produced, refined and scaled-up may provide insights and technological solutions for multiple outcomes, including adaptation and sustainability. We need to understand in what ways agricultural knowledge can be combined, integrated, refined and incorporated with formal science and policy to make it even more effective and viable for location specific adaptation.

Pressurised Irrigation to Improve Crop Productivity with Poor Quality Water

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Introduction

Agriculture sector is a major consumer of available fresh water resource and will remain. But, water demand of other sectors i.e. domestic, industrial, recreation, power generation etc. is also increasing day by day. Therefore, it is being realized that marginal quality water may be used to overcome the anticipated fresh water scarcity problem in agriculture. But, poor quality water utilization requires sound knowledge and understanding to avoid further problems in agricultural field. The poor quality water irrigation is associated with accumulation of salt in the soil, which might be harmful to plants, and diminishing yields. However, non-toxic saline water has an agricultural potential, if irrigation can be managed in such a way that provides high soil moisture content and, consequently, high soil water potential within the whole root zone (Michelakis *et al.,* 1993). Moreover, when saline water is skillfully used, it can be beneficial for agricultural production, particularly in orchards (Hoffman *et al.,* 1986). Saline water utilization in agricultural offers several additional benefits: i) re-use (instead of disposal) during the entire year, with minimal environmental risk (Oron, 1993); and ii) high total soluble solids and an extended shelf life of fruits and vegetable products because of adaptation of the plant to the stressful growing conditions, fetch premium market price (Mizrahi & Pasternak, 1985). The sustainability of a viable, irrigated agriculture with poor quality water requires constant monitoring to ensure salts stay within the acceptable range, and farmers need to be prepared to accept lower-than-average yields. To address these issues, suitable management practices including effective management of irrigation needs to be adopted. Application of poor quality water through pressurized irrigation systems can help in reducing salt build in the root zone by applying in small quantity in comparison of traditional methods. High irrigation frequency in pressurized irrigation results in adequate moisture availability throughout the crop growing season and offset osmotic effects.

Pressurized Irrigation

Pressurized irrigation system is designed and installed to supply water under pressure through pipe network, fitting, control valves, emitting devices from water source to cropped area. In this method of irrigation, conveyance and distribution losses are minimum or negligible. The system provides opportunity for controlled water application, results in saving of not only water but energy used to pump the irrigation water. A well-designed pressurized irrigation system also minimizes the possibility of deep percolation and surface runoff. The pressurized irrigation system can achieve irrigation efficiency up to 80 to 90 percent or even more depending upon its type. Sprinkler and drip irrigation methods are the most common pressurized irrigation system and have proven to be an efficient technique of water saving and improving water use efficiency. They have proven their superiority over traditional methods for crop production with poor quality water also.

Sprinkler Irrigation

Sprinkler method of irrigation applies water above or below the crop canopy in the form of a spray resembling rainfall. Water is distributed in field using pipe network and the spray is obtained by applying water under pressure through small orifice nozzles referred to as sprinklers. The irrigation water can be applied more uniformly than surface irrigation methods and at a rate to suit the infiltration rate of the soil. This method is adaptable to most soils and topographical conditions. However, it is usually not suitable for the soil having infiltration rate less than 4 mm per hour. This method is especially suitable for sandy soils and steep slopes or irregular topography without intensive land preparation where other methods of irrigations may not be equally efficient. Almost all field crops like wheat, gram, pulses, fodder, tea, coffee, cotton, vegetables etc can be successfully grow with sprinkler irrigation. But, the large water droplets discharged from larger sprinklers' nozzles may damage delicate crops like lettuce.

In comparison of conventional methods, more area can be brought under irrigation with the same amount of water by adopting sprinkler-irrigation and suitable cropping pattern in the water-scarcity regions. This system provides more land for cropping as no field channels or bund is required, which also helps in reducing interference with the movement of farm machinery. Fertigation is also possible using this system and water-soluble fertilizers, herbicides and fungicides can be applied along with irrigation water at controlled rate and desired time. Sprinkler irrigation can also be used for soil and crop cooling, frost protection, delaying fruit and bud development, controlling wind erosion and for germination of seeds, seedlings and young plants. The major limitation of this system is its initial investment cost. Sprinkler system also requires high power requirements, clean water, ensured power and water supply, distortion of sprinkler water-application pattern due to high winds.

Water and Salt Distribution under Sprinkler Irrigation

The depth of water applied beneath a sprinkler is not uniform over the entire area. The water depth varies with the distance from the sprinkler nozzle. The area near the sprinkler receives higher depth of water while area falling towards periphery receives fewer amounts. This variation is known as water distribution pattern. The water distribution pattern is affected with pressure at the nozzle, size of the nozzle, speed and uniformity of rotation, the characteristics of the driving mechanism, height and angle of risers, wind direction and velocity, angle of the stream trajectories and turbulence in the stream of water entering and leaving the nozzle. It is suggested that to place sprinklers in such way that they overlap each other from both directions and ensure a uniform spraying over the entire area. Sprinklers can be placed in square, rectangular or in triangular pattern. The spacing between sprinklers should not exceed 65 percent of the wetted diameter in the square and rectangular patterns under light to moderate wind conditions. The coverage area of two sprinklers should be 50 percent overlapped in strong wind conditions for higher distribution uniformity. In high wind condition, wind speed > 3.5 m/s, sprinkler is not suggested.

Sprinkler irrigation ensures distribution of water uniformly results in better leaching of the salts. It facilitates salt leaching better in sandy soil and undulating terrains also than traditional irrigation methods due to ability of applying irrigation more uniformly without any land modification. Sprinkler irrigation system improves salt leaching efficiency with minimum amount of water by sprinkling water at lower rate than infiltration rate of soil to favour unsaturated flow (Hamdy, 1996). The lower water content and lower pore-water velocity at which water moves in soil under the sprinkler method reduce the preferential flow and increase the efficiency of salt leaching. Salt load under sprinkler is least in upper soil layer and increases with soil depth (Fig 1.). Agarwal and Khanna 1983, found lower salt build up in 0-120 cm soil layer in sprinkler irrigated *kharif* and *rabi* crops as compared to surface irrigated fields and the difference increased with the increase in the salinity of irrigation water. However, Robinson *et al.* (1986) observed reduction in salinity in upper soil layer (60 cm) under sprinkler irrigation as compared to surface irrigation method with high saline water (12 meq l^{-1}) application in wheat, barley, safflower and flax grown on moderate soil (EC_e 3.5 dS m^{-1}).

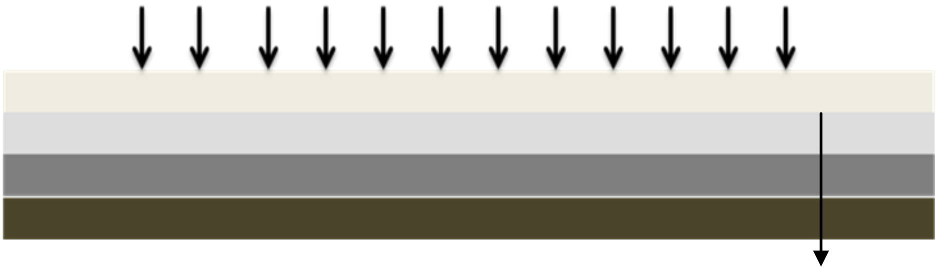

Fig. 1. Salt accumulation pattern in surface soils under sprinkler irrigation

Crop Response to Use of Poor Quality Water

The threshold value of saline sprinkler irrigation varies with depth of water applied, frequency of irrigation and soil types and climatic conditions. In a field experiment, salinity threshold value of 5.11 dS/m was recorded for winter wheat grown under rain shelter with sea water on clay-loam textured soils under saline sprinkler irrigation, that was lower by 12-15 percent (Tekin, 2014) than the reported threshold limit of 5.8-6.0 dS/m for wheat grown in medium textured soils with surface irrigation method (Maas and Grieve, 1990). In a well-drained light textured sandy loam soil (ECe, of 2.7 dS m^{-1} , pH 7.8, exchangeable sodium percentage, ESP, of 8.3 and organic matter content of 2.9 g kg^{-1} , the rate of decline of wheat yield was found to be 2.7 percent per unit increase in water salinity with sprinkler irrigation (Singh *et al.*, 2009). A number of long-term experiments conducted at the same site reported 3.9 percent reduction in wheat yield with per unit increase in water salinity for conventional flood method (Minhas and Gupta, 1992). This indicates that wheat productivity can enhance using sprinkler system for saline water (EC < 10 dS/m) irrigation.

The findings of various field experiments conducted under the umbrella of AICRP on management of salt affected soils and use of poor quality water in agriculture confirmed that yield reduction is associated with water salinity and moisture gradient under sprinkler irrigation (Anonymous 2004-2016). Sprinkler irrigation at well-drained sandy loam soil recorded wheat yield of 4.27 t/ha with 2.70 cm depth of irrigation, which reduced to 2.96 t/ha when water depth reduced to 0.75 cm in each irrigation for the same water salinity of 3.6 ds/m (Anonymus, 2007). However, applications of high saline water (9.5 dS/m) through sprinkler, reduced wheat yield by 16 percent as compared to sprinkling water salinity of 3.6 dS/m. The relationship developed at sandy soil revealed that groundnut yield increases up to the depth of 50 cm, further increase in depth of saline irrigation has adverse effect on crop performance (Anonymous, 2007). Saline sprinkler irrigation should be avoided for grapes, citrus and most vegetable and trees, which are sensitive to relatively low concentration of sodium and chloride and may absorb toxic amount of these from water falling on the plant leaves under low humidity conditions. Water containing 750 ppm salts used with relative humidity lower than 20 per cent is very harmful to citrus and lettuce. However, with relative humidity higher than 20 per cent salt water containing 1,600 to 1,800 ppm salts has been used successfully (Singh, 1998). Saline water up to ECw 9.6 dS/m with sprinkler irrigation has no injurious effect on forage and vegetable crops. However, some damage has been reported under the conditions of extremely high temperature. The guidelines for determining allowable soil salinity and water quality levels in sprinkler irrigation are the same as for surface irrigation. For alkali water use through sprinkler, amount of water applied in each irrigation, has significant effect on crop yield. The wheat grain yield declined by 35 to 37 percent with the reduction in depth of sprinkler irrigation from 2.65 cm to 0.74 cm with RSC water at sandy loam soil (Anonymous, 2011). Experiments conducted at loamy sand soil showed higher grain yield in 6 cm depth of sprinkler irrigation with alkali water than 4 and 5 cm water depth. The grain yield of pearl millet increased 13.1 and 18.5 percent in 5 and 6 cm irrigation depth for 12 meq/l RSC water as compared to 4 cm depth under sprinkler irrigation regimes in sandy loam soil (Biennial report, 2014-16). In sprinkler irrigation, optimum water depth in each irrigation was found to be 3 cm for wheat in sodic vertisole soil having ESP 35-40.

Drip Irrigation

Drip system is an advance method of irrigation, based on the fundamental concept of irrigating root zone only rather than the entire land surface, which resulted in higher water use efficiency and enhanced crop yield. The drip irrigation is in fact a technology to grow crops under controlled conditions of soil moisture, fertilizer, salinity and pest control. In drip irrigation, water is applied precisely but slowly in the form of discrete drops, continuous drops, tiny streams or miniature sprays. In this method, water flows through valves, filters and pipe network consisting main, submain, laterals and is then discharged almost at atmospheric pressure near the plants through point source (dripper, bubblers, microtubes and micro-sprinklers) or line source such as porous tube or perforated pipes. The water moves vertically as well as horizontally inside the soil to a limited extent and generally 10 to 50 per cent soil surface is wetted depending on the stage of the crop. The flow regime is two or three dimensional and the water-holding capacity of the soils is of less importance due to frequent irrigation. Drip irrigation can be categorized as either line source or point source based on wetting front.

The drip irrigation has some proven advantages over other irrigation methods like i) makes possible to grow crop in all types of soils ii) achieves higher water use efficiency iii) saves water and fertilizer and improves fertilizer use efficiency through fertigation (Singh *et al.*, 2002 , Kumar *et al.* 2009.), iv) reduces labour and energy requirement iv) reduces incidence of pests and diseases v) achieves uniform plant growth and higher yield vi) early and uniform maturity of the crop and improved produce quality. Drip irrigation saved 32% water, reduced fruit cracking by 10.9% which fetched higher marketable yield and water productivity of pomegranate in dry eco-region compared to surface irrigation (Kumar *et al.*, 2013). The additional advantage of this method is that system performs well with minimum adverse impact on crop production when either land or water or both resources are of poor quality (Pandey *et al.*, 2008). This system can also be used efficiently for vegetable production in canal command with the provision of auxiliary reservoir that provides regular water supply to the crop (Kumar *et al.*, 2009). The initial cost of the drip irrigation equipment is considered to be its main limitation for large-scale adoption.

Water and Salt Distribution under Drip Irrigation

In drip irrigation, distribution of dissolved salts follows the pattern of the water flux in the soil profile with the tendency of accumulation at the periphery of the wetted soil mass (Fig. 2). In the wetted zone below the emitter, most of the roots concentrate and function remains free from salts during the irrigation season with low to medium salinity values. Near the surface, due to evaporation, the salt accumulation is five times greater than in the deeper layers and increases with distance from the emitters. This, in combination with the use of poor quality irrigation water and the application of fertilizers through the system, will cause a salinity build-up, which might become a problem in areas where the annual rainfall does not exceed 250 mm (Phocaides, A. 2007). In these cases, it is essential to flood the total area once a year, at the end of the season, with adequate amounts of water in order to leach the salts beyond the rooting depth.

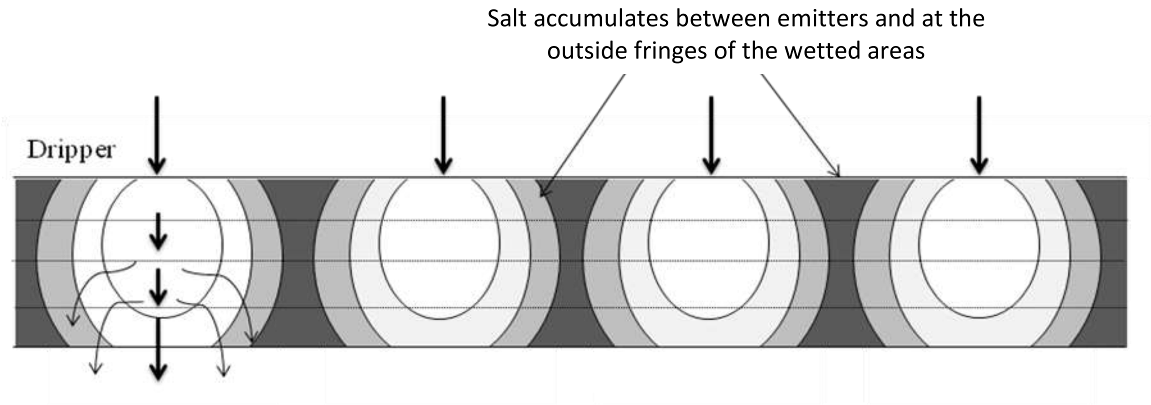

Fig. 2. Salt accumulation pattern in surface soils for drip method of water application
Salinity ranges from low (unshaded) to high (darkened). (Source: RS Ayers and DW Westcot, 1985).

The irrigation water quality and quantity and amount of fertilizers added decide salinity level in the root zone. The accumulation of salt in the vicinity of the drippers is less than half that between the dripper lines. The EC value of the saturation extract beyond the driper is 2-3 times the ECiw, and six to ten times higher between the lines. This high salt content can be controlled only by leaching or by reducing the fertilizer dose during the growing season. In no case should the fertilizer concentration in the irrigation water exceed EC 0.5 dS/m, that is added to the total salinity of the irrigation water. In drip irrigation, extra leaching with increased quantities of water every application during the irrigation season is not recommended unless salt accumulation reaches hazardous levels (Phocaides, A.2007). Leaching should take place after the crop harvest, between irrigation seasons, where the salt content is excessive and the rainfall is not sufficient.

Crop Response to Use of Poor Quality Water

Drip irrigation has distinct advantage over other methods for poor quality water use such as root zone salinity is similar to the original irrigation water salinity (Mantell *et al.*, 1985), prevents any chance of leaf burning as water applies directly into soil near to plant root zone (Yaron *et al.*, 1973), flexibility of frequent water application also minimizes the adverse effect of osmotic stress due to minimal matric stress period and results in high production and productivity in most crops. Field studies conducted on use of poor quality water through drip system have also been reported that crops can tolerate saline environment better under drip than surface irrigation method because of low matric stress that is a characteristic of the drip irrigation (Table 1). Experimental result on relative performance of surface irrigation method, surface drip and subsurface drip reveals significant differences in radish yield and water use efficiency of saline (ECiw 6.5 dS/m) and fresh water (Eciw 0.25 dS/m) irrigation (Table 2). The yield reduction with saline water as compared to fresh water was found to be 12, 10 and 40 percent in case of sub surface drip, surface drip and surface method that clearly indicates higher crop tolerance limit under frequent drip irrigation (Agrawal and Khanna, 1983). However, radish yield was highest in subsurface drip, but it may be mentioned that benefits of subsurface drip are not always forthcoming and the usefulness of sub surface drip has to be investigated considering the soil, crop, salinity of the soil and water etc.

Drip irrigation of tomato and brinjal crops using saline water (4 and 8 dS m^{-1}) and canal water at three IW/CPE levels (0.75, 1.00 and 1.25) at 2, 3 and 4 days irrigation interval gave better yield at higher IW/CPE ratios (CSSRI, 2000). A yield increase of 13 and 33 per cent was observed in irrigation intervals of 3 and 4 days in comparison to the 2 days interval with similar amount of water applied. In another study, yield decreased in saline drip irrigation was found as 24 per cent with water of salinity of 5 dS m^{-1} in comparison to 0.21 dSm^{-1} (Kadam and Patel, 2001). Singh *et al.* (2000) compared drip and basin methods with 0.4, 4.0, 8.0, and 12.0 dSm^{-1} irrigation water in terms of plant performance and soil salinity buildup. Plant performance was better and salinity build-up after three years was less in case of drip irrigation as compared to the basin method. The effect of dripper discharge rate (1.2, 2.4 and 4.2lph) and irrigation levels of 0.6, 0.8 and 1.0 IW/CPE was studied for saline drip irrigation of tomato crop. The result promotes to use low discharging dripper when using saline water as average tomato yield decreased significantly with the increase of discharge rate of emitters from 1.2 to 2.4 lph. As compared to 100 percent fresh water (EC of 0.38 dS/m) application, mixed water (75percent fresh and 25 percent saline water) recorded tomato yield reduction of only 11%, but tomato fruits quality was better. The EC of saline water used was EC 19.5 dS/m (Nangare *et al.,* 2013). They recommended that saline water can be used through drip system for quality tomato production in water limiting areas having poor groundwater quality. Saxena *et al.* (2013) reported that even at 8 dSm^{-1} irrigation water salinity, 77% of Okra yield to the check could be obtained with drip system.

Table 1. Improving cauliflower productivity by using saline water through drip irrigation system

Treatments	Crop yield (q/ha)			Water use efficiency (q/ha-cm)	
	DI	SI	Mean	DI	SI
Canal water (0.4 dS/m)	435.7	383.4	409.6	17.8	12.2
Saline water (2.5 dS/m)	432.5	367.2	399.9	17.7	11.7
Saline water (5.0 dS/m)	413.9	326.3	370.1	16.9	10.4
Saline water (7.5 dS/m)	366.0	256.2	311.1	14.3	7.7
Mean	412.0	333.3			
CD (5%)	Irrigation method (I) : 13.1, Salinity (S) : 18.6, I x S : 23.4				
SI- Surface irrigation, DI- Drip irrigation					

Source: AICRP Annual report (2016-17).

Table 2. Water use efficiency under different methods of irrigation with saline and good quality water

Methods of Irrigation	Good water (EC 0.25 dS/m)		Saline water (EC 6.5 dS/m)	
	Yield (t/ha)	WUE (kg/ha/cm)	Yield (t/ha)	WUE (kg/ha/cm)
Sub-surface drip	2.68	3000	2.36	2600
Surface drip	1.75	1900	2.36	1800
Surface irrigation at 35 mm CPE	1.64	1400	0.99	900
Surface irrigation at 60 mm CPE	1.39	1200	0.67	600

The suitability of pressurized irrigation methods (drip and sprinkler) was studied for vegetable production on sodic soil with alkali water at Trichy. Results were compared with farmer's practice i.e. furrow irrigation (AICRP Annual report, 2016-17). It was found that drip and sprinkler irrigation produce more yield than furrow irrigation for selected vegetables crops under sodic environment (Table 3). Sprinkler and drip irrigation methods were found more suitable than furrow irrigation method. Study suggests that drip irrigation is the most suitable water application method for sustainable use of limited surface and ground water resources with improved efficiency and productivity in sodic soil environment.

Table 3. Effect of Irrigation Methods on Yield of Vegetables (kg ha^{-1}) in Sodic Environment

Treatments	Crop			
	Cluster bean	Bhendi	Vegetable cowpea	Onion
Drip irrigation	41.20	51.60	92.64	40.19
Sprinkler irrigation	37.15	45.82	79.10	34.90
Flood irrigation	28.80	38.56	54.26	26.92
Mean	35.72	45.33	75.33	34.00
CD(5%)	*1.20*	*3.33*	*5.11*	*5.80*

Source: AICRP Annual report (2016-17).

Limitations of Pressurized Irrigation Systems

Economic consideration usually limits the use of pressurized irrigation system despite of several advantages in water management. In addition to that, clogging of emitting devices is considered to be the main constraint especially using saline water or in salt affected soils. Precipitation of salts may occur on the outlet of emitters especially on drying of waters containing higher soluble salts. The main causes of clogging of emitters are suspended matter, chemical precipitation and bacterial growth (Adin and Sacks, 1991). The solution of clogging problems is to prevent entering of foreign material in to the system and by chemical treatment. Some methods that can be adopted for proper functioning of pressurized irrigation systems are:

Flushing: The fine sand, silt and other suspended solids present in water may clog dripper's opening. A provision of efficient filtration unit can reduce chances of emitters clogging. Apart from filtration unit, main, submain and lateral pipelines should be flushed regularly to prevent emitter clogging from the gradual deposition of particles, which are too small to be filtered, but settle out or flocculate at the distal ends of pipelines. Flushing velocities must be high enough (at least 0.6 m/sec) to transport and flushed heavy particulate matter from the pipelines.

Chlorination: Bacterial slime either can be a direct cause for clogging of drippers, or some time, it can induce minerals to stick together and form large aggregates to clog the opening of dripper. The chance of dripper's clogging is more when iron, manganese, and sulfide are available in irrigation water. Chlorine injection is the most common and least expensive method to control biological causes responsible for clogging of drip irrigation systems. Iron and manganese precipitating bacteria can be controlled by chlorine treatments, aeration or polyphosphates. Chlorine injection will cause oxidation and precipitation of iron and manganese and kill any iron and sulfur precipitating bacteria.

Acid Treatment: Saline water has high levels of salt and there are chances of recombination during transport and precipitation and clogging of dripper opening. In drip irrigation system, emitter clogging with saline water use is closely related to the formation and aggregation of chemical precipitation (Hills *et al.*, 1989; Aali *et al.*, 2009; Sahin *et al.*, 2012). The dripper's clogging in saline drip irrigation can be prevented by reducing the pH of irrigation water, using magnetized saline water and through microbial treatment using *Bacillus subtilis OSU-142* (Hills *et al.*, 1989;Eroglu *et al.*, 2012; Sahin *et al.*,2012). The values of different constituents present are listed in table 4, that can be used to assess the clogging potential of drip emitters and accordingly above discussed practices can be adopted for smooth and effective functioning of drip irrigation system.

Table 4. Constituents and their values indicating clogging potential of drip emitter
Source: www.smart-fertilizer.com

Constituent	Level of Concern		
	Low	Moderate	High
Ph	<7.0	7.0-8.0	>8.0
Iron (Fe) mg/L	<0.2	0.2-1.5	>1.5
Manganese (Mn) mg/L	<0.1	0.1-1.5	>1.5
Hydrogen Sulfide (H_2S) mg/L	<0.2	0.2-2.0	>2.0
Total Dissolved Solids (TDS) mg/L	<500	500-2000	>2000
Total Suspended Solids (TSS) mg/L	<50	50-100	>100
Bacteria Count (#/ml)	<10,000	10,000-50,000	>50,000

Conclusion

The sustainability of irrigated agriculture with poor quality water demands managing salts within acceptable range in plant root zone and farmers need to be prepared to accept crop yield lower than normal. Maintaining high soil moisture and low salinity level using pressurised irrigation method, provides opportunity to achieve economically viable crop yield in saline environment. However, drip irrigation has better potential for utilizing saline and sodic water in crops. Water application into root zone directly in drip irrigation avoids any chances of damage to crop besides benefits of higher yield and better quality. Clogging of drip emitting devices is found to be the main constraint while using saline water, but solution of clogging problems is available.

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Soil and Water Management Practices for Fruit Cultivation in Salt Affected Soils

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Introduction

Presence of excess salts in soil and groundwater is a severe impediment to crop production in severeal irriagted and rainfed areas of the world. A recent estimate puts the global extent of salt-affected land area at 1128 m ha, which is considerably higher than previous estimates (831-955 m ha) (Wick*e et al.,* 2011) indicating a steady rise in the problem. Although soil salinity caused by the natural factors has been reported from about 100 countries of the world, relentless development of irrigation-induced waterlogged salty lands is increasingly jeopardizing agricultural sustainability and food security in many araes. Severity of the problem is evidenced by the fact about 20% of global irrigated lands have either become less productive or completely unsuitable for crop production due to waterlogging and the accompanying rise in salinity or sodicity. If current trends continue unabated, nearly half of the global arable lands would become salinized by 2050. Besides direct adverse effects on soil properties and crop growth, salinity also deteriorates groundwater quality (UNCCD, 2017).

While salinity onslaught continues to threaten sustainable land use, a sizeable portion of arable lands is also increasingly being grabbed by housing, infrastructure and industrial sectors resulting in the net loss of the cultivated land (Chand, 2017). By comparison, global food demand has steadily increased and is expected to rise in the foreseeable future. These developments have placed considerable pressure on productive, yet shrinking, land resources. Available evidence suggests that intensive input use devoid of environmental concerns often causes irreparable losses in soil quality; a fact evidenced by secondary salinization, fresh water depletion and a range of other environmental problems in many parts of north-west India (Sharma *et al.,* 2016). These observations lead to the conclusion that while productive farmlands need to be safeguarded from further degradation, less productive or abandoned lands must be restored for meeting the ever rising food and nutritional needs.

'Salt-affected soils' (SAS) is a collective term to describe soils with either excess soluble salts or exchangeable sodium. Depending on soil saturation paste extract values of electrical conductivity (EC_e), pH (pH_s) and exchangeable sodium percentage (ESP), soils are grouped into saline ($EC_e \geq 4$ dS m^{-1}, $pH_s < 8.2$, ESP< 15) and sodic ($EC_e < 4$ dS m^{-1}, $pH_s > 8.2$, ESP >15). When both EC_e and ESP exceed the threshold values, the soil is called 'saline-sodic'. Conventionally, saline soils are reclaimed by leaching with fresh water and sodic soils by applying suitable amendments followed by water ponding to remove the salts below the root zone. Over the years, however, growing fresh water shortages have emerged as a serious hurdle in the reclamation increasing the interest in alternative means of soil reclamation. India has an important place in the production of many horticultural crops and is currently the second largest producer of fruits in the world. In comparison to majority of the field crops, fruit cultivation can generate higher incomes and employment opportunities while ensuring nutritional security of the farm families. Notwithstanding considerable increase in fruit production in the last few decades, India still remains a net importer of fruits and vegetables (Mukherjee *et al*., 2016). Poor orchard upkeep coupled with the losses caused by biotic and abiotic stresses, and high post harvest losses are the major factors responsible for low production and reduced availability of fruits. While attempts to increase average productivity may come at the cost of environmental degradation, extending fruit cultivation to prime croplands is virtually impossible. Fierce competition for land use among different sectors of economy and decreasing availability of fresh water imply the need to harness the productivity of marginal lands for expanding the area under fruit crops. In light of these facts, this article presents an overview of feasible soil and water management options for growing fruit crops in salt-affected soils.

Managing Salt Affected Soil for Fruit Production

The options available for growing fruit crops in salt-affected soils can broadly be grouped into four categories, *viz*., 'salt tolerant crops and cultivars', 'improving the root zone conditions', 'reducing crop evapotranspiration losses' and 'irrigation management for reducing salt hazard'. The strengths and weaknesses of such salinity management techniques and practices are discussed in the following sections:

1. Salt Tolerant Crops and Cultivars

1.1. Salt tolerant crops: Notwithstanding the fact that majority of fruit crops exhibit high sensitivity to salinity (Bernstein, 1980), there are several species that perform well under saline conditions. Such species, in addition to producing nutrient rich fruits, have other significant social and environmental roles making them an inseparable part of the local farming systems. Some of the prominent examples include Indian jujube, bael and jamun. While the former two are potential crops for dryland saline areas, jamun shows tolerance to waterlogging prone saline soils. Indian jujube and related species are widely distributed in saline arid and semi-arid regions of western India. Both bael and jamun trees are popular backyard trees in several states of India. Notwithstanding their critical livelihood supporting roles in areas where they are conventionally grown, such potential species largely remain underutilized in terms of production and trade. These observations, however, do not imply that other fruit crops are unsuitable for saline and sodic soils. In fact, relatively high salt tolerance in some cultivars even in extremely salt sensitive crops like citrus and mango coupled with improved management practices have been instrumental in their commercial cultivation in salt-affected soils. Excess salts may not always be the sole limitation to fruit cultivation in salt-affected soils. Other stresses including shallow watertable, drought and nutrient toxicities often co-exist with salinity. Occurrence of two or more such stresses together can be more problematic to deal with. This suggests the need to identify cultivars that can perform well under such situations. Much of the existing knowledge on physiological basis and management of salt tolerance in fruit crops comes mainly from crops like citrus and grapes (Singh and Sharma, 2018) reflecting their huge economic values. Nonetheless, the precise basis of salt tolerance even in such extensively studied crops is poorly understood impeding the development of salt tolerant cultivars through genetic improvement.

1.2. Salt tolerance threshold: Based on a review of information available from different sources, Mass and Hoffman (1975) published a list indicating the relative salt tolerance of different agricultural crops including some fruit crops (Table 1). While ranking different species for salt tolerance, they considered only those studies that reported both root zone salinity and the corresponding yield data. However, non-availability of yield data prompted the use of growth related data in some fruit and nut crops. Furthermore, insufficient quantitative data in some crops necessitated the use of qualitative data for drawing plausible conclusions. However, these data only indicate the relative salt tolerance of a particular crop, and the absolute tolerance would vary with genotype, agro-climatic conditions and crop management practices. Marin *et al.* (1995) screened 26 olive cultivars using 100 mM NaCl solution. After 49 days of salt treatment, relative growth decreased by 16-70% in different cultivars. Relative growth was below 30% that of control in salt sensitive cultivars (Pajarero, Chetoui, Galego and Meski), 60-70% in most tolerant cultivars (Nevadillo, Jabaluna, Escarabajuelo, Caiiivano and Picual) and intermediate in others like Zorzariega, Redondil, Alamefio and Arbequina. Such studies demonstrate that crop genotypes vary widely in salt tolerance.

Table 1. Salt tolerance threshold in selected fruit crops (Source: Maas and Hoffman, 1975)

Fruit crop	Salinity at initial yield decline (dS m^{-1})	% Yield decrease per unit increase in salinity beyond threshold	Salt tolerance rating
Almond	1.5	19	S
Apple*	….	….	S
Apricot	1.6	24	S
Avocado*	….	….	S
Berries (*Rubus*)	1.5	22	S
Date palm	4.0	3.6	T
Grape	1.5	9.6	MS
Grapefruit	1.8	16	S
Lemon*	….	….	S
Olive*	….	….	MT
Strawberry	1.0	33	S

**Assessment based on qualitative data. Note: S- Sensitive, T- Tolerant, MS- Moderately sensitive, MT- Moderately tolerant.*

1.3. Salt tolerant rootstocks: Salt tolerant rootstock cultivars have also been identified in many fruit crops (Table 2). They protect the scion cultivars from salt injury mainly by partially excluding Na^+ and/or Cl^- ions, and restricting their transport to the shoots and leaves. Again, some such rootstocks also exhibit selective uptake of K^+ and Ca^{2+} to overcome Na^+ toxicity, enhanced accumulation of osmolytes (e.g., proline) and maintenance of photosynthesis for lessening the salt injury. It is, however, pertinent to mention that most of the observations reported here (Table 2) are based on results of relatively controlled pot experiments and may not be reproducible under field conditions. This is because researchers often employ a single salt (NaCl) for developing salinity while salt composition may be quite different in the field soil (Grieve et al. 2012). Again, factors other than salt composition including soil texture, watertable depth and nutrient constraints (e.g., boron toxicity) are likely to greatly influence salt tolerance response under field conditions. These observations imply that in order to accurately predict salt tolerance threshold, diverse genotypes need to be screened under conditions closely mimicking the local field conditions.

Table 2. Salt tolerant rootstocks in different fruit crops

Crop	Rootstock	References
Apple	'M 26', 'M9'	Motosugi *et al*. (1987)
Citrus	'Cleopatra', 'Gou Tou Cheng'	Levy *et al.* (1999)
	'Rangpur lime'	Storey (1995)
Guava	'Crioula'	Sá *et al.* (2016)
Grape	'Dogridge', 'Salt Creek' (syn. 'Ramsey')	Upreti and Murti (2010)
	V. berlandieri × *V. rupestris* (110R, 1103P, 99R, B2/56)	Jogaiah *et al*. (2014)
	'1103 Paulsen'	Walker *et al*. (2004)
Indian jujube	*Z. rotundifolia*	Gupta *et al*. (2002)
	Z. nummularia	Meena *et al*. (2003)
	Z. spina-christi	Sohail *et al*. (2009)
Mango	'13-1'	Kadman *et al*. (1976)
	'Gomera-1'	Duran *et al.* (2003)
	M. zeylanica	Schmutz (2000)
	'GPL-1' and 'ML-2'	Damodaran *et al*. (2013)
	'Olour', 'Nekkare'	Pandey *et al*. (2014)
Prunus spp.	'GF_{677}'	Massai *et al*. (2004)
	'Myrobalan', 'Bright's Hybrid'	El-Motaium *et al*. (1994)
Pear	*Pyrus betulifolia*	Okubo and Sakuratani (2000)
Pistachio	*P. atlantica*, `UCB-1'	Ferguson *et al*. (2002)
Pomegranate	'Tab-o-Larz'	Karimi and Hassanpour (2017)

It has also been shown that salt exclusion efficiency of some rootstocks diminishes upon prolonged exposure to salinity and grafting with commercial scion cultivars. A relevant example in case is the grape rootstock 'Dog Ridge' introduced in India for commercial use in drought- and salt-affected soils. While own rooted 'Dog Ridge' performed well to short-term exposure to NaCl-induced salinity (≤6.5 dS m^{-1}), grafted plants could not endure prolonged exposure to saline irrigation. Saline irrigated 'Thompson Seedless' vines on 'Dog Ridge' and 'Salt Creek' rootstocks showed leaf blackening and necrosis symptoms during ripening stage due to lower K^+ and toxic Na^+ levels in leaf blades. In contrast, vines on 'B2-56' and '1613C' maintained a higher K^+: Na^+ ratio resulting in less injury (Sharma *et al*., 2011). Some potential salt tolerant rootstocks also exhibit poor graft compatibility with commercial scion cultivars. For example, incompatibility of jujube rootstock *Z. nummularia* with scion cultivars like 'Gola' is ascribed to poor callus production at the graft union, phloem degeneration in scion shoots and development of a necrotic layer between the scion and rootstock which eventually result in 'inverted bottleneck' symptoms in the composite plants (Verma et al. 2000). Non-availability of planting material (e.g., seeds, cuttings) in sufficient quantities may also hinder commercial applications of salt tolerant rootstocks in propagation.

2. Improving the Root Zone Conditions

2.1. Improved Methods of Orchard Establishment: A survey of literature reveals few innovative ways of orchard establishment which improve tree establishment, reduce mortality, ensure resource conservation and come at a lower cost than conventional pit method of planting in salt-affected soils.

In situ planting: When moved from nursery to the field, tree saplings suffer from some kind of stress necessitating adequate care in planting for better establishment. Improper transplanting can particularly be detrimental to plant survival and growth in stressful situations. In salt-affected soils, newly planted saplings often decline and succumb due to twin constraints of water deficit (osmotic shock) and ion toxicities. Two tide over this problem, *in situ* planting of rootstocks and subsequent budding/grafting with desired scion cultivars can be a better choice. In this method, polybag grown nursery rootstock seedlings directly planted in the field are budded after attaining proper height and thickness (Pathak, 2003). *In situ* orchard establishment techniques have been developed in crops like aonla, bael, ber, jamun and grapes. Ber orchards developed by *in situ* method tend to develop a deep tap root system capable of drawing water from the lower depths. Successful *in situ* budding of 'Gola' scion buds on different rootstocks (*Z. rotundifolia*, *Z. spina-christi* and *Z. mauritiana* cv. Tikadi) has been demonstrated under waterlogged saline conditions (ICAR-CSSRI, 2018).

Planting on elevated beds: In soils with a shallow saline watertable (≤2 m below the surface), oxygen deletion in the root zone and direct exposure of roots to salts often considerably increase tree mortality. Even salt tolerant fruit crops fail to establish when planted on surface of such lands. This problem can partly be overcome by planting on raised beds. Ridge planting (45 cm high) could ensure the survival of 50% of the aonla plants while complete mortality was seen in sub-surface planting treatment; apprantely due to considerable reduction in root zone salinity in the former than in latter system (EC_e 12-18 dS m^{-1}) (Tomar and Gupta, 1985). Commercial mango cultivation on saline soils (EC_e 2.5-3.5 dS m^{-1}; pH 8.0-8.5) was possible through the adoption of improved management practices including planting on 60 cm high and 180 cm wide ridges (Gunjate et al. 2009). Guava (cv. Allahabad Safeda) and bael (cv. NB-5) plants could endure high soil salinity (EC_e 4.0-10.0 dS m^{-1}) when planted on raised beds (~2 feet) and irrigated with marginally saline water (3-4 dS m^{-1}). While raised bed planting minimized the possibility of direct contact between plant roots and saline watertable, application of less saline water enhanced salt leaching beyond the root zone (Singh et al. 2018).

Planting in auger-holes: In some sodic soils, presence of an impenetrable sub-surface clay pan impedes water and air flows and root growth. Studies have shown that tractor drawn auger can be used to pierce this hard pan for overcoming these limitations. Ber, guava, jamun and tamarind could be successfully grown in a degraded alkali land (pH 10.5) by planting in the gypsum treated augerholes (~25 cm diameter and 160-180 cm deep) (Singh et al. 1997). Ber, guava, jamun and karonda showed complete survival when planted in amendment treated auger-holes (120 cm deep, 45 cm dia. at surface and 20 cm at base) in a sodic soil (pH_2 >10.0; ESP ~90.0) having ~40 cm thick precipitated $CaCO_3$ layer (Singh et al. 2008).

2.2. Soil and water amendments: In addition gypsum, some other amendments also improve plant establishment and growth in salt-affected soils when applied before planting. Planting pit treatment with sand and FYM (20 kg each pit^{-1}) was found effective for litchi (cv. Rose Scented) cultivation in a sodic soil (Saxena and Gupta, 2006). Incorporation of gypsum and FYM in the pit soil mitigated the adverse effects of diluted spent wash (EC 0.93 dS m^{-1}, SAR 7.3 $(mmol/l)^{½}$ irrigation in ber, sapota and pomegranate (Meena *et al.*, 2011). Banana plants receiving gypsum, FYM and 120% higher dose of potassium had higher bunch weight than non-treated plants in sodic soils (Sathiamoorthy and Jeyabaskaran, 2001). Application of pyrite, FYM and sand in planting pits considerably reduced soil ESP, bulk density, penetration resistance and EC such that mango and litchi could grow profusely (Singh *et al*. 2001). Studies have also shown that amendment applications can also overcome salinity hazard in irrigation water. Gypsum and sulphitation pressmud treated grapevines produced 11.3% and 31.0% higher yields, respectively, than vines receiving sodic tubewell water (RSC 6.4 meq L^{-1}) alone (DARE, 2015). Mixing of polyacrylamide (PAM @ 10 and 20 ppm) in irrigation water (EC_{iw} 6.2 dS m^{-1}) decreased water repellency index by 27 and 40%, respectively, compared to control in pomegranate orchard soils. Higher dose of PAM (20 ppm) could completely ameliorate the adverse effects of saline irrigation (Tadayonnejad *et al*., 2017).

2.3. Arbuscular mycorrhizal fungi: Arbuscular mycorrhizal fungi (AMF) treatment can improve crop salt tolerance by increasing the availability of major nutrients like N, P, Ca and Mg, maintaining a favourable K^+/Na^+ ratio, increased accumulation of benign osmolytes and maintain leaf photosynthesis. AMF treated salt stressed pomegranate plants had higher root and shoot P and lower shoot Cl^- than control plants (Arab Yarahmadi *et al*., 2018). AMF inoculation, either alone or in combination with bacterial consortium, improved plant water balance, K^+/Na^+ ratio and leaf photosynthesis in salt treated (NaCl 150 or 250 mM) grape rootstock 'Dogridge' (Upreti *et al*., 2016). AMF treatment decreased electrolyte leakage, enhanced P and K uptake, and higher proline accumulation in salinized rough lemon (*C. jambheri*) seedlings (Zarei and Paymaneh, 2014).

2.4. Plant growth substances: Some authors have found that exogenous applications of certain plant growth substances improve plant salt tolerance. Watering with 1.0 mM salicylic acid (SA) solution alleviated NaCl (35 mM) effects on strawberry growth by improving leaf relative water content, chlorophyll and nutrient levels, and decreasing the electrolyte leakage (Karlidag *et al*., 2009). Pretreatment with SA (0.5 and 1.0 mM) partly negated the adverse effects of 200 mM NaCl in olive cv. Oueslati by restricting Na^+ translocation to the leaves, and enhancing the activity of non-enzymatic antioxidants (polyphenol and flavonoid) (Methenni *et al*., 2018). In 'Nemaguard' peach, saline irrigation caused about 60% reduction in plant growth. However, paclobutrazol (PBZ) treated plants showed only 30% reduction in growth, less defoliation, lower extent of salt injury symptoms, and higher rates of leaf gas exchange than salinized plants. Regardless of salinity level, PBZ application had a repressive effect on Na^+ and Cl^- accumulation in different plant parts (El-Khashab *et al*., 1997). Combined use of PBZ (250 ppm) and putrescine (50 ppm) improved proline and Ca^{2+} accumulation while restricting Na^+ transport to the leaves in salt treated sour orange seedlings (Sharma *et al*., 2013).

2.5. Overcoming nutritional constraints: Plants is saline soils suffer both from ion toxicities and mineral ion imbalances. Reduced uptake of essential nutrients can be ascribed either to direct competitive inhibition by Na^+ and Cl^- ions or to a decrease in soil osmotic potential restricting the mass flow of nutrients to plant roots. Again, a considerable amount of many nutrients often leach to the groundwater after drainage or leaching. High pH, ESP, poor organic matter, oxygen depletion and degraded physical environment can further accentuate nutrient deficiencies in sodic soils (Swarup and Yaduvanshi, 2004). Nutrient recommendations for fruit crops in salt-affected soils should be based on factors like spatial-temporal variations in root zone salinity, depth and distance of active root growth, soil physical conditions and irrigation water quality. Nutrient plans should be in sync with soil and leaf nutrient status. Fertilizers having Na^+ (e.g., $NaNO_3$) or Cl^- (e.g., KCl) can exacerbate the salinity problem and should be avoided. Frequent (low concentration) applications along with irrigation water (*i.e*., fertigation) can give better results than a single time soil application (Boman *et al*., 2005). Certain organic manures and composts, besides partly alleviating salt injury, can ensure a steady supply of nutrients for an extended period of time. However, despite being less costly, organic inputs need to be applied in large amounts for good results and this may restrict their commercial use. In soils where high pH and associated problems suppress micronutrient availability, foliar application of single nutrients instead of nutrient mixtures is suggested.

3. Reducing Crop Evapotranspiration Losses

3.1. Mulching: Excess irrigation with fresh water only temporarily reduces the root zone salinity. Salts tend to move upward in response to evaporation gradient and re-accumulate in the surface layers within a few months of leaching. Even if fresh water is easily available, over-irrigation may have some undesirable effects including decrease in soil temperature and the consequent adverse effects on root growth. Evidently, other measures would be required to keep salt levels in check without altering the soil properties (Dong *et al*., 2009). Mulching with organic and inorganic materials can be an easy solution to prevent upward movement of salts with additional benefits like improved soil moisture availability, reduced weed growth, stable soil temperature and reduced erosive impact of rainfall. Plastic film and concrete mulches significantly reduced crop ET in a Chinese jujube (*Zizyphus jujuba* Miller) orchard in a saline soil resulting in higher WUE than control without any adverse effects on fruit yield and quality (Sun *et al*., 2012). Baggase or plastic mulch coupled with spray of a biodegradable acrylic polymer reduced grape irrigation water requirement by 25% (Sharma and Upadhyay, 2013). Mulching with sugarcane baggase, wheat and safflower reduced the actual water requirement by 30-70% in a drip irrigated pomegranate orchard. Baggase mulched trees (7-10 kg plant^{-1}) displayed the highest WUE and fruit yield (Meshram *et al*., 2017). Application of chipped pruned branches as *in situ* organic mulch has potential for improving soil organic matter and nutrient availability, and controlling soil erosion in Mediterranean citrus groves (Cerdà *et al*., 2018). Mulched drip irrigation (MDI), involving surface drip irrigation and film mulching, is a popular practice in some arid areas of China. Besides curtailing soil evaporation losses and improving soil thermal regime, MDI results in higher WUE and precise delivery of water and nutrients. However, surface accumulation of salts in MDI fields is a significant concern. Applied water percolates only up to 60 cm depth suggesting the needs for further refinements in design and management of MDI systems for sustained benefits (Zhang *et al*., 2014).

3.2. Canopy management: Slow growing dwarf plants can sometimes outperform their tall counterparts in salt exclusion; a fact attributable to low transpiration rates and consequently less water (and salt) absorption by small sized plants. This implies that pruning of excess growth may partly arrest water loss through transpiration resulting in relatively less salt uptake. Fruit trees adapted to dry saline areas often have sparse foliage; at least during a part of the year probably to lessen the harmful impacts of heat, water and salinity stresses. For example, better adaptation of aonla and ber to rainfed saline soils than other fruit trees can be ascribed partly to a thin foliage and partly to a deep root system arresting the transpiration rate and facilitating water absorption from lower depths, respectively. Aonla trees exhibit 'fruitlet dormancy' with fruitlets (fertilized ovaries) remaining dormant during hot summer months and resuming active growth in the rainy season. Ber trees also shed the leaves and enter into dormancy during summer months. These morphological adaptations mean that virtually no water is required for supporting growth in the summer season; a period witnessing heat stress and evaporation induced salt accumulation in the upper soil surface.

3.3. Windbreaks: Planting of windbreaks improves water availability in crop fields by regulating the microclimate and reducing the evapotranspiration (Campi *et al*., 2012). Windbreaks modify the orchard microclimate by decoupling it from atmospheric influences, reducing the wind speed and evaporation. Because rate of water removal from the sheltered area is generally lower than open fields, humidity increases and evaporation decreases. Sheltered fields also experience lesser advective influence on evaporation resulting in more efficient water use by the fruit trees and vines. Increase in humidity may also partly nullify adverse effects of low temperature and unseasonal frost (Norton, 1988). Biofencing with casuarina reduces the impact of hot winds on mango trees in salt-affected soils (Gunjate *et al*., 2009).

3.4. Anti-transpirants: Plants utilize only a fraction of absorbed water in metabolism while the rest (~99%) is lost to the atmosphere through transpiration. Obviously, reduced transpiration can minimize water stress. Foliar spray of some chemicals called anti-transpirants can reduce the transpiration rate in three ways: by reducing the absorption of radiant energy and thus lowering the leaf temperature; forming a thin transparent film on leaves hindering water loss, and by preventing full stomatal opening decreasing the loss of water vapor (Davenport *et al*., 1969). Kaolin, a silicate mineral, prevents water loss from leaves by partially reflecting photosynthetically active radiation and reducing stomatal conductance. Kaolin application reduced crop ET losses while improving photosynthetic water productivity in well watered bean and Clementine tangor, and in salt stressed tomato plants (Boari *et al*., 2015). Kaolin application alleviated drought stress in olive cv. Chondrolia Chalkidikis by increasing the leaf water content, succulence and CO_2 assimilation rate (Denaxa *et al*., 2012). Supplemental irrigation and anti-transpirant (folicote and vapor-guard) sprays improved plant growth and fruit yield of fig (*Ficus carica*) in an arid rainfed area (Al-Desouki *et al*., 2009).

4. Irrigation Management for Reducing Salt Hazard

4.1. Supplemental irrigation using rainwater: Supplemental irrigation with harvested rainwater can stabilize fruit production in rainfed saline areas. A variety of structures like field bunds, trenches, terraces and micro-catchments have been found suitable for *in situ* rainwater harvesting while farm ponds and tanks can be used to store rainwater *ex situ*. Harvested water can be directly used either in irrigation or for groundwater recharge for improving groundwater quantity and quality. *In situ* water harvesting in continuous trenches has been found an efficient technique for preventing decline and improving fruit yields in Nagpur mandarin orchards in Vertisols of Central India (Panigrahi *et al*., 2015). Shallow conical micro-catchments (1.0 m radius) should be constructed for improving soil moisture availability in ber orchards in arid areas (Ojasvi *et al*., 1999). Rainwater harvesting in farm ponds is a viable solution for mitigating the growing water scarcity; especially in areas frequently impacted by droughts resulting in crop failures. Rainwater stored in farm ponds is used for assured irrigation of pomegranate and grapes in many areas of Maharashtra (SANDRP, 2017). A rooftop rainwater harvesting structure (557.7 m^2) has been developed for providing supplemental irrigation to crops like guava and pomegranate in arid areas (Kumar *et al*., 2006).

4.2. Conjunctive use of fresh and saline groundwater: High salinity in groundwater often renders it unsuitable for irrigation. Nonetheless, growers facing fresh water supply constraints have no other option but to irrigate their lands with low quality water. Field trials conducted in north-west India have indicated the possibility of irrigation with saline and canal (fresh) water in cyclic and/or blending modes provided there is sufficient rainfall to leach a major part of salts accumulated during the irrigation season. Conjunctive irrigation can partly reduce the dependence on fresh water while preventing the further rise in watertable. However, little is known about the viability of this practice in perennial fruit crops. Storage of canal water in an auxiliary reservoir of 1500 m^3 capacity was used to drip irrigate pomegranate, Kinnow and guava crops in a salt-affected soil at Abohar, Punjab. Drip irrigation resulted in up to 30% saving in water use than surface irrigation (Kumar et al. 2013). In some saline areas of Haryana, canal water stored in farm ponds is mixed with saline groundwater for irrigating fruit crops like Kinnow and ber. However, storage and blending practices come at an additional expenditure raising the cost of production. Evidently, rainwater harvesting can minimize such expenses.

4.3. Pitcher irrigation: In this method, porous clay pots placed in the soil provide controlled irrigation to plants with rate of water diffusion being governed by factors like crop ET and soil water tension. Crop water use efficiency in pitcher irrigation is several times higher than surface methods of irrigation and sometimes even higher than drip irrigation. Unlike drip irrigation, however, there is less clogging problem and no power requirement in pitcher method (Bainbridge, 2002). It is due to these benefits that pitcher irrigation offers an easy means of getting stable crop yields in salt-affected soils, and has been successfully used for establishing fruit plantations in arid saline regions. Singh *et al*. (2011) reported that rainwater collected in underground water tanks was applied through pitchers to raise ber and lasora trees in an area where saline groundwater was the only source of irrigation. Pareek *et al.* (2003) observed that planting of cactus cladodes at 5 cm depth in east-west direction and provision of slow water releasing pitchers ensured the highest biomass production than planting in north-south direction and irrigation by basin method.

4.4. Drip irrigation: Leaching of salts beyond the root zone is necessary for the sustained application of saline irrigation waters. Application of excess water than actually required for crop ET needs is termed as the 'leaching requirement'. Depending on factors like climatic conditions, root zone salinity and crop salt tolerance, either occasional or seasonal or regular leaching may be necessary. Although surface methods of irrigation leach a considerable portion of salts, they require the heavy use of water. Again, in many situations, development of shallow watertables restricts the downward movement of salts. Owing to these constraints, drip and sprinkler methods of irrigation are suggested for curtailing water wastages, ensuring high WUE and achieving leaching in salt-affected soils. Among these two methods, drip irrigation is more better than sprinkler method because salts do not accumulate on foliage and are constantly leached out of the active root zone (Hanson and May, 2011). Depending on crop, drip irrigation can result in up to 50% reduction in irrigation water use without any adverse effects on soil properties and crop yield (Stevens *et al*., 2012). Drip irrigation has been successfully used to grow fruit crops in many salinity affected areas of India; guava at Abohar, Punjab (Mandal *et al*., 2007), mango at Jamnagar, Gujarat (Gunjate *et al*., 2009) and in sapota, ber and pomegranate at Indore, Madhya Pradesh (Meena *et al*., 2011). In spite of potential benefits and an enabling policy environment, slow penetration of drip technology in India remains a concern. Furthermore, in states like Maharashtra where drip technology has gained farmers' acceptance, recommended irrigation scheduling is often ignored resulting in the excess application of water and the consequent problems of waterlogging and salt accumulation (Marathe & Babu, 2017).

Conclusions

Preceding discussion highlights the potential of several doable technologies for enhancing the salt tolerance of fruit crops. Depending on factors like crop species, climate and salinity level, a combination of techniques is likely to give better results than a single intervention in the long run. In spite of high potential, less than expected use of some techniques like use of salt tolerant rootstocks and drip irrigation remains a concern.

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Agroforestry Models for Saline Ecologies

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Introduction

Salinity is becoming one of the most brutal environmental stresses that hamper crop productivity with serious ecological concerns worldwide. This can be directly linked with the significant yield losses from the existing landuses. The total area of salt affected soils in the world is 831 mha which include 397 and 434 mha of saline and sodic soils, respectively. In India, 6.75 mha land area is salt affected (Mandal *et al.,* 2010) and is likely to increase upto 20 m hectares by the end of 21^{st} century (CSSRI, 2013). A major threat to world agriculture involves production of 70% more food for an additional 2.3 billion people by 2050 worldwide (FAO 2009). Approximately 76 million-hectare (Mha) salt-affected lands are affected by human induced salinization and sodification (Olderman *et al.,* 1991). The expansion rate of salinization and sodification is between 0.25 to 0.50 M ha $annum^{-1}$ (FAO, 2000). Agricultural productivity is directly governed by osmotic and specific ion effects in saline soils (Yadav *et al.,* 2007; Munns and Tester 2008). Conventional agricultural practices are not economically feasible on such soils because of expensive inputs (Qadir *et al.,* 2002). It is imperative to explore the options for rehabilitating degraded landmasses to bring them under productive cultivation. The methods for rehabilitation of saline ecologies involve hydrological, agronomic and/or phyto-remediation practices. Hydrological and agronomic practices are cost and labour intensive and need developmental strategies. Whereas, phyto-remediation that too with agroforestry practices is the easily executable option for using saline soils. The recent research efforts have greatly improved understanding of biology and management of woody plantations for improving the productivity of saline environments (Dagar *et al.,* 2016). Therefore, forestry and agroforestry systems are the potential alternative land use options for saline ecologies.

Saline Soils

Chemically saline soils has electrically conductivity EC_e 4 dS m^{-1} or more with dominance of chlorides and sulfates of Na, Ca, Mg and pHs always < 8.2. Physically, these are stable in structure, permeable to water and air with other physical characteristics like normal soils. High osmotic pressure of soil solution, toxicity of specific ions-Na, Cl, etc. are the reasons of poor plant growth in saline soils. Leaching and drainage are the options for its efficient use in production functions.

Saline soils usually remain flocculated due to presence of excess salts. Inland, coastal and deltaic are the location specific broad groups of saline soils in India (Sharma, 1998). In India, these soils are generally distributed in parts of Haryana, Punjab and Rajasthan representing arid and semi-arid regions of the country. Saline-alkali soils of Indo-Gangetic alluvium mostly confined to regions with around 550 mm mean annual rainfall. Inland saline soils are distributed in parts of East Champaran, West Champaran, Muzzafarpur, Saron and Sahara districts of Bihar. Inland salt-affected medium and deep black soils (vertisols) exist mainly in parts of Madhya Pradesh, Maharastra, Rajasthan, Andhra Pradesh, Telangana, Gujarat and Karnataka.

Selection Criteria of Tree Species for Plantation

Choice of proper tree species depends upon local agro-climate, land capability, purpose of planting, tolerance to salinity and waterlogging/drought. In general, plantations for fuel wood were rated better for salty soils than the timber species in earlier days. But, with the change in time, the objectivity of afforestation on such soils has also changed. Now, the recent efforts are on the exploration of tree species which also should give timber and environmental benefits. Socio-economic aspects with ameliorative role of trees are the priority of the current times in selection of trees for agroforestry on saline soils.

The other features of tree species adapted to saline soils:

- Capability to grow in salty conditions with tolerance to frost and occasional flooding.
- High water and nutrient use efficiency.
- Resilience against climate changes by providing income during extreme climate.
- Greater potential for CO_2 sequestration in saline soil.

- Perennial in nature, easy to establish and manage in saline conditions.
- Fast growing with capacity to pollard and coppice for realizing quick returns.
- Multipurpose to cater the demand of firewood, timber, food, fodder, fiber, edible or non- edible oils, medicinal value, paper pulp, ability to fix atmospheric nitrogen, etc.
- Drought resistant as sometimes high salt concentrations in soil may cause physiological drought.
- Do not have allelopathic effect.
- Capacity to improve physical, chemical and biological properties of soils through addition of organic matter and creation of better microclimatic conditions.
- Fast decomposition rate to increase soil CO_2 for dissolution of native $CaCO_3$ in soil.
- Capable of producing a prolific root system to facilitate drainage from waterlogged saline soils to drawdown the ground water table.
- Species should be in the farmers' perspective point of view.

Afforestation Practices in Saline Soils

Creation of favorable environment for tree root establishment and growth in saline soils needs special package and practices. There are different points which must be taken into consideration for success of plantations.

The comprehensive accounts of such points are as:
- Identification of nature and degree of salinity
- Quantity and quality of available irrigation water
- Choice of the suitable tree species
- Selection of proper planting methods
- Protection of plantations during the initial years

Before going for plantation, it is essential to diagnose the nature and magnitude of the problem i.e. salinity level in this case. Once, the causative factors established, exacting practices must be opted to carry out the successful plantation activities.

Plantation Technology

Selection of proper planting technique is of utmost significance. The plantation techniques for afforestation in saline soils are mainly governed by site and soil conditions, species to be planted and the purpose of plantation. There are several methods for planting on normal soils but in case of saline soils we have only left with limited options to make the plantations survive. Only those methods are suited to saline soils which either eliminate or alleviate the constraints due to salinity especially during establishment of plantations. The technique should be such that the rainwater is utilized to the maximum possible extent and the salt concentration in the active root zone of young seedlings is kept at a minimum level. The traits which are desired in planting methods suited to saline soils are as below:

- Help in pushing the salts down to deeper soil layers through leaching.
- Reclaim more soil volume for proper root growth.
- Maintain low salinity in rhizosphere.
- Reduce water application cost.
- Help in *in-situ* conservation of rain water and alleviate waterlogging problems.
- Cost effective

Pit planting: The objective of creating planting pits is to aerate and loosen the soil in which the plants will grow. When these planting pits are prepared, they should not be left empty with the excavated soil lying on the ground but refilled immediately; otherwise sun and wind will dry out the soil completely (Fig. 1).

In pit planting method, salts get mixed up and distributed uniformly in the dugout zone. Even the good soils used for back filling the pits turn saline within few months. Thus, pit planting method is an utter failure in saline soils. Salt distribution patterns suggest that salts do not move far away and deep into the profile. Most of the salts stay closer to active root zone. Consequently, the plantation establishment and survival rarely exceeds 25 per cent with this method in strongly saline soils (CSSRI, 1995).

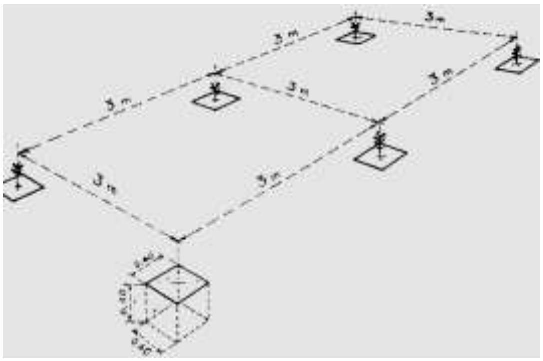

Fig. 1. Pit planting (40 cm^3) at 3m × 3m (Square planting)

Ridge-trench method: It is usual practice in low lying areas along the roads, railway lines and canal embankments where water stagnates in burrow pits. Saplings are planted in the center of the ridge or close to edges of the ridge flats in staggered double row planting system (Fig. 2). Ridges prepared in saline soils enhance salt accumulation on exposed surfaces of the ridges. Accumulation of salts on the berms and top of the ridges reduces the stability of ridges and make them highly prone to erosion during monsoon season. Hence, ridge-trench planting method is only suitable for saline soils existing in water logged areas.

Post-auger hole planting: This planting method is suitable for breaking of hardpans generally found in alkali soils. But, this method is of significance in case of saline-sodic soils where salinity and hard $CaCO_3$ (*kankar*) layer co-existed. In this method, bore holes of 15-30 cm in diameter are dug up to 120 cm or more with the help of tractor mounted auger hole (Fig. 3).

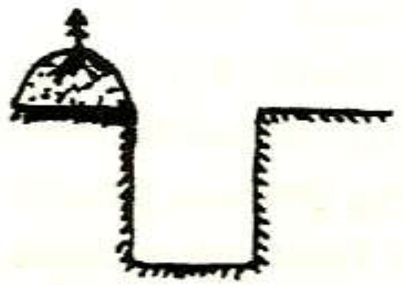

Fig. 2. Ridge–trench planting

Fig. 3. View of auger hole pit

Furrow planting: Furrow planting has been successful in establishment of tree saplings on saline soils (Dagar et al. 2016). In this method, tractor is to be used for creating furrow to the size of 60 cm wide and 20 cm deep (Fig. 4). The saplings are to be planted at sill of the furrows. It is efficient in desalinization of the soil with the help of rainfall thus creating a favorable zone of low salinity below the sill of the furrow through the downward and lateral fluxes of water making salts move away from the root zone (Tomar *et al.,* 1998; Dagar *et al.,* 2016).

Sub-surface planting and furrow irrigation method (SPFIM): This is improved version of furrow planting. The basic concept envisages that salinity is usually higher in the surface layers and decreases with depth down to water table in waterlogged saline soils**.** Soil moisture contents are minimum near the surface and the maximum near the water table. Therefore, to take advantages of low salinity and better soil moisture regimes in sub-surface layers, saplings planted at the sill of the 15-20 cm deep irrigation furrows, such that roots are exposed in 20-35 cm soil layer from original surface (Fig. 5). This method performed satisfactorily in large scale field trials conducted on highly saline soils (CSSRI 1995, 2016; Dagar *et al.*, 2016). Furrows are subsequently used for irrigating saplings which helps in pushing the accumulated salts to deeper soil layers.

Fig. 4. *Eucalyptus tereticornis* plantations in furrow planting method in saline soils

Among the entire range of plantation methods related to saline soils, only ridge–trench, sub-surface and furrow found to be the best in arid and semiarid regions with underlying saline groundwater.

Fig. 5. *Eucalyptus* plantations in SPFIM

Agroforestry Systems for Saline Ecosystem

There are three basic approaches in practice to fight against salinization. These are (1) improving the drainage, (2) selection and breeding for salt tolerance, and (3) alternate land uses. The alternate land use approach raises the possibility of using the vast stretch of saline soils for alternative production. Such approach can halt the further expansion in degradation besides augmenting the supply of food, forage, feed, timber wood and above all ecosystem services. Here, the possible agroforestry systems for productive utilization of saline ecologies are discussed in the light of their significance, cause and effect relationship.

Sequential agroforestry system (Trees and/or arable crops): Trees and arable crops can be grown in sequence instead of growing them simultaneously. This system is quite helpful in improving the fertility status of the soil. Nitrogen fixing trees (NFTs) with fast growing nature can be grown for at least 4 to 5 years and then felled for fuel wood, fodder or other small requirements. After this, land can be put under arable farming due to its improved and nutrient enriched nature (Singh *et al.*, 2004; Dagar *et al.,* 2016). Rao and Gill (1990) studied this system where *Sesbania sesban* was grown initially for 4 years and then followed by rice-wheat cropping sequence. 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 plots. About 0.85 Mg ha^{-1} additional grains as well as 17 kg ha^{-1} of additional N ha^{-1} was derived from mineralization of organic residues. The total N uptake of crops in the control was 142 kg ha^{-1} and in *Sesbania* plots 222 kg ha^{-1}. The organic fertilization was 2.5 times more effective than inorganic N fertilization.

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 trees. Series of experiments were conducted at CSSRI, Karnal on reclaimed or normal soils to identify crops and crop sequences that can be grown in association with established plantations. But, much was not done as far as saline soils are concerned. Although, good number of *Eucalyptus*-based systems with varying densities and under crops were developed for waterlogged saline soils (Dagar *et al.,* 2016). The ICAR-CSSRI has initiated the work to develop *Eucalyptus tereticornis* and *Melia composita*-based agrisilviculture system for saline ecologies. Low water intensive crops like Peral millet and Mustard have been taken as intercrops (*details given in case study section*).

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. Singh *et al*. (2004) and Dagar *et al.* (2008) recommended that *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-Central Soil Salinity Research Institute, Karnal Haryana revealed that different fruit based agroforestry systems have been developed and commonly practiced by the farming communities of the region. The systems comprised of Bael (*Aegel marmelos*), Aonla (*Emblica officinalis*) and Karonda (*Carrisa carandas*) as tree components and cluster bean (Kharif) and barley (Rabi) as subsidiary components have been found practically and economically feasible with the moderate (ECiw 4 to 5.8 dS m^{-1}) to high salinity (ECiw 8.2 to 10.5 dS m^{-1}) water (Dagar *et al.,* 2008, 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 (Sharma *et al*., 2014).

Silvopastoral system (Trees + grasses): The production of woody plants combined with 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. In waterlogged saline areas, several grasses such as *Leptochloa fusca*, species of *Aeluropus*, *Eragrostis*, *Sporobolus*, *Chloris*, *Panicum*, *Bracharia* can be successfully grown along with salt tolerant trees for viable and sustainable silvopastoral systems to sustain livestock productivity. *Aeluropus lagopoides*, *Sporobolus helvolus*, *Cynodon dactylon*, *Brachiaria ramosa*, *Paspalum* spp., *Echinochloa colonum*, *E. crusgalli*, *Dichanthium annulatum*, *Vetiveria zizanioides*, and *Eragrostis* sp. are important grasses which are tolerant to both salinity and stagnation of water; and can successfully grown in silvopastoral systems. Species of *Ziziphus*, *Atriplex*, *Kochia*, *Suaeda*, *Salsola*, *Haloxylon* and *Salvadora* are prominent forage shrubs of saline regions and browsed by camel, sheep and goat (Dagar, 2014).

Most suited tree species for the system in saline soils are *Prosopis juliflora*, *Salvadora persica*, *Acacia nilotica*, *Pithocellobium dulce*, *Parkinsonia aculeata, Casuarina equisetifolia*, *Terminalia arjuna*, *Tamarix articulata* and *Pongamia pinnata.* In silvopastoral system where *P. juliflora* and *L. 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.

Multipurpose woodlots (Trees): In this system, special location specific MPTs are grown mixed or separately planted for various purposes such as wood, fodder, soil protection, soil amelioration, etc. Salinity tolerant MPTs are raised in block plantation with close spacing. In addition to biomass production, trees help in amelioration by improving physical, chemical and biological properties of saline soils.

Saline aquaforestry/Saline aquaculture (Trees + fish): Twin problems of salinity with waterlogging, as existing in many parts of south western Haryana and Punjab, has necessitated the development of alternative approaches to reclaim such landmasses. The degraded soil and water resources in these regions can be put to profit through shrimp and fish farming (Purushothaman *et al.,* 2014). Inland saline aquaculture is popular practice in saline tracts of Australia, Israel and USA (Allan *et al.,* 2009). The ICAR-CSSRI, Karnal, Haryana (India) has worked out the feasibility of commercial fish farming in highly saline conditions at Nain Experimental Farm, Panipat, Haryana. Despite constraints such as high salinity of pond water (4-25 dS m^{-1} depending on season), low water availability and high evaporative losses, fish growth was about 400-600 g in 6 months and 600-800 g in one-year period (CSSRI, 2013). On the peripheries of the pond agroforestry trees can be grown to cater the needs of the farmers. Eucalyptus can be successfully grown on the berms of the ponds and will be helpful in keeping the surface soil salinity under check. However, such combinations are not still investigated thoroughly but such practices will be helpful in the economic sustenance of farms in the saline ecologies.

Homestead/multi-enterprise agriculture model: The multi-enterprise model is developed in ICAR-CSSRI, Karnal, Haryana (India) 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; Sharma *et al.,* 2016). Such models are standardized for highly saline black soils of Gujarat and coastal saline soils of West Bengal (Singh, 2009; Sharma and Chaudhari, 2012).

Fig. 6. View of acquaforestry model

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 at it absorbs the same amount of carbon dioxide while growing. Therefore, it is the cheapest, eco-friendly and renewable source of energy. India, being a fast-growing economy with large import of crude oil makes it more relevant in the present context. Fuel-wood accounts for 20-30 per cent of all energy needs in India and more than 90 percent of this is in domestic sector. India needs 6-7 per cent energy growth per year. Wood energy can be technically efficient, economically viable and environmentally sustainable fuel option during the current energy deficit scenario. It is equally important to feed the fuelwood for domestic consumption with environmental and social benefits (Banyal 2013). 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.

Case Studies

Agroforestry Systems in Dryland Saline Ecologies

***Prosopis cineraria* - based agroforestry for hot arid regions of Gujarat and Rajasthan**
People not only plant this tree on their farm lands but also protect and take care of randomly growing tree or seedlings regenerated. Maintaining 833 trees per ha at 2-3 years, 417 trees per ha at 4-6 years, 278 trees per ha at 6-7, 208 trees per ha 11 years or above age plantations found to increase 10-15 per cent crop yield as compared to sole crop growing without trees. In addition to crop yield *P. cineraria* provides fruit of 350-1040 g per tree used as vegetable and 0.85 Mg $ha^{-1}year^{-1}$ leaf fodder at 12 years of age with 208 trees per ha (Singh, 2009).

***Salvadora persica* - potential tree for agroforestry on highly saline black soils (Vertic Haplustept)**
Salvadora persica is a potential species for the arid saline land restoration program. It is considered as one of the best source for sustaining livelihood of the populace. It is one of the dominant tree species of Kutch region (north– west saline desert) of Gujarat State in India. Attempts were made by CSSRI, Regional Station Bharuch, Gujarat to assess the growth, biomass production, seed and oil yield as well as cost/benefit ratio of growing *Salvadora persica* on highly saline black soils. The studies revealed that the sapling could be raised with saline water of ECiw 15 dSm^{-1}. The cost of raising 500 saplings worked out to be ₹455. The cost of field operations including raising of nursery was ₹2760 per hectare in the first year. In subsequent years, the recurring costs would be mainly the labour for fertilizer application and harvesting. By fifth year, the plants gave seeds @1800 kg ha^{-1} thus giving net returns to the tune of ₹8400 per hectare (Rao *et al.*, 2013). The cost/benefit ratio was very high in the first year after planting due to high initial planting costs and low seed yield. The cost/benefit ratio decreases with advancement of age indicates that this apart from providing returns also adds to the environmental stability with ecological restoration of highly saline black soils in Gujarat. *Salvadora persica* is very promising species for saline soil where arable farming is not possible directly.

Agroforestry System for Irrigated Saline Ecologies

ICAR-CSSRI, Karnal, Haryana, India has been actively involved in developing suitable agroforestry systems for saline ecologies. In a case study, *Eucalyptus tereticornis* and *Melia composita* -based farm production agroforestry systems are being evaluated for saline conditions. Low water intensive crops namely Pearl millet in *kharif* and mustard in *rabi* seasons were grown as intercrops. Both the trees and under crops were given saline irrigation with varying salinity of ECiw from <1 dS m^{-1} (good quality water) to 12 dSm^{-1}. The soil of experimental site was saline with poor quality of ground water and the soil ECe ranged from 4 to >30 dS m^{-1}. The soil pH was ranged from 7.21 to 9.25. The plantations of *Eucalyptus tereticornis* and *Melia composita* were done in line geometry with 4m x 3m and 6m x 3m spacing. Plantation was done in sub-surface furrow irrigation method. *Melia composita* could be the potential plant due to its wider adaptability and multidimensional uses. Therefore, this was taken for the first time to test under salinity conditions to have *Melia* based production models for saline soils.

The *Eucalyptus* and *Melia* trees showed good establishment (98%) and growth performance under saline conditions when resorted to saline irrigation in cyclic mode. However, the values of growth parameters showed decreasing trend with increase in salinity level in irrigation regimes. Pearl millet performed well with both the plantations. The yield of pearl-millet was higher (859 kg ha^{-1}) in the plots irrigated with good quality available water (ECiw <1 dS m^{-1}) and found to show decreasing trend with the increase in salinity level in irrigation water in *Eucalyptus* plantations up to ECiw 12 dS m^{-1}. The lowest yield (541 kg ha^{-1}) was obtained in the plots irrigated with higher salinity (ECiw 12 dS m^{-1}) water. The pearl-millet yield somewhat higher (641 kg ha^{-1}) in BC (below crop) than Ac (away crop) (480 kg ha^{-1}) under *Eucalyptus* based systems. Pearl-millet yield was higher (692 kg ha^{-1}) under the plantations than the open conditions (140 kg ha^{-1}). The highest yield (789 kg ha^{-1}) was observed in the plots irrigated with good-quality available water (ECiw<1 dS m^{-1}) and the lowest (541 kg ha^{-1}) was with higher salinity level. The values of EC_2 and pH showed consistent increasing trend from low (ECiw <1 dS m^{-1}) to higher (EC_{iw} 12 dS m^{-1}salinity levels. EC_2 and pH of soil were lower than the initial status in the plots irrigated with good quality water and there was buildup of salinity towards higher level of salinity. Tree + crop gave low values of EC_2 and pH from initial status followed by sole crop and sole tree. The mustard yield showed similar trends as it was maximum (1338 kg ha^{-1}) in low salinity and minimum (7.04 kg ha^{-1}) in higher salinity in rabi season with *Melia* plantations. The yield difference between treatment combinations of tree + crop and sole crop lowered down with the increase in the salinity level of irrigation water in both the seasons. The higher inter crops yield under plantations may be ascribed to the synergistic effect of trees with crops. Soil salinity analyzed based on electrical conductivity and pH values at the time of sowing and harvesting of intercrops gave invariable response to the irrigation regimes. The soil conditions improved in plots irrigated with low saline water and vice-versa there was salt buildup in both the seasons. It was found that pH and EC_2 value of the plots with crops were lesser than fallow plots while compared with the initial soil status.

The irrigation with best available water (ECiw ~1 dS m^{-1}) having tree + crop was found the best treatment to have better establishment and growth of trees, higher yield of under crops with positive remediation effect on soil in both the developed farming systems. The establishment of both tree species especially *Melia composita* on such ecologies is the uniqueness of the developed agroforestry systems from others. The findings are only based on the initial trends and may differ with the passing time as trees get older. But, it is definite that the synergistic effect of trees and intercrops certainly make saline soils of service use which results in the economic and ecological security of the farming communities (Banyal et al. 2017).

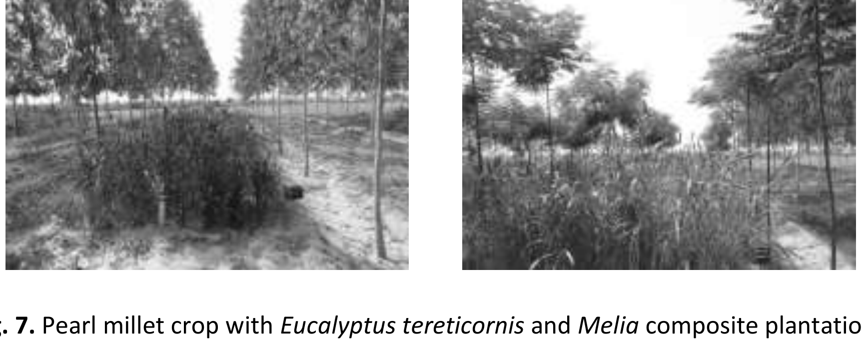

Fig. 7. Pearl millet crop with *Eucalyptus tereticornis* and *Melia* composite plantations

Among fruit trees *Feronia limonia, Ziziphus mauritiana, Carissa carandus, Emblica officinalis* and *Aegle marmelos* could be established irrigating with saline water up to EC 10 dS m^{-1} and intercrops in wider spaces between rows (5 m) such as cluster bean, mustard and barley could be raised with success applying one or two irrigations (Dagar et al. 2016). This appears very viable agroforestry system for such soils. Grasses such as

Panicum maximum, P. coloratum, P. antidotale, P. laevifolium, P. virgatum, Brachiaria mutica, Cenchrus ciliaris and *C. setigerus* could successfully be grown with saline irrigation up to ECiw 10 dS m^{-1}. These along with trees may form productive silvo-pastoral system in dry regions. Many medicinal plants such as *Plantago ovata, Withania somnifera, Ocimum sanctum, Catharunthus roseus, Achyranthes aspera, Lepidium sativum, Aegle marmelos, Cassia angustifolia,* and aromatic grasses *Vetivaria zizanioides* and *Cymbopogon flexuosus* could be cultivated with success as crop in isolation and as intercrops with forest and fruit trees.

Agroforestry Systems for Inland Waterlogged Saline Ecologies

Introduction of canal irrigation in dry regions without provision of drainage causes rise in ground table leading to waterlogging and salinity. For lowering down water table conventional drainage is the best option but that is costly preposition and has environmental consequences. Recently, biodrainage options have been found successful. Trees such as *Eucalyptus tereticornis* planted in blocks or on boundaries of cultivated fields have shown a promise. Ram *et al.* (2010) shown that the system is effective and socially accepted by the farming community.

The results suggested that in a rotation of six years, 1 m x 1 m spacing for strip plantation of *Eucalyptus* in paired rows on farm acre line was the optimum for achieving higher water table draw down, wood biomass production, carbon sequestration and crop productivity on waterlogged fields.

Agroforestry Systems for Coastal Regions

Many technologies have been developed to sustain crop production in coastal saline soils of the country. 'Dorovu' technology to skim fresh water floating on the saline water has gained immense popularity in many coastal regions. Other such technologies include *rabi* cropping in mono-cropped coastal saline soils, rainwater harvesting in dugout ponds, salt tolerant rice varieties (*Sumati* and *Bhootnath*), efficient nutrient management and integrated rice-fish culture (Sharma and Chaudhary 2012). *Casuarina* and *Eucalyptus*-based agroforestry systems are common in sandy soils having saline underground water. Mattsson et al. (2009) documented the success story about the protection of area with home gardens in Hambantota district, Sri Lanka. They found that houses with home gardens or near neighbors' home gardens received less damage than those without home gardens during the *tsunami* period. For coastal regions Samphire (*Salicornia bigelovii*) is very important salt bush, which yields about 28.2% seed oil, 31.2% protein, 5.3% fiber and 5.5% ash from seeds.

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Improved Management Practices for Sodic Vertisols in Madhya Pradesh

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In India salt affected soils occurs in an area of about 6.73 m ha. Out of which 24.2 thousand ha is found in Madhya Pradesh. The reclamation and utilization of sodic soils are of prime importance in view of ever increasing population pressure for demand of food grains with available resources. In black soils (Vertisols) the main problem is of sodicity. Soil sodification induces higher swelling and water retention. Amendment like gypsum is one of the most effective amendments for reclamation of sodic soils. Other pyrites or acids application on the surface followed by light irrigation to achieve field capacity moisture regime so as to have maximum oxidation of pyrites or acid power while gypsum is mixed in plough layer made much effective and fast reclamation. Plantation of Marvel, Para and Karnal grasses for a period of three to four years are found more beneficial in amelioration of the black soils. Soil ESP decreased up to tune of 15-20 unit and thus it reduced the quantity of gypsum up to 8-12 t/ha. Improved surface irrigation design guideline and use of pressurized irrigation systems including drip and sprinkler have been established to ensure light and frequent irrigations essential for the salt affected soils. Raised and sunken bed system, textural modification, raising of grasses and reclamation through afforestation are very innovative approaches that can be utilized very efficiently to reclaim alkali soils even under rain fed conditions. Recent technologies approaches of reclamations like microbial reclamation and biotechnological approaches are found good tools for raising satisfactory crop production.

The arid and semi-arid climate associated with certain elements of topography and groundwater hydrology are often responsible for the accumulation *in situ* or transport and deposit of salts in other places and manifestation of saline and alkali characters in the soils. Such soils form an important ecological entity in India. These soils become unproductive when the accumulation of salts is beyond a certain proportion so that the ecologically adapted plants fail to survive on them. The genesis, nature and occurrence of salt affected soils differ considerably, thereby calling for site specific reclamation/ management practices and utilization of such soils. The semi-arid tracts of central and southern region of the country (Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu) and arid and semi-arid tracts of black soils affected by salinity and sodicity problems.

Vertisols and associated soils occur in Peninsular India between 8° 45′ and 26° 0′ N latitude and 66° 0′ and 83° 45′ longitude and occupy about 76.4 million ha area (Murthy *et al.*, 1982) which is 23.2% of the total geographical area of the country. These swell shrink clay soils having dominating smectitic mineralogy are distributed mainly in the States of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, Orissa and Bihar. The first six states of Indian Union cover about 94% of the total black soil area that occur in the Deccan Plateau of India. On sodification these soils are coined as *kharcha, khari* or *kharland* or black alkali soils and taxonomically coined as Vertisol- sodic phase (Sharma, 1982).

Characteristics and Distribution of Salt Affected Soils

Two distinct classes of salt-affected soils- saline and sodic- vary with each other in genesis and physico-chemical properties. Saline soils, due to presence of excess soluble salts, exhibit saturation extract electrical conductivity (ECe) values equal to and/or above 4 dS m-1 at 25°C and higher salt concentrations render them unsuitable for majority of the arable crops. The sodic soils, on the contrary, have high exchangeable sodium percentage (ESP; >15) which adversely affects the crop growth (Singh, 2009). While the physical properties and water permeability in saline soils is comparable to their normal counterparts (Singh, 2009), plant growth in sodic soils is hampered due to poor physical environment which adversely affects water and air flux, water holding capacity, root penetration and seedling emergence (Murtaza *et al.*, 2006). The South Asian region, including India, has about 52 m ha salt-affected area. A large pool (~85%) the global saline area is only slightly to moderately affected by high salt concentrations while the remainder (15%) suffers from severe to extreme limitations for crop cultivation (Wicke *et al.*, 2011). In India, the present estimated area under salt-affected soils- 6.73 million ha could significantly increase in ensuing decades. The five leading states accounting for almost 75% of saline and sodic soils in the country are Gujarat (2.22 m ha), Uttar Pradesh (1.37 m ha), Maharashtra (0.61 m ha), West Bengal (0.44 m ha) and Rajasthan (0.37 m ha). Many of the salt-affected states, particularly those in arid- and semi-arid climates such as Rajasthan, Haryana and Punjab also greatly suffer from the problem of saline and sodic waters (Singh, 2009).

Table 1. State wise salt affected soils in India

Name of state	Area (Mha)	Name of state	Area (Mha)
Andaman Nicobar	0.08	Maharashtra	0.61
Andra Pradesh	0.27	Orisa	0.15
Bihar	0.15	Punjab	0.15
Gujarat	2.22	Rajasthan	0.37
Haryana	0.23	Tamilnadu	0.37
Karnataka	0.15	Uttar Pradesh	1.37
Keral	0.02	West Bengal	0.44
Madhya Pradesh	0.14	Total	6.73

(Source: Mandal et al., 2010)

Out of 6.73 M ha of salt affected soils reported in the country (Mandal *et al*., 2010) about 0.242 m ha are in Madhya Pradesh (Sharma, 1996). The salt affected soils in MP are mostly located in the semi-arid regions of black area and in Chambal and Harsi Command is of Gwalior region. The survey revealed that in black soil region about 34,000 ha is affected by salinity/sodicity problem. In the Malwa and Nimar region of Madhya Pradesh approximately 21965 ha was found to have salt problems due to natural causative factors, whereas in the Sheopurkalan tehsils nearly 11,255 ha land was affected due to secondary salinization through canal irrigation.

Table 2. Salt affected districts of Madhya Pradesh

S. No.	Name of district	No. of salt affected villages	Area (ha)
1.	Indore	103	5800
2.	Ujjain	303	8370
3.	Dhar	105	4440
4.	Dewas	38	730
5.	Shajapur	11	550
6.	Ratlam	38	685
7.	Mandsour	146	15437
8.	Neemuch	10	3150
9.	Khandwa	2	40
10.	Khargone	37	1200
11.	Sheopur	127	19547
12.	Bhind	159	25127
13.	Datia	265	9425
14.	Gwalior	131	28613
15.	Morena	181	22592

Characteristics of Sodic Vertisols

The sodicity and salinity problems are observed in Vertisols and associated soils of Nimar and Malwa regions of Madhya Pradesh. The area represents a case of contemporary sodicity developed due to combination of factors like basaltic parent material, low and basin topography poor drainage and semi-arid climatic conditions exist together. The area is having moderate rains of 500-800 mm annually along with inadequate irrigation facilities. Basu (1950) opined that it is the basic nature of the parent material, aridity of the climate, nearness to sub-soil water, poor drainage condition and topography that are responsible for development of the sodic problem in Vertisols and associated soils. Most of the area under black soils falls in semi- arid tropics with low leaching intensity and alternate wet and dry seasons. Thus, the climate conditions are favourable for the build-up of salt in the root-zone to a level detrimental to normal plant growth particularly under restricted condition. Vertisols are potentially saline/ alkaline in compacted sub-surface horizons (Murthy *et al*., 1981). Due to compacted sub-surface horizons coupled with low infiltration characteristics the black soils are prone to sever erosion and exhibits as high as 40 % runoff and soil loss to the tune of 60 Mg per ha per year. In black alkali soils the ESP beyond 10 leads to sever structural degradation (Gupta and Verma, 1983) due to high degree of clay dispersion. The dispersed clay clogs the pores and induced increased water retention (Sharma *et al*., 1998) at all suctions. With increasing ESP the rate of drying front declines and moisture changes in lower layer are much slower. With higher water retention and increasing alkalinity, deep cracks do not develop in sodic Vertisols (Sharma *et al*., 1998; Verma and Sharma, 1998) which is a qualifying characteristic of Vertisols.

Physico-Chemical Properties of Vertisols

Physical properties

A. Nature of the soil: The physico-chemical characteristics of black alkali soils occurring in the state of Maharashtra, Madhya Pradesh, Gujarat and adjoining area has been identified. These soil have been classified as fine montmorillonitic hyperthermic family of Typic Haplusterts – alkali phase (clay >35%, silt > 30%, sand < 15%, $CaCO_3$ < 3%, pHs8.6, ESP > 15 and CEC > 35 c mol (+) kg^{-1}). The clay fraction is dominantly montmorillonite (78%) and the soil exhibit swell-shrink properties.

These soils reveal the following broad characteristics:

- The soluble salts (mainly chlorides and sulphates of sodium) are confined primarily to the upper soil layers.
- The exchange complex is dominantly saturated with sodium throughout the soil profile.
- The soils generally contain calcium carbonate to the extent of 5-15% in the surface layers with an increasing trend. Clay pan exist in the subsurface horizons.
- Soluble and exchangeable calcium are often low and pHs seldom goes beyond 9.5. the critical ESP in black soils at which the physical properties start deteriorating lies in between 8-10 and low water transmission properties are main cause the unproductively of these soils.

B. Bulk density: The alkali soils become highly compact after drying. The bulk density values, as high as 1.7 Mg m^{-3} are common in the surface layers at high ESP levels. The bulk density of the surface layers decreases in sodium content on exchange complex.

C. Soil structure: The dispersion ratio increased steadily up to 15 ESP (Table 3). Thereafter the dispersion ratio remain almost similar up to 60 ESP. This suggest that the floc value at 15 SP is such that the smectitic alkali soil present similar structural degradation as at ESP 60 because of high buffering nature of clay mineral. Most of the fine clay remains in dispersible condition causing severe erosion losses during the runoff. The soil structure of black alkali soils starts deteriorating with increasing soil ESP.

D. Infiltration: A micro lot study was conducted at Indore revealed that the basic infiltration rate and cumulative infiltration of black clay soil decreases sharply as soil ESP increases up to 15. The infiltration becomes almost negligible at an ESP of 38. The transient infiltration rate is considerably less at higher soil ESP.

E. Cracking behavior: High amount of sodium on the exchangeable complex the soil causes high dispersion these soils swell on wetting, and get puddle and on drying become hard. Thin flakes get peeled off as drying further proceeds. If drying continues for longer periods, it does not produce large and wide crakes at higher ESP values so the losses of water from deeper layers remain low. The cracking behaviour of the alkali soil exhibits development of narrow, shallow and more number of micro crakes with increasing soil ESP. thus these soils lack in nature deep wide cracks which is the qualifying characteristics of Vertisols.

F. Moisture retention: The moisture in 10 bar suction range increases with the soil. The saturation percentage ranges from 55 to 68% by volume in ESP range of 6 to 58 due to swelling which increases with ESP levels.

G. Evaporation: The evaporation of moisture from initially wet micro plots reveals that the total soil water loss decreases with increasing soil ESP. in normal soil the evaporation is comparatively higher than alkaline soils. Cumulative evaporation at any time during the 100 days of study period was lower for higher ESP plots.

Table 3. Physico-chemical properties of sodic Vertisols (Indore) (0-15cm) at different ESP levels

ESP	pHs	ECe	B.D. (Mgm^{-3}) 0-15 cm	Water dispersible clay (%)	Dispersion ratio	Infiltration rate ($mm\ h^{-1}$)	Depth of crack (cm)	Width of crack (cm)	No. of flakes (m^2)
6	7.9	0.8	1.62	16.3	0.63	12.6	>90	5.6	-
10	8.1	1.4	1.58	26.3	0.76	5.7	50	2.3	2.5
15	8.1	1.8	1.64	34.3	0.83	1.5	30	1.2	5-10
22	8.2	3.1	1.60	38.3	0.83	0.5	10	0.5-1.0	10-30
38	8.3	6.4	1.63	40.4	0.85	0.0	<2	0.2-0.3	30-50
58	9.3	11.1	1.68	42.3	0.85	0.0	0.1-0.2	0.05-0.10	80-100
>60	-	-	-	-	-	-	Negligible	Absent	Nil

Improved Management Practices for Sodic Vertisols

Sodic Vertisols occurs in association with normal soils (Vertisols and associated soils) in a given landscape in Madhya Pradesh. Swelling-shrink nature, low permeability and in absence of irrigation water, the amelioration and economic utilization of these soils is difficult. The chemical amelioration in basically gypsum based viable technologies for reclamation of these soils depending upon soil texture and initial ESP, 15 to 40 Mg ha^{-1} of gypsum is required to reclaim the upper 15 cm soil for raising crops. This also requires large amount of fresh water supplies for leaching of salts again a very high cost technology for poor farmers looking to the returns.

1. Crops and varieties for sodic Vertisols: Studies were conducted in sodic soils for evaluation of salinity and sodicity tolerance of important economic crops of the regions viz., cotton, sorghum, rice, maize, safflower, mustard, wheat and barley. The critical limits of crop tolerance (on the basis of 50% reduction in yield) have been found out in respect of the above crops. Screening of elite varieties/hybrids of different crops was carried out in sodic soils in field conditions at different ESP levels achieved through application of gypsum @ 0, 33, 66 and 100% gypsum requirement (GR). The best performing varieties of different crops in sodic soils are presented in table 4.

Table 4. Crops and their varieties tolerant to salinity/sodicity

Crop	Critical limits EC_e (dSm^{-1})	ESP	Varieties
			Rabi crops
Safflower	10-15 15-20	40-45 45-58	JSF-1, IC-11839 IC-11750, JSF-144
Barley	15-20	48-56	DL4-106, 120, 157, 165, BHS-12
Mustard	15-20 15-20	20-45 48-56	CSN-3, 6, 13, 14, 15 Th-17, UP-70, RLM-632, RIC-1012, 1013, Varuna, Pusa bold
Wheat	15-20	45-55	Kalyan sona, NP-404, Malavraj, K-227 WH-157
			Kharif crops
Rice	10-15	50-55	CSR-4, Kalarata, Jhona-349, SAR-328
Cotton	10-15	50-56	Maljari, Vikram 70-IH-452, Khandwa-2, KH 33/1146
Maize	5-10	15-24	Ganga – 5
Sorghum	5-10 5-10	<10 50-60	CSH-1 and 3, 1584 61-1-1, SPV-235

2. Green manuring: The green manuring of dhaincha along with gypsum is useful practices in restoring of physical condition and enriching the soil in nitrogen and organic matter. Mulching reduce the moisture evaporation from surface soil and prevent salinization. Suitable crop rotation including salt tolerant crop has also proved successful.

Grain yield of paddy and wheat decreased significantly with increase in soil ESP. Incorporation of green manure significantly increased the grain yield over control (Table 5). Highest grain yield of paddy and wheat was recorded in case of dhaincha (3.96 and 3.68 t ha^{-1}) followed by sunhemp (3.57 and 3.50 t ha^{-1}) at soil ESP of 25. Lowest grain and straw yield was observed in control plot. The interactions between ESP and FYM/ GM were also found significant for grain yield of wheat. Further data presented in Table 5 indicated that incorporation of green manures/ FYM significantly decreased the ESP at all the levels. The lowest average ESP (22.62) was recorded under incorporation of dhaincha followed by sunhemp (25.90). However the pHs and ECe of soil did not alter significantly.

Table 5. Grain yield of paddy and wheat (tha^{-1}) and ESP of the soil after harvest of wheat as influenced by application of green manures/FYM at different ESP levels

Green manures	ESP Levels				Mean
	25±2	35±2	45±2	50±2	
Paddy					
Control	2.79	2.57	1.90	1.35	2.15
FYM @ 10 t ha^{-1}	3.16	2.81	2.14	1.86	2.49
Sunhemp	3.57	2.96	2.44	2.03	2.75
Dhaincha	3.96	3.18	2.62	2.35	3.02
Mean	3.37	2.88	2.28	1.90	
	ESP	FYM/GM	ESP x FYM/GM	FYM/GM x ESP	
CD (5%)	0.15	0.15	NS	NS	
Wheat					
Control	2.33	2.04	1.70	1.53	1.90
FYM @ 10 t ha^{-1}	2.92	2.53	2.15	1.88	2.37
Sunhemp	3.50	3.06	2.62	2.10	2.82
Dhaincha	3.68	3.29	2.82	2.20	3.00
Mean	3.11	2.73	2.32	1.93	
	ESP	FYM/GM	ESP x FYM/GM	FYM/GM x ESP	
CD (5%)	0.14	0.08	0.19	0.16	
ESP					
Control	22.55	31.05	39.20	43.07	33.97
FYM @ 10 t ha^{-1}	18.14	25.14	33.42	38.38	28.77
Sunhemp	17.05	23.03	31.18	32.34	25.90
Dhaincha	14.27	20.72	26.83	28.67	22.62
Mean	18.00	24.98	32.66	35.61	
	ESP	FYM/GM	ESP x FYM/GM	FYM/GM x ESP	
CD (5%)	0.80	0.62	1.33	1.25	

(Source: Anonymous, 2017-18)

3. Use of solid waste/spent wash: Many distilleries that end up with large volume of non-hazardous solid waste mounds can now process their wastes much more efficiently and create lush green belts or even cash crops, depending on their geo-climatic conditions using this unique mycorrhizal-based technology.

The field experiment was carried out on different organic amendments for improve the chemical properties of sodic Vertisols at Salinity Research Farm Barwaha, Indore (Table 6). Khandkar *et al*. (2017a) reported that among the different organic amendments, application of spent wash @ 5.0 lakh L ha^{-1} significantly improved the organic carbon, available, N, P and K as compared to other organic amendments. Similarly, pHs. ECs and ECP also lowering due to application of Spent wash @ 5.0 lakh L ha^{-1}.

Table 6. Effect of different amendment on soil properties

Treatment	OC (%)	Av. N (kg/ha)	Av. P (kg/ha)	Av. K (kg/ha)	pH_s	EC_e (dS/m)	ESP
Control	0.39	176.0	7.9	321	8.22	1.33	35.7
FYM @ 5 t ha^{-1}	0.45	182.0	8.5	329	8.10	1.29	35.1
Vermicompost 5 t ha^{-1}	0.46	184.2	8.9	334	8.10	1.26	34.3
Gypsum @ 75% GR	0.45	184.8	9.2	347	8.10	1.23	23.8
Gypsum @ 75% GR +FYM @ 5 tha^{-1}	0.49	187.3	9.8	355	8.05	1.21	22.8
Gypsum @ 75% GR + Vermicompost 5 t ha^{-1}	0.53	190.0	10.0	365	8.05	1.20	21.6

Spent wash @ 2.5 lakh L ha^{-1}	0.61	195.9	10.1	398	8.05	1.18	19.6
Spent wash @ 5.0 lakh L ha^{-1}	0.71	210.1	11.5	430	8.05	1.18	17.5
Spent wash @ 10. lakh L ha^{-1}	0.75	215.7	11.7	454	8.05	1.17	17.1
CD (5%)	0.07	7.2	NS	35	NS	0.08	1.5

(Source: Khandkar et al., 2017a)

4. Reclamation through afforestation: The data on physico-chemical properties of plough layers soil (0-15 cm) collected before tree plantation and after fourteen years are reported in table 7. Tree plantation in general caused a remarkable reduction in soil pH, EC and ESP, whereas, soil organic carbon, available nitrogen and phosphorus content had increasing patterns with progress in time. The soil infiltration rate also improved remarkably due to tree plantation. This gradually favorable improvement in physico-chemical properties may be attributes to an increased biological activity in barren soil as result of cultivation, growing of grasses, root penetration, litter fall and nitrogen fixation. The maximum changes occurred in the plots where *Prosopis juliflora*, *Azardirachta indica* and *Eucalptus tereticornis* were planted in comparison to all other tree species (AICRP, Indore 2004).

Table 7. Change in physico-chemical properties of saline-alkali black clay soil after 14 years of plantation

Tree	pH_s	EC_e (dSm^{-1})	ESP	OC (%)	Av. N ($kgha^{-1}$)	Av. P ($kgha^{-1}$)	HC ($cmhr^{-1}$)
Initial status (1990)	8.8	4.0	35.0	0.35	185	3.4	Negli.
Cassia siamea	8.2	1.29	15.0	0.69	263	16.8	0.25
Acacia nilotica	8.3	1.52	22.4	0.65	250	13.6	0.21
Albizia lebback	8.0	0.95	18.8	0.56	235	14.0	0.16
Hardwickea binnata	8.0	0.96	21.0	0.56	235	13.6	0.18
Casurina equisetifolia	8.1	0.75	16.6	0.56	235	9.6	0.18
Prosopis juliflora	8.1	0.81	8.4	0.82	284	19.2	0.66
Azardirachta indica	8.3	0.62	12.6	0.69	263	23.2	0.49
Acacia catechu	8.3	0.62	18.4	0.50	200	13.2	0.16
Eucalyptus tereticornis	8.3	0.94	19.2	0.65	250	18.0	0.38

5. Evaluating tree and fruit plantation for alkali black soils: The evaluation of sodicity tolerance of different tree species was done (Verma *et al*., 2006). It was observed that apart from the native check plant *Prosopis juliflora*, *Azardirachta indica* and *Eucalptus tereticornis* were the tree species which revealed better survivl and growth in alkali soils under rainfed conditions. Anola, Spota, Ber, Jamun and Drumstick plant were found to be sodicity tolerant fruit plants.

6. Raised and sunken bed system: The black alkali soils are generally characterized by poor hydraulic conductivity, high bulk density, high water dispersible clay and have low production potentials (Gupta and Verma, 1985). Survival of crops and crop growth in such soils suffer heavily on both the accounts (due to water stress or temporary water logging). The reclamation of these soils needs ample of water for efficient chemical reactions and leaching of reaction products below the root zone. These soils are normally found in arid and semiarid areas. The effective depth of reclamation remains a limiting factor even after adopting all the recommended management practices and techniques. Under such circumstances no farmer can think about rehabilitation of such typical black alkali soils for crop production. Gupta and Verma (1985) and Sharma and Verma (1998) reported that these soils have almost negligible infiltration at soil ESP beyond 35. Thus the soil can work as impervious sheet and may prove good for storing of surface runoff during rains. *In-situ* and *ex-situ* rainwater harvesting can provide sufficient water for reclamation and crop production in black alkali soils.

Michel (1978) reported that the crops like paddy which is one of the tolerant and can be cultivated under submerge conditions and at higher ESP levels. The other alkali tolerant crops are cotton, sorghum and safflower but they require proper drainage (Gupta *et al.,* 1994). Tree species like *Azardirechta indica*, *Accacia nilotica* and *Prosopis juliflora*), Fruit trees (Ber and Sapota) and certain grass species (Para, Marvel and Karnal) are also advocated for planting on raised beds for reclamation and rehabilitation of such soils. The increased awareness due to shortage of usable water and land in different parts of worlds has resulted in greater attention on water and degraded land management related issues. The conceptual model was developed to reclaim the degraded black clay soil up to a greater depth through adoption of raised and sunken bed system and enhance the crop production through rainwater management under rain fed situation in arid or semiarid region having sodic black clay soils.

The paddy grain yields for five consecutive years recorded from sunken beds (Table 8) revealed that the mean paddy yield was 4.00, 2.51, 1.52, 4.76 and 5.55 t ha^{-1} during the years 1994, 1995, 1996, 1997 and 1998 respectively being maximum during 1998 due to higher amount of water available either from *in-situ* or *ex-situ* harvesting. The number of irrigations supplied through storage tank during water stress was one in 1997 and two in the 1998. In all the years' maximum paddy yields (4.11, 2.56, 1.68, 4.71 and 5.61 t ha^{-1}) were obtained in sunken beds of 7.5 m width, followed by 6 m bed and 4.5 m width due to easy management of 7.5 m strips. It was also observed that paddy can survive in reclaimed black alkali soils but moisture stress in some crop physiological stages may result in low crop yield. As such, the system was supplemented with rainwater recycling through the on-farm storage tank as discussed in section on design of water storage tank. The highest seed cotton yield (Table 8) was recorded on raised beds having width of 6.0 m and was followed by 7.5 m in all the years. The lowest yield was in 4.5 m bed width. The crop was provided irrigation in the year 1998 during a long dry spell. The crop yield was in general not affected by the amount of rainfall but mostly by distribution pattern that is why the cotton yield was more during 1995 as compared to 1994 and 1996. The assured irrigation through harvested rainwater during last two years resulted in higher cotton yield.

Table 8. Paddy and seed cotton yield in raised and sunken beds under different width and years

Treatments	Paddy yield (tha^{-1})					Seed cotton yield (tha^{-1})				
(bed width in m)	1994	1995	1996	1997	1998	1994	1995	1996	1997	1998
4.5	3.90	2.49	1.43	4.66	5.52	0.24	0.43	0.25	0.37	0.47
6.0	3.99	2.48	1.46	4.92	5.52	0.36	0.46	0.33	0.57	0.61
7.5	4.11	2.56	1.68	4.71	5.61	0.42	0.49	0.44	0.51	0.60
Mean	4.00	2.51	1.52	4.76	5.55	0.34	0.46	0.34	0.48	0.56

Changes in Soil ESP: The soil alkalinity reduced to the tune of 40 % till 2001 to a depth of 45 cm. As said before, the reduction in soil alkalinity was comparatively higher in sunken beds as compared to raised beds. It was observed that the ESP started building-up after 3 years of application of gypsum on raised beds and after 4 years in sunken beds, which suggested that the gypsum should be reapplied after 4 years. Results of earlier experiments also indicated build-up of ESP after 4 years.

Table 9. Changes in soil ESP after adopting raised and sunken bed system

Depth (cm)	Initial	1999	2000	2001	2002	2003	2004
Raised Bed							
00-15	37.0	31.0	28.0	27.0	34.0	44.0	46.0
15-30	41.0	34.5	29.0	28.0	35.0	45.0	46.0
30-45	48.0	45.5	36.5	36.0	44.5	46.5	48.0
45-60	50.0	48.3	48.3	50.0	53.3	53.3	53.3
60-90	52.0	51.8	51.8	53.0	53.8	53.8	53.8
Sunken Bed							
00-15	37.0	21.5	20.0	18.0	24.0	28.0	34.6
15-30	41.0	25.8	22.0	20.0	26.0	32.0	36.0
30-45	48.0	34.4	32.0	30.0	36.0	42.0	44.2
45-60	50.0	40.8	40.0	39.0	45.0	50.0	51.6
60-90	52.0	53.0	53.0	53.0	53.0	53.0	53.0

7. Management through gypsum and amendments: The results (Table 10) obtained in alkali black clay soil reveal that sole application of gypsum resulted in better performance of rice and wheat than split application. Application of @ 75% of GR in black soil was better than @ 50% GR either as sole or split. However, gypsum use efficiency was the maximum when gypsum was applied @ gypsum 25% GR. Gypsum @ 50 and 75% GR gave maximum efficiency after third and fourth cropping seasons suggested that much of gypsum remained un-dissolved in the first year.

Table 10. Effect of frequency of gypsum application on grain yield (qha^{-1}) of rice-wheat in sodic black soils

Treatments (Gypsum @ % GR)	Sodic black clay (Barwaha)			pH_s	EC_e	ESP
	Rice	Wheat	Total			
Control	1.78	4.84	6.62	8.4	2.1	29.0
25	8.63	9.00	17.63	8.3	1.8	23.1
50	18.13	15.12	33.25	8.4	1.6	24.4
25+25	11.30	11.69	22.99	8.4	1.5	16.8
75	25.84	23.09	48.93	8.3	1.7	20.1
25+50	15.18	15.16	30.34	8.4	1.3	16.3
50+25	20.55	18.89	39.44	8.4	2.1	29.0
25+25+25	15.96	13.22	29.18	8.3	1.8	23.1
CD (5%)	9.24	3.88	-	8.4	1.6	24.4

(Source: Sharma et al., 1998)

Studies on relative effectiveness of various amendments revealed that at chemically equivalent rates (80% GR), the sulphuric acid was as effective as gypsum in terms of improving the soil chemical properties over a period of five years during 1970-75 (Table 11). Application of sulphuric acid gave the highest yield of rice (46.3 q ha^{-1}), while the highest yield of wheat (27.5 q ha^{-1}) was recorded with the application of gypsum @ 80% GR.

Table 11. Reclamation effect of different amendments on soil properties and yields (qha^{-1})

Amendment	Dose (% GR)	Black clay soil				
		pH_s	EC_e	ESP	Rice	Wheat
Initial status (1970)		8.7	4.6	50.0	-	-
Control	0	8.4	2.1	29.0	14.6	13.1
Gypsum	40	8.3	1.8	23.1	25.8	21.1
$Al_2(SO_4)_3$	40	8.4	1.6	24.4	26.5	21.2
Gypsum	80	8.4	1.5	16.8	42.0	27.5
H_2SO_4	80	8.3	1.7	20.1	46.2	25.3
Gypsum	100	8.4	1.3	16.3	43.1	27.0

(Source: Sharma et al., 1988)

The physico-chemical properties of sodic Vertisols as influenced by different amendment (Table 12.). Results revealed that application of sulphuric acid recorded the lowest pHs (7.5) and ECs (0.18 dSm^{-1}). Among the various amendments, maximum hydraulic conductivity (4.77 mm hr^{-1}) was noted under gypsum @ 100% GR. Similarly, lowest water dispersible clay (8.0%) and dispersion ratio (0.09) was also recorded with the application of gypsum @ 100% GR.

Table 12. Effect of different amendments (applied @ 100% GR) on physical properties of sodic Vertisols

Amendment	pH_2	EC_e (dSm^{-1})	Hydraulic conductivity (mm hr^{-1})	Water dispersible clay (%)	Dispersion ratio
Control	8.8	9.80	0.05	37.2	0.41
Gypsum	7.9	0.72	4.77	8.0	0.09
Pyrites	8.0	0.31	1.64	32.4	0.36
H_2SO_4	7.5	0.18	2.98	30.4	0.34
$Al_2(SO_4)_3$	7.6	0.27	4.49	8.9	0.09
$FeSO_4$	7.9	0.85	1.59	33.7	0.37
CD (5%)	0.35	0.20	0.97	3.5	0.37

(Source: Verma et al., 1985)

The field experiment was conducted on sodic vertisols at Research Farm Barwaha on to study the effect of pyrites and organic residue on grain yields of rice and wheat during 1985-86 and 1986-87 (Table 13). Results showed that application of FYM 15 t ha^{-1} + Pyrites @ 100% GR gave highest grain yield of rice (39.06 q ha^{-1} in 1985-86 and 33.05 q ha^{-1} in 1986-87) as compared to other treatments. Similarly during the *rabi* season the highest grain yield of wheat crop (20.83 q ha^{-1} in 1985-86 and 31.78 q ha^{-1} in 1986-87) was recorded with the application of FYM 15 t ha^{-1} + Pyrites @ 100% GR as compared to other treatments.

Table 13. Effect of pyrites and organic residues on the grain yield of rice and wheat yields in sodic Vertisols

Treatments	Rice yield (q ha^{-1})		Wheat yield (q ha^{-1})	
	1985-86	1986-87	1985-86	1986-87
Control	1.49	4.50	2.40	6.41
Wheat straw 15 t ha^{-1}	2.45	5.53	4.01	8.01
Wheat straw + Pyrites @ 50% GR	18.11	16.20	10.03	16.69
Wheat straw + Pyrites @ 100% GR	34.45	27.79	18.33	30.98
Groundnut husk 15 t ha^{-1}	2.53	7.07	4.27	7.35
Groundnut husk + Pyrites @ 50% GR	19.99	16.71	11.08	18.03
Groundnut husk + Pyrites @ 100% GR	36.22	26.88	16.83	30.45
FYM 15 t ha^{-1}	3.27	8.10	4.27	7.88
FYM 15 t ha^{-1} + Pyrites @ 50% GR	25.54	20.32	12.02	19.10
FYM 15 t ha^{-1} + Pyrites @ 100% GR	39.06	33.05	20.83	31.78
Pyrites @ 50% GR	18.11	17.42	12.42	16.29
Pyrites @ 100% GR	31.61	29.32	18.16	29.25
CD (5%)	3.92	2.50	2.01	1.18

(Source: Sharma, 1988)

The experiment on use of distillery waste (spent wash) was conducted in randomized block design with nine treatments and replicated thrice during *kharif* season of 2010 and 2011 at Salinity Research Station, Barwaha (Khargone) M.P. with soybean (var. 9305). The experimental soil belongs to fine montmorillonitic hyperthermic family of typic heplusterts (sodic phase). The soil was sodic Vertisols with pH 8.5, EC 1.4 dSm^{-1} and ESP 40. The treatments comprised of control, FYM @ 5 t ha-1, vermicompost @ 5 t ha-1, gypsum @75% GR, gypsum @75% GR + FYM @ 5 t ha-1, gypsum @75% GR+ vermi-compost @ 5 t ha, spent wash @ 2.5 lakh L ha-1, spent wash @ 5.0 lakh L ha-1 and spent wash @ 10.0 lakh L ha-1. The treatments were applied once in a year during preceding three years (2007, 2008 and 2009) under paddy-wheat cropping sequence i.e. 30 days prior to transplanting of paddy seedlings for reclamation of sodic soils.

The grain and straw yield of paddy and wheat as influenced by different amendments over control (Table 14). The highest paddy grain (5.78 and 5.02 Mg ha^{-1}) and straw (6.55 and 5.92 Mg ha ha^{-1}) yield was recorded in 10.0 lakh L ha ha^{-1} spent wash level during 2007-08 and 2008-09, respectively, but it was statistically at par with 5.0 lakh L ha ha^{-1}. Further data presented in table 15 showed that maximum wheat grain (4.35 and 4.17 Mg ha^{-1}) and straw (4.97 and 4.47 Mg ha ha^{-1}) yield was recorded in 10.0 lakh L ha ha^{-1} spent wash level during 2007-08 and 2008-09, but it was statistically at par with 5.0 lakh L ha ha^{-1}. Application of amendments significantly decreased the ESP of soil after harvest of wheat. The lowest ESP (17.2 and 17.0) were noticed when 1.0 million L ha^{-1} spent wash was applied which was followed by addition of spent wash @ 0.5 millionL ha^{-1} during 2007-08 and 2008-09, respectively.

Table 14. Yield of paddy and wheat and ESP after harvest of wheat as influenced by different treatments

Treatments	Paddy yield (tha^{-1})		Wheat yield (tha^{-1})		ESP
	Grain	Straw	Grain	Straw	
Year 2007-08					
Control	4.00	4.50	2.95	3.00	36.0
FYM (5 Mg ha^{-1})	4.55	5.10	3.03	3.38	35.5
Vermicompost (VC 5 Mg ha^{-1})	4.67	5.23	3.20	6.60	34.4
Gypsum (75% GR)	4.93	5.63	3.57	3.98	23.0
Gypsum (75% GR) + FYM (5 Mg ha^{-1})	5.13	5.83	3.65	4.13	22.0
Gypsum (75% GR) + VC (5 Mg ha^{-1})	5.42	5.92	3.72	4.23	21.3
Spent wash (0.25 million L ha^{-1})	5.43	60.5	3.90	4.43	19.4
Spent wash (0.50 million L ha^{-1})	5.75	6.40	4.27	4.85	17.8
Spent wash (1.0 million L ha^{-1})	5.78	6.55	4.35	4.97	17.2
CD (5%)	0.31	0.33	0.24	0.26	1.39
Year 2008-09					
Control	3.47	3.95	2.17	2.29	35.4
FYM (5 Mg ha^{-1})	3.58	4.12	2.27	2.44	34.6

Vermicompost (VC 5 Mg ha^{-1})	3.67	4.23	2.33	2.54	34.2
Gypsum (75% GR)	4.05	4.70	3.00	3.35	24.5
Gypsum (75% GR) + FYM (5 Mg ha^{-1})	4.27	4.97	3.40	3.49	23.5
Gypsum (75% GR) + VC (5 Mg ha^{-1})	4.35	5.05	3.47	3.55	21.9
Spent wash (0.25 million L ha^{-1})	4.38	5.13	3.52	3.85	19.7
Spent wash (0.50 million L ha^{-1})	4.85	5.70	4.02	4.35	17.1
Spent wash (1.0 million L ha^{-1})	5.02	5.92	4.17	4.47	17.0
CD (5%)	0.43	0.53	0.48	0.40	1.6

(Source: Khandkar et al., 2017b)

The soybean crop was raised under same plots after three years without any treatment after reclamation with the use of distillery waste i.e. spent was during the year 2007, 2008 and 2009. Data presented in table 15 revealed that higher number of pods/plant (29.30) and seed index (11.07 g), seed (2.48 t ha^{-1}) and straw (3.05 t ha^{-1}) yield of soybean were recorded with the application of spent wash @ 10.0 lakh L ha^{-1} over other treatments except spent wash @ 5.0 lakh L ha^{-1}.

Table 15. Yield attributes and yields of soybean as influenced by different amendments

Treatments	No. of pods/plant	Seed index (g)	Seed yield (t ha^{-1})	Straw yield (t ha^{-1})
Control	14.34	8.50	0.87	1.06
FYM (5 Mg ha^{-1})	16.67	8.64	0.96	1.23
Vermicompost (VC 5 Mg ha^{-1})	18.84	8.74	1.07	1.28
Gypsum (75% GR)	23.24	9.29	1.53	1.85
Gypsum (75% GR) + FYM (5 Mg ha^{-1})	24.14	9.38	1.60	1.96
Gypsum (75% GR) + VC (5 Mg ha^{-1})	24.40	9.41	1.74	2.07
Spent wash (0.25 million L ha^{-1})	25.65	9.60	2.00	2.28
Spent wash (0.50 million L ha^{-1})	28.10	10.82	2.30	2.87
Spent wash (1.0 million L ha^{-1})	29.30	11.07	2.48	3.04
CD (5%)	2.34	0.30	0.25	0.26

(Source: Khandkar et al., 2012)

The data in Table 16 showed that the grain and straw yield of paddy as well as wheat increased significantly due to application of amendments over control. Addition of LS 5 t ha^{-1} + RSW @ 2.5 lakh L ha^{-1} significantly improved grain and straw yield of both the crops as compared to gypsum @ 75 % GR as well as LS @ 10 t ha^{-1} and PM @ 5 t/ha application. Highest grain (2.98 and 3.49 t ha^{-1}) and straw (6.35 and 4.72 t ha^{-1}) yield was noticed in case of LS 5 t ha^{-1} + RSW @ 2.5 lakh L ha^{-1} application in respective crops. ESP of post harvest soil was reduced significantly with the application of different amendments. Lowest values of ESP were observed under the application of Lagoon Sludge @ 5 t ha^{-1} +Raw Spent Wash @ 2.5 lakh L ha^{-1} after harvest of paddy and wheat.

Table 16. Yield of paddy and wheat and ESP after harvest of crop as influenced by different treatments

Treatments	Paddy yield (tha^{-1})		Wheat (tha^{-1})		ESP	
	Grain	Straw	Grain	Straw	Paddy	Wheat
Control	1.40	2.97	1.99	2.69	36.4	36.1
GR @ 75 %	2.33	4.95	3.08	4.14	22.0	21.2
RSW @ 5 lakh L/ha	2.60	5.52	3.35	4.50	19.1	18.6
LS @ 10 t/ha	2.22	4.71	2.86	3.84	23.0	22.5
PM @ 5 t/ha	2.14	4.57	2.70	3.63	25.9	25.5
LS @ 5 t/ha +RSW @ 2.5 lakh L/ha	2.98	6.35	3.49	4.72	16.5	16.1
PM @ 2.5 t/ha +RSW @ 2.5 lakh L/ha	2.46	5.29	3.27	4.45	20.2	19.9
SEm±	0.05	0.09	0.06	0.08	0.49	0.42
CD (5%)	0.14	0.26	0.17	0.24	1.46	1.23

(Source: Anonymous (2014-15)

Recent Technological Approaches of Reclamation

Microbial reclamation: It is important to find out alternative option in place of amendments like gypsum, pyrites etc. for reclaiming sodic soils as both their availability and cost can be a bottleneck. Microorganisms are able to survive in extreme soil physical and chemical environments. It is a fact that the potential of using microbes for a multitude of activities is heavily underutilized. Paikray and Singh (2012) have developed a consortium of microorganisms (fungi and bacteria) along with molasses and farm yard manure that is able to reclaim sodic soils upto deeper layers through removed of excess sodium and its leaching. Removal of sodium that is primary cause of sodicity, improve the soil aggregation and its water holding capacity. The acids produced during the microbial decomposition leads to lowering of pH along with the exchangeable sodium percentage of the soil.

Biotechnological approaches: Biotechnological tools and their application have been developing at a very fast pace and in today's scientific world, gene flow has no barriers. Gene identified for a specific traits in a specific can be easily incorporated into another species with the tools available with the scientists. Powerful new molecular tools for manipulating genetic resources are becoming available, but the potential of these technologies are yet to be fully utilized to introduce new genes for tolerance into current cultivars. Increased salt tolerance requires new genetic sources of this tolerance, and more efficient techniques for identifying salt tolerant germplasm.

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Application of Municipal Solid Waste Compost for Reclamation of Sodic Soils

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Introduction

Salt stress is one of the most serious limiting factors for crop growth and production in arid and semi-arid regions of the world. The addition of organic amendments in conjunction with gypsum is an option to reduce the deleterious impact of sodicity on soil properties. Further, the demand of cattle manure for household energy and narrow window for cultivation of green manure has developed necessity of alternative management practices for the maintenance and enhancement of soil organic matter. Therefore, to mitigate the decline in organic matter content of Asian soils, municipal waste compost (MWC) is gaining interest as an alternate organic amendment source for nutrient supply.

Management of waste has become one of the major challenges in the developing nations like India. Adoption of environment-friendly waste-to-energy and compost production technologies are effective alternatives in reducing the load of waste, their disposal and utilization. Due to several legislative, environmental, economic and social constraints (Adani *et al.*, 2000), management of municipal waste is always questionable. Consequently, the management of the MSW needs to be revamped to accommodate the changes in the quantity and quality to ensure the longevity of the environment.

Application of MSW compost in agricultural soils can directly improves soil physico-chemical properties viz., soil structure, water retention capacity, buffering capacity and nutrient status (Tejada *et al.*, 2006). It provides readily available plant nutrients; stimulates microbial activity and contributes in maintaining organic matter pools. The fertilizer value of MWC can be significant, but varies considerably depending on origin and processing prior to application (Peterson *et al.*, 2003).

Composition of Solid Waste Generated in India

Rapid pace of urbanization and changing lifestyles has led to rising demand of scarce land for waste disposal. This alarming situation has become critical with the passage of time. Over the past few years, solid waste handling has become a major environmental challenge.

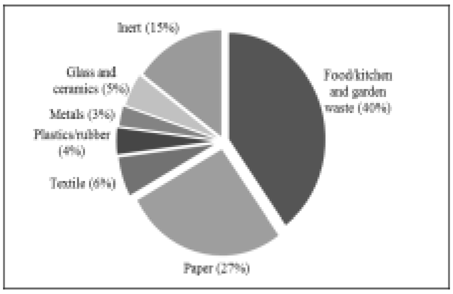

Fig. 1. Composition of Indian Municipal Solid Waste:
(Source: Arceivala and Asolekar, 2012)

In 2009, the Department of Economic Affairs (DEA) reported an approximate generation of 80,000 MT of total solid waste per day in India. It projected that by 2047, India would be producing 260 million tonnes of waste annually needing over 1,400 sq km of landfills (http://www.cseindia.org/). At present, about 62 million tonnes of waste is generated annually in the country, out of which 5.6 million tonnes is plastic waste, 0.17 million tonnes is biomedical waste, hazardous waste generation is 7.90 million tonnes per annum and 15 lakh tonne is e-waste (MoEFCC, 2016). The per capita waste generation in Indian cities ranges from 0.2 to 0.6 µg a day. The estimated annual increase in per capita waste generation is about 1.33 per cent. In 1998, municipal solid waste production in Asia was 0.76 million tons per day with an annual growth rate of 2–3% in developing countries and 3.2–4.5% in developed countries (Jin *et al.*, 2006). Composition of MWC varies widely, depending on the quality of the waste used for its production. Both beneficial and adverse effects of MWC have been reviewed (Epstein, 1997). The chemical composition of MSWC of two different cities is given in table 1.

Table 1. Chemical composition of composts

Parameter	Unit	Karnal compost	Delhi compost	FCO Std
pH $_{(1:5)}$	-	7.32±0.02	7.79±0.01	6.5-7.5
EC $_{(1:5)}$	(dS m^{-1})	10.8±0.05	9.58±0.1	<4
TOC	(%)	10.8±0.1	9.58±0.4	>16.0
Total N		0.64±0.02	0.67±0.02	>0.5
Total P	(mg kg^{-1})	547.61±69	511.27±48	-
C:N Ratio	-	16.4±1.0	14.2±0.9	20 or less
Fe	(g kg^{-1})	16.41±2.68	20.88±1.2	-
Mn	(mg kg^{-1})	234.97±42.7	335.13±76.2	-
Zn		422.07±75.9	826.97±53.3	<1000
Cu		244.33±38.9	614.23±69.4	<300
Cd		1.34±0.7	2.96±0.2	<5.0
Cr		48.52±2.2	173.45±66.5	<50.0
Ni		10.81±6.1	25.56±8.5	<50.0

(Sundha et al., ICAR-CSSRI Annual Report, 2017)

Municipal Solid Waste (MSWC) as Potential Organic Amendment Source

The modern concept of environmental management is based on the recycling, reuse and composting of waste organic sources for reclamation and rehabilitation of degraded soils. MSWC can be used in agriculture to meet crop nitrogen requirements and other plant essential nutrients. Intensive agriculture has led to decline in soil fertility. So, there is need to supply the diminished nutrients back to the soil by integrated nutrient management. In recent decades, the application of organic wastes from different origins (manure, sewage sludge and municipal organic wastes) to degraded soils is a practice that is globally accepted to recover, replenish and increase organic matter, fertility and building greening vegetation and reducing the wide gap between availability. With declining available sources of organic amendments, urban waste could serve the purpose at best. Sodic soils are nutrient deficient and compost amendments will provide essential nutrients (N, P, K and others secondary and micronutrients); it improve soil physical and chemical properties, and enhances microbial populations and activities **(**Bronick and Lal, 2005). The addition of MSWC in conjunction with gypsum has been successful in reducing adverse soil properties associated with sodic soils (Clark *et al.,* 2009). Several researchable issues that could be addressed are:

- Identification of composting or treatment sites, rate of their availability and characterization for further recommendations of safer field applications.
- Optimum application rate of MSWC in different textured salt affected soil to obtain maximum nutritional benefits.
- Because of the presence of both beneficial (nutrients and organic matter) and non-beneficial (heavy metals and soluble salts) components in MSWC, it is necessary to conduct systematically study to find out the impacts of MSWC amendment on plant growth, and on the soil physical and chemical properties through different application rates.
- Amendment and irrigation balance to maximize the nutrient availability to plants and reduced leaching to groundwater.

Reclamation of Sodic Soil using MSWC

Soil salinity and sodicity are the two major environmental concerns leading to land degradation in irrigated areas of arid and semi-arid regions of the world**.** The extent of degraded lands in our country is approximately 146.82 Mha (NAAS Report, 2010). These soils are poor in their organic matter content and offer low productivity which affects the national food security. The extent of salt-affected soil in our country is 6.73 mha land (Singh *et al.,* 2010); sodic soils covering 3.77 mha and saline soils 2.96 mha. The excessive amounts of salts adversely affect soil physical and chemical properties, as well as the microbiological processes resulting in dramatic decline in agricultural production. Reclamation of sodic soils involves the replacement of exchangeable sodium by calcium. The typical source of calcium can be an amendment which provides soluble calcium within the soil. The replaced Na^+ is removed either below the root zone or out of the soil profile by applied water during reclamation. Concerning the rehabilitation of salt-affected soils, a wide array of organic soil amendments, with varying levels of processing and characterization are used in reclamation programme. The use of wastes in agriculture and for land reclamation is increasingly being identified as an important issue for both soil conservation and residual disposal. With the declining availability of farm yard manure, utilization of municipal solid waste could be the alternative options. Increased urbanization and industrialization, especially in developing countries, requires municipal authorities to handle larger volumes waste, often with limited resources.

Research studies have also reported the benefits of using organic materials to remediate salt-affected soils by improving their physical, chemical and biological properties (Tejada *et al*., 2006; Walker and Bernal, 2008). The maintenance of adequate soil physical and chemical properties in salt affected soil may be achieved by using good quality water, rational use of fertilizers, and associated appropriate cultural practices viz., application of adequate quality and quantity of compost.

Improvement in Physico-chemical Properties of Soils

Addition gypsum and MSWC to the surface soil decreases dispersion and decline in EC of the subsoil, compared to the addition of gypsum alone (Vance *et al*., 1998). Pascual *et al*., (1999) observed that addition of municipal solid waste compost (MSW) to the soil improves soil quality for a long period (eight years) after application; therefore, it is a suitable technique for the regeneration of soils in semiarid regions. Tejada *et al*. (2006) reported that the application of MSWC on saline soils could accelerate NaCl leaching, decrease both the exchangeable sodium percentage and electrical conductivity, and increase water infiltration, water-holding capacity and aggregate stability. Moreover, compost application to soil is used to maintain and improve soil structure (Lillenberg *et al.*, 2010) and whole array of nutrients to soil (Zheljazkov and Warman, 2004a) because the organic matter content can counteract the natural decline in intensively cultivated soils. It increases beneficial soil organisms and reduces plant pathogens (Abawi and Widmer, 2000) and improves water holding capacity. Experiment carried out in saline soils with organic amendments showed lower EC in pearl millet field compared to sole RDF (Recommended dose of fertilizer) and treatment with MSWC + 50% RDF decreased salt content by 16% compared with the control at 120 days (Meena *et al*., 2016a). Application of 10t/ha of prepared compost from treatment T7 (MSW+farm wastes+ earthworms+microbes) in combination with gypsum in the sodic soils under rice-wheat cropping system resulted in reduction of soil pH was reduced from 9.80 to 8.84 and organic C content enhanced to 0.32 compared to initial value of 0.13 per cent. The exchangeable sodium percent (ESP) reduced substantially from 78.3 to 28.0 (Singh *et al.*, 2017).

Table 2. Change percent of cations mass (C_M%) compared to control for applied treatments under saline SAR water leaching

Treatment	Calcium		Magnesium		Sodium		Potassium	
	SAR 5	SAR 15	SAR 5	SAR 15	SAR 5	SAR15	SAR 5	SAR 15
GR_{25}	29.7^{ab}	20.2^{d}	43.6^{b}	36.0^{abc}	0.4^{b}	-1.1^{a}	25.3^{c}	3.0^{b}
GR_{50}	24.7^{ab}	83.1^{ab}	80.4^{a}	53.8^{a}	2.9^{ab}	-0.6^{a}	27.9^{c}	3.3^{b}
$GR_{25}F_{10}$	24.5^{ab}	44.8^{bcd}	37.5^{b}	38.6^{abc}	6.0^{ab}	-2.1^{a}	107.5^{b}	25.2^{b}
$GR_{25}F_{20}$	36.1^{ab}	75.3^{abc}	44.6^{ab}	45.9^{ab}	6.6^{a}	1.9^{a}	238.2^{a}	139.9^{a}
$GR_{25}KC_{10}$	26.4^{ab}	32.6^{cd}	55.1^{ab}	19.4^{cd}	4.6^{ab}	-3.2^{a}	26.0^{c}	13.9^{b}
$GR_{25}KC_{20}$	14.1^{b}	55.7^{bcd}	57.8^{ab}	7.4^{d}	5.8^{ab}	0.6^{a}	74.5^{bc}	9.6^{b}
$GR_{25}DC_{10}$	13.6^{b}	67.9^{abc}	60.7^{ab}	21.3^{bcd}	3.2^{ab}	1.2^{a}	48.6^{c}	2.9^{b}
$GR_{25}DC_{20}$	50.9^{a}	101.8^{a}	61.2^{ab}	59.0^{a}	5.9^{ab}	1.5^{a}	115.8^{b}	21.8^{b}
Mean	27.5	60.19	55.1	35.17	4.4	-0.22	83.0	27.47

[Numbers followed by different uppercase letters are significantly different at P ≤ 0.05 by Tukey'smultiple-range test] (Sundha et al., 2018b) GR= Gypsum requirement; F=Farm yard manure; KC= Karnal compost; DC= Delhi Compost

Improvement in Nutrient Availability

Nutrient availability is substantially improved in soils receiving organic amendments. Compared with the unamended soil, soil treated with organic amendments showed apparent increases of organic matter, total N, P, K, Ca and Mg. Salt-affected soils limit crop production because of salinity/sodicity stress and deficiency of plant nutrients and degraded soil structure.

Individual studies carried out in gypsum and MSWC amended saline-sodic soil when leached with different water quality and revealed that reclamation efficiency increased with application of 20 t ha^{-1} organic amendment (MSWC) in conjunction with GR25; likewise change percent of cations mass (C_M%) for Ca was greater in GR_{25}+Organics (50.9) followed by other inorganic-organic combinations when low SAR water was used for leaching. Similarly, higher doses of organic amendments also showed significantly greater leaching of Ca even for the high SAR water used for leaching (Sundha *et al.,* 2018b).

Organic amendments of municipal solid waste compost (MSWC) and rice-straw compost (RSC) with and without mineral fertilisers in saline soils resulted in increase in available N, P and K with RSC + 50% RDF compared with the control. Soil treated with RSC + 50% RDF had 14%, 17% and 9% higher N, P and K than soil treated with 100% RDF, after pearl millet harvest in the second year of study. Soil salinity decreased by 55% and 48% with MSWC + 50% RDF and RSC + 50% RDF, respectively, relative to the control at 120 days of pearl millet growth (Meena *et al.,* 2016a)

The low availability of essential plant nutrients in sodic soils is because of scanty vegetative cover and low biological transformation (Kaur *et al.,* 2008). Further, the high pH and exchangeable Na (ESP) inhibit nitrification and promote ammonium volatilization (Rao and Batra, 1983). Applications of gypsum largely improve aeration, infiltration, soil structure and curb the impedance effect of ESP and high pH. But, sole application of gypsum can create disturbance on availability of soil P to plant because of insoluble Ca-P formation (Nayak *et al.,* 2013). In such condition, integration of organic amendments e.g. green manure, farm yard manure has shown increase in reclamation efficiency and availability of nutrients for plant nutrition. Integrated use of gypsum and organics in sodic soil can reduce the harmful impact of sodicity and improve soil fertility for a better crop (Tejada *et al.,* 2006). Gypsum application in sodic soil reduces N and P availability; MSWC application with gypsum can compensate for N and P shortage and reduces the demand of gypsum for sodic soil reclamation (Sundha *et al.,* 2018a). In an soil incubation cum column leaching experiment revealed that GR_{25} and 20 t ha^{-1} MSWC may be practiced for reducing alkalinity and salinity stress of soil and combat the SAR stress of applied irrigation for leaching, besides supplying cations for exchange reaction and liberating organic acids (Sundha *et al.,* 2018b).

Enhancing Soil Biological Activities

Different effects of MSW compost application on soil microbial biomass and activity have been reported by numerous researchers. According to some studies, appreciable amount of heavy metals in characterized MSWC does not seem to have any detrimental influence on microbial biomass and enzyme activities in soil. But there are some reports which show that heavy metals present in MSWC decrease the proportion of microbial biomass C in total soil organic matter. The application of biosolids increases soil microbial biomass and some soil enzymatic activities such as urease, alkaline phosphatase and β-glucosidase linked to N, P and C cycles (Tejada *et al.,* 2006). In fact hydrolytic enzymes are sensitive indicators of management induced changes in soil properties due to their strong relationship with soil organic matter content and quality (Masciandaro *et al.*, 2004). According to Liang *et al.* (2005), the incorporation of organic amendments to soil stimulate dehydrogenase activity providing rapid and accurate information on changes in soil quality. Meena *et al.,* (2016b) evaluated the efficiency of combined use of organic amendments viz. MSWC, gypsum enriched compost (GEC), rice straw compost (RSC) and chemical fertilizers as reclamation agents for improving biological and chemical properties of saline soil in a mustard–pearl millet cropping system. It was found that integrated use of 25% recommended dose of fertilizer (RDF) along with organic amendments (RSC@3.5 t ha^{-1}+GEC@3.5 t ha^{-1}+MSWC@4 t ha^{-1}) resulted in significantly higher amount of microbial activities and organic C and 50 and 56% higher microbial biomass carbon over unfertilized control plot after mustard and pearl millet harvest respectively. Treatment receiving 100% RDF improved dehydrogenase activity (DHA), alkaline phosphatase activity (APA) and urease activity by 39, 26 and 23%, respectively over unfertilized control plot after harvest of pearl millet crop. Besides this, unsegregated municipal solid waste may contain some pathogenic microbes that may cause health hazards if entered into food chain (Fig. 2). The microbial count and pathogen test of urban waste must be carried out to test the presence of pathogenic microbes in compost before application for soil reclamation.

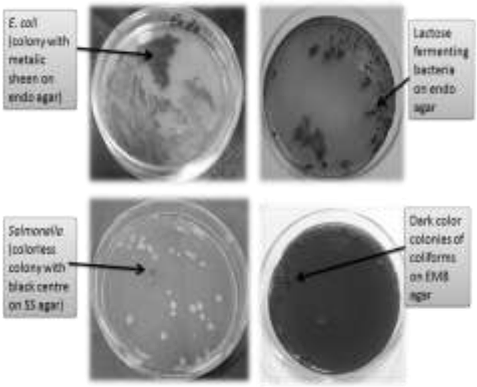

Fig. 2. Microbial count in sewage-sludge and municipal solid waste compost

Impact on Plant Growth

The MSW compost potentially improves growth as reported by researchers. Compost application is an option to improve the growth of ryegrass and tall fescue (Festuca arundinacea) (Park *et al.,* 2011), cultivation of crops such as rice, wheat (Qadir, Ghafoor, and Murtaza 2001), sugarcane (Choudhary *et al.,* 2004), H. maritimum Lakhdar *et al.,* 2008), cotton, and tomatoes (Mitchell et al., 2000). Lakhdar *et al.,* (2012) investigated the effect of composted municipal solid waste (MSW) and sewage sludge (SS) on photosynthetic activity and plant biomass production of wheat (*Triticum durum* L.) and found that 100 t ha^{-1} MSW compost was optimal for the plant growth, which showed 78% stimulation as compared to the control. Other parameters studied were chlorophyll fluorescence and gas exchange parameters at application of up to 300 t ha^{-1} of MSW. Several studies have reported a strong relationship between the higher photosynthetic activity and the adequate nutrient supply provided by MSWC (Chen *et al.,* 2005). The utilization of compost may promote nutrient availability and plant growth, stimulate respiration, photosynthesis (Gurrero *et al.,* 2001), and chlorophyll content (Tejada and Gonzalez, 2006).

Growth of wheat plants cultivated on soil amended with MSW compost was improved due to the positive relationship between nutrient content and photosynthesis (Lakhdar *et al.,* 2008). Similarly, barley yield was significantly higher under 50 t ha^{-1} MSW application (Zhang *et al.,* 2000).

Environmental Benefits: Greenhouse Gas (GHG) Reduction

Greenhouse gas reductions can be quantified when organic wastes are diverted from landfills to composting and processed under controlled conditions. MSW organics buried in a landfill break down anaerobically and produce landfill gas that consists primarily of methane (CH_4) having approximately 25 times the global warming potential of carbon dioxide (CO_2), making landfills a significant contributor to GHG emissions. Recycling of organic matter (OM) to soil provides carbon restoration and humus formation (ICF, 2005). Reductions in chemical fertilizer use as a result of compost applications also provide energy savings.

Socio-Economic Feasibility of MSWC

One of the major problems being faced by cities and towns relates to best possible handling of municipal solid waste (MSW). Growing population in the urban as well as rural areas has worsened the environmental problem arising from unscientific and indiscriminate disposal of municipal garbage. Unscientific method of disposal is causing environment pollution. To restrict such predicaments in near future, reduction in waste generation would be an important factor. If management measures are adopted, 62 million tonnes of waste can be converted into compost. This endless source of compost can be used for the replenish nutrients and reclamation of problematic soils. The composted material could be a potential source of slow release of organic matter and nutrients to the soil that can improve its physico-chemical and biological properties at very cheaper rates. Also the application of organic residues may reduce the need of mineral fertilizers It may even replace traditional farm manure whose availability in areas of intensive agriculture is often very poor. With the declining other available sources of organic amendments, urban waste could serve the purpose at best.

Challenge and constraint in application of MSWC in agriculture: Environmental issues

In addition to the potential beneficial nutrients, some waste materials may also contain non-essential elements, persistent organic compounds and microorganisms that may be harmful to plants (Chukwuji *et al.,* 2005). For instance, the presence of toxic heavy metals in municipal solid waste composts (MSWC) raises serious concerns about the adverse environmental impact as a result of excessive application to agricultural lands (Ayari *et al.,* 2008; Mahvi, 2008). However, repeated compost application can lead to accumulation of trace metals in soils that could eventually contaminate human and other animal food chains (National Research Council, 2003). The addition of MSWC to soils has different effects on metal availability, depending upon the particular metal, the soil, and the characteristics of the organic matter added, particularly the degree of humification (Walker *et al.,* 2004). The regular practice of this may also cause the problem of percolation of leachates that may contain the toxic compounds into the deeper layers of soils, thereby contaminating the groundwater as well as the soil of the area. However, the main constrains remain the possible accumulation and eventual transfer of contaminants into the crops and soils. Here is a big issue of research to study the solubility of heavy metals in the leaching solutions, their mobility and migration in the soil and their potential release into the environment.

Way forward

According to the recent advancements, Department of Fertilizers, Ministry of Chemicals and Fertilizers should provide market development assistance on city compost and ensure promotion of co-marketing of compost produced from MSW. Also, the Ministry of Agriculture should provide flexibility in Fertilizer Control Order for the manufacture and sale of compost, propagating use of compost on agricultural land, set up laboratories to test quality of compost produced by local authorities or their authorized agencies. Knowledge of how nutrient availability is affected in gypsum and municipal solid waste compost amended saline-sodic soils is important in adopting apt management practices to satisfy plants' nutritional needs and improve yields.

The studied literature revealed that organics from municipal composts affects the availability and mobility of heavy metals in the soils by reducing the bioavailability of heavy metals in soils by adsorption or forming stable complexes with humic substances, thus decreasing the proportion of the metal in the extractable fraction whereas in other studies OM dissolved in soil solution can supply organic chemicals to serve as chelates and increase metal bioavailability (Kaschl *et al.,* 2002). This mechanism may contribute a different picture under sodic soil conditions. This could be better understood through laboratory and field experiments. The composition of organic amendment, its degree of maturation and its influence on soil chemical properties, as well as the pattern of decomposition may orientate metal availability in the upper soil or taken up by plants and re-entrance in the food chain or metal leaching through the soil profile and groundwater pollution (Narwal and Singh, 1998; Almas *et al.,* 1999) are areas of further research.

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Climate Smart Technologies for Rice-wheat Cropping System in North Western India

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Introduction

In South Asia, home to about 1.5 billion people, slowdown in the growth rate of cereal production and increasing population pressure have emerged as formidable challenges for the future food and nutritional security. These challenges will be more intense under emerging scenarios of natural resource degradation, energy crisis, volatile markets and risks associated with global climate change. During 1965 to 2015, in process of achieving multi-fold increase in crop production in the region, inefficient use and inappropriate management of non-climate production resources (water, energy, agro-chemicals) have vastly impacted the quality of the natural resources and also increased vulnerability to climatic variability affecting farming adversely. The natural resources in South Asia especially Indo-Gangetic plains (IGP) are 3-5 times more stressed due to population, economic and political pressures compared to rest of the world. This can potentially add to adversity of climatic risks, making a large number of people in the region vulnerable to climate change. Business-as-usual scenarios of population growth and food consumption patterns indicate that agricultural production will need to increase by 70 percent by 2050 to meet global demand for food. The impacts of climate change will reduce productivity and lead to greater instability in production in the agricultural sector (crop and livestock production, fisheries and forestry) in communities that already have high levels of food insecurity and environmental degradation and limited options for coping with adverse weather conditions. As agriculture accounts for up to 30 per cent of global greenhouse gas emissions, it's crucial that Climate Smart Agriculture is developed to achieve future food security and climate change goals. By promoting agricultural best practices, particularly Integrated Crop Management, conservation agriculture, intercropping, improved seeds and fertilizer management practices, as well as supporting increased investment in agricultural research, CSA encourages the use of all available and applicable climate change solutions in a pragmatic and impact-focused manner. Resilience will be key, but 'climate smart' is broader and underscores the need for innovation and proactive changes in the way farming is done to not only adapt but also mitigate and increase productivity sustainably. The agricultural sector can be an important part of the solution to climate change by capturing synergies that exist among activities to develop more productive food systems and improve natural resource management. Climate-smart agriculture is rooted in sustainable agriculture and rural development objectives which, if reached, would contribute to achieving the Millennium Development Goals (MDGs) of reducing hunger and improved environmental management. Sustainable utilization of natural resources will require management and governance practices based on ecosystem approaches that involve multi-stakeholder and multi-sectoral coordination and cooperation. This is a crucial element for the transformation to climate-smart agriculture. More productive and resilient agriculture is built on the sound management of natural resources, including land, water, soil and biodiversity. Conservation agriculture, agroforestry, improved livestock and water management, integrated pest management and ecosystem approaches to fisheries and aquaculture can all make important contributions in this area.

The production intensification in India during 'Green Revolution' has been guided by: (a) the improvement of genetic potentials of crops; (b) greater application of external inputs of agrochemicals for plant nutrition and pest; and (c) increased network of irrigation and mechanization. In agriculture production systems, the implicit assumption with this approach is that if more output is required, then more inputs must be applied. This approach is now known to be ecologically intrusive and economically and environmentally unsustainable, and leads to soil and environmental degradation and sub-optimal factor productivities and yield levels that are difficult and expensive to maintain over time. In 1990's, Conservation agriculture (CA) was practiced to foster natural ecological processes to increase agricultural yields and sustainability by minimizing soil disturbance, maintaining permanent soil cover, and diversifying crop rotations. Its approach is to manage agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. This encompasses natural resource management at the farm, village, and landscape scales to increase synergies between food production and ecosystem conservation. As such, its implementation varies considerably depending on the context, and it can include diverse practices such as agriculture and livestock management.In 20th Century, the convergence of CA technologies with other technologies called 'climate smart agriculture (CSA)'was realized to cope with climate change effects and to increase the adaptive capacity of crops, cropping/farming systems while ensuring the food security.

Climate Change and Rice-wheat System

Rice-wheat (RW) is the most important cropping system for food security in South Asia (13.5 Mha), providing food for more than 400 million people (Ladha et al., 2003). The concerns of natural resource degradation and increased intensity of risks associated with weather variability in the intensively cultivated IGP, the food bowl of South Asia, are multiplying. The area under the RW system covers ~32 and 42% of total rice and wheat area, respectively (Saharawat *et al*., 2012) and is almost static and the productivity and sustainability of the system are threatened because of the inefficiency of current production practices, shortage of resources such as water and labour, open field burning of crop residues and socioeconomic changes (Ladha *et al*., 2003; Chauhan *et al*., 2012; Lohan *et al*., 2018). Further, climate change on the one hand, and changing land use pattern, natural resource degradation (especially land and water), urbanization and increasing pollution on the other hand could affect the ecosystem in this region directly and also indirectly through their impacts on climatic variables (Lal, 2016). For example, about 51% of the IGP may become unsuitable for wheat crop, a major food security crop for India, due to increased heat-stress by 2050 (Lobell *et al.,* 2012; Ortiz *et al.,* 2008). Similarly, water table in north western IGP being depleted at 13 to 17 km^3 yr^{-1} (Rodell et al., 2009) due to over-pumping for rice will have serious impacts on rice production. Therefore, adaptation to climate change is no longer an option, but a compulsion to minimize the loss due to adverse impacts of climate change and reduce vulnerability (IPCC, 2014). Moreover, while maintaining a steady pace of development, the region would also need to reduce its environmental footprint from agriculture. Management practices that provide opportunities to reduce GHGs emission and increasing carbon sequestration is required for resilience in production systems (Sapkota et al., 2014). Considering these multiple challenges, agricultural technologies that promote sustainable intensification and adapting to emerging climatic variability yet mitigating GHG emissions are scientific research and development priorities in the region (Dinesh *et al.*, 2015).

In Indian IGP (Indo-Gangetic Plains) as well as in other plains, despite significant success on all fronts of agriculture, it is increasingly being realized that the strategies adopted in the past for faster agricultural growth would require a relook to address the second generation problems of Green Revolution. Rice-wheat cropping system is the dominant cropping system in Indian IGP. The recent agricultural trends have shown the signals of stagnation in production mainly due to decline in factor productivity; degrading soil health; inefficiency of current production practices; scarcity of resources, especially good quality of water and labour; changes in land use, driven by socio-economic factors and resource constraints (good fertile lands going out of cultivation due to urban development and industrial use); and policy fatigue. The problem is likely to be further exacerbated by the climate change. Climate extremes and water scarcity will necessitate growing more food with limited available land and water in coming years. This warrants a growth model that will conserve and sustain its finite natural resources such as land, water and biodiversity while contributing significantly towards meeting the demands for food not only for Haryana but for the whole country.

The problem in rice-wheat systemis further intensified with the inefficient use and mismanagement of production resources, especially water, energy and agro-chemicals. The sharp rise in the cost of energy, diversion of human capital to non-farm sectors, volatility of food prices and climate change-induced vulnerability, pose major challenges to farmers and our society. Overall, the challenge of achieving sustainable productivity with less available resources can only be achieved by adopting CSA technologies which includes agronomic management for increasing resource use efficiency, laser land levelling, direct seeded rice (DSR), use of micro-irrigation, zero or strip tillage, raised bed planting, crop diversification, and developing crop cultivars to adapt under a particular set of environment to tolerate biotic and abiotic stresses.

Climate Smart Agriculture (CSA)

Climate SMART (sustainable management of agricultural resources and techniques) agriculture is an approach of crop production deals with the management of available agricultural resources with latest management practices and farm machinery under a particular set of edaphic and environmental conditions. CSA seeks to increase sustainable productivity, strengthen farmers' resilience, reduce agriculture's greenhouse gas (GHG) emissions and increase carbon sequestration. It strengthens food security and delivers environmental benefits.

CSA includes proven practical techniques *viz*., mulching, intercropping, CA, crop rotation, integrated crop-livestock management, agroforestry, improved grazing, and improved water management and innovative practices such as better weather forecasting, more resilient food crops and risk insurance. CSA may be defined as “agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals.” Thus SMART, if CA implemented at right time with required resources, techniques and knowledge in a particular typological domain, will lead towards food security while improving adaptive capacity and mitigating potential for sustainable agriculture production.

CSA is a holistic concept. It unites numerous issues related to agricultural development and other global development objectives. It covers environmental issues, for example energy and water, as well as social issues, such as gender, and economic issues. Achieving the four dimensions of food security (availability and access to of food, utilization of food for adequate nutrition, and stability of food supply) needs to be the overall goal of food production and distribution systems in developing countries. Multiple components contribute to food security, and adapting food systems to climate change involves a diversity of approaches and resources. The CSA has three pillars i.e. food security; adaptive capacity; and mitigation potential (Fig.1). Climate-smart agriculture strives to sustainably increase productivity and incomes, build resilience and adaptive capacity, and where possible reduce greenhouse gas emissions. It works to enhance the achievement of national food security and development goals. CSA is location specific and tailored to fit the agro-ecological and socioeconomic conditions of a location. Interventions that work in one area may not be applicable in another.

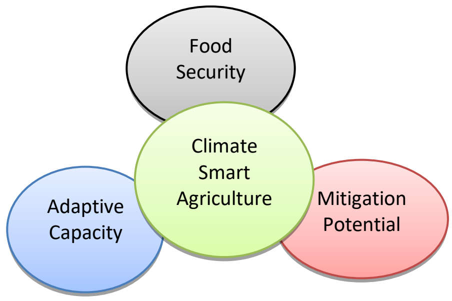

Fig. 1. Pillars of Climate smart agriculture (CSA)

Food Security: CSA is as an approach to farming that seeks to increase food security, alleviate poverty, conserve biodiversity and safeguard ecosystem services. Negative impacts from climate change are likely to be greatest in regions that are currently food insecure and may even be significant in those regions that have made large gains in reducing food insecurity over the past half-century. These notable achievements of Green Revolution in South Asia were largely due to both vertical and horizontal increase in food production owing to use of external inputs such as high-yielding varieties, chemical fertilizer and irrigation. However, recently (at the dawn of 21st century), the problem of food security with added challenges of natural resource degradation has further been surfaced and intensified with indiscriminate use of resources, sharp rise in the cost of production inputs, diversion of human capital from agriculture and shrinking farm size. In South Asia, the ever increasing population growth is interlinked with these challenges and the natural resources in the region are 3-5 times more stressed due to population, economic and political pressures compared to the rest of the world. In the region, the inefficient use and mismanagement of production resources, especially land, water, energy and agro-chemicals, has vastly impacted the health of the natural resource base and contributing to global warning led climatic variability. Studies (Sivakumar and Stefanski, 2011) show that there would be at least 10% increase in irrigation water demand in arid and semi-arid region of Asia with a 1° C rise in temperature. Thus, climate change could result in the increased demand for irrigation water, further aggravating resource scarcity.

Adaptation capacity: Climate change presents a profound challenge to food security and development. CSA practices can contribute to making agricultural systems more resilient to climate change. Ithas been proven to reduce the farming systems’ greenhouse gas emissions and enhance its role as carbon sinks. Adaptation in the agricultural sector is being given a high priority within this effort because of the inherent sensitivity of food production to climate and the strong inter-linkages that exist between climate, agriculture, and economic growth and development. The purpose is to identify and summarize potential climate change impacts on agriculture in regions examine the causes of vulnerability, provide information on where investments are needed to better climate-proof agriculture, and describe the relevance of current efforts to achieve more sustainable agriculture to that of managing climate risks for adaptation.Water, nutrient, carbon, energy, knowledge and weather smart practices are able to quickly respond to critical needs that address the concerns (e.g. adaptability, productivity and climate change) faced by South Asian agriculture (Sharma *et al.,* 2002; Barclay, 2006, Ladha *et al*., 2009; Saharawat *et al*., 2012). The CA based interventions are increasingly being adopted by farmers in the rice-wheat belt of the IGP in South Asia because of several advantages of labour saving, water saving, and early planting of wheat (Gupta and Sayre, 2007; Gupta and Seth, 2007; Saharawat *et al.,* 2010).

Mitigation potential: The problem of food security with added challenges of natural resource degradation, sharp rise in the cost of production inputs, diversion of human capital from agriculture and shrinking farm size. Moreover, while maintaining a steady pace of development, the region will also have to reduce its environmental footprint from agriculture. There are a wide range of CSA based interventions (Table 1) that have the potential to increase adaptive capacity of production system, reduce emissions or enhance carbon storage yet increasing food production. In CSA, besides adaptation measures we need to have a look on mitigation strategies including in agricultural practices. Improved agricultural management enhances resource-use efficiencies, often reducing emissions of GHGs. The effectiveness of these practices depends on factors such as climate, soil type, input resources and farming system. About 90% of the total mitigation arises from sink enhancement (soil C sequestration) and about 10% from emission reduction (Ortiz-Monasterio*et al.*, 2010). Reduction in CH_4 emission from agriculture can, to a large extent, be accomplished by growing rice aerobically by wetting and drying, planting rice on beds, increasing water percolation and DSR. This not only reduces amounts of water application but also reduces CH_4 emissions (Hobbs and Govaerts, 2010). The emissions of oxides of nitrogen also can be reduced through alternate practices of N fertilization management (33% application at planting time and remaining post-planting) matched N fertilization better with crop demand and reduced combined NOx and N_2O emissions by more than 50% and NO_3^- leaching by more than 60% (Matson *et al*., 1998). Optimizing fertilizer application rates and synchronizing them with crop development will further increase yields while reducing costs and emissions of N_2O (Verhulst *et al*., 2011).

Portfolio of Interventions for CSA

The CSA adopts a portfolio of smart interventions that cover the full spectrum of farm household activities. These include water smart practices (rainwater harvesting, laser land levelling, micro-irrigation, raised bed planting, crop diversification, alternate wetting and drying in rice, direct seeded rice), weather smart activities (ICT-based agromet services, index-based insurance, stress tolerant crops and varieties), nutrient smart practices (precision fertilizer application using Nutrient Expert decision support tools, GreenSeeker and Leaf Color Chart (LCC), residue management, legume catch-cropping), carbon smart practices (Legume integration, agroforestry, zero tillage, residue management, land use system, livestock management),energy smart practices(zero tillage, residue management, legumes, DSR. precision water management) and knowledge smart activities (farmer-farmer learning, capacity enhancement on climate-smart agriculture, community seed banks and cooperatives). These interventions work together to increase a community's resilience to climatic stresses while ensuring household food and livelihood security. The idea is to integrate CSA into village development plans, using local knowledge and expertise to develop climate smart villages (CSVs). CSVs are sites where researchers from national and international organisations, farmers' cooperatives, local government leaders, private sector organisations and key policy planners come together to identify which climate-smart agriculture interventions are most appropriate to tackle the climate and agriculture challenges in the village. In South Asia, CSVs were initiated in 2011, first in Haryana and Bihar in India.

Prioritising CSA interventions in NW India

In intensive cereal based systems, the success of alternative, efficient and climate resilient croppingsystems depends on the resource endowments of the region and the full range of activities carriedout by farm households. The selection of CSA practices and technologies was donebased on Village committees comprising of farmers, researchers and local planners in consultationwith local community for prioritising and implementing key climatesmart interventions relevant forthe community as different farmer typologies. Potential benefits of some of the interventions in terms of climate change adaptation are listed in Table 1.

Table 1. Potential benefits of the key climate smart interventions in terms of climate change adaptation relative to conventional practices

Climate smart practices	Potential benefits relative to conventional practices
Laser land levelling (LLL)	Reduce GHG emissions, increased area for cultivation and crop productivity
Zero tillage	Reduced water use, C sequestration, similar or higher yield and increased income, reduced fuel consumption, reduced GHG emission, more tolerant to heat stress
Direct seeding of rice (DSR)	20-30 % Less requirement of irrigation water, time saving, better post-harvest condition of field, deeper root growth, more tolerance to water and heat stress, reduced methane (CH_4) emission
Alternate wetting and drying in rice (AWD)	Reduces methane (CH_4) emission by an average of 48% compared to continuous flooding, reduce irrigation requirement by 15-20%
Sustainable intensification	Efficient use of natural resources (water, soil and energy) , increased income, increased nutritional security, conserve soil fertility, reduced risk
Permanent raised bed planting	Less water use, improved drainage, better residue management, less lodging of crop, more tolerant to water stress
Leaf colour chart (LCC)	Reduces fertilizer N requirement, reduce N loss and environmental pollution, reduced nitrous oxide emission
Nitrification inhibitors	Increase N use efficiency, reduce N loss and environmental pollution
Green seeker	Optimize fertilizer N requirement, reduced N loss and environmental pollution, reduced nitrate leaching
Nutrient Expert-decision support tool	Optimize fertilizer requirement, reduced nutrient losses and environmental pollution, reduced GHG emission
Crop residue management/ mulching	Moderates soil temperature, improves soil quality, reduces soil erosion, reduces evaporation losses and conserves soil moisture, increases C sequestration, avoids burning and reduces environment pollution, increases tolerance to heat stress, reduces weed infestation.
Micro irrigation system	Increases water and nutrient use efficiency, reduces GHG emissions, increased productivity
Agroforestry	Sequester carbon in the soil and prevent soil erosion, enhancing biodiversity, improve the ecosystem
ICT services to access weather and agro advisories	Vital source of information on climate change, weather forecasts, new seed varieties, climate smart farming practices and tips on CA, helps in overall behaviour change towards adapting to climate change and in the uptake of new practices and technology

(Source: Wassmann et al. (2009a, b)

CSA in North-west India

To support food security and boost incomes, agricultural systems in developing countries will be under pressure to increase productivity sustainably and strengthen the resilience of agricultural landscapes. Improved agricultural systems can also potentially emit lower levels of greenhouse gases. Strategies exist to sequester carbon and reduce greenhouse gas emission reductions in the agricultural sector. Many of these strategies also improve food security, foster rural development and help communities adapt to climate change. The IGP contain some of the most productive agricultural land in South Asia, providing staple grain for 400 million people, primarily through a rice-wheat rotation system practiced on 13.5 million hectares. Yields of rice and wheat in this highly intensive system have stagnated and, in some cases, declined over the past few decades (Ladha *et al*., 2003). Wheat is currently near its maximum temperature range, with high temperatures during reproductive growth and grain filling, representing a critical yield-limiting factor for wheat in much of the IGP. Incremental increases in temperature could thus have a large impact. For example, Ortiz *et al*. (2008) estimate that by 2050 approximately half of the highly productive wheat areas of the IGP could be reclassified as a heat-stressed short-season production mega-environment. Rice yields are also expected to be affected, with an estimated decrease of 10 percent for every 1°C rise in night time temperatures (Peng *et al*., 2004).

Rice-wheat system of IGP being important for food security and challenged by projected climate change consequences, A participatory strategic research trials was conducted to evaluate the portfolios of agriculture practices (CSAPs) under six scenarios to understand what combination of practices (portfolio of practices) are more important in terms of maximizing crop productivity and profitability. Rice yield was not different under different scenarios in the first year (2014), but in second year, the higher yield (7.14 t ha^{-1}) was recorded with

CSA-H and found at par with IFP and CSA-M (Table 2). However, in third year, IFP recorded the higher (7.09 t ha-1) and at par yield with other scenarios compared to IFP-AM and CSA-L (Table 2). On 3 years mean basis rice grain yield ranged from 6.73 to 6.90 t ha^{-1} under different scenarios.

Wheat grain yield was influenced significantly with layering of various crop management practices in all the years (Table 2). Climate smart agriculture practices (CSAPs-) produced similar and higher wheat yields across the years compared to FP and IFPs (mean of IFP and IFP-AM). CSA-H, CSA-M and CSA-L recorded 16, 14 and 12% (3 yrs' mean) higher yield compared to that of FP, respectively. Improved farmer's practices (mean of IFP and IFP-AM) and CSAPs (mean of CSA-L, CSA-M and CSA-H), recorded 4 and 14% (3 yrs' mean) higher yield respectively, compared to farmers' practice (FP) (Table 2). The unusual weather reduced conventional-till (FP) wheat yield by 0.84 t ha^{-1} under farmers' practice compared to zero-till (Happy Seeder sown) wheat in CSAPs in first year, whereas, during normal year (second and third year) wheat yield was lowered by 0.6 t ha^{-1} in FP compared to CSAPs (Table 2).Higher system (rice equivalents) productivity was recorded with CSAPs (CSA-L, CSA-M and CSA-H) compared to FPs (FP, IFP and IFP-AM) in all the years except at par with IFP in 2016-17 (Table 2). System productivity was increased by 8, 6 and 4% (3 yrs' mean) in CSA-H, CSA-M and CSA-L, respectively compared to farmers' practice (Table 1). CSAPs and IFPs with varied intensity of adaptive measures increased the system productivity by 6 and 2% (3 yrs' mean) respectively, compared to farmers' practice (11.97 t ha^{-1}).

Table 2. Scenario notations and description of management protocols under different scenarios in rice-wheat (RW) rotation

Scenarios		Tillage	Crop Establishment	Laser Land levelling	Cultivars	Residue Management	Water Management	Nutrient Management	ICT	Crop Insurance
Name	Details									
FP	Business as usual (FP)	CT	TPR with random geometry. CTW using seed broadcasting	No	Pusa44; PBW343	FP, Residue removed	FP	FFP	No	No
IFP	FP with low intensity of adaptive measures (IFP)	CT	TPR with random geometry. CTW using seed broadcasting	No	Pusa44; PBW343	100% of rice and 25% of wheat residue incorporated	FP	FFP	No	No
IFP-AM	IFP with high intensity of adaptive measures (IFP-AM)	RT	DSR sown with MCP. RTW sown with RDD	No	Pusa44; HD2967	Same as in IFP	SR	RDF	No	No
CSA-L	CSA with low intensity of adaptive measures (CSA-L)	RT-ZT	DSR sown with MCP. ZTW sown with HS	Yes	PR114; HD2967	100% rice residue retained and 25% wheat residue incorporated	SR	RDF	No	No
CSA-M	CSA with medium intensity of adaptive measures (CSA-M)	ZT	DSR and ZTW sown with HS	Yes	PR114; HD2967	100% of rice residue and 25% of wheat retained	Tensiometer based	RDF + GS guided N	Yes	Yes
CSA-H	CSA with high intensity of adaptive measures (CSA-H)	ZT	Same as in CSA-M	Yes	PR114; HD2967	Same as in CSA-M	Tensiometer based	NE + GS guided N	Yes	Yes

Where: *FP: Farmer's practice, IFP: Improved farmer's practice, CSA: Climate smart agriculture, CT: Conventional tillage, RT: Reduced till, ZT: Zero till, TPR: Transplanted rice, CTW: Conventional till wheat, DSR: Direct seeded rice, MCP: Multi crop planter, RTW: Reduced till wheat, RDD: Rotary disc drill, ZTW: Zero till wheat, HS: Happy Seeder, SR: State recommendation for irrigation, FFP: Farmer's fertilizer practice, RDF: Recommended dose of fertilizer, NCU: Neem coated urea, GS: GreenSeeker, NE: Nutrient expert based fertilizer recommendation, ICT: Information and communication technology*

(Source: Kakraliya et al., 2018)

The costs of cultivation were mainly attributed to field preparations, fertilizer dose, irrigation and man-days used. Higher cost of cultivation was observed with the FPs compared to CSAPs during all the years (Table 3). Farmers' practice and IFP recorded the highest (USD 934 ha^{-1}; 3 yrs' mean) and CSA-H recorded the lowest (USD 760 ha^{-1}; 3 yrs' mean) cost of cultivation during all the three years. In rice, wheat and RW system, net returns were higher in order of CSA-H>CSA-M>CSA-L>IFP-AM>IFP>FP based on 3 yrs` mean (Table 3). On an average, CSAPs increased the net returns from rice, wheat and RW production by 15, 21 and 19% (3 yrs' mean), respectively compared to farmers' practice (USD 824, 1009 and 1833 ha^{-1}, respectively). Compared to current farmers' practice (FP), CSA-H increased the net return by 21, 24 and 23% (3 yrs' mean) in rice, wheat and RW system, respectively (Table 3). Climate smart agriculture practices (CSAPs) and IFPs improved system profitability by 19 and 5% (3 yrs' mean) respectively, compared to farmers' practice.

Table 3. Effect of management practices portfolios on grain yield, cost of cultivation and net returns under different scenarios during year 2014-15, 2015-16 and 2016-17

Scenarios[a]	Grain yield (t ha^{-1})			Cost of cultivation (USD ha^{-1})			Net return (USD ha^{-1})		
	Rice	Wheat	System[c]	Rice	Wheat	System	Rice	Wheat	System
2014-15									
FP	6.59^{Ab}	4.70^{C}	11.46^{C}	549^{A}	327^{A}	876^{A}	795^{D}	959^{C}	1753^{D}
IFP	6.59^{A}	4.65^{C}	11.41^{C}	549^{A}	328^{A}	877^{A}	794^{D}	947^{C}	1740^{D}
IFP-AM	6.52^{A}	5.31^{B}	12.02^{B}	486^{B}	326^{A}	812^{B}	842^{CD}	1117^{B}	1961^{C}
CSA-L	6.55^{A}	5.44^{AB}	12.18^{AB}	466^{C}	314^{B}	779^{C}	869^{BC}	1163^{AB}	2033^{BC}
CSA-M	6.60^{A}	5.52^{AB}	12.31^{AB}	418^{D}	313^{B}	731^{D}	927^{AB}	1183^{A}	2110^{AB}
CSA-H	6.64^{A}	5.66^{A}	12.50^{A}	402^{E}	311^{B}	713^{E}	951^{A}	1222^{A}	2173^{A}
2015-16									
FP	6.73^{B}	5.19^{C}	12.11^{D}	570^{A}	386^{B}	956^{A}	803^{D}	1023^{B}	1825^{E}
IFP	6.88^{AB}	5.30^{C}	12.37^{BC}	570^{A}	386^{B}	956^{A}	832^{CD}	1055^{B}	1887^{DE}
IFP-AM	6.70^{B}	5.44^{BC}	12.33^{BC}	486^{B}	398^{A}	885^{B}	879^{C}	1081^{B}	1960^{D}
CSA-L	6.71^{B}	5.70^{AB}	12.61^{AB}	477^{C}	348^{C}	825^{C}	891^{BC}	1200^{A}	2091^{C}
CSA-M	6.84^{AB}	5.80^{A}	12.85^{A}	441^{D}	340^{D}	781^{D}	953^{B}	1237^{A}	2189^{B}
CSA-H	7.14^{A}	5.87^{A}	13.22^{A}	426^{E}	334^{E}	760^{E}	1031^{A}	1262^{A}	2293^{A}
2016-17									
FP	6.86^{AB}	5.30^{B}	12.33^{B}	572^{A}	398^{B}	970^{A}	875^{C}	1045^{C}	1920^{C}
IFP	7.09^{A}	5.49^{B}	12.77^{AB}	572^{A}	397^{B}	969^{A}	924^{BC}	1098^{C}	2021^{C}
IFP-AM	6.72^{B}	5.40^{B}	12.31^{B}	490^{B}	410^{A}	900^{B}	929^{BC}	1060^{C}	1989^{C}
CSA-L	6.69^{B}	5.77^{A}	12.66^{AB}	486^{B}	359^{D}	845^{C}	925^{BC}	1212^{B}	2138^{B}
CSA-M	6.76^{AB}	6.00^{A}	12.97^{A}	468^{C}	364^{C}	831^{D}	960^{AB}	1269^{A}	2228^{AB}
CSA-H	6.91^{AB}	6.01^{A}	13.13^{A}	452^{D}	355^{D}	808^{E}	1007^{A}	1280^{A}	2287^{A}
Mean of three years									
FP	6.73^{A}	5.06^{D}	11.97^{D}	564^{A}	370^{B}	934^{A}	824^{E}	1009^{D}	1833^{E}
IFP	6.85^{A}	5.15^{D}	12.18^{CD}	564^{A}	370^{B}	934^{A}	850^{DE}	1033^{D}	1883^{E}
IFP-AM	6.64^{A}	5.39^{C}	12.22^{CD}	488^{B}	378^{A}	866^{B}	883^{CD}	1086^{C}	1970^{D}
CSA-L	6.65^{A}	5.64^{B}	12.48^{BC}	476^{C}	340^{C}	816^{C}	895^{C}	1192^{B}	2087^{C}
CSA-M	6.73^{A}	5.77^{AB}	12.71^{AB}	442^{D}	339^{C}	781^{D}	946^{B}	1229^{AB}	2176^{B}
CSA-H	6.90^{A}	5.85^{A}	12.95^{A}	427^{E}	333^{D}	760^{E}	996^{A}	1255^{A}	2251^{A}

[a]*Refer table 2 for scenario description*

[b]*Means followed by a similar uppercase letters within a column in a given year are not significantly different at 0.05 level of probability using Tukey's HSD test*

[c]*System grain yield was expressed as rice-equivalent yield (t ha^{-1}).*

(Source: Kakraliya et al., 2018)

Conclusion

Climatic events like cold wave, heat wave, terminal wheat, drought, abnormal rains and floods have demonstrated the significant potential of weather factors to influence the production of food crops. Therefore, there is a need for using modern science combined with indigenous wisdom of the farmers to enhance the resilience of modern agriculture to climate change. Development of efficient and diverse cropping systems, CSA based managementcan help in improving the adaptive capacity of the farming system and mitigating the adverse impact of climate change and variability. Resource conserving technologies and alternate land use systems and other biological carbon capture systems can also help in both adaptation and mitigation while maintain the food security sustainably. Climate smart agriculture practices (CSAPs) related to water (e.g. direct seeded rice, laser land leveling, alternate wetting and drying and weather forecast based irrigation), nutrient (e.g. SSNM through nutrient expert tools, green seeker, slow release nitrogen fertilizer), carbon (e.g. residue retention and incorporation), weather (index based crop insurance), energy (e.g. laser land leveling, direct seeded rice, zero tillage) and information and knowledge (e.g. ICTs) have been developed and validated (Jat et al., 2016). However, these CSAPs in isolation may or may not play their potential role in adapting to climate risks and mitigating GHG emissions in RW production system. Therefore, layering of these practices and services in optimal combinations may help in adapting to climate risks and building resilience to extreme weather and climate variability, under diverse production systems and ecologies to ensure future food security.Policy decisions for promotion of clime smart agriculture portfolio of interventions and capacity building for weather and risk forecasting mechanisms and adaptation of climate resilient technologies must be in place both at local and regional level.

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Advance Breeding Techniques for Development of Salt Tolerant Rice Genotypes

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Introduction

Various abiotic stresses like drought, salinity, sodicity, submergence, toxicities of Fe and Al and deficiency of P and Zn limit rice production in about half of the global rice area (Gregorio *et al*., 2002; Lafitte *et al*., 2004). Among these stresses, salinity has a particularly long-lasting effect on plant productivity because transient stresses like drought etc. can be relieved by irrigation; it is extremely difficult to remove salts from agricultural soils. Climate change induced sea level rise is a global phenomenon. The global sea levels are projected to rise continuously at an accelerated rate in the 21st century causing by the thermal expansion of local and regional climatic fluctuations and the melting of glaciers and ice sheets. Thermal expansion is associated with the sea water expansion and it is the effect of high sea surface temperature. The level of the water in the ocean is the result of water volume increase which is caused by increase of sea surface temperature. Sea levels in the Indian Ocean are raising twice the global average due to wind and heat. Sea levels in the North Indian Ocean was rising at the rate of about 0.3 mm a year for decades and from 2004 onwards gained rise of about 6 mm annually (Mimura. 2013). Salinity intrusion due to sea level rise decreases agricultural production of hitherto non saline areas and eventually leads to soil degradation. Salinity also decreases the terminative energy and germination rate of some plants (Rashid *et al*., 2004; Ashraf *et al*., 2002). Ali (2005) investigated the loss of rice production in a case study and found that rice production in 2003 was 1,151 metric tons less than the year 1985, corresponding to a loss of 69 per cent primarily due to conversion of rice field into shrimp pond which allowed introduction of sea water. Practicing shrimp cultivation in saline water decreases rice production due to degraded soil quality. Salinity and alkalinity (sodicity) seriously threaten rice production in south Asia. Improving screening methodologies for identifying sources of tolerance is crucial for breeding salt tolerant rice. Rice genotypes of varying tolerance (tolerant, semi-tolerant and sensitive) were screened in saline soil of electrical conductivity, ECe 4 and 8 dS/m and alkali soil of pH 9.5 and 9.8 in lysimeters. Vegetative growth events were less affected by both the stresses in comparison to reproductive stage. Grain yield was reduced by 26.7%, 45.7% and 50.3% at ECe 8 dS/m in tolerant, semi tolerant and sensitive genotypes, respectively (Krishnamurthy et al., 2014a, Krishnamurthy et al., 2016c). Similarly, at pH 9.8 the reduction was 25.1%, 37.2% and 67.6% in the corresponding three groups. Higher floret fertility contributed to higher seed set and grain yields in tolerant genotypes whereas higher spikelet sterility led to poor seed set and lower grain yields in sensitive genotypes. The 1000 grains weight was also significantly reduced at ECe 4 or pH 9.8. Screening at reproductive stage for morphological traits like floret fertility is thus more useful to identify rice genotypes tolerant to both salinity and alkalinity stress (Krishnamurthy, 2010; Krishnamurthy, 2011). Genotypic (G) and environmental (E) effects and GE interactions were highly significant for the growth attributes and grain yield (Krishnamurthy *et al*., 2016a; Krishnamurthy *et al*., 2016d, Krishnamurthy et al., 2017). The threshold salinity at which the yield of rice is affected can be as low as 3 dSm^{-1} (Maas and Hoffmann, 1977). However, this sensitivity to salt not only varies between genotypes as previously mentioned, but between stages of plant development, as depicted in Fig. 1 for a typical 120-day rice variety. Germination is relatively tolerant, but growth becomes very sensitive during the early seedling stage (1–3weeks), gains tolerance during active tillering, but becomes sensitive during panicle initiation, anthesis, and fertilization, and finally is relatively more tolerant at maturity (Khatun and Flowers, 1995a; Lutts *et al*., 1995; Makihara *et al*., 1999; Singh *et al*., 2004; Shereen *et al*., 2005).

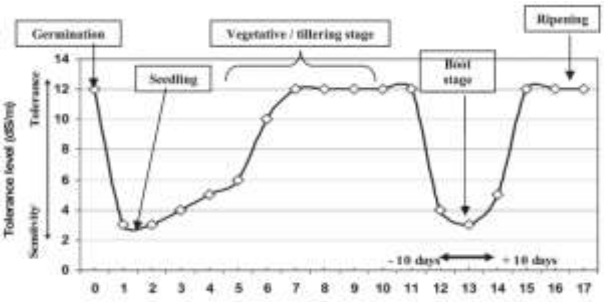

Fig. 1. Rice growth stages vis-à-vis salt tolerance (Singh *et al*., 2008).

Genetic Tailoring of Salt Tolerant Rice

Reclamation of problematic soils by chemical amendments and drainage interventions could be one options but it invariably involves higher costs and community participation which are generally beyond the economic access of poor and marginal farmers inhabiting such areas. Another approach could be genetic improvement of the crop plants for salt tolerance involving conventional plant breeding and recent molecular techniques. Third approach is combination of both approaches. This is perceived to be more realistic, cost-effective, and efficient approach. Recent studies indicate that combination of 25 % GR with salt tolerant rice varieties can achieve almost the same level of yield at just the half of gypsum cost (Singh *et al*., 2016). This is more relevant in view of resource poor farmer's sodic soils. Enormous variability within cultivated rice (*Oryza sativa* L.) for tolerance to soil salinity has been explored and utilized in breeding programme. Therefore, uses of salt tolerant rice varieties are very important to sustain and increase rice productivity and effectiveness in these salt affected eco-systems.

Breeding programs for salt-stressed areas

Salinity tolerance is a complex quantitative trait with less heritability and phenotypic responses of plants to salinity are greatly influenced by environment (Krishnamurthy *et al*., 2015a; Tack *et al*., 2015; Krishnamurthy *et al.*, 2017). The situation is further worsening by the linkage drag in using landraces for transferring salt tolerant genes into traditional local varieties with undesirable traits. In view of drawbacks of traditional breeding procedures, there is an increased exploitation of molecular breeding methods and OMICS approaches. An amalgamation of different approaches would be a valuable strategy for development salt tolerant rice lines.

A. Conventional Approaches

Conventional plant breeding involves introduction, selection and improving genetic makeup of a plant to meet specific needs. Generally conventional breeding involves two fundamental steps. The first step is to generate a breeding population that is highly variable for desirable traits by identifying parents having traits of interest. The second fundamental step involves selection among the segregating progeny for individuals that combine the most useful traits of the parents. (Manshardt, 2004). There were many attempts to enhance tolerance through conventional breeding tools such as the use of in vitro selection, pooling physiological traits, inter-specific hybridization and using halophytes as alternative crops (Flowers, 2004). The challenge is to combine the tolerance traits through breeding to develop stress-tolerant cultivars. There are many success stories as regards the development of salt tolerant cultivars in India and other countries. Conventional breeding methods should not be replaced but be supplemented with biotechnological tools including molecular markers technology. Through recent development in biotechnology, it seems make the breeders or scientists easier to select and produce their desirable traits to be incorporated through recombinant gene (Bonilla *et al*., 2002).

1. Selection and Introduction: Breeding for any trait starts with the assembly of genetic variation through the collection and evaluation of the target germplasm. If sufficient variability is not available within a local germplasm, introduction of the exotic germplasm can be resorted to. This classical approach is still very relevant in all breeding strategies. Few varieties with salinity tolerance have been developed worldwide using selection and introduction approaches. The salt-tolerant rice varieties Damodar (CSR 1), Dasal (CSR 2), and Getu (CSR 3) were pure-line selections from local salt-tolerant traditional cultivars prevailing in the Sunderban areas in West Bengal. Similarly, Jhona 349, SR26B, Bhura Rata 4-10, Patnai 23, Hamilton, and Vytilla 1 were also very site-specific selections from landraces. In the mid-1970s, attempts were made to transfer the salinity tolerance from highly tolerant traditional varieties such as Pokkali and Nona Bokra to the improved genetic backgrounds but the recombinants generated were either not equally tolerant or carried many undesirable traits originating from donors. However, with the development of better screening techniques in the late 1980s, many salt-tolerant rice varieties in the improved backgrounds were developed in different countries following recombination breeding (Gregorio *et al*., 2002).

2. Pedigree Method: This is a classical method in which the lineage of the plant selection in the segregating generation is maintained until it is stabilized in the F_7 or F_8 generation. But, due to cumbersome procedures and the involvement of more resources, breeders are modifying this method and not adhering to it strictly. Many salt tolerant rice varieties have been developed through pediogree method at ICAR-CSSRI, Karnal namely CSR10, CSR13, Basmati CSR30, CSR36, CSR46, CSR49, CSR52, CSR56 and CSR60.

3. Modified Bulk Pedigree Method: A combination of pedigree and bulk breeding methods, this is almost as effective as the pedi-gree method, with relatively less use of resources. It has flexibility and is useful for less heritable traits, with the individual F_2 plants harvested in bulk up to the F_4 or F_5 generations, followed by panicle selection and handling of the population as in the pedigree method. However, for highly heritable traits, the individual plants are selected in the earlier generations (F_2 or F_3), followed by bulking for a few generations and ultimately single-plant or panicle selection in the F_5 or F_6 generations.

B. Non-conventional Approaches

Molecular markers aided selection (MAS): With the availability of a series of DNA based markers such as Restriction fragment length polymorphism (RFLP), Random amplified polymorphic DNA(RAPD), Amplified fragment length polymorphism(AFLP), micro satellites and Inter simple sequence repeats (ISSR) etc., the genetic dissection of recalcitrant traits can be made much simpler, easy and repeatable. Identification of molecular markers tightly linked to salt tolerant genes can serve as landmarks for the physical localization of such genes facilitating marker assisted selection (MAS). In rice, a major gene for salt tolerance has been mapped to chromosome 7 using RFLP markers (Zhang *et al*., 1995). Random amplified polymorphic DNA markers were also shown to be liked to salt tolerance using the same population (Ding *et al*., 1998). Sahi *et al*. (2003) found six novel clones which showed insignificant homology to any of the existing expressed sequenced tagged (EST) database and are differently regulated in salt tolerant (CSR27 and Pokkali) and sensitive (Pusa Basmati 1) rice varieties under salt stress. Several QTLs for salinity tolerance have also been identified (Prasad et al. 2000). Lang et al. (2001) detected one micro satellite marker, RM 223 associated with salt tolerance at vegetative stage. Based on RFLP markers, Koyama *et al*. (2001) have identified the QTLs for Na and K uptake and Na / K ratio. Major QTLs were found on chromosome 6, 4, 1 and 9. IRRI (1997) also reported major gene for salinity tolerance on chromosome 1 which could be similar to the SalT gene of the rice Cornell map. Glenn *et al*. (2002) also tried to construct an AFLP map with the help of 206 markers and found major QTLs for high K absorption, low Na uptake and low Na / K ratio on 5 chromosomes (4, 12, 3, 1 and 10). Haplotypes analysis of Saltol QTL have been used by researchers for improvement of salt tolerance at seedling stage (Krishnamurthy *et al*., 2014b; Babu *et al*., 2014; Krishnamurthy *et al*., 2015b; Choudary *et al*., 2016; Babu *et al*., 2017a; Ravikiran *et al*., 2017). Molecular markers based approach (MAS) has enormous potential to be used as reliable tool to the breeders for the effective, foolproof and early generation screening.

Based on limited segregation analyses and DNA polymorphism pattern, few crosses like CSR27/MI-48 and CSR11/ MI-48, were identified and were used to develop permanent mapping populations called as recombinant inbred lines (RILs). Initially 150 ESTs and SNP markers at 15 centimorgan (cM) distance covering whole genome of about 1500 cM are being used for the identification of the QTLs for salt tolerance. Indeed it is not the breeding methodology but it is the most robust tool which supplements the conventional breeding approach by identifying the recombinants for two or more tolerance mechanisms in segregating populations using molecular marker (Singh *et al*., 2002). Through phenotyping and genotyping of CSR27/MI48 mapping population, a QTL *SSIFSH8.1* conferring higher spikelet fertility, has been identified on chromosome 8 in rice.

MAS has been preferred as the selection through markers that may be carried out at seedling stage with high reliability and precision, the variety development is accelerated through the use of markers and more importantly this strategy is not influenced by environment, there is no need to carry undesired plants till maturity which will permit a more effective breeding design. MAS is practiced in Bulk and Pedigree methods of breeding followed by effective phenotypic screening.

A large number of major and minor QTLs have been identified and mapped for both seedling and reproductive stage salt tolerance on almost all chromosomes of rice genome. QTL mapping but only one major seedling stage, large effect *Saltol* locus located on short arm of chromosome 1 has been prominently used in the MAS programme till date for incorporating seedling stage salinity tolerance. This QTL was mapped in an IR29/Pokkali derived recombinant inbred line (RIL) population showing LOD score of 14.5 and explaining 81% of phenotypic variation. *Saltol* governs three salt related traits namely high K^+, low Na^+ and low Na^+/K^+ ratio (Gregorio 1997). The markers for the mapped region have been developed and effectively used to select positive lines during selection steps. Bonilla *et al*. 2002 indicated the region flanked by RM23 (~10.7Mb) and RM140 (~12.3Mb) whereas Lin *et al*. 2004 described the QTL for shoot K^+ concentration flanked by RFLP markers C1211 (~9.81Mb) and S2139 (~11.28Mb) in NonaBokra/Koshihikari population.

For marker-assisted backcrossing (MAB), the molecular markers are generally employed at three stages. First, the markers aid in the selection of target alleles whose effect was difficult to assess phenotypically and that too at very early stage (*foreground selection*). The second step, *recombinant selection* helps in identifying plants where recombination near the target locus produces target chromosome with minimal donor segment and maximal recipient genome. This minimizes the inclusion of unwanted donor segment to prevent linkage drag. The third step is the *background selection* where the unlinked markers are employed to select plants having recipient genome segments on all chromosomes except the target allele. After two backcrosses, 87.5% average recipient genome recovery is expected. The selection of progenies with maximum recipient background was achieved after two or three backcrossing using molecular markers hence reducing the number of generations required to obtain 98 or 99% recurrent parent genome (Holland, 2004; Frisch *et al*., 1999). The product developed through MAB was a near isogenic line (NIL).

Marker assisted breeding (MAB) is currently used to transfer salt tolerance QTL (*Saltol*) into popular high yielding varieties of many countries of South and South-East Asia. IRRI in partnership with many countries has been utilizing MAB on a wide scale and most of the product/varieties developed are in the advanced stage of testing and release. In most of the cases FL478 (IR66946-3R-178-1-1), a RIL developed from IR29/Pokkali has been used as donor line. In FL478 the *Saltol* region has been introgressed from IR29, the sensitive parent but the salt tolerance was activated due to the presence of positive alleles of IR29 (Walia *et al*., 2005). The *Saltol* fragment was between 10.6 – 11.5 Mb (Kim *et al*., 2009). Alam *et al*. (2011) positioned the *Saltol* region between RM1287 and RM7075. In most of the backcrossing programmes RM8094, RM3412 and RM493 microsatellite markers were giving the best result for foreground selection (Thu Vu *et al*., 2012). Linh *et al*., 2012 used RM 493 and RM3412b for selection in BT7/FL478 whereas Huyen *et al*., 2012 found AP3206f and RM3412 the most informative foreground markers in transferring *Saltol* into Vietnamese variety *AS996*. Bangladesh varieties BR11, BRRI dhan 28 and BRRI dhan 29 have been improved for salt tolerance through the transfer of *Saltol* in collaboration between IRRI and BRRI (Gregario *et al*., 2013). Moniruzzaman *et al*., (2012) improved Binadhan-5 for salinity tolerance by transferring *Saltol* from FL478. IR64-*SalTol* was developed at IRRI whereas Vietnamese variety, BT7 was improved by MAB (Thu Vu *et al*., 2012). A strong IRRI-India Marker-assisted backcross programme is underway in India where six varieties namely Sarjoo 52, Pusa 44, PR114, Gayatri, Savitri, MTU1010 and ADT45 are being improved for seedling stage salinity tolerance. Similarly, efforts are being made to improve basmati rice through MAB (Singh *et al*., 2016). The Saltol QTL have been introgressed in different rice varieties in India (Singh *et al*., 2016; Babu *et al*., 2017; Geetha *et al*., 2017). The currently ongoing MAB programmes are employing dense SNP assays for background selection which gives more precise information of genome recovery and help eventually the breeders in selecting the best recovered NIL. The success of MAB can only be realized if the genotyping is followed by rigorous phenotyping or vice-versa and then selecting the line which is most close to the recurrent parent.

Not only at seedling stage but also QTLs were mapped for reproductive stage salinity tolerance (Ammar *et al*., 2009; Pandit *et al*., 2010; Reza *et al*., 2013). Pandit *et al*., (2010) reported a significant QTL for spikelet fertility (*qSSISFH8.1*) on chromosome 8 in a population of recombinant inbred lines (RILs) derived from cross between salt-tolerant variety CSR 27 and salt sensitive variety MI48. The QTL positions between marker interval HvSSR08-25 (9.27Mb) and RM3395 (10.29Mb) with LOD score 4.17 explaining 8% of the phenotypic variance; the QTL was contributed by MI48. At IIRR, Hyderabad, India, the lines generated from a population of BPT5204/ CSR27 showed the presence of reproductive stage salinity tolerance (personal comm.). Also recently Hossain *et al*. (2014), identified QTLson chromosomes 1, 7, 8 and 10 affecting salinity tolerance at reproductive stage in Cheriviruppu/Pusa Basmati1 derived F_2 mapping population. It is emphasized that introgression of both seedling and reproductive stage salinity tolerance QTLs into major rice varieties will give an overall protection cover for higher yields in salt stressed regions.

Transgenic Approach

Transgenic plants have genes inserted into them that are derived from another species. The inserted genes can come from species within the same kingdom (plant to plant) or between kingdoms (bacteria to plant). In many cases the inserted DNA has to be modified slightly in order to correctly and efficiently express in the host organism. Transgenic plants are used to express proteins like the cry toxins from *Bacillus thuriengensis*, herbicide resistant genes and antigens for vaccinations. Genetic modification of plants is achieved by adding a specific gene or genes to a plant, to produce a desirable phenotype. The plants resulting from adding a gene are often referred to as transgenic plants. Genetic modification can produce a plant with the desired trait or traits faster than classical breeding because the majority of the plant's genome is not altered.

Inspite of the complexity of salt tolerance, claims are common in the literature that the transfer of a single or a few genes can increase the level of tolerance of plants to saline conditions. Transgenic plants are those that contain gene(s) that are artificially inserted from another unrelated organism and commonly known as genetically modified (GM) plants. The world's first transgenic plant was reported in 1983, and most of the transgenics that have been produced were made for herbicidal tolerance especially in soybean and maize. Recent reviews on transgenics in rice provide good overview of the transgenic research for herbicide, biotic, a biotic, and nutritional factors (Cherian *et al*., 2006; Kathuria *et al*., 2007). For salt stress, transgenics have been produced since 1993 (Flowers, 2004) with the preponderance involving Arabidopsis; report transgenic rice with claims for altered salt tolerance. It is apparent from the experiments that increasing the synthesis of compatible solutes such as glycine betaine (Su *et al*., 2006) or proline does enhance growth (Anoop and Gupta, 2003) and yield (Wu *et al*., 2003) under saline conditions.

Improvements in tolerance have also been seen in transgenic plants that express a Na+/H+ antiporter from yeast (SOD2 Zhao *et al*., 2006) and various transcription factors (SNAC1 Hu *et al*., 2006; ZFP252 Xu *et al*., 2008; ONAC045 Zheng *et al*., 2009) as does the production of sedoheptulose-1,7-bisphosphatase in chloroplasts (Feng et al., 2007). However, the expression of some genes can enhance sensitivity to salt (auaporin Katsuhara *et al*., 2003; nonexpressor of pathogenesis-related protein Quilis *et al*., 2008; and the transcription factor OsABI5 Zou et al., 2008). Transgenic technology will undoubtedly continue to aid the search for the tolerance mechanisms, but the complexity of the trait is will be the challenge for this technique to succeed (Flowers, 2004). The TPSP (*Trehalose Phosphate Synthase Phosphatase*) gene discovered from *E. coli*, a bacterium species at Cornell University, USA and reported that effective in conferring tolerance to abiotic stresses like salinity and drought (Garg *et al*., 2010). Transgenic plants accumulated increased amounts of trehalose and showed high levels of tolerance to salt, drought, and low-temperature stresses, as compared to the non transformed plants. These results demonstrate the potential use of transgenic approach in developing new rice cultivars with increased abiotic stress tolerance and enhanced rice productivity. Four *TPSP* transgenic events were evaluated in salinity micro plots in transgenic glass house and for grain yield per plant , ICG A-18 performed better than wild type IR64 (58%) in high salinity (EC_{iw}~10dS/m) conditions (CSSRI, Karnal Annual Reports 2009-10).

The breeding efforts at CSSRI got drive with the identification, selection and introgression of salt tolerance from land races like Damodar (CSR1), Dasal (CSR2) and Getu (CSR3) which were native to the coastal Sunderban areas in West Bengal. These are traditional, tall and photo-sensitive selections which served as donors for salt tolerance for developing high yielding salt tolerant, semi-dwarf and early maturing varieties with better grain quality. CSSRI is pioneer in developing following 7 salt tolerant rice varieties from time to time for various agro-edaphic conditions in India. These varieties possess different agro-morphological and grain quality characteristics which are presented in Table 1. The first systematic attempt to breed salt-tolerant varieties in the early 1980s initiated by CSSRI, Karnal, resulted in the development of the first semi-dwarf, high-yielding, alt-tolerant and early-maturing rice variety, CSR10. It was released in 1989 by the Central Variety Release Committee (CVRC) for sodic and inland saline soils of India. This variety can withstand highly deteriorated sodic (pH2 9.8–10.2) and inland saline (ECe 6–10 dSm^{-1}) soil conditions under the transplanted irrigated management system (Mishra et al. 1992). However, because of its short stature, it is not suited for coastal saline soils where water stagnation is a problem. Its yield potential is 5–6 t ha^{-1} under normal soil and 3–4 t ha^{-1} under highly deteriorated salt-affected soils. Under moderate stress, it can yield from 4 to 5 t ha^{-1} (Dagar *et al*., 2001; Flowers *et al*., 2000).

Table 1 Salt tolerant rice varieties developed by CSSRI, Karnal and their salient features

Name of variety	CSR10	CSR13	CSR23	CSR27	CSR30	CSR36	CSR 43
Parentage	M40-431-24-114/ Jaya	CSR1 / Bas.370 // CSR5	IR64// IR4630-22 -2-5-1-3/ IR964-45-2-2	NONA BOKRA / IR565-33-2	BR4-10 /Pak. Basmati	CSR13/ Panvel 2//IR36	KDML 105 / IR 4630-22-2-5-1-3// IR 20925-33-3-1-28
IET No.	10349	10348	13769	13765	14720	17340	18259
Year of release	1989	1998	2004	1998	2001	2005	2011
Plant height(cm)	85	115	115	115	155	110	100

Maturity days	120	145	130	125	155	140	110
Tolerance limits Salinity (EC_e:dS/m) Sodicity (pH_2)	 <11.0 <10.2	 < 9.0 <10.0	 <10.0 <9.9	 <10.0 < 9.9	 <7.0 <9.5	 <11.0 <10.0	 <9.0 <10.0
Yield (t/ha) Non stress Salt stress	 >6.0 >3.0	 >6.0 >3.0	 >6.5 >4.0	 >6.5 >4.0	 >3.0 >2.0	 >6.5 >4.0	 >6.5 >3.5
Grain type	Short bold	Long slender	Long slender	Long slender	Basmati type	Long slender	Long slender
Recommended ecology	Acts as Biological amendment for highly deteriorated sodic and inland saline soils.	Sodic and inland saline soils of UP, Haryana, Gujarat and Maharastra.	Coastal saline areas of Maharastra. Gujarat, Tamil Nadu, Kerala and West Bengal.	Sodic soils of UP & Haryana and coastal saline soils of Maharasthra, Gujarat, Kerala, TN and WB.	First salt tolerant basmati variety developed f sodic areas of UP, Haryana and Punjab.	Sodic soils of Haryan U.P. and Pondi-cherry	Sodic soils of U.P

Conclusion

Although progress has been attained in developing rice varieties tolerant to salinity, much has yet to be done to fully exploit the productivity increase. First, genetic variation exists in rice germplasm for salt tolerance that could be exploited through breeding. Second, screening and phenotyping techniques have been developed that allow for a more precise estimation of the true genetic worth of both donors and breeding products in terms of tolerance of abiotic stresses. Third, modern tools such as molecular markers and techniques such as marker-aided selection as well as more innovative but conventional diallel selective mating system that allows for a more systematic creation or assembly of the desired genetic variability on which to practice directional selection to obtain desirable genotypes in a precise and rapid manner. Fourth, new varietal release systems are being adopted in countries such as India that facilitate the testing and release of MAS developed products, particularly those involving simple value addition in which single genes or a few genes are integrated into widely adapted genetic backgrounds. Finally, newly developed technology promotion strategies such as farmers' participatory varietal selection and breeding programs should increase the likelihood of adoption for the stress-tolerant varieties in the future. Pyramiding salt stress tolerance with biotic stress resistance yield, and grain quality should bring breeders closer to the accepted goal of producing the rice ideotypes suiting to emerging requirements of farmers, consumers and industry.

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Wheat Improvement for Salinity and Alkalinity Environments

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Introduction

Wheat is the major staple crop after rice in India and cultivated in 30.6 m ha of 29 states (DES, 2017). Out of these states Uttar Pradesh, Madhya Pradesh, Punjab, Rajasthan, Haryana and Bihar accounts for about 87% of the crop area and 91% of production, the rest have marginal share (Ramdas et al., 2012). However wheat basket i.e Uttar Pradesh (1.37 m ha) Madhya Pradesh (0.14 m ha) Rajasthan (0.38 m ha) Punjab (0.15 m ha) Haryana (0.23 m ha) and Bihar (0.15 m ha) are affected salinity or sodicity. According to estimates, the present area under salt-affected soils (6.73 million ha) in country would almost treble to 20 million ha by 2050 (Sharma *et al.*, 2014). In most of the salt-affected environments, prevalence of poor quality (saline and sodic) waters is also noted. The states of Rajasthan, Haryana and Punjab, lying in the north-western arid part of the country, greatly suffer from the problem of marginal quality waters (Singh, 2009). Abiotic stress (soil fertility, soil sodicity/salinity, terminal heat, poor crop strand and waterlogging) cause more that 42% of yield losses in north eastern plain zone (NEPZ). The problem of soil salinity had also caused yield loss of 1.0 qt/ha at the country level. Within NEPZ the yield loss from soil salinity and temporary water logging has been estimated nearly 3.0 qt/ha. Among all the crops, wheat suffered the highest production loss of 4.06 million ton along with monetary loss of Rs. 56.49 billion due to salt stress (Sharma *et al.*, 2015).In this context, concerted efforts to improve salt tolerance in wheat cultivars is highly crucial for enhancing the productivity in land affected by soil salinity, alkalinity and poor quality of waters.

How salt stresses influence the plant growth?

Salt stressis a situation of excess soluble salts in the rhizosphere, which affects the plants growth by increased osmotic pressure of the soil solution, interference in normal nutrient uptake mechanism and also induces ionic toxicity and associated nutrient imbalances.Ionic toxicity resulting from the accumulation of specific ions, such as Na and Cl, in the cytoplasm or apoplast interferes with plant metabolic functions (Greenway and Munns 1980). Under mild salt stress plants increase internal solute concentrations using a portion of their photosynthates and regulate their ionic balance to maintain normal metabolism. For example, uptake and translocation of toxic ions, such as Na and Cl, are restricted, and uptake of K, is maintained or increased. Consequently plants does not show water-deficit symptoms and metabolize normally under low to moderate salinity levels, the additional energy requirements for maintaining normal metabolism driven from photosynthate diversions from growth (Gale and Zeroni 1985). This leads to a reduction in leaf area, light utilization efficiency and, ultimately a reduction in growth and yield. At higher salinity levels plant die due to breakdown of physiological mechanismsand consequent ionic toxicity.

Salt stress triggers a wide range of plant responses, from alterations in gene expression and cellular metabolism to changes in growth rate and crop yield. The duration, severity, and rate at which a stress is imposed all influence plant response. Several other stress(water deficit, elemental toxicity, deficiency and nutritional imbalances and soil texture and structure etc.) in combination with salt stress influence the plant response which may be different from that caused by a single stress. Moreover, resistance and sensitivity to stress depends on species, genotype, developmental stage, and organ or tissue type (Fig. 1).

Plant growth in alkaline or calcareous soils is inhibited by low availability of Fe, Zn, Mn and B. Tolerance to such soils is achieved by mobilization of Fe and Zn via exudation of chelating compounds such as organic acid.However main constraints to plant growth in saline soils are low osmotic potential and ion toxicity (Na, Cl, sulphate) as well as ion imbalances (low K/Na ratio). Salt tolerance mechanisms can be divided into salt exclusion (reduced uptake, increased efflux) and salt inclusion (compartmentation into the vacuole, release of salts via salt glands, antioxidant enzymes) (George *et al*., 2012). To avoid water loss, plants accumulate osmotically active compounds to retain water in the cells. Under osmotic stress plant unable to uptake water from the soil. However plant water availability is determined by the water potential of the soil, which is the sum of matric and osmotic potential, in relation to potential of the root tissues. The threshold value for sufficient water extraction for most plants lies at a soil water potential of around 1500 KPa. This critical value is reached lower for saline soils because of the greater contribution of osmotic potential to water potential. Moreover, at a given ECe, the water potential decreases with decreasing soil water content (Fig. 2).

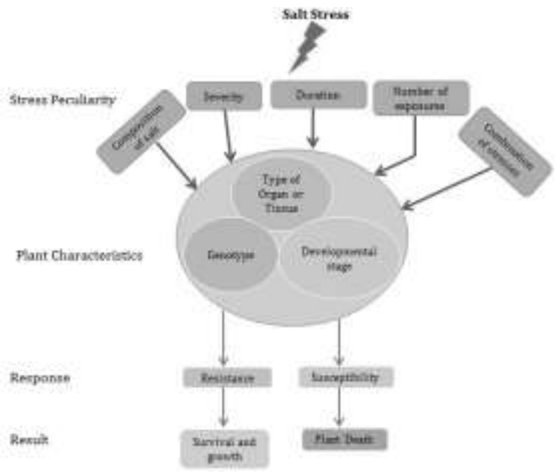

Fig. 1. Response of plants to Salt Stress

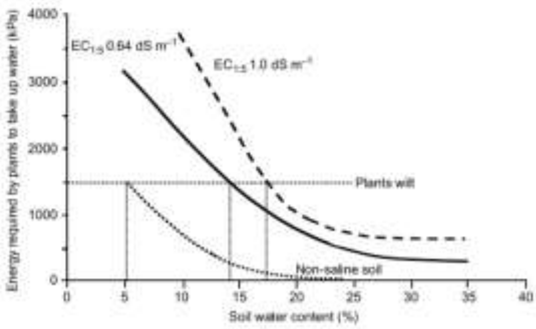

Fig. 2. Energy required by plants to take up water (= soil matric + osmotic potential) from a sandy loam soil at different EC1:5 (EC measured in a 1:5 water extract) and soil water content
(Source: Rengasamy, 2006)

The electrical conductivity of the soil saturation extract (ECe) is commonly used as a measure of soil salinity, i.e. the concentration of soluble salts or solute. Solute concentration and composition is used to estimate the osmotic potential of the solution so that its influence on plant growth is to bepredicted. The electrical conductivity and the osmotic potential of the soil-water extract are directly related (Fig. 3).

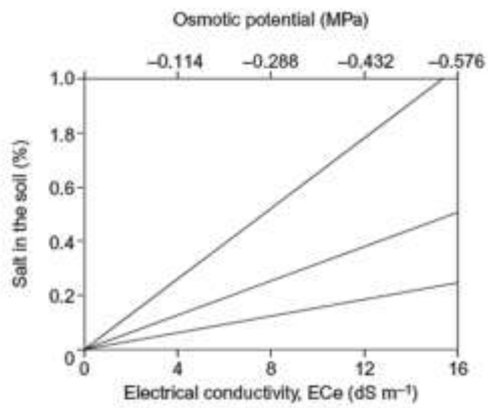

Fig. 3. Relationship between the salt concentration in the soil and the EC for different amounts of water in the paste. Based on US Salinity Laboratory Staff (1954).

Osmotic potential of the soil-water extract can be estimated form electrical conductivity of saturated paste as follow:

$$\text{Osmotic potential } \Psi o \text{ (bar)} = -\ 0.36 \times \text{EC dSm}^{-1}$$

Without the minus sign, the same relation could be used to calculate values for osmotic pressure as well.This relationship works well for soil solution extracts in the range 3–30 dS m^{-1} (Bresler et al., 1982).The concentration of solutes in terms of their ionic strength (I) can also be estimated from EC according to the following expression developed by Griffin and Jurinak (1973):

$$\text{I (mole l}^{-1}\text{)} = 0.0127 \times \text{EC dS m}^{-1}$$

For most soils, the soluble salt concentration in the saturation extract is about one halfthe concentration of the soil solution at field capacity and about one fourth the concentrations atpermanent wilting point (Maas and Hoffman 1977). Researchers observed that seed germination was better in soils with low osmotic potential and was adversely affected beyond 13 bars. Germination enhanced with decreasing osmotic potential. Ion toxicity across the seeds when exposed to various plants was observed in the following descending order: $NaHCO_3$> $Na2CO_3$>NaCl> $CaCl_2$. (Ramakrishanan 1960 and 1973). For most soils, the soluble salt concentration in the saturation extract is about one half the concentration of the soil solution at field capacity and about one fourth the concentrations at permanent wilting point (Maas and Hoffman 1977).

Strategic Framework for Wheat Improvement under Salt Stress

To commence the breeding programme for salt tolerance in wheat following sequence of steps should be considered:

1. **Define the Target region**: Single salt tolerant variety can't not grow in all types of salt affected soilsuniversally. Since concentration and constitution of soluble salt changes depend on the physical and chemical structure of soils and its equilibrium with variable moisture content.

2. **Define the plant growth stage:** By the reason of different sets of genes functioning at different stage of plant development during the stress response. For example in wheat salt tolerance increase with later stage of development, however relatively sensitive to germination and early seedling growth.

3. **Selection of screening methodology:** For salt stress genetic improvement remains a challenging task because of the difficulties in defining precisely the target environment, which is a prerequisite to focusing genetic improvement. Further, serious obstacles to genetic improvement of salinity tolerance are the diversity of physiological mechanisms that determine the level of tolerance to salinity, their multigenic nature of inheritance, and the lack of appropriate screening methodology, appropriate selection criteria for evaluation of germplasm, and segregating material.

Screening in Natural Salt Affected Environments

Field salinity inherently occur in spatial (for examle 4.0 to 40 dS m^{-1} within experimental plot); variation i.e horizontally and vertically and temporal within and between growing seasons. Spatial variation in a saline soil enhanced further by irrigation (Shainberg et al 1984); on the other hand, variable moisture-stress conditions in addition to variable salinity effects exacerbate the variability in plant growth development. Plant roots avoid more saline soil areas and take up water and nutrients from nearby less saline areas (Meiri 1984). Plant growth under such variable saline conditions may be more a result of escape than of genetic differences in tolerance (Blum 1988).Consequently under natural field variability in salinity it is very difficult to evaluate germplasm lines under field conditions. Accordingly effects of environmental variance likely to be moreexceedingthan genetic component, thereby making selection for genetic improvement has to be difficult. Such spatial variability can be reduced to some extant through long plot trials.

LPT (Long Plot Trials): The field gradient of Soil salinity is determined by soil tests at small intervals of space and a long strip running full length across the salinity/ sodicity gradient is allotted to each genotype. The plots generallymeasured 2 to 3 rows of each variety, 20-30m long. This allows exposure of all genotypes to varyingsalt stress conditions to a comparable degree. The layout of these tests are generally of incompleteblock design with a set of check varieties representing resistant and susceptible types is replicatedmany times to take note of general growth conditions, possible mortality owing to reasons other than the salt stress. This method is being used in case of wheat at CSSRI.

Irrigation with Saline Water

Irrigation with saline waters of predetermined composition is also practiced to establish desired soilSalinity levels particularly when relative sensitivity of different growth stages is desired to be compared.The effect of salt stress caused in plants are determined by the salinity levels of the solid liquid phase in the root zone and not by the salinity of irrigation water as suchbecause salinity build-up in the root zone is also related to soil type and other environmental conditions. Hence, periodical monitoring of the soil status is essential. Saline water can also be prepared as in above mention protocol. A soil is considered saline when the ECe is above 4 dS m^{-1} which is equivalent to approximately 40 mMNaCl (Fig. 4). It is assumed that the growth of most crop plant species will be negatively affected at ECe>4 dSm^{-1}. However, the effects of soil salinity also depend on the soil texture, its water content and the compositionof the salts (George *et al*., 2012).

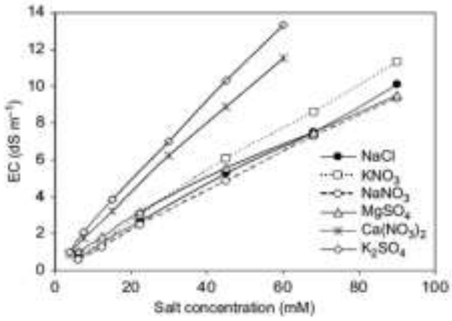

Fig. 4. EC_e at different concentrations of various salts

Controlled Environments

Most researchers use controlled environments, such as greenhouses or growth chambers, for the preliminary evaluation of germplasm lines. This helps to reduce the number of lines to more manageable levels for more rigorous testing at a later stage under controlled-environment or field conditions. Also, selection of breeding materials in early generations involves exposure of plants to salinity in a relatively controlled environment to minimize environmental variance and maximize genetic variance. Plants are then grown in containers with a salinized media. Salt concentrations for selection vary with species sensitivity. For most glycophytic crop plants, the concentrations used for screening range between 50 and 300 mMNaCl (Blum 1988).

Germination trays

In this approach wooden or iron germination tray is being used for screening of large number of genetic resources. They arevery useful in control of salinity, sodicity and moisture. We can alos studied simulation of germination responseand survival rate. Relative delays in germination could also be attended in different genotypes under, Salinity as wellas in sodicity stress.To speed up the screening procedure make more than one run of the same set ofgenotypes or of different sets of genotype can also be taken up within a season. These trays are used for screening of genotypes at seedling stage only.Reduced leaf area, whitish appearance of lower leaves, leaftip death, leaf rolling and seedling death are some of the visual symptoms of salinity stress.

Microplots

A series of dug-out cavity structure has made ofbrick-mortar-concrete materials with the dimension of 2 x 2 x 0.80 meter have been developed at CSSRI Karnal. These structures sometimes called lysimeters. Each micro plot filled withartificially prepared saline soil or Original saline soil of different grades brought from salt affected fields. The mimicry of salinity stress could be helpful to maintain desired levels of sodicity and salinity in these microplotscomparable to field conditions. So that spatial and temporal variability due to salinity stress could be minimize in microplots, because in field experiments local control is used to reduce the experimental error. It is also possible to maintain high level of monitoring of salt flux in the profile of these microplots.Because of a very good control overmicroenvironment, it is highly representative of the genotypic performance.

Choosing the suitable selection criteria

Genotypes may be evaluated for vigor, leaf damage, survival, and ability to grow under saline conditions. A salinity level is chosen to select about 10% of the material for further evaluation over a range of salinity levels. The parameters that might be used in assessing the effect of salinity on a particular species include survival, leaf damage, and vegetative growth and yield. Of courseall parameters are interrelated.

Based on Germination: Selection on the basis of germination tests shows little promise as a means of improving salinity tolerance in subsequent growth stages (Dewey, 1962). However, lack of association does not mean that germination tests are not useful in a salt-tolerance breeding program. In many situations, the ability to germinate and establish a good plant stand in saline soils is an important factor in crop production. However, this depends on the crop under consideration and the associated agronomic practices.

Based on Survival: Plant survival at high salt concentrations, irrespective of their growth rate and productivity under moderate salinity levels, has been proposed as a selection criterion for wheat (Epstein and Norlyn 1977). The ability of a genotype to survive and complete its life cycle at very high salinity levels, irrespective of its yield potential at moderate salinity levels, is considered tolerance in the absolute sense. Also, yield is regulated by a number of genetic factors not contributing directly to salinity tolerance. Once sources of very high levels of salinity tolerance are identified, attempts can be made to combine these with high-yield potential through standard breeding procedures.

Based on Leaf Damage: Most crop plants are glycophytes and, unlike halophytes, cannot tolerate high-salt levels (mainly Na and Cl) in their leaf tissues. Therefore, one important factor in the physiological mechanisms operating in glycophytes is preventing Na and Cl ions from translocation to the shoot. Beyond a certain critical level of salinity stress, this regulation breaks down, resulting in the translocation of large amounts of Na and Cl to the shoot, causing ionic toxicity. Critical levels vary among genotypes, varieties, and crops and usually determine the differences in the level of tolerance. Leaf damage (bleaching or necrosis) is a symptom of a breakdown in ionic regulation. Therefore, selection against leaf damage should lead to the identification of genotypes that have more efficient ionic regulation and other physiological mechanisms that contribute to higher tolerance levels (Subbarao and Johansen 1999).

Based on Growth and Yield: Inherent differences in growth habits of various genotypes do not permit a valid assessment of their relative salinity tolerances using absolute yield or growth criteria at a particular salinity level. For example, a genotype may suffer a severe yield reduction at a given level of salinity and yet yield more than another genotype whose yield is unaffected by salinity (Rawson *et al*., 1988).The crop response to salinity is usually described as a decreasing function with an increase in the ECe of the soil solution. It has been suggested (Maas and Hoffman 1977, Lunin *et al.,* 1963) that a reduction in crop yield due to salinity can be linearly related to the ECe of the soil solution after a certain threshold value of ECe is reached. This can be expressed as:

$$\frac{Y}{Y_{max}} = 1 - b(ECe - a)$$

Where,
Y =yield
*Y*max = yield of nonsaline control
a =salinity threshold value, EC*e*units (dS m^{-1}), that is, the maximum soil salinity that does not reduce yields below those produced under nonsaline conditions
b = slope, the relative reduction per unit salinity increase from threshold

The relative productivity of wheat with increasing salt concentration in the root zone

Relative productivity (Percent) at selected EC_e (dS m^{-1})														Per cent productivity decrease with EC increase	Salinity threshold EC_e
6	7	8	9	10	11	12	13	14	15	16	17	18	19	7.1	6.0
100	93	86	79	71	64	57	50	43	36	29	21	14	7		

(Source: Carter, 1981)

Assessment of genotypic variability for salt tolerance in various traits

Analyses of variability are needed to establish that genetic variability exists and that it can be utilized in breeding. This requires formal studies on the heritability of the stress response and related physiological and morphological characteristics. Varietal testing for salt tolerance often reveals only small differences among the limited numbers of varieties examined, although greater variation for salt tolerance is more likely to occur among species of halophytic origin. Systematic large-scale screening of available gene pools of wheat and barley using hydroponic systems has been attempted with the specific aim of selecting genotypes suitable for seawater culture (Epstein and Norlyn 1977; Kingsbury and Epstein, 1984; Sayed, 1985).Screening plants from germination to maturity using large-scale solution culture systems is the best option for identifying genotypes or genetic materials that are tolerant to salinity at all growth stages. If different genotypes respond differently at different growth stages, however, this suggests that salt tolerance is under separate genetic control at each of the developmental stages. If this is so for the crop under improvement, then genetic sources may need to be identified that possess higher levels of tolerance for each of the growth stages, with the assumption that tolerance at each growth stage could be an independent attribute. It might then be possible to integrate differential tolerances at specific stages into a single highly tolerant cultivar with a high-yield potential.

Initiate hybridization programme to combine various traits from different sources (breeding methods)

Evaluation and breeding work starts with the introduction, collection, evaluation and systematic cataloguing of available India and exotic germplasm. All the conventional breeding methods can be followed i.e. introduction, selection hybridisation, mutation and shuttle breeding approach for the development of salt tolerant varieties. At CSSRI Karnal, four salt tolerant wheat varieties, KRL-1-4 KRL-19, KRL 210 and KRL 283 have been developed and released through CVRC through modified bulk pedigree approach however one variety KRL 213 was developed through mass selection. Where individual F2 plants harvested as bulk up to F4 generation followed by individual plant selection and handling the population as in pedigree method. Other selection approachesi.e. Bulk Method, Selected Bulk, Pedigree and Single Seed Descent can also be followed.

It also was demonstrated that, using cumulative crosses involving a number of tolerant cultivars, one could develop varieties with higher levels of tolerance than their parents. Crosses using two of the most salt-tolerant cultivars have demonstrated overdominance for salt tolerance in F1, and many progeny lines of F3 are far more tolerant than either of the parents (Moeljopawiro and Ikehashi, 1981).

Multilocation testing in salt affected production environment

Efforts made over the last three decades at the Central Soil Salinity Research Institute, Karnal, for the development of salt tolerant varieties in wheat. Various approaches have been taken to improve the salt tolerance of wheat by introducing genes for salt tolerance into adapted cultivars, including screening of large number of landraces and germplasm collections. Extensive testing of advanced breeding materials developed through conventional breeding approaches and selected cultivars were conducted in field conditions as well as in controlled conditions (various levels of salinity and sodicity in microplots).Good success achieved in deployment of salttolerance in high yielding background with the help of conventional approaches. The newly evolved advanced breeding lines were tested at more than ten locations in Uttar Pradesh, Rajasthan, Gujarat, Punjab and Haryana under All India Co-Ordinated Salinity/Alkalinity Trial to test their yield potential in salt affected production environments. Consequently during last three decades seventy three salt tolerant wheat advanced breeding (Viz. KRL 1-4, KRL 2-2, KRL 2-22, KRL 3-4, KRL 4-1, KRL 4-3, KRL 4-4, KRL 5, KRL 6, KRL 7, KRL 8, KRL 9, KRL 10, KRL 11, KRL 12, KRL 13, KRL 14, KRL 15, KRL 16, KRL 19, KRL 20, KRL 21, KRL 22, KRL 23, KRL 24,

KRL 25, KRL 26, KRL 32, KRL 35, KRL 38, KRL 39, KRL 59, KRL 60, KRL 63, KRL 75, KRL 82, KRL 99, KRL 100, KRL 104, KRL 105, KRL 113, KRL 115, KRL 117, KRL 119, KRL 123, KRL 130, KRL 131, KRL 132, KRL 144, KRL 147, KRL 191, KRL 210, KRL 213, KRL 238, KRL 239, KRL 240, KRL 249, KRL 250, KRL 251, KRL 273, KRL 283, KRL 302, KRL 304, KRL 327, KRL 330, KRL 331, KRL 345, KRL 346, KRL 347, KRL 348, KRL 349, KRL 350, KRL 351) were tested in multilocation trials. Out of these four advance breeding lines i.e.KRL1-4, KRL19, KRL210 and KRL213 were released during the year 1990, 2000, and 2010 respectively through Central Variety Release Committee and notified for salt affected area of Uttar Pradesh, Rajasthan, Gujarat, Punjab and Haryana. However one breeding line i.e. KRL 283 was release in the year 2015 by State Variety Release Committee and notified for salt affected area of Uttar Pradesh. Furthermore three salt and waterlogging genetic stocks have been registered with NBPGR, New Delhi. KRL 35 registered in the year 2004, for salt tolerance and it has also been rated as the genotype most tolerant to B toxicity. KRL 99 registered in the year 2007 for salt and waterlogging tolerance and it has been shown excellent performance under 15 days of waterlogging after 22 days of sowing at high sodicity (pH_2: 9.5). However KRL 3-4 registered in the year 2009 for salinity, sodicity and waterlogging tolerance. It has shown high level of tolerance for sodicity, salinity and waterlogged sodic conditions in comparison to 'Kharchia 65' the most salt-tolerant landrace of wheat in the world. Excellent performance under waterlogging for 20 days after 22 days of sowing has also been observedin KRL 3-4. The superiority of KRL 3-4 over Kharchia 65 was confirmed by the fact that Kharchia 65

Could not survive the rigours of stress at pHs 9.80 beyond 40 days of sowing, whereas KRL 3-4 not only survived but provided grain yield also. KRL 3-4 and Kharchia 65 maintained relatively lower Na and higher K levels and lower Na/K ratio in their different plant parts and these features enabled to them to avoid the ion toxicity under sodic stress to a large extent.These elite lines maintained at CSSRI, Karnal and frequently used as donors or recipient in wheat improvement programme for salt and waterlogging tolerance. In that way, these will be aiding us to tailor and develop the desired genotypes suitable for salt and waterlogging situations.

Factors Affecting Salt Tolerance in Crop Plants

Growth stage response: Information on the growth-stage response to salinity within a crop is important in adopting suitable genetic and management strategies for saline soils.The plant's ability to respond to salt stress depends on the genes that are functioning at the stage of development during which the stress occurs (Epstein and Rains 1987). Thus, salinity effects may vary depending on the growth stage at the time of stress. For example that salt tolerance at germination is not consistently related to tolerance during emergence, vegetative growth, flowering, or fruiting. Sensitivity to salinity in durum and bread wheat decreases with age, indicating the importance of keeping soil salinity levels low during germination and seedling emergence (Maas and Poss 1989). One of the reasons for the decreasing sensitivity with age could be a gradual acclimation of the crop to salinity. This indicates that if cowpeas or wheat are irrigated with water containing salt levels below the threshold, before the flowering stage, higher levels of saline Irrigation water could be used at later growth stages without any deleterious effect on yield (Maas and Poss 1989**)**. This would complicate the screening and selection process, if it is based on a single growth stage.

Environmental interactions: Interactions between salinity and soil, water, and climatic conditions change the plant's ability to tolerate salinity. A basic understanding of the interactions between salinity and the environment is necessary for an accurate assessment of salt tolerance. In addition to precipitation, temperature and atmospheric humidity can markedly influence salt tolerance. Many crops are less tolerant when grown under hot dry conditions than under cool humid conditions (Maas and Hoffman 1977). This is mainly due to decreased ion accumulation and/or improved plant water relations (Leary 1975, Salim 1989). In wheat, a higher transpiration rate occurred at low RH and high temperatures, thus increasing the mass flow of salts into the transpiration stream and their accumulation to toxic levels in the shoot. Further, salts may accumulate in the rhizosphere with increased transpiration (Sinha and Singh 1976).

Effects of different salts compositions: Specific ion toxicity is the primary cause of plant mortality at higher levels of salinity (Levitt, 1980). Different salts have different threshold osmotic concentrations for injury, and the relative toxicities of specific salts are not constant for all crop plants under all conditions (Levitt, 1980). For example, cotton, rice, and wheat are less resistant to NaCl than Na_2SO_4 salinity (Strogonov *et al*., 1963, Tur *et al.*, 1980, Verma *et al*., 1981), but *Phaseolus*, guayule, flax, and chickpea show the reverse relationship (Sharma and Gupta 1986; Sheoran and Garg 1983). Alfalfa is more affected by Na_2SO_4, K_2SO_4, and NaCl salts than $MgCl_2$ and $MgSO_4$ salts (Redman, 1974).Beans and wheat are more affected by $CaCl_2$ compared with NaCl salinity (Bernstein, 1964; Aceves *et al*., 1975), whereas the response is the opposite with corn (Sharma and Gupta 1986). Mung bean and red kidney bean were equally affected by NaCl, Na_2SO_4, KCl, and K_2SO_4 (Sheoran and Garg 1978; Gauch and Wadleigh, 1944). For many crops, carbonates are more toxic than Cl^- and/or SO_4 (Sharma and Gupta, 1986).

Conclusion

Traditional breeding approaches can be used for genetic improvement in salinity tolerance ina target crop species.More concerted attempts should be made to integrate physiological research in plant salinity tolerance with genetic aspects so that a combined physiological-genetic approach may be realized. Biotechnological approaches,will play a more prominent role than hitherto in the development of salt-tolerant crop varieties.

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Development of Indian Mustard and Soybean for Salinity Tolerance

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Introduction

Salinity is one among the major environmental stresses which negatively affects plant growth and productivity across the world. Around the globe, one billion hectare area is affected by salt stress (Fageria *et al.*, 2012). Further, arid and semi-arid areas are associated with saline underground water, which has to be used for irrigation due to unavailability or utilization of good quality water to non-agricultural purpose that ultimately makes the soil unfit for crop cultivation (Pons *et al.*, 2011). Crops are affected by multiple stresses due to salinity, including unbalanced nutrient uptake, accumulation of toxic ions, oxidative and osmotic stress (Verslues *et al*., 2006).

Response to abiotic stresses is a very complex phenomenon as various stages of plant development can be affected by a particular stress and often several stresses simultaneously affects the plant (Chinnusamy *et al.,* 2004). An elevated intracellular NaCl concentration due to salinity (soil and water) leads to an ionic and osmotic imbalance that disturbs the delicate cellular ion homoeostasis and water potential, resulting in metabolic disruption, growth retardation and significant yield reduction (Pandit *et al.,* 2011) in all the crops. Soil and irrigation water salinity creates a bottleneck for normal growth and development of crops. The adverse effects of salinity on crops are the reduction in seed germination and early seedling growth, plant height, size and yield by affecting a variety of physiological and biochemical processes (Singh *et al.,* 2014). Recurring incidences of abiotic stresses posed a major challenge for maintaining crop yield. Thus, there is further need to upgrade and genetic enhancement of popular and already develop varieties for maintaining optimum yield levels under abiotic stresses using genomic tools, such as molecular markers and gene profiling methods that can greatly improve the efficiency of breeding programs, and should be fully exploited for conventional breeding initiatives and results in the multi-stress tolerant genotypes of oilseed and pulses for obtaining optimum yield.

Mustard is cultivated worldwide but the major growing countries are India, Canada, China, Pakistan, Poland, Bangladesh, Sweden and France. Among them India is one of the largest rapeseed - mustard growing country, occupying first position with 20% area and second position with 12% share to the global production (USDA, 2014). Mustard is one of the best crop in mitigating the effect of climatic change, greater magnitude of interspecific variation for salinity tolerance, low input requirement, low cost but very healthy oil having good consumer preference and greater scope for improving area and productivity by development of salt tolerant mustard genotype and expansion of cultivation in non-traditional and abiotic stress prone, especially, 6.74 mha salt affected area.

Similarly, Soybean is one of the globe's most important legume crops classed as an oilseed rather than a pulse by the UN Food and Agriculture Organization. United States, Brazil, Argentina, China, India and Paraguay represent more than 87% of global soybean production. Soybean is grown as a *Kharif* crop in India. The top three largest Soybean growing states are Madhya Pradesh, Maharashtra and Rajasthan shared 45, 40 and 8.2% in production, respectively (*http://www.gktoday.in/blog/key-facts-about-soyabean-production-in-india/*). However there is 1.33 mha salt affected area lies in these major growing states [Madhya Pradesh (0.14 mha), Maharashtra (0.61 mha) and Rajasthan (0.38 mha)] out of total 6.74 mha salt affected area of the nation.

Soybean seed is a major source of high-quality protein and oil for human consumption (Katerji *et al.,* 2001). It valued for its high protein (38–45%) and oil content (20%). Approximately 85% of the world's soybean crop is processed into meal and oil, the remainder processed in other ways or eaten whole. The unique chemical composition of soybean has made it one of the most valuable agronomic crops worldwide (Thomas *et al.,* 2003). Its protein has great potential as a major source of dietary protein. The oil produced from soybean is highly digestible and contains no cholesterol (Essa and Al-ani, 2001).

Growth, development and yield of soybean are the result of genetic potential interacting with environment. Soybean seed production may be limited by environmental stresses such as soil salinity (Ghassemi-Golezani *et al.,* 2009). Researchers showed that environmental stresses may hasten the seed filling rate and decrease grain filling duration (Yazdi-Samadi *et al.,* 1977). This can influence final yield of all grain crops such as soybean. Seed filling period is under genetic control and it is sensitive to salt stress (Brevedan and Egli, 2003). Soybean seed protein and oil contents may be also influenced by environmental factors such as salinity (Nakasathien *et al.,* 2000). Relative to other crops little is known about intrinsic ability of soybean to tolerate salt stress. High salt significantly hampered its productivity and imposes negative impacts on growth, nodulation, agronomy traits, seed quality and quantity and thus reduce the yield of soybean. However Threshold limit is 5 dS/m (Maas and Hoffman, 1977; Chinusamy *et al.,* 2005). Hence, there is an opportunity to develop salt tolerant soybean genotype and expanding cultivation in additional to existing cultivated area of 11 mha.

Developments in Mustard Breeding for Salt Tolerance

The development and use of plant species that can tolerate high salt level is important for sustainable crop production on such soils and water conditions and is cost effective. This may be achieved by making use of variations in tolerance both, between and within cultivars.

Classical genetics of salt tolerance in mustard: Exploration of the heritable potential of a certain trait within the existing germplasm for a given crop would supply information on factors such as salt tolerance for breeders. Sinha *et al.* (2002); Kumar and Mishra (2006) and Singh and Sharma (2012) opined that Principal component analysis and Genetic component analysis revealed; higher estimates of GCV, PCV, heritability and genetic advance as percent of mean under saline condition was recorded for main shoot length (40.7, 24.5, 55% and 29.5%, respectively); number of siliqua on main shoot (20.5, 12.4, 35.9% and 17.8%, respectively) and Yield (19.4, 10.6, 46.2 and 24.8%, respectively).

These characters may be controlled by additive genes and could be criteria for improving seed yield effectively merely by selection. The results indicated the involvement of both additive and non-additive gene actions in the inheritance of characteristics. High narrow-sense heritability estimates were observed for Ca^{2+}, K^+, Na^+, K^+/Na^+, Ca^{2+}/Na^+ and stress tolerance index, indicating the prime importance of additive effects in their genetic control.

Molecular basis of salt tolerance in mustard: Molecular mechanism of salt tolerance revealed in the model plants will facilitate identification of candidate genes and development of transgenic plants with salt tolerance in Brassica crops. Overexpression of genes encoding enzymes related to abiotic stresses enhanced crop salt tolerance. Transgenic *B. rapa* spp. chinensis plants expressing a choline oxidase (codA) gene from *Arthrobacter globiformis* showed a significantly higher net photosynthetic rate and a higher photosynthetic rate under high salinity conditions than wild-type plants (Wang *et al.* 2010). Dalal *et al.* (2009) proved that LEA4-1 plays a crucial role in salt stress tolerance during the vegetative stage of *B. napus* and that transgenic *Arabidopsis* plants overexpressing BnLEA4-1 have enhanced tolerance to salt stress. Glutathione (GSH) plays an important role in cell function and metabolism as an antioxidant. Bae *et al.* (2013) developed transgenic plants by introducing the γ-ECS (Glutamylcysteine synthetase) gene from *B. juncea* (BrECS) into rice. Overexpression of BrECS confers plants with significantly enhanced tolerance to salinity by sustaining a cellular GSH redox state to avoid attacks from reactive oxygen species produced by salt. Furthermore, the transgenic rice plants also exhibited a 15–18% increase in grain yield under general paddy field conditions.

Breeding of salt-tolerant Brassica crops: Recently, studies of salt tolerance in plants have covered genetic mapping to molecular characterization of salt-induced genes. Increasing the understanding of biochemical pathways and mechanisms that participate in plant stress responses has made it possible to genetically improve the salinity performance of new varieties through various routes. Currently, transgenic plants have been used to test the effect of overexpression of specific plant genes that are known to be up-regulated by salt stress. Great progress of salt tolerance has been made in major crops, such as rice, wheat and tomatoes. A number of QTLs have been mapped and some important genes have been cloned. However, studies on QTLs or genes controlling salt tolerance in *Brassica* oil crops are still very limited. Researchers and breeders endeavor to understand the mechanisms of salt tolerance and screen for stable salt-tolerant genotypes to use in breeding programs. Attempts have also been made to develop salt-tolerant transgenic *Brassica* crops with candidate genes with proven roles in ion homeostasis and osmolytes accumulation. With the sustained breeding efforts and robust testing of genotypes under salinity and alkalinity stresses in India over the years, five salt tolerant high yielding varieties of Indian mustard (CS 52, CS 54, CS 56, CS 58 and CS 60) have been developed by ICAR-CSSRI, Karnal.

Soybean Research and Development around the Globe

The adverse effect of salinity became pronounced with passage of time and increase in salinity level. Salinity reduced growth, water balance and ion uptake mechanism of plant were affected adversely. (Shereen and Ansari, 2001). A quantitative relationship has been observed between ions and water uptake. the wild soybean was able to maintain higher water potential and relative water content (RWC), accumulate more amount of proline and glycine-betaine, reduce the contents of Na^+ and Cl^- by faster efflux, and cut down the efflux of the K^+ as well as keep higher K^+/Na^+ ratio compared to the cultivated soybean. Wild soybean had different tolerance mechanisms and better salt resistance. It should be used as eminent germplasm resource to enhance the resistant ability of cultivated Soybean (Wu *et al.,* 2014).

The effect of salinity stress on eleven (Co-1, CoSoy-2, DS-40, GujratSoy-1, JS-80-21, MACS-13, MAUS-2, NRC-2, PalamSoy, Pusa-16 and Shilageet) Indian soybean varieties were analyzed under increasing salinity levels (0, 120, 180, 240 and 300 mM) of NaCl. Salinity had adverse effects on germination and all the physiological parameters (root length, shoot length, root/shoot ratio, dry matter production in root and shoot, moisture content in root and shoot) for early seedling growth. The results revealed that varietal difference was present for all the parameters. The varietal difference was pronounced at high (240 and 300 mM) salt concentrations of NaCl. Co-1, GujratSoy-1 and NRC-2 varieties were salt sensitive and CoSoy-2, DS-40, PalamSoy, Pusa-16 varieties were salt tolerant, and rest varieties were moderate in their response to salt (Kondetti *et al.,* 2012).

Classical genetics of salt tolerance in soybean: Abel, 1969 and Shao *et al.* (1994) reported the genetic control of saline tolerance in soybean. A single dominant nuclear gene controls saline tolerance in soybean. The gene symbol *Ncl* was proposed for the dominant Cl^- excluder, whereas *ncl* was proposed for the recessive Cl^- includer. In contrast to above results, Luo *et al.* (2004) reported that minor genes control soybean saline tolerance. The results from these different studies may have been inconsistent because of the differences in the genetic background of parental cultivars and the evaluation method for scoring plant saline stress injury. It was not surprising that no major gene could be detected when two crossed parents contained the same allele in a major tolerance gene locus. Lee *et al.* (2009) studied the inheritance of saline tolerance in wild soybean accession PI483463. They concluded that the wild soybean accession PI483463 had a single dominant gene for saline tolerance, which differed from the gene found in the cultivated cultivar. The symbol *Ncl2* was proposed for this new saline tolerance allele.

Molecular basis of salt tolerance in soybean: The identification of high throughput and robust markers as well as the deployment of salt-tolerant cultivars are effective approaches to minimize yield loss under saline conditions. Patil *et al.* (2016) utilized high quality (15x) whole-genome re-sequencing (WGRS) on 106 diverse soybean lines and identified three major structural variants and allelic variation in the promoter and genic regions of the *GmCHX1* gene. Guan *et al.* (2014) fine mapped a soybean (*Glycine max* (L.) Merr.) population derived from the commercial cultivars Tiefeng 8 and 85–140 to identify GmSALT3 (salt tolerance-associated gene on chromosome 3), a dominant gene associated with limiting the accumulation of sodium ions (Na^+) in shoots and a substantial enhancement in salt tolerance in soybean. GmSALT3 encodes a protein from the cation/H^+ exchanger family that localized to the endoplasmic reticulum and which is preferentially expressed in the salt-tolerant parent Tiefeng 8 within root cells associated with phloem and xylem. The *GmSALT3* has the potential to improve soybean yields in salinized conditions.

However, GmSALT3 does not contribute to an improvement in seedling emergence rate or early vigor under salt stress. When 12-day-old seedlings were exposed to NaCl stress, the tolerant lines accumulated significantly less leaf Na^+ compared with their corresponding sensitive, while no significant difference of K^+ concentration was observed between tolerant and sensitive. These results indicated that *GmSALT3* mediated regulation of both Na^+ and Cl^- accumulation in soybean, and contributes to improved soybean yield through maintaining a higher seed weight under saline stress (Liu *et al.,* 2016).

Recently, a series of studies consistently revealed a major quantitative trait locus (QTL) for saline tolerance located on linkage group N (chromosome 3) around the SSR markers Satt255 and Sat_091; other minor QTLs were also reported. In the case of sodic tolerance, most studies focused on iron deficiency caused by a high soil pH, and several QTLs associated with iron deficiency were identified. A wild soybean (*Glycine soja*) accession with high sodic tolerance was recently identified, and a significant QTL for sodic tolerance was detected on linkage group D2 (chromosome 17). These studies showed that saline and sodic tolerances were controlled by different genes in soybean. DNA markers associated with these QTLs can be used for marker-assisted selection to pyramid tolerance genes in soybean for saline and sodic stresses (Xu and Tuyen, 2012).

Breeding of salt-tolerant soybean: Salt tolerance in cultivated soybean (G. max) was mainly due to prevention of Cl^- ion transport from the roots to the upper portion of the plant preventing toxic accumulation in stems and leaves. In contrast, leaves of salt tolerant wild soybeans (G. soja) were not as susceptible as *G. max* to Cl toxicity but were more susceptible to Na^+ accumulation. Salt tolerance in *G. soja* was primarily from exclusion of sodium ions preventing accumulation at toxic concentrations in stems and leaves. This indicates that interspecific crosses between *G. max* and *G. soja* offer the possibility of improving salt tolerance in soybean cultivars (Lee *et al.,* 2009). Qi *et al.* (2014) identified the salt tolerance gene *CHX1*, which conferred the capacity of lowering the Na+ content in leaves. Using this gene, a subsequent study developed high-throughput SNP markers for salinity tolerance in soybean (Patil *et al.,* 2016). Do *et al.* (2016) isolated gene *Ncl* that regulates ion (Na^+, K^+, Cl^-) transport and accumulation, and demonstrated that higher expression of *Ncl* in the root led to lower ion accumulation in the shoot. These studies indicate that it is feasible to screen for or breed genotypes with an improved capacity of regulating the specific ions responsible for salt tolerance.

Out of 126 soybean varieties released In India till date, none of the variety was released for salt affect area. Now, ICAR-CSSRI has taken initiative in the direction of the soybean breeding for salt tolerance. The main aim is to categorize soybean germplasm for salt tolerance and identification of donors for salt tolerance and its introgression in to high yielding varieties.

For this unique initiative a total of 191 diverse soybean germplasm accessions were collected from different institutes located in the country. Screening of 191 accessions was done at control, EC_{iw} 5.0 and 8.0 dS m^{-1}. Saline irrigation was continued until the harvest of the crop for recording yield. Plant sampling for ionic study was done at the harvesting stage. At maturity, three plants per pot were harvested and air dried prior to recording their grain yield. Seed yield of all the genotypes under different salinity regimes was also recorded. Out of 191 only 108 survived till maturity under saline condition. The higher salinity significantly reduced Seed yield/plant and 100-Seed weight. Whereas, Na/K ratio in root and shoot was significantly increased with increasing salinity levels as compared to control. Similarly, all the 191 accessions were also evaluated under the field sodicity conditions (Control, pH 9.0 and pH 9.3). Out of 191, only 108 survived till maturity under sodic condition. Impact of sodicity was more pronounced on pods/plant and seed yied/plant which significantly reduced these traits.

All the genotypes respond differentially for different traits at stress level. Hence, reaching on a consensus to identify an ideal accession under salinity stress, AMMI Bi-plot analysis was performed. It indicates multiplicative portion of GE interaction into specific pattern of response of genotypes and the environments. Principal components PC1 and PC2 explained the 100% (90.1+9.9%) of interaction effects. The accession G24 (PS 1225), G44 (JS 2029) and G49 (AGS 7513) were considered as stable being falls on base line. G80 (SL 1243) and G83 (SL 1254) are specifically adapted for salinity stress that occur close to particular environments (E2 and E3; ECiw 5 and 8 dS/m, respectively) on the PCA2 vs. PCA1 bi-plot. GGE Bi-plot analysis showed that G24 (PS 1225) is the most ideal genotype as it was located almost on the AEC abscissa and had a near zero projection onto the AEC ordinate. This indicates that its rank was highly consistent across saline environments.

AMMI Bi-plot and GGE Bi-plot analysis also performed for sodicity condition. Principal components PC1 and PC2 explained the 100% (85.1+14.9%) of interaction effects. The accession G57 (SL 1205) and G75 (SL 1234) were considered as stable being falls on base line. G51 (SL 1113), G60 (SL 1210), G68 (SL 1226) and G81 (SL 1258) are specifically adapted for sodicity stress that occur close to particular environments (E2 and E3; pH 9 and 9.3, respectively) on the PCA2 vs. PCA1 bi-plot. GGE Bi-plot analysis showed that no genotype was ideal as none of them was located on the AEC abscissa and had zero projection onto the AEC ordinate.

Hence, there is an opportunity to develop salt tolerant soybean genotype and expanding cultivation in about 13.30 lakh ha salt affected area lies in major producing states of the country (MP, MH and Raj.) additional to 11 million ha.

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Sugarcane Breeding for Salt Affected Soils of Sub-tropical India

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Introduction

In India, salt affected soils area is about 6.73 m ha, out of which 1.9 m ha falls in sub-tropical sugarcane growing states. In sub-tropical sugarcane growing states 1.2 m ha area is saline and remaining is sodic. Saline and sodic soils are also coupled with the problems of water logging, elements and micronutrients toxicity and deficiencies. In view of this, both saline and sodic soils contribute significantly in affecting cane yield and sugar recovery. Sugarcane is considered moderately sensitive to salinity (US Salinity Laboratory staff, 1954) with a threshold for yield reduction at 1.7 dS m^{-1}. Management of salt affected soils and development of salt tolerant varieties is therefore important in increasing sugarcane growing area under these states. Breeding for these target soils will require different strategies depending upon the concentration of excess salts in the soil. The sodic soil contain excess water soluble salts capable of alkaline hydrolysis such as $NaHCO_3$, $NaCO_3$, and sodium silicate and contain sufficient exchangeable sodium salts to interfere with growth of most of plants.These have ≥8.5 pH of saturate paste. Saline soils contain neutral salts (Cl^- and SO_4^{-2} of Na^+, Ca^+ and Mg^{++}). These have ≤ 8.5 pH of saturated paste, more than 4 dS m^{-1} of EC_e and exchangeable sodium percent more than 15%. There is very less information in sugarcane with respect to specific tolerance to different salt affected conditions. High pH soils have been reported for toxicities of Mn, Al, Fe, carbonates, bicarbonates & deficiencies of Ca, Mg & Zn. These soils therefore, affect plant growth in variable manner as per the level of toxicities of different element and micro elements. These influence physiological traits such as chlorophyll content, Na^+ exclusion K^+/Na^+ discrimination and Cl^- exclusion and affect root and leaf elongation, biomass and cane yield. It is therefore required to explore possibilities and plan specific breeding strategy for salt tolerance. Selection efficiency under salt stress is an important factor for breeding as selection at the target site is very difficult due to soil heterogeneity. Thus there is a need for salt stress screening in labs, pots and microplots. It is also required to identify precise growth that limited productivity. Selection under different stress level is also important strategy to find genotypes for wider adoptability. Multiples salt tolerance indices can be workout for comparing different genotypes. Physiological parameters can also be incorporated for better screening of genotypes. Further the knowledge of balance of target soils is important for varietal screening of salt tolerant genotype.

The major concern for breeding under stress is to increase the selection efficiency under stress. Therefore there is need to select genotypes under artificially created environments along with target sites.

Artificial Environments

Selection under natural field conditions or target sites is the best way for better results. However a number of problems limit this sort of selection. Salt affected soils have a lot of variability with respect to salt stress. Artificial environments creation is a much better strategy to take care of soil heterogeneity.

Microplots: Soil heterogeneity and spatial variability hinders the reliability of the response of the genotypes in true and dependable way. At CSSRI mini field environments have been developed with varying levels of controlled salinity and sodicity environments for wheat, rice, mustard and other crops. Simmilarly microplots have been developed at Sugarcane breeding institute Coimbatore to carry out research related to salinity tolerance. Although the plot size is very small but there is good control over micro environment.

Pots: For more precise study of the individual plant response under a constant stress, round porcelain pots of 20 or 30 cm diameter, with a capacity of 8 or 16 Kg. soil with a provision to allow or plug off leaching from bottom, are used for most of the crops however in sugarcane pots of diameter 45 cm with 25 kg soil capacity are required.

Trays: For large scale screening of varieties at germination and seedling stage, shallow-depth wooden germination trays provided with polythene sheet lining on the inner face are being used. They are very useful in control of salinity, sodicity and moisture. They allow a simulation of germination response of the field.

These studies give indications about relative germination and survival rates. These trays are used for seedling stage studies only.

Estimation of salt tolerance: Salt tolerance is the ability of the plant to withstand the effects of high salts in the root zone or on the plant's surfaces without a significant adverse effect. It is a complex function of yield decline across a range of salt concentrations. The salt tolerance in a particular crop can be measured on the basis of the following two parameters.

Threshold EC or pH and salt tolerance index: Crop yields are generally not decreased significantly until the EC_e or pH or ESP exceeds a specific value for each crop. This value is known as the threshold level for that crop which varies widely for different crops. However, the ralative tolerance of a crop is evaluated on the salinity/alkalinity level at which 50% decrease in yield may be expected as compared to yield on normal soil under comparable growing conditions. Threshold EC is the salinity that is expected to cause the initial significant reduction in the maximum expected yield $Y_{max.}$

Germination studies as selection criteria: Large number of investigations on differential responses of crops or varieties has been reported at germination stage and attempts have been made to utilize this information in extrapolating tolerance limits for the final performance of those crops or varieties. More than often such attempts are likely to be frustrating because tolerance characteristics at the two stages may be quiet unrelated, for example in our experiments, we have found that one variety is comparatively more tolerant at germination but another variety is relatively better than that for grain yield. Therefore, the tolerance of crops/varieties has to be assessed in relation to the specific component and specific situation at particular stage of plant development and trait which is responsible for the economic yield. Standardization of screening techniques is an essential pre-requisite before the screening is undertaken and plant variables are adequately monitored so that performance of a genotype is suitable assessed. The evaluation can be made by measuring different parameters like germination under salt stress, absolute yield under salt stress and yield and growth under salt stress conditions compared to be performance under normal soil conditions.
Soil salinity/alkalinity may affect germination by increasing the osmotic pressure of soil solution to the point that will restrict the intake of water. These retard/prevent the germination, resulting in poor stand of the crop. Among the vegetative growth phase, seedling stage is the most efficient stage for screening large number of genotypes for salt tolerance. Germination rate is another way to distinguish between genotypes under stress. Germination rate or emergence rate is calculated as emergence index. Genotypic values of this index are calculated as follows:

$$\frac{\text{Percentage of emerged seedlings}}{\text{days to first count}} + \frac{\text{\% of additionally emerged seedlings}}{\text{days to second count}} + \frac{\text{\% of additional emerged seedlings}}{\text{days to final count}}$$

The values obtained at each count are summed up at the end of the germination test to obtain the emergence index. With the help of these values, it is possible to differentiate between two genotypes which are having some value of germination percentage under same salt stress conditions. Means faster in germination is considered to be better under salt stress conditions.

Physiological Parameters for Salt Tolerance

The concentration of toxic ions increases in the saline solution. For example, Na^+ concentration in saline soil solutions may exceed that of K^+ and yet the Na^+: K^+ ratio in plants growing on these soils may be near one or even less. This high specifically for K uptake is present in wide range of plants. Higher K^+/Na^+ (or lower Na^+/K^+) ratio would characterize a tolerant variety and a low ratio value, the relatively susceptible one. In preliminary analysis of leaf samples of 10 varieties (through ICP technique) grown under drained sodic conditions, clear toxicities due to Al and Fe in most varieties was observed. Additional toxicities of Na, B and Mn also occur in several varieties. Grain yield under sodic stress was found to be correlated with leaf Ca, Mg and S concentrations. Selection for grain yield under sodic stress can be done indirectly by selecting genotypes based on there higher K/Na ratio, leaf Ca, Mg and S concentrations and lower Na, Al and Fe concentrations in the initial growth stage. In sugarcane it has been observed that leaf shoot elongation is the most sensitive stage. Salinization reduces the rate of photosynthesis, stomatal conductance and transpiration and increases leaf temperature. In tolerant genotypes Na is retained in basal internodes. The leaf sheath tries to restrict the increase in Na and Cl concentration in leaf blade.At high salinity sugar accumulation is reduced but at moderate salinity there is no apparent effect however salinity delays the maturity.

Genetic variability for salt tolerance: A number of varieties have been screened sodicity and salinity. These varieties have been categorized under three categories: medium tolerant: medium sensitive and sensitive for the purpose of standardization and making comparisons. The sugarcane variety Co 7717 was a medium tolerant variety. At present Co 0238 a variety developed at ICAR Sugarcane breeding institute regional center Karnal has medium tolerance to different salt stresses as well as waterlogging tolerance. Co 0118 and Co 98014 are the two varieties having waterlogging tolerance trait.

Breeding for Salt Tolerance

Genetic adaptation of crops to salinity requires that sufficient heritable variability exists within species to permit selection of salt tolerant strains and those plant characteristics which confer salt tolerance, be identified. By exploiting the inherent variability in wild species, it has been suggested that the production under saline conditions could be more than double. In case of salt resistance, it would seem that it is essential to work hand to hand with the plant physiologists and soil scientists to provide appropriate conditions for selection and development of effective selection parameters for salinity tolerance.

In view of the above, effort was made to screen 32 genotypes of sugarcane of diverse genetic background against soil salinity at Nain farm of CSSRI, Karnal) during 2015-16. The soil salinity of the experimental area varied greatly from 2.25 dS m^{-1} to 29.04 dS m^{-1} at different crop intervals. Observation were made on germination, tillers, NMC, single cane weight, cane height, cane diameter and juice extraction %, sucrose content (brix, pol and purity) at 10^{th} and 12^{th} crop month stage. Nine entries viz. IK 76-48, GU 07-3774, Co 1148, IND00-1038, AS 04-635, AS04-1687, AS04-2097, AS04-245 and standard CoS 767 were found promising. Based on the performance of these entries, an experiment was planted for further evaluation at ICAR-SBI-RC, Karnal under four salinity levels of irrigation waters viz., Normal, 4, 8, and 12 dS m^{-1}. In this experiment irrigation was provided with normal water up to germination stage and further irrigation was given with different EC_{iw}. There was 7.57, 44.57 and 54.0% reduction in CCS yield (t/ha), 15.14, 39.89 and 48.89 reduction in cane yield (t/ha) at 4, 8 and 12 dS m^{-1} respectively over control. Five clones viz., GU04-2097, GU07-3774, IND00-1038, AS04-635 and Co 13035 were identified as tolerant and six clones namely; Co 11027, Co 05011, Co 98014, Co 13036, Co 15023 and Co 12027 were moderately tolerant whereas, Co 0237, Co 06034, Co 12026, Co 13033, Co 05009 and Co 14035 were highly sensitive clones. These tolerant and moderately tolerant clones may be utilized in breeding programme towards development of salinity tolerant varieties.

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35. Strategies for Genetic Enhancement of Vegetables in Salt Affected Soils

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Vegetables are important constituents of Indian agriculture and nutritional security. Our country is blessed with diverse agro-climates and distinct seasons, making it possible to grow a wide range of vegetable crops. In an estimate, 31% (375 million) of Indians are vegetarian; therefore vegetables play a significant role in nutrition of the diet of a vegetarian, especially as sources of vitamins (A, C, B1, B6, B9, E), minerals, dietary fiber and phytochemicals. Vegetables are generally low in fat content and calories. They are also an important source of mineral nutrients such as phosphorus, potassium, calcium, magnesium, iron, copper, manganese, selenium and zink (Demir *et al*., 2010). They provide essential amino acids and antioxidants that the human body needs to function normally. Almost all vegetables used world-over are free of cholesterol. Vegetables, if eaten fresh or partially cooked can help counter many of the common diseases such as cancer, diabetes, blood pressure, vision loss, heart diseases and a number of intestinal disorders (Khan, 1979, Shukla and Naik, 1993). In India, between 1999 and 2012, per capita consumption of vegetables has doubled (120 g to 230g/day). But based on projections 2030, further increases in vegetable production will be needed to meet the demand for fresh, export and processing purposes under changing food scenario.

Globally, India ranked second in vegetable production and contributed 15.8 and 14% to global vegetable area and production, respectively. During 2015-16, India produced 166.6 million tonnes of vegetable from an area of 9.58 million hectare with an average productivity of 17.4 t/ha (NHB, 1). India ranked first in production of okra in the world (73 % of world production) and second in brinjal (27.55 %), cabbage (13 %) and tomato (11 %). The major vegetable growing states in India are West Bengal (14.1%), Uttar Pradesh (11.4%), Bihar (9.3%), Madhya Pradesh (8.0%) and Gujarat (7.1%).

Vegetables are especially important crops for farmers with small holdings because an appreciably higher income per hectare can be generated by growing vegetables than from conventional staple crops (Genova *et al.*, 2006). However, vegetables are generally considered more vulnerable than staple crops to stressful environmental conditions including extremes of temperatures, drought, salinity, alkalinity, water logging, mineral nutrient excesses and deficiency (Chinnusamy *et al*., 2005). These environmental stresses are likely to be exacerbated by the prevalent climatic changes in many parts of the world.

In India, 6.73 M ha of land are affected by salinity and sodicity stresses. These areas are either barren or affected by low yields. Salt tolerant varieties are the best option for these areas as these varieties can cut down the cost of reclamation to a great extent. More over in areas affected by poor quality waters, salt tolerant varieties are the best option. Excessive amounts of soluble salts in soil in many regions of the world, particularly in arid and semi-arid areas, limit production of most crops including vegetables (AVRDC, 2006). Like other crops, considerable crop to crop variation in vegetable crop salinity tolerance has been reported (Maas, 1990). The salt tolerance of vegetable species is important because the cash value of vegetables is usually high compared to field crops. Despite the dietary importance and economic value of vegetables, much less is known about the physiological and molecular responses of these to salt stress.

Effects of Salinity on Vegetable Growth and Nutrition quality

Salts affect plant growth due to increasing soil osmotic pressure and to interference with plant nutrition. A high salt concentration in soil solution reduces the ability of plants to acquire water, which is referred to as the osmotic or water-deficit effect of salinity. Damage occurs when the concentration is high enough to begin reducing crop growth. Mass (1990) reported broccoli, cabbage, cauliflower, tomato, eggplant, potato, turnip, radish, lettuce, pumpkin, cucumber, and pepper as moderately sensitive, red beet (Beta vulgaris) is moderately tolerant, where as okra, pea, onion, and carrot are highly sensitive to salt. Although salinity stress has been reported to adversely affect the growth and productivity of okra, it is considered a semi tolerant or moderately tolerant crop compared with many other vegetable crops (Unlukara et al., 2008). Salinity (NaCl) had a considerable inhibitory effect on seed germination of okra with Na+, sugar, and phenols increased, and K^+, starch, and amylase activity decreased significantly in the cotyledons of germinating seeds (Dkhil and Denden, 2010). Fifty percent reduction in fresh fruit yield of okra has been reported at 6.7 dS m^{-1} (Minhas and Gupta, 1993). Mangal *et al*. (1993) studied the performance of a number of vegetables crops at different soil salinity levels (ECe) and found that beans are highly sensitive to salinity as their yield is reduced to 50% even at low ECe of 3 ds/m, whereas, broccoli, cucumber, fennel and squash are relatively tolerant as no reduction at ECe of 3 ds/m. Spinach, celery and cabbage are highly tolerant as 50% reduction in yield takes place at a high ECe of 10 ds/m (Table 1). Fennel seed yield decreased by 4.7 and 20 % with alternate irrigation of low (4.6 ds/m) and high (8.7 ds/m) saline water and high (8.7 ds/m) saline water irrigation (Yadav *et al*., 2013).

Table 1. Percent reduction in yield of different vegetable crops under saline environment

S. No.	Vegetables	Reduction at a given ECe (ds/m)			
		None	25 %	50 %	100 %
1	Beans	1	2	3	5
2	Broad bean	2	4	7	12
3	Broccoli	3	6	9	12
4	Carrot	1	3	6	8
5	Cabbage	2	6	10	16
6	Celery	2	6	10	16
7	Chilli	1	4	6	11
8	Cucumber	3	5	7	12
9	Fennel	3	6	9	12
10	Garlic	2	3	7	10
11	Lettuce	1	3	5	9
12	Muskmelon	1	4	6	11
13	Onion	1	3	5	8
14	Okra	2	4	6	-
15	Palak	2	5	8	15
16	Pepper	2	3	7	10
17	Potato	2	4	7	11
18	Radish seed	2	5	8	14
19	Spinach	2	5	10	16
20	Sweet potato	2	4	6	10
21	Sweet Corn	2	4	6	10
22	Squash	3	5	6	-

Source: Mangal (1993)

In radish, about 80% of the growth reduction at high salinity could be attributed to reduction of leaf area expansion and hence to a reduction of light interception. The remaining 20% of the salinity effect on growth was most likely explained by a decrease in stomatal conductance (Marcelis and Van Hooijdonk, 1999). Salt accumulation in the root zone causes the development of osmotic stress and disrupts cell ion homeostasis by inducing both the inhibition in uptake of essential elements such as K+, Ca_2+, and NO_3− and the accumulation of Na+ and Cl−. Specific ion toxicities are due to the accumulation of sodium, chloride, and/or boron in the tissue of transpiring leaves to damaging levels. Accumulation of injurious ions may inhibit photosynthesis and protein synthesis, inactivate enzymes, and damage chloroplasts and other organelles. These effects are more important in older leaves, as they have been transpiring the longest so they accumulate more ions. Calcium deficiency symptoms are common when the Na+/Ca2+ ratio is high in soil water. However, lower calcium uptake by tomato plants has been linked with decreased transpiration rate rather than competition effects with Na+ (Adams & Ho, 1999). Salt stress effects on root architecture/morphology currently are poorly understood. However, root biomass has been reported to be generally less affected by excess salinity than above ground organs. Salinity reduced root biomass has been reported in broccoli and cauliflower and root length density (RLD) in tomato (Snapp *et al*., 1991). Visual symptoms of salt injury in plant growth appear progressively. The first signs of salt stress are wilting, yellowed leaves and stunted growth. In a second phase the damage manifests as chlorosis of green parts, leaf tip burning, and necrosis of leaves, and the oldest leaves display scorching [29]. Salt stress decreases marketable yield due to decreased productivity and an increased unmarketable yield of fruits, roots, tubers, and leaves without commercial value. Irrigation with saline water has been shown to enhance the occurrence of blossom-end rot in tomato, pepper fruits, and eggplants, a nutritional disorder related to Ca2+ deficiency. However, salinity has some favorable effects on the quality of the edible part of the vegetable crops. In general, salt stress, with the exception of visual appearance (size, shape, and absence of defects), improves the quality of edible part of vegetable crops. In general, salinity increased fruit dry matter content, total soluble solids (TSS) and acid content of melon, tomato, sweet pepper and cucumber. Salt stress increased carotenoid content and antioxidant activity of tomato (De Pascale et al., 2015). Overall, the nutritional quality (e.g., glucosinolate, polyphenol content, etc.) of the edible florets of broccoli was improved under moderate saline stress (López-Berenguer). Salt stress increased polyphenol content and decreased nitrate ion and oxalic acid concentration in spinach [33]. The effect of salinity on vegetable yield and quality was also affected by the timing of application of salt stress, which could be important for improved irrigation (e.g., deficit irrigation) and fertilization management strategies. In two melon cultivars (Galia and Amarillo Oro), the application of salt stress from fruiting to harvest did not reduce marketable fruit yield and increased fruit quality (TSS) and maturity index in both cultivars (Botia *et al*., 2005).

Screening and Characterization of Salt Tolerant Germplasm Lines

In vitro screening of forty one genotype of tomato was done under 0 mM, 50 mM, 100 mM, 200 mM and 250 mM of NaCl. Root assay and fresh weight assay were performed to compare the tolerance response of these genotypes. Five genotypes viz., BARI-2, BD7260, BD-7290, BD-7286, and BARI-11 showed excellent performance of tolerance up to 50 mM of NaCl. BD-7302 showed better performance under high salt concentrations i.e., at 100 mM and 200 mM (Rashed *et al*., 2016). Singh *et al*., (2012) reported that increasing salt stress negatively affected growth and development of tomato. When salt concentration increased, germination of tomato seed was reduced and the time needed to complete germination lengthened, root/shoot dry weight ratio was higher and Na+ content increased but K+ content decreased. Among the varieties, Sel-7 followed by Arka Vikas and crosses involving them as a parent were found to be the more tolerant genotypes in the present study on the basis of studied parameters. Twenty-five tomato genotypes were evaluated under glasshouse under controlled conditions with three simulated soil salinity levels (control, 10 and 15 dS m^{-1}). Out of these ANAHU, LA-2821, LO-2752, LO-2707, PB-017909, LO-2831-23 and 017860 reported as salt tolerant genotypes. Saxena *et al*., (2013) found significant change in the yield of okra (Var: Mahyco-10 Hy) at 1% level of significance. It was found that even at 8 dS.m^{-1} irrigation water salinity, 77% of okra yield to the check could be obtained. Twenty melon (Cucumis melo L.) cultigens (cultivars and breeding lines) were tested for salt tolerance using drip irrigation at three salt salinity levels (ECw = 1.2, 7.5, or 14.0 dS/m). Nineteen of the 20 cultigens proved to be salt-sensitive, as measured by reduction in fruit weight, but not necessarily to the same degree (i.e., some cultigens were tolerant at ECw = 7.5, whereas others were not). One line, 'Evan Key', was salt-tolerant at ECw= 14.0. Increasing salinity levels did not affect the number of fruits produced in most cultigens. Overall, increasing salinity reduced netting quality but increased the total soluble solids content and shortened mean time to harvest in seven cultigens. Comparative salt tolerant varieties of different crops are given in Table 2.

Table 2. Comparative salt tolerant varieties of different crops

Crop	Variety/line	Crop	Variety/line
Brinjal	Black Beauty, R-34	Garlic	HG-6
Cabbage	Golden Acre	Okra	Pusa Sawani, Kashi Kranti, VRO-112.
Musk melon	Pusa Madhuras	Peas	P-23, New Line Perfection, Market Prize
Kharif onion	Basant	Potato	JE-808, Kufri Chamatkar, CP-2059, JE-303, Kufri Sindhuri
Onion	Hisar-2, Punjab Selection, Udaipur-102, Bombay Red, Pusa Ratnar,	Tomato	EC-2791, DT-10, EC-13904 and C-11-2, Hybrid 14, NT-3, Marglobe, Kalyanpur, T-1, Sabour Suphala, At-69, Hisar Arun, Moneymaker
Chilli	C-4, Musalwadi, Jwala, Chaman		

Marker Assisted Breeding

Marker-assisted breeding is a viable approach for enhancing stress tolerance in vegetables. To this end chromosomal regions bearing quantitative trait loci have been explored. Foolad *et al*. (1997) identified QTLs (quantitative trait loci) important for tomato salt tolerance during the initial growth stage. Two Lycopersicon species and cultivars, salt sensitive UCT5 (Lycopersicon esculentum) and salt tolerant LA716 (L. pennellii) were used in this study. These cultivars were genotyped through 84 genetic markers, 16 isozymes and 68 RFLPs (restriction fragment length polymorphism). In this process, eight genetic regions were identified on seven chromosomes of tomato showing that the salt tolerance mechanism is polygenically controlled during germination. The salt-tolerant cultivar showed favorable QTL alleles on chromosome number 1, 3, 9, and 12 while the sensitive cultivar showed alleles on chromosomes 2, 7, and 8. Foolad and Jones (1993) also reported five QTLs in chromosomes1, 3, 7, 8, and 12 markedly affecting salt tolerance in tomato and these were later studied using tomato populations derived from L.esculentum, L.pennellii and L. pimpinellifolium (Foolad and Jones, 1993). These findings indicate the potential benefit of marker-assisted selection and breeding for enhanced salt tolerance in tomato (Foolad *et al*., 1997). The expression of genes involved in salt tolerance of tomato has also been studied. Ouyangetal (2007) reported that the microarray analysis of tomato cultivars LA2711 and ZS-5 showed differential expression of 201 non-redundant genes and most of them were not previously reported as salt stress–associated genes. From this report it is also clear that salt tolerance is a complex mechanism which is controlled by more than one gene

Lycopersicon species can be categorized into two groups, those species with most genetic variability (*L. chilense, L. hirsutum, L. peruvianum, and L. pennellii*) and those with least (*L. cheesmanii and L. pimpinellifolium*) (Breto *et al*., 1993). Salt tolerance generally increases with age and plants are more tolerant at the vegetative stage than at the seed stage (Bolarin *et al*., 1993). As a result, efforts have been made to enhance salt tolerance at various stages (Jones and Qualset, 1984; Foolad, 2004). In order to study phenotypic and genetic relationships for salt tolerance at different developmental stages, various approaches have been adopted (Foolad, 2007). For example, evaluation was made in the F4 population of a cross between a salt-sensitive tomato breeding line and a primitive cultivar (PI174263) for salt tolerance at seed germination as well as at the vegetative stage. There was significant variation in salt tolerance in families of F4 populations during both seedling and vegetative stages but a non-significant correlation between the tolerance at one stage with that observed at the other stage (Foolad and Lin, 1997a). It can be concluded that genetic and physiological mechanisms are different for salt tolerance at different growth stages.

Grafting

The commercial success obtained through traditional breeding programs with regard to salinity tolerance has been very scarce because of the complexity of the plant response to the stress. One way of avoiding or reducing losses in production caused by salinity in high-yield genotypes would be to graft them onto rootstocks capable of reducing the effect of external salt on the shoot. This strategy could also provide the plant breeder with the possibility of combining good shoot characteristics with good root characteristics and of studying the contribution of genes transcribed in the roots to their performance on the shoot. Grafting in tomato has been found very effective in enhancing the crop salt tolerance (He *et al*., 2009; Ghanem *et al*., 2011). For example, a commercial tomato hybrid cv. Jaguar was grafted on rootstocks of several tomato genotypes with the potential for salt exclusion. The grafting process itself was not effective in enhancing crop yield when plants were grafted onto their own rootstocks but when they were grafted onto other rootstocks considerably enhanced salt tolerance was observed. For example, when cv. Jaguar was grafted onto the rootstocks of cvs. Radja-best, a Na+ excluder (P´erez-Alfocea *et al*., 1996), Pera-best, Na^+ includer (P´erez-Alfocea *et al*., 1993a, 1993b), and hybrid Volgogradskij x Pera, yield increase up to 80% was achieved. Rootstock grafted plants showed less salt-induced oxidative damage due to high activities of catalase, ascorbate peroxidase, dehydroascorbate reductase and glutathione reductase. Despite increasing activities of antioxidant enzymes, grafting also improved net Co_2 assimilation rate and efficiency of photosystem II (He *et al*., 2009). However, an appropriate rootstock needs to be carefully selected and grafting timing, salt stress level, and time of salinity exposure to grafted plants need to be given due consideration (Martinez-Rodriguez *et al*., 2008). Recently, it has been reported that the positive effect of rootstocks on salt tolerance of grafted cultivars is related to the capacity to maintain ionic homeostasis in leaves by reducing the accumulation of toxic ions and maintaining the acquisition of essential nutrients like K^+ (Albacete et al., 2009). This capacity has been related to an enhanced production and root-to-shoot transport of cytokinins and their effects on source sink relations (P´erez-Alfocea *et al*., 2010). Cytokinins help to delay leaf senescence and to maintain shoot growth and fruit yield (Albacete *et al*., 2009, Ghanem *et al*., 2011). Hence, root-targeted breeding and biotechnology are being considered as powerful strategies to improve salt tolerance in crop species.

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Uses of Halophytic Plants to Remediate Saline Soils and Forage Production

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Introduction

The increase in soil and water salinity in many agricultural areas of the world has created major challenges in the production of food crops, it has also presented some new prospects for livestock agriculture. India shares 24% livestock population of the world and livestock production is the backbone of Indian agriculture contributing around 7% to national growth domestic product. In India, livestock population is expected to grow at the rate of 0.55% in the coming years and the livestock population is likely to be around 781 million 2050. The major concern is to ensure availability of green fodder throughout the year as there is a net deficit of 35.6% of green fodder, 26 % dry-crop residues and 41% of concentrate feed ingredients in India (Anonymous, 2013). Due to the increasing industrialisation/urbanisation and ever increasing cultivation of cereals and cash crops resulted in shrinking land for fodder cultivation which is the major constraint in production of green fodder. One of the alternatives of the above problem is to cultivate the barren salt affected lands and reclamation of these lands by cultivating salt tolerant crops and grasses which could be used as fodder for grazing livestock or as components of mixed rations to replace roughage.

Salt-tolerant forages, especially halophytic grasses that could grow well under saline irrigation, would be potentially valuable alternative forage resources and could play a major role in sustaining livestock production (Masters *et al*., 2007). There are many halophytes and salt-tolerant shrubs, grasses and legumes which could be established in saline lands for feeding livestock (e.g. *Kochia* sp., *Juncus* sp., *Leptochloa fusca*, *Acacia* sp., *Suaeda fruticosa*, *Nitraria retusa*, *Salsola* sp., *Atriplex* sp., *Paspalum distichum* and *Scirpus litoralis*). There are plants that grow under saline conditions, and historically, they have been opportunistically used as fodder for grazing livestock or as components of mixed rations to replace roughage. Limited attempts have been made to make these plants more suitable for animals either through agronomic or genetic manipulation of the plant or through identification of the species or class of animal best suited to the plants. The fodder quality of these plants depends on a combination of climatic, soil and plant factors. There are already several examples known for the utilization of halophytes for industrial, ecological, or agricultural purposes. Halophytes have been tested as vegetable, forage, and oilseed crops in agronomic field trials. The most productive species yield 10 to 20 t ha^{-1} of biomass on seawater irrigation, equivalent to conventional crops. *Salicornia bigelovii*, an oilseed halophyte, for example, yields 2 t ha^{-1} of seed containing 28% oil and 31% protein, which is similar to soybean yield and seed quality (Glenn et al., 1999). Many plant species have been used traditionally as herbs and vegetables and hence rediscovery of the potentials of several promising halophytic plant species to be farmed as leafy vegetables is going on for a couple of decades. Some of the halophytes are good fodder and hence can be used for animal feeding in saline-prone areas. However, it is to be taken into consideration that some halophytes may cause nutritional barrier due to partially high salt content and anti-nutritional compounds (Hasanuzzaman *et al*., 2014).

Currently, salinity is a basic issue of discussion for which strong decision is to be taken for sustainable development and future availability of land for agriculture. The agricultural scenario is thus getting worse as the agricultural land is limited and salt - resistant varieties of crop plants are not available, so there is an emergent need to make the crop plants suitable to this changing scenario. In this situation, one of the ways is to make and select the crop plants genetically engineered to sustain their growth and productivity in such challenging environments. This requires exploring gene pool of wild relatives of crop plants with high salt tolerance. Salinity limits plant growth and productivity through the toxic effects of Na^+ and Cl^+ ions, which leads to ionic imbalances, osmotic and oxidative stress (Munns and Tester 2008). Salinity which is usually found in semi-arid and arid regions, is one of the major causes of land degradation (Hasegawa et al., 2000; Zhu, 2003) reducing total arable land area and crop productivity hindering countries economy up to greater extent (Mahajan et al, 2005). Salt-affected soils usually contain a variety of inorganic salts with cations like Na+, Ca2+, Mg2+, and K+, and anions like Cl^-, SO_4^{2-}, HCO^{3-}, CO_3^{2-}, and NO_3^- (Tanji 2002) which adversely affect plant growth and productivity due to causing ion toxicity or osmotic effect on plants (Parida and Das 2005; Läuchli and Grattan 2007). Globally, salinity and sodicity stresses contributes about 1128 m ha area.

South Asia, including India, has about 52 m ha salt-affected area. In India, the area under salt-affected soils is about 6.73 million ha with states of Gujarat (2.23 m ha), Uttar Pradesh (1.37 m ha), Maharashtra (0.61 m ha), West Bengal (0.44 m ha) and Rajasthan (0.38 m ha) together accounting for almost 75% of saline and sodic soils in the country. Largely, salt affected environment also contains poor quality of water adversely affecting growth of plants.Few north western states of India also suffers from availability of poor quality of water for cropping including Rajasthan, Haryana and Punjab further affecting salinity concentration of soil(Singh, 2009). According to estimates, the present area under salt-affected soils (6.73 million ha) in country would almost treble to 20 million ha by 2050 (Sharma et al., 2014). Most of the plant suffers from water and nutrient scarcity caused by salinity in soil. This inturn reduces the plant growth in these areas thereby further making the soil unused for agriculture. On the other hand, limited agricultural lands on earth and incremental increase of food demand, more productive use of existing land areas becomes a necessity. Therefore improvement of saline soils and their economic use are extremely important (Woods 1996). Halophytes have great potential to grow in saline soil. Halophytes, although constitute about 1% of the world's flora, but survive to reproduce in environments where the salt concentration is around 200 mM NaCl or more which kills 99% of other species. Therefore, it has become imperative to search for suitable alternatives and develop ecologically sustainable and economically sound biological systems that can use poor quality water and drought affected saline lands to produce plants of economic importance. A promising but not yet deeply investigated field is represented by the use of halophytic plants in association with crops cultivated in conditions of saline stress. The salt uptake and accumulation by the halophytes can reduce the severity of the stress at a rhizospheric level, providing better conditions for the growth of the agricultural species and better yields. Halophytic plants can be grown in the soil containing high salt concentration, can become a substitute for conventional crops, and can be used as a source of food, fuel, fodder, fiber, essential oils, and medicine (Lokhande and Suprasanna, 2012). At the same time, halophytic plant species can be harvested (above ground portion of the plant) which bear potential capability of desalination and restoration of saline soils as well as phytoremediation. By developing these precious strategies, unused and marginal land can be brought under cultivation and existing agricultural land will be more productive which will open a new door to sustain crop productivity.

Fodder Yielding Halophytes

High palatability, digestibility and good nutritional value (high protein and low fibre, ash and oxalate contents) signify high fodder quality (El Shaer, 2006). Salt accumulation reduces the nutritional value and feeding quality of most plants. The potential of halophytic grass species as fodders was also investigated by Pasternak (1990) and Bustan et al. (2005). Indeed, although less salt tolerant than species of *Atriplex*, the ash content of all tested *Distichlis spicata* accessions never exceeded 11 % of the dry matter, about half the amount found in the salt-accumulating chenopods, highlighting its potential as a fodder crop (Bustan et al., 2005). The protein content of *D. spicata* varied widely between the accessions, and ranged from a minimum of 9.2 % to a maximum of 18.9 % of dry matter, similar to the protein content reported by Pasternak (1990) for *A. nummularia*. In Pakistan, cultivating the halophytic species *Leptochloa fusca* (Kallar grass) not only resulted in high productivity [20 t dry matter ha^{-1} from 4–5 cuts per year (Mahmood et al., 1994)], but also successfully improved the soil conditions of the existing saline sodic soils, showing increased vegetation growth after a 5 year period (Hollington et al., 2001). The anatomical adaptation of grasses for salt secretion evidently contributes to the maintenance of low leaf salt levels and relatively low (compared with those existing in dicotyledonous halophytes) Na/K ratios (Flowers and Colmer, 2008). Liphschitz et al. (1974) reported the existence of active salt secreting glands on the leaves of Rhodes Grass (*Chloris gayana* Kth.). In a similar manner, Bermuda grass (*Cynodon dactylon*) was determined as a salt-secreting species (Liphschitz and Waisel, 1974; Eshel and Waisel, 2007), which was confirmed by Hameed et al. (2013) by an increased number of vesicular trichomes for the exclusion of toxic ions. Thus these plants attract interest as important candidates for economic utilization in saline environments (Liphschitz et al., 1974). Grasses have also been used in combination with other chenopods apart from *Atriplex* species. *Salicornia bigelovii* was tested as a protein-rich fodder crop for saline irrigation (Glenn et al., 1991), but its high ash content (up to 39 %) limited its nutritional potential and its fodder quality (Basmaeil et al., 2003). To overcome this problem, Glenn et al. (1992) substituted 50 % of a Rhodes Grass-based fodder with *S. bigelovii*. Plants were grown on complete seawater and directly after harvest the plant biomass was soaked in seawater. This action reduced the NaCl content by half to approx. 8–13 %, resulting in an ash content of 16.7 %. Glenn et al. (1992) also noted that the protein content of the *Salicornia* biomass was higher if the seeds were not removed prior to animal feeding. The conclusion drawn from an experiment feeding *S. bigelovii* straw or seed meal to lambs showed that this halophyte could be used as an acceptable feed substitute in arid coastal regions where fresh water for crop irrigation is limited (Swingle et al., 1996). In another study, the replacement of 12.5 % alfalfa by *Salicornia herbacea*, the locally occurring *Salicornia* in Kuwait, in the basal diet resulted in the highest body weight gain and feed consumption of Australian wither lambs, as compared with the other treatments (Abdal, 2009). On the other hand, in a camel feeding trial, the incorporation of 25 % seawater-irrigated *S. bigelovii* biomass in the diet had an adverse effect on the nutritive value of the feed in comparison with Rhodes Grass diet. In particular, ADF (acid detergent fibre) and NDF (neutral detergent fibre) digestibility decreased by approx. 50 and 20 %, respectively, which might have indicated an increased flow of undigested dietary components out of the rumen (Basmaeil et al., 2003). The usefulness of *Salicornia* spp. as an animal feed for ruminants seems to be directly related to its salt content, which can be adjusted by the plant portion in the diet. Selection for low-salt-accumulating varieties may increase the feeding value of *Salicornia* for small ruminants. For other species, Belal and Al-Dosari (1999) successfully included 40 % *Salicornia* meal in fish (Nile Tilapia) feeds as a replacement for the conventional fish meal diet, with no adverse effect on fish growth and body composition.

Potential Use of Halophytes under salinity

In the latter half of the twentieth century some studies were explored potential for the use of halophytes as crops (Rozema et al., 2013).In Israel, database of halophytes and their economic uses were developed on the basis of research on saline agriculture during the 1960s (Aronson, 1989). Up to now, many halophytes have been evaluated for their potential use as crop plants (Flowers et al., 2010; Rozema et al., 2013.), for the revegetation and remediation of salt and industrially polluted areas (Cambrolle et al., 2008; Lewis and Devereux, 2009), as floricultural crops (Cassaniti et al., 2013) and as biofilters for aquaculture effluents (Buhmann and Papenbrock, 2013).

The saline area in the world is continuously increasing due to rapid climate change and currently there is an ample need to develop highly salt-tolerant crops to cope with the adverse climatic conditions. Halophytes are able to provide satisfactory yield under high salt condition. Halophytes have been tested as vegetable, forage, and oilseed crops in agronomic field trials.

Use of Halophytes

Fodder crops: Good fodder quality represents high palatability, digestibility and good nutritional value i.e. high protein and low fibre, ash and oxalate contents (El Shaer, 2006). As salt accumulation reduces the nutritional value and feeding quality of most plants. Norman et al. (2013) concluded the successful mixed plantation i.e. halophytic grasses and shrubs to get the benefits of using halophytes by managing their negative consequences. Some of the halophytes are good fodder and hence can be used for animal feeding in saline-prone areas. Grasses have also been used in combination with other chenopods apart from *Atriplex* species. The most productive species yield 10 to 20 t ha^{-1} of biomass on seawater irrigation, equivalent to conventional crops.

Energy crops: Factors like nutritive value and voluntary feed intake should also be considered before halophytes may compete with traditional fodder species (Norman et al., 2013). Halophytes could also be used as a new source of energy crops that will not compete with conventional agriculture for valuable resources of fertile soil and fresh water e.g. Salt cedar (*Tamarix* spp.) if irrigated with reclaimed sewage and brackish water. *Tamarix* yielding between 26 and 52 t ha^{-1} $year^{-1}$; a level not less than that obtained for common cash crops on arable land (Eshel et al., 2010). Growing such salt tolerant energy crops on marginal agricultural land would help to counter concerns that the biofuel industry reduces the amount of land available for food production (Qadir et al., 2008).

Human food: Halophytes have been used for human consumption for a long time e.g. a perennial salt grass *Distich-lispalmeri* as a food crop, the native South Americans used from many centuries and as the main staple crop for the indigenous Cocopah people who lived along the lower Río Colorado in Mexico. Yensen, (2006) reported that in various parts of the world this species is used for making biscuits and bread because it has higher fibre content then wheat (8.4% vs 2.6%, respectively). It produces grains of high nutritive value (1.25 t ha^{-1}) even under flooded and sea water salinities (Pearlsteina *et al*., 2012). Similarly, quinoa (*Chenopodium quinoa*) can tolerate salinity up to 40 dS m^{-1} and is regarded as an exotic food which is also the staple foods of native South Americans (Adolf *et al*., 2013). It has higher nutritive value than traditional cereals (Vega-Gálvez *et al*., 2010). Its seeds are rich in lysine (an essential amino acid), iron, magnesium, vitamin E, copper and phosphorus as well as being gluten free (James, 2009).In Argentina, Gómez *et al.,* (2011) concluded that this crop has a grain yield potential of up to 5.2 tha^{-1} under temperate environments. Likewise, pearl millet (*Pennisetum typhoides*) can also tolerate salinity greater than 30 dSm^{-1} and can be grown as a food crop with a seed yield of upto 1.6 t ha^{-1} (Jaradat, 2003).

- In Delaware (USA), the yield of *Atriplex triangularis* was 21.2 t ha^{-1} under sea water irrigation and these are used for human consumption in the Netherlands, Belgium and Portugal because the taste of leaves are similar to those of spinach (Leith *et al.,* 2000).
- *Salicornia bigelovii* is grown for the USA and European fresh produce markets (Zerai et al., 2010; Ventura *et al.,* 2011) and can be used as an alternative source of omega-3 poly unsaturated fatty acids for human consumption. This species is also a good source of the antioxidant-carotene, ranging from 4.7 to 15.9 mg/100g fresh weight (Lu *et al.,* 2010).
- Perennial wall rocket (*Diplotaxis tenuifolia*) is also commonly cultivated and used as a leafy vegetable in many parts of the world (de Vos *et al.,* 2013).
- In Columbia, many mangrove species are used as food e.g. *Avicennia marina* and *A. germinans* (Leith *et al.,* 2000).
- In different regions of India, the young shoots and leaves of *Chenopodium album* and *Amaranthus spp*. Are being used as salads and vegetables, and raw fruits of *Capparis decidua* are used for pickles (Rameshkumar and Eswaran, 2013).

Animal feeds: Live-stock such as sheep, camels, and cattle thrive well on certain halophyte-based feeds. Biomass production; nutritive value and voluntary feed intake (Norman *et al.,* 2013) are the criteria for successful use of halophytes as forage for livestock production (Rogers *et al.,* 2005). The traditional ingredients in domestic animal diets can be replaced from halophytes (forage seed products) although there are restrictions on their use due to high salt content and anti nutritional compounds present in some species. *Pennisetum clandestinum* (kikuyu grass), contain anti methanogenic properties that reduce methane gas production in grazing sheep and cattle hence help in reducing green house gas (GHG) production in ruminant livestock (Muscolo *et al.,* 2013). In Egypt, the halophytic grasses *Leptochloa fusca, Spartina patens* and *S. virginicus* are used for forage production. Pearl millet (*P. typhoides*) can be grown as fodder also, yielding upto 6.5 tDMha^{-1}. Halophytics pecies, such as *Terminalia catappa, Aeluropus lagopoides, C. dactylon* and *Brachiaria mutica* are used as forage for cattle, camel and goats (Dagar, 2005) in India.

The plant species with yield potential of 10–20 tDMha^{-1} of biomass whenirrigated with saline water are considered as most productive halophytes are equivalent to conventional forage species under non-saline conditions. The use of halophytes should be in combination with a grain supplement to provide additional energy (ICBA, 2007; Norman et al., 2013) to ensure animals are productive and healthy.

Oilseeds and protein crops: *Salicornia bigelovii,* an oilseed halophyte, for example, yields 2 t ha^{-1} of seed containing 28% oil and 31% protein, which is similar to soybean yield and seed quality. *Suaeda moquinii* (Weber *et al.,* 2001), *Suaeda aralocaspica* (Wang *et al.,* 2012), *Salvadora persica* (Reddy *et al.,* 2008), *Batis maritime* (Marcone, 2003). *Suaeda salsa, Chenopodium glaucum* and *Descurainaia Sophia* (Yajun *et al.,* 2003) are some known potential sources of edible oil and proteins. Significant higher concentrations of salt are present in the shoot biomass particularly in the leaves and seeds are relatively salt free (Jaradat, 2003). *S. bigelovii* has been trial led in various parts of the world such as the Middle East (Jaradat, 2005; Abdal, 2009), Mexico (Grattan *et al.,* 2008), and Africa (Zerai *et al.,* 2010).

- *S. bigelovii* seed has oil and protein content of 30% and35%, respectively (Ho and Cummins, 2009) and this oil is similar in properties to safflower oil (Zerai *et al.,* 2010). Studies were carried out by Rameshkumar and Eswaran (2013) in India also.
- Seedsof *Suaeda fruticosa* has 74% unsaturated fatty acid so it can be used as a source of edible oil for human consumption (Weber *et al.,* 2007).
- *S. persica* is used as a source of seed oil in India and it can tolerate the salinity from 25 to 65 dS m^{-1}; however, seed yield declined by 40–47% at salinity of 55– 65 dS m^{-1} compared with 25–35 dS m^{-1} (Rao *et al.,* 2004). The seed of this plant contains 40–45% of oil rich in lauric (C12) and myristic (C14) acid widely used in the cosmetic and pharmaceutical industries (Reddy *et al.,* 2008).

Energy crops (biofuel and fuelwood): Halophytes can also be a highly valuable source of fuels such as bioethanol, biodiesel and fuelwood. The world'sbiofuel reserves will be substantially depleted by the coming few centuries (Shafiee and Topal, 2009). Consequently, the use of bioethanol as a renewable energy source has been steadily increasing (Demirbas *et al.,* 2011; Abideen *et al.,* 2012) and is regarded as a viable alternative substitute for gasoline in the transportation sector (Del Campo et al., 2006). Halophytes can be grown without competing with food crops for good quality soil and water resources (Qadir *et al.,* 2008) and can exploit saline lands such as coastal zones for this purpose (Liu *et al.,* 2012). Indeed, salt tolerant plants are often used to provide fuel for cooking and heating in developing countries (Ladeiro, 2012). Biofuel from the halophytic lingo-cellulosic biomass (i.e. plants dry matter which is composed of cellulose, hemicelluloses and lignin) will be an environmentally sound and sustainable alternative to address the food versus fuel production debate.

The growing of halophytic plants solve the dual purpose i.e. provide relief for the world's dependence on fossil fueland also help to reduce the issue of global warming by reducing production of greenhouse gas. Species like *Tamarix chinensis, Phragmites australis, Miscanthus* spp. and *Spartina alterniflora* were evaluated as biofuel crops for ethanol production in the coastal zone of China; *Halopyrum mucronatum, Desmostachya bipinnata, Phragmites karka, Typhadom ingensis* and *P. turgidum* in the coastal region of Pakistan. The halophytic grass *Panicum virgatum* has been shown to produce similar yields of ethanol to corn (Z. mays) which is grown extensively as a conventional food crop as well as for ethanol production. *Prosopis* and *Tamarix* sp. are also highly suitable for fuel wood production.

Medicinal plants and other commercial products: Halophytic plants can also be used for medicinal purposes e.g. *Ipomoea pescaprae* sp. is used to treat fatigue, strain, arthritis, rheumatism and menorrhagia (Rameshkumar and Eswaran, 2013). *Ipomoea* sp. contain many biologically active constituents such as alkaloids, phenolics, coumarins, flavonoids and analgesic, antimicrobial, and anticoagulant properties (Meira *et al.,* 2012) hence it plays an important role in treating diseases in different parts of the world. *T. catappa* leaf has some anti-bacterial activity and it is used as a cardiac stimulant, for treating dermatosis and hepatitis in India (Chanda *et al.,* 2011) and for liver diseases in Taiwan and is used for its polyol-rich food which is known to have disease-preventing functions. Agarie *et al.* (2009) noticed the disease resistance by taking polyol-rich food as *Mesembryanthemum crystallinum* and anti-aging, anti-inflammatory and anti-carcinogenic properties are also found in the phenolic compound of this species (Mandloi *et al.,* 2013). Halophytes also have a range of other uses such as *Parthenium argentatum* (guayule) is a source of natural rubber that can be grown under salinity upto7.5dSm^{-1} (Hoffman *et al.,* 1988). In India, a succulent chenopod (*Suaeda monoica*) is used in the paper industry.

Role of Halophytes in Salinity Stress Management

Understanding the mechanism of tolerance in halophytes at morphological, anatomical, physiological, biochemical, and molecular levels is crucial to improve the tolerance of the crop plants and their adoption under abiotic stress conditions to exploit such problem soils. Halophytes have also been utilized practically for managing the stressful environment and shown to be involved in increasing the economy of developing countries in many parts of the world. Halophytes have shown their role in desalination of saline lands from arid and semi-arid regions as well as the stabilization of saline lands along the coastal sides, phytoremediation of heavy metal contaminated sites and wetland restoration and revegetation through introduction of variety of halophyte species. This has led to developing agriculture on saline lands for supporting the sources of food, forage, fodder, medicine, ornamental and important plant-based chemicals to ever-growing human population. In addition, this may also help in reducing the burden on the crop plants which are facing the productivity problems due to exposure to various abiotic stresses. Considering these applications, constructive strategies have to be developed and implemented for the protection of world's non-renewable resources, wherein available halophyte diversity can be utilized as an important source (Khan and Qaiser 2006; Rabhi *et al.,* 2010a, Rabhi *et al.,* 2010d, Zaier *et al.,* 2010; Al-Oudat and Qadir 2011).

Desalination: Desalination is a process that removes minerals from saline water. The reclamation of saline soil using biological means is also referred as desalinization (Zhao, 1991), which is an issue for agriculture. Phytodesalination is a biological approach that aims to rehabilitate sodic and saline sodic soils by Na-hyperacumulating halophytes. Halophytes are naturally evolved salt-tolerant plants that are present in about half the higher plant families. Some have potential as a source of "tolerance genes" and others may be suitable as cash crops under saline conditions. The potential of plants to accumulate enormous salt quantities depends often on the capacity of their aboveground biomass (hyper-accumulating plants) (Rabhi *et al.,* 2010). This ability could be significant particularly in the arid and semi-arid regions where insufficient precipitations and inappropriate irrigation systems are unable to reduce the salt burden in the rhizosphere of plants and suitable physicochemical methods are too expensive (Shahid, 2002). Boyko (1996) was the first person to suggest that halophytic plants could be used to desalinate soil andwater. Ke-Fu (1991) found that *Suaeda salsa* produces about 20 tons dry weight ha^{-1} containing 3-4 tons of salt. Hamidov *et al.* (2007) reported that *Portulaca oleracea* accumulated highest salt uptake (497 kg ha^{-1}) with biomass production of 3948 kg ha^{-1}. Ravindran *et al.* (2007) observed that *S. maritima* and *Sesuvium portulacastrum* exhibited greater accumulation of salts in their tissue and higher reduction of salts from the saline land. It is estimated that these two halophytes could remove 504 and 474 kg of NaCl, respectively, from the saline land from 1 ha in 4-month time. Rabhi *et al.* (2008) reported that *Arthrocnemum indicum*, *Suaeda fruticosa,* and *Sesuvium portulacastrum* seedlings grown on a saline soil significantly reduced the soil salinity and EC by absorbing soluble salts mainly sodium ions and they also reported that *Sesuvium portulacastrum* was able to accumulate nearly 30% of Na^+ content in shoot over the 170 d. Al-Nasir (2009) reported that different halophyte plant species showed different decline in soil salinity of all plots at the end of the experiment as the salinity decreased from an average electrical conductivity (soil paste) of 84 to 5.46, 5.04 and 6.3 mS/cm at the top layer (0-30 cm depth) and from 49.6 to 5.46, 13.45 and 7.14 mS/cm for the lower soil (30-60 cm depth) for *Atreplix hallimus* L., *Atriplex numularia* L and *Tamarix aphylla* L., respectively. Zorrig et al. (2012) estimated phytodesalination capacity in Tunisian sabkha at about 0.65 t Na^+ ha^{-1} in summer and 0.75 t Na^+ ha^{-1} in winter. Kumar *et al.* (2016) found that pH was reduced from 9.5 to 9.15 and from 10.0 to 9.6 in alkaline/sodic soil. Whereas, in saline microplots, ECe reduced from 15 to 3.2; 25 to 6.4 and 35 to 14.4 dSm^{-1} respectively. On the other hand, in combined saline and sodic stress, ECe reduced from 10 to 6; 15 to 7.2; 20 to 9.2 dSm^{-1} and pH reduced from 9 to 8.27, 8.33, 8.35, respectively by growing grass and non-grass halophytes. Ion accumulation in succulent halophytes, where these are sequestered in high concentration in vacuolar sap is therefore an important mechanism of interest for salt hyperaccumulation from phytoremediation point of view. The concept and practice of use of suitable plants to hyperaccumulate components of salinity, particularly Na^+, is in an exciting stage.

Phytoremediation: a non-destructive clean up method in which plants can be used as a tool to decontaminate the soil and water. Plants may degrade organic pollutants and remove or stabilize metal contaminants. This may be done through one or a combination of the methods (Fig. 1).

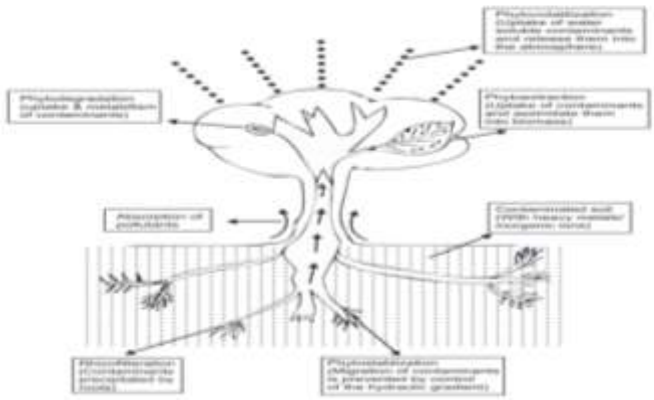

Fig. 1. Overview of phytoremediation

Phytoremediation is known as a plant based green technology using plants to remediate contaminated-environments or that depends upon the remarkable quality of some plants to remediate toxic chemicals. It is cheap, non-instructive, and effective means of pollutant cleanup (Salt *et al*., 1998; Parsad, 2004; Sarma, 2011; Arthur *et al*., 2005). This technique is potentially applicable to a variety of contaminants, including some of the most significant such as heavy metals (Cu, Cd, Zn, Mn, Fe, Pb, Hg, As, Cr, Se, Ur, etc.), radionuclides, petroleum hydrocarbons, chlorinated solvents, pentachlorophenol (PCP), and polycyclic aromatic hydrocarbons (PAHs) and it encompasses a number of different methods that can lead to contaminant removal through accumulation (phytoextraction and rhizofiltration) or dissipation (phytovolatilization), degradation (rhizodegradation and phytodegradation), or immobilization (phytostabilization) (Schnoor, 1997; USEPA, 2001; Pletsch, 2003; Pilon Smits, 2005; Fletcher, 2006). Phytoremediation constitutes a group of strategies meant not only to reduce the metal load at the contaminated site but also to stabilize the site. These strategies are:

- Rhizosphere enhanced bioremediation or Phytostimulation: enhancement of the microbial community and increase of biodegradation in the rhizosphere.
- Phytodegradation/Phytotransformation: enzymatic degradation of the pollutants in the plant tissue.
- Phytostabilization: stabilization of heavy metals in the soil/root surface and reduction of heavy metal mobility.
- Phytoextraction/Phytoaccumulation: transfer of atmosphere pollutants from the soil and accumulation in the above ground parts of the plant.

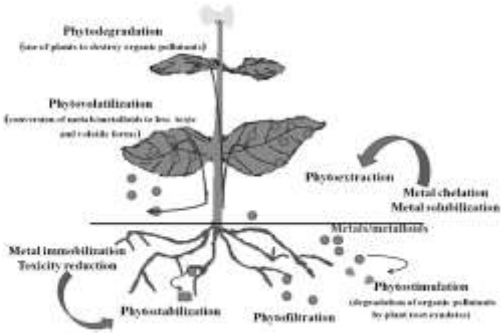

Fig. 2. Different techniques of phytoremediation

- Rhizofiltration: transfer of pollutants from the soil and accumulation in the roots of the plant.
- Phytovolatization: transfer of pollutants from the soil to the atmosphere.
- Phytoexcretion: excretion of heavy metals from the leaves.
- Rhizofiltration: transfer of pollutants from the soil and accumulation in the roots of the plant.
- Phytovolatization: transfer of pollutants from the soil to the atmosphere.
- Phytoexcretion: excretion of heavy metals from the leaves.

Several investigations of the halophytic plants for remediation of saline soils by accumulating high salt concentration in their above ground biomass. Some relevant reports are tabulated (Table 1).

Table 1. Some case studies involving halophytic plants in salinity remediation through hyperaccumulation.

S. No.	Hyperaccumulator plant(s) used; site and nature of studies	Quantification of remediation	Reference
1.	*Suaeda fruticosa,* Pakistan	Accumulation (Na^+ and other salts)of 9.06 % salt on a fresh weight basis	Chaudhari *et al.*, 1964
2.	*Suaeda maritima*, Pakistan	Could remove 504 Kg of NaCl from saline land from 1 ha in 4 month time	Ravindran *et al.*, 2007
3.	*Juncus rigidus* and *Juncus acutus*, Egypt	EC of the soil decreased from 33 to 22 dSm^{-1} in single growth period	Zaharan and Abdel, 1982
4.	*Suaeda Salsa*, Northern Egypt	Produces 20 tons dry weight ha^{-1} containing 3-4 tons of salt	Ke-Fu, 1991
5.	*Portulaca oleracea*	Highest salt uptake (497 Kg ha^{-1}) with biomass production of 3948 Kg ha^{-1}	Hamidov *et al.*, 2007
6.	*Apocynum lancifolium, Chenopodium album*; Girlan, Khirezm Region, northwest Uzbekistan	*Chenopodium album* produced 3.25 t ha^{-1} $year^{-1}$ dry biomass removing 569.6 Kg ha^{-1} salt ions from 0.3 m of the soil profile amounting to 1.47% of the soil salts	Hamidov *et al.*, 2007
7.	*Sesuvium portulacastrum*	Accumulation of 30 % of Na^+ content in shoot over the 170 d	Rabhi *et al.*, 2008
8.	*Suaeda fruticosa, Suaeda nudiflora, Salsola baryosma, Haloxylon recurvum* and *Atriplex lentiformis* grown in salinity microplots at CCS HAU, Hisar	These plants were found to be best salt hyperaccumulators and also had high biomass. These plants had the potential of desalinization of saline soils from 16 dSm^{-1} to 2 dSm^{-1} in 4.9 to 6.1 years	Datta and Angrish 2006, Devi *et al*., 2008, 2016
9.	Wild growing *Tecticornia indica* and *Suaeda nudiflora*; Soliman sub lake, north-east Tunisia.	Both perennial plants exhibited high productivities and Na^+ accumulation i.e. *T. indica* 7.4 t dry weight ha^{-1} and Na^+ 0.7 t ha^{-1} and *S. nudiflora* 0.75 t ha^{-1} and 0.22 t ha^{-1}, respectively.	Ouni *et al*., 2013

10.	*Urochondra setulosa*, *Suaeda nudiflora, Sporobolus marginatus*, *Aleuropus lagopoides,* sodic, saline and saline-sodic microplots, Karnal, India	Soil pH_s and EC_e reduced considerably in sodic and saline treatments. In saline-sodic soils, EC_e reduced from 10 to 6; 15 to 7.2; 20 to 9.2 dS m^{-1} and pH reduced from 9 to 8.27, 8.33, 8.35, respectively.	Kumar *et al.*, 2016

Advantages

- Phytoremediation with tree and grasses is beneficial because these can be utilized as fodder, timber and fuel
- It is less costly and easy to install both *in situ* and *ex situ*
- Physiology of plants can be easily studied
- It is very eco-friendly, aesthetically pleasing and publicly acceptable
- The process of phytomining increases the possibility of the re-use of valuable metals
- It is more economically viable using the same tools and supplies as agriculture.
- It is less disruptive to the environment
- It reduces the risk of spreading the contaminants by avoiding excavation

Limitations

- Phytoremediation is limited upto the spreading of the roots.
- It is a time consuming process
- It also requires the screening of hyperaccumulator plants
- Toxicity of the contaminants leads to the death of the plant
- There is recycling of the contaminants by entering into the food chain or released into the environment during autumn season
- Environmental damage may be increased due to greater solubility or leaching of the contaminants
- In India, breeding work for salt resistance is carried out at Central Soil Salinity Research Institute (CSSRI), Karnal and its various regional stations. In India, two types of approaches are followed for salt tolerance breeding:

  - Improving yield level of salt tolerant cultivars: Traditional cultivars of salt affected areas are improved for their productivity without affecting their salt tolerance ability.
  - Transfer of salt tolerant genes to high yielding cultivars. Salt tolerant genes from locally adapted (Salt tolerant) cultivars are transferred to high yielding cultivars through hybridization and selections.

It is evident from the literature also that halophytic species (*Chenopodiaceae*) were able to phytoremediate the saline soils very efficiently and effectively. These plants also provide fodder, vegetables, grain, fuel wood and oil and hence are economically viable plants as well for livestock and rural people. These also stabilize consistently ever eroding saline lands. Another feasibility in the near future is the production of bio-salt or vegetable salt from these hyperaccumulator plants. Natural sun's energy is used by the plants to remove salt ions from soil. Core of hyperaccumulation technologies include transpiration/translocation mediated and active uptake and sequestration of salt ions into the vacuole. Various saline parks could be raised where co-cultivation of these salt hyperaccumulators along with other commercial crops could be undertaken for soil salinity amelioration on an ongoing basis. In recent years, phytoremediation of saline soils has been studied by researchers that some of. Identification of novel genes with high biomass yield characteristics and the subsequent development of transgenic plants with superior remediation features would be crucial for such type of research.

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Advance Methods of In-situ (EM-38) determination of Electrical Conductivity of Soils

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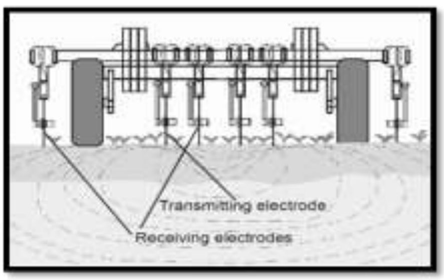
Introduction

Soil salinity is one of the major environmental problems that affect the crop yield, soil health and consequently the socio-economic condition of the farming community. Monitoring the progressive development of soil salinity and assessment its degree of severity is important to quantify its adverse effect on production and productivity and on environmental degradation. Presently, the monitoring of soil salinity is based on traditional methods that is visual or by analyzing the samples in the laboratory. The visual salinity assessment unable to detect trends within the growing season, whereas the laboratory methods are time, capital and labour intensive, which is a serious disadvantage in large scale or periodic monitoring. Therefore, there is a need to develop and standardize the methods, which are rapid, non-destructive and measure the soil salinity directly in the field. The advantage of such methods over the presently available methods are rapidity, cost-effective and limited effect of spatial variability on measurement and possibility to use under dry wet, stony, cropped and uncropped soil conditions.

Advantages of Electrical and Electromagnetic Sensors

- Non destructive
- Less Time consuming
- Non tedious
- Less man power required
- Detection of Buried Agricultural Drainage Pipe
- Compatible with GPS

Principles of operation



Transmitter coils (Produces signal)	Receiver coils (Receives signal)

Fig. 1. Conceptual figure of Principles of operation

Where the subsurface is homogeneous there is no difference between the fields propagated above the surface and through the ground (only slight reduction in amplitude). If a conductive anomaly is present, the magnetic component of the incident EM wave induces alternating currents (Eddy currents) within the conductor. A transmitter coil located at one end of the EM instrument induces circular eddy-current loops in the soil with the magnitude of these loops directly proportional to the electrical conductivity in the vicinity of that loop. Each current loop generates a secondary electromagnetic field that is proportional to the value of the current flowing within the loop. A fraction of the secondary induced electromagnetic field from each loop is intercepted by the receiver coil of the instrument and the sum of these signals is amplified and formed into an output voltage which is related to a depth-weighted soil electrical conductivity, EC_a. The amplitude and phase of the secondary field will differ from those of the primary field as a result of soil properties (e.g., clay content, water content, salinity), spacing of the coils and their orientation, frequency, and distance from the soil surface (Hendrickx and Kachanoski, 2002).

The signal received by the receiver coil measures both

- Quad phase (Q/P) – used to measure conductivity (mS/m)
- In phase (I/P) – also called magnetic susceptibility measure (ppt)

Pathways of Electrical Conductance

Three pathways of current flow contribute to the ECa of a soil: (i) a liquid phase pathway – or soil solution pathway, the dissolved solids contained in the soil water is the most domonent factor influencing ECa measurement (ii) a solid–liquid phase pathway primarily via exchangeable cations associated with clay minerals, and (iii) a solid pathway via soil particles that are in direct and continuous contact with one another (Rhoades et al., 1999a). These three pathways of current flow are illustrated in (Fig. 2).

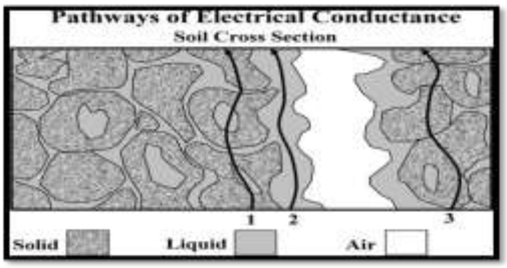


Fig. 2. Three conductance pathways for the EC_a measurement.

Factors Affecting Conductivity

- Soil is generally a good conductor (and air has no conductivity)
- Amount of salts (ionic content, higher conductance)
- Clay content (higher clay content, higher conductance)
- Soil moisture content (higher ϴ, higher conductance)
- Compaction (higher compaction, higher conductance)
- Presence of soluble salts(Ca, Mg, K, Na) and exchangeable salts
- Temperature: As temperature decreases to the freezing point of water, soil EC decreases slightly. Below freezing, soil pores become increasingly insulated from each other and overall soil EC declines rapidly.Electrolytic conductivity increases at arate of approximately 1.9% per^{0}C increase in temperature. For that reason customarily, ECa is expressedat a reference temperature of 25^{0}C for purposes of comparison. The apparent conductivity measured at particular temperature can be adjusted to reference conductivity at 25^0 C by following equations

$ECa_{25} = f_t \, ECa_t$……….(Handbook 60, U.S. Salinity Laboratory Staff, 1954),
Where, f_t is the temperature conversion factor

Modes in taking reading

EM-38 (Geonics Pty Ltd) can provide a rapid measure of EC_a to a maximum depth of 1.5 m. The ground placement of the EM38 determines the shape of the primary electromagnetic field emitted from the instrument into the soil. This determines the zone of sensitivity of the measurement in the soil profile. When the instrument is placed on the ground horizontally, the primary field (EM_h) is strongest at the soil surface and declining with depth, while the primary field for the vertical placement (EM_v) is strongest at 0.35 m depth and declining in sensitivity to a depth of 1.5 m (McNeil 1980). Slavich (2002) suggested that the average of profile EC_a or $(EM_h+EM_v)/2$ provides a better representation of the root zone salinity compared to the value of EM_h or EM_v alone, and the relative value between EM_h and EM_v can be used to estimate the distribution of soil salinity in the soil profile. If the measurement is conducted over time, the relative values of EM_v and EM_h can be used to assess the salt leaching mechanism.

Fig. 3. EM38 measurement in (a) vertical mode (b) horizontal mode

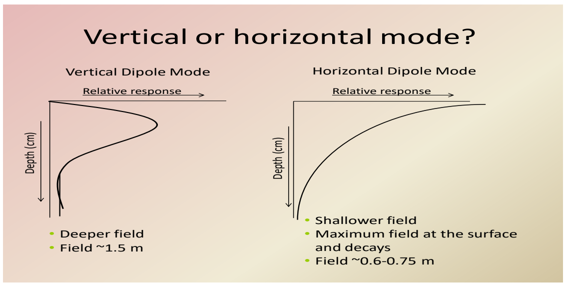


Fig. 4. Response of vertical and horizontal Dipole mode

Calibration of Instrument

EM-38 set-up and calibration procedures

Battery Test: The battery test should be carried out at the beginning of each day, and anytime the battery voltage is suspected of being low. Check the battery voltage by setting the POWER switch to BATT: the Q/P displayed reading will be between -1500 and -720 for a good battery. Any reading outside this range indicates that the battery should be replaced.

Calibration Method for Phasing and Instrument Zero

This calibration should be carried out at least 3 to 4 times per day; over ground that is relatively resistive (i.e. #10 mS/m), the procedure should be repeated more frequently.

Because of the high sensitivity of the EM38 it is advisable to remove all metal objects from wrists, fingers, neck and pockets during the calibration procedure. Sensitivity to metal objects. Turn the instrument on by setting the Power switch to ON and allow the instrument to warm-up for 5-15 minutes before calibration. The length of the "warm-up" period is recommended to be longer if the instrument transportation/storage area temperature is substantially different than the temperature of the survey area.

Step 1: Lift the EM38 to a height of about 1.5 meters (5 feet) from ground surface.

Step 2: Set the Q/P (quad phase, or "conductivity") reading to zero using the Q/P Zero control knob.

Step 3: Set I/P (inphase, or "magnetic susceptibility") reading to zero using I/P Coarse and Fine controls. Ensure that the Q/P still reads zero; if not, adjust the Q/P to read zero as previous using the Q/P Zero control knob.

Step 4: Now adjust the Q/P Zero control so that an arbitrary value (i.e. H = 10 mS/m, where H is thereading in the horizontal dipole mode) appears on the Q/P display. Without changing the instrument height, rotate the EM38 to the vertical dipole mode and note the reading (hypothetically, V = 16 mS/m). Subtract the horizontal dipole reading from the vertical (V-H = 6 mS/m).

Step 5: Finally, with the instrument returned to the horizontal dipole mode, rotate the Q/P Zero control until the Q/P display reads the value calculated in Step 7. In this example it would be 6 mS/m. Now, when you rotate the EM38 to the vertical dipole mode, the reading should be 12 mS/m.

How many measurements?
What transect interval is required?
Purpose of use
Variability of soil- if soil is more variable more no. of reading required for representation of that area.

How do you know what the EM38 is measuring?
Need to establish the relationship between the EM38 reading and the soil feature of interest
Generally for drainage investigation

- Soil Texture
- Total soluble salts
- Electrical Conductivity
- Cations and anions
- Presence of impermeable layer

Case studies (Narjary *et al*., 2017) **:** Area: Mokrakheri, Rohtak, Haryana

Fig. 5a. Location area

Fig. 5b. EM-38 Survey area

EM-38 horizontal and vertical survey readings were collected from Mokrakheri sites on approximate 100 x 100m grid spacing. In field, EM-38 horizontal (H) and vertical (V) readings ranged from 20 to 90 dS/m (H) and 15 to 95 dS/m (V).

Soil samples from the same sites in the depth range of 0-15, 15-30, 30-45, 45-60, 60-75 and 75-90 cm depth were collected from 8 location points, processed, and the EC of the saturation paste extract and SAR was determined. It was found that EC_e of the soil ranges between 5-45 dS/m and SAR 20-120 meq/l. A good correlation (r^2= 0.74) was found between apparent conductivity (H) with actual electrical conductivity and SAR (r^2= 0.83)

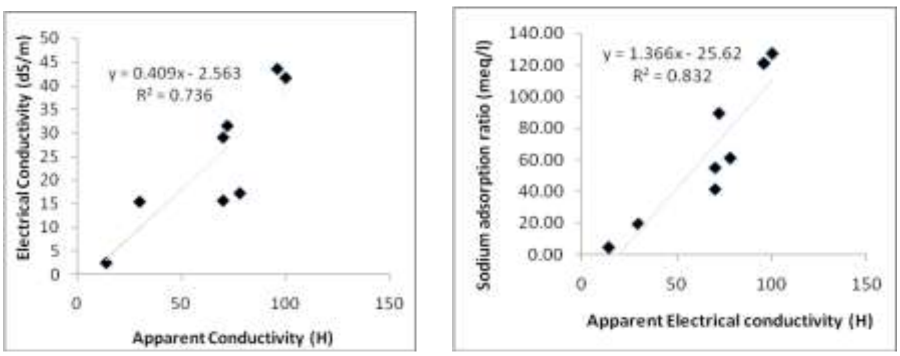


Fig. 8. Relationship between apparent EC and (a) actual EC, (b) SAR

Predicted salinity equation: **Y= 0.4093X-2.5639** where X= apparent Conductivity (H)

Case study 2:

Estimating salt leaching by comparing the horizontal (EM_h) and vertical (EM_v) measurements made using the EM38 instrument.

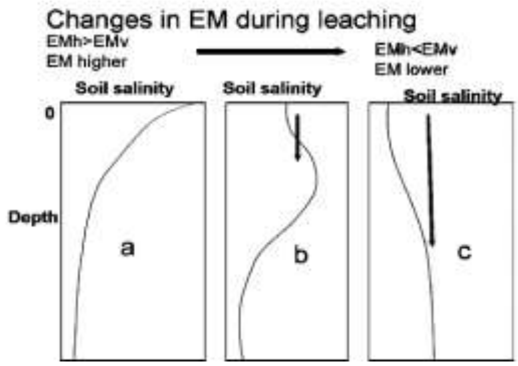


Fig. 9. Soil salinity profiles and EM readings
(a) infiltration of sea water /initial soil salinity (b) after some leaching, (c) after greater leaching

Notes on mapping electromagnetic conductivity

- Air has no conductivity so only measuring the soil (so only measuring soil
- Measuring EM at field capacity? This will elevate all readings and give an enhanced response but the trend relative will still be the same (provided there is uniform irrigation)
- External signals – power cables, steel toe cap shoes, watches, irrigation pipes should be avoided

Recommendations

- Take EC measurements when the soil is neither excessively moist nor very dry
- Know where you took the measurements (and what were the overlaying field conditions)
- Collect data on measurement pass spacing no greater than about 20 m. Experience shows that 5-15 m intervals provides a map that adequately identifies the spatial patterns of a field

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Organic Input Management for Sustaining Productivity of Seed Spices under Saline Water Irrigation

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Introduction

Water is one of the most important resources for the growth and development of human communities. Water demand for agriculture is increasing worldwide to meet the increasing demand for food by the rapidly growing population and to improve the living standard standards of population. For crop production in drylands, the major source of water is rainfall, which is often limited and erratic, especially in semiarid and arid regions. Generally, in irrigated agriculture, farmers, planners and policy makers emphasized on short term crop productivity than on long term soil resource sustainability. When poor quality water, particularly high saline water, is used for irrigation, new approaches are needed that address the short term productivity concerns and long-term sustainability issues of the soil resources simultaneously. Dwindling supplies of quality water for irrigation and competition from other users are forcing farmers to use saline water for irrigation. Several studies have indicated that when saline water is used for irrigation, due attention should be given to minimize root zone salinity (Shalhevet, 1994, Katerji *et al*., 2003).

Availability of fresh water supplies to agriculture sector in future is likely to reduce world over and particularly in the Asian countries due to alarming population pressure, high living standards and inter-sector competition. Inadequacy of water for irrigation is often a major factor limiting crop production in arid and semi-arid regions. The estimates for India show that reduction could be 10 to 12% by 2025. In the back drop of this grim scenario, agriculture sector will be left with no alternative than to use poor quality water for its irrigation requirement. The ground water surveys in India indicate that different states use of poor quality ground water constitutes about 30-80 per cent of total ground water development. Groundwater of arid regions is largely saline and in semi-arid regions it is sodic in nature. Groundwater is being increasingly exploited to meet the water requirement of crops or to bridge the shortfall of water available from other sources vis-à-vis the water required by the crops. A shift towards the rice based cropping systems in the semiarid parts of north western India has forced the farmers to exploit ground waters to the maximum for supplementing the limited surface water resources. This over-mining of groundwater is causing decline in ground water levels at alarming rates in better ground water quality zones while in other areas, farmers are left with no option but to use poor quality underground waters. However, 30-80 % of the groundwater aquifers especially in the states of Rajasthan, Haryana and Uttar Pradesh are considered unfit for irrigation, as their use is likely to build-up salinity, sodicity or toxicity in the soils. Salinity and sodicity of underground irrigation water coupled with nutrient deficiencies and/or specific ion toxicity pose a serious problem for sustaining crop productivity in the country. Indiscriminate use of poor quality water for irrigation deteriorates productivity of soils through salinity, sodicity and toxic effects. In addition to reduced productivity, it deteriorates the quality of produce and also limits the choice of cultivable crops.

The use of marginal and poor quality waters is not considered safe for irrigation since the continuous use of such water causes salinity and sodicity hazards in the soils. It is now known that with appropriate techniques i.e. specialized soil–water-crop management practices, the waters that are conventionally considered unfit be profitably used for crop production. The management practices for optimal crop production with saline and sodic water irrigation must aim at preventing the build-up of salinity/sodicity and toxic ions in the root zone to levels that limit the productivity of soils, control the salt balances in soil-water system as well as minimize the damaging effects on crop growth. Efficient, balanced and integrated nutrient management strategies are extremely important to increase yields to match the potential yields obtained under good quality irrigation water. Therefore, we focus on the ionic interactions and nutrient dynamics as influenced by salinity/sodicity of irrigation water and discuss how these issues relate to the nutritional problems and suggest long-term remedial measures to utilize poor quality waters for improving and sustaining crop productivity. Many more areas with good quality acquifers are endangered with contamination as a consequence of excessive withdrawl of ground water.

Given a limited water supply, fertilizers and organic manure applications, over which farmers have a better control, need to be managed properly. In general, the incorporation of organic manures in soil, improves the physical, chemical and biologiocal properties of the soils. The addition of organic wastes to soils reduces evaporation and moderate the soil temperature which can reduce the stress on plant roots and enhance productivity by supplying nutrients. One of the measures being adopted to relieve environmental problems arising from agricultural production is to recycle animal wastes and other organic products as manures and soil amendments (Eneji *et al*., 2001; Bolan *et al*., 2004). The importance of organic matter in improving soil physical properties such as porosity, structure and water holding capacity is already well known (Hamblin, 1991; Ouedraogo *et al*., 2001; Goldberger, 2008). Therefore, the application of organic waste could benefit soil conservation, especially degraded soils or soils susceptible to erosion and leaching. The soils in arid and semiarid regions are often characterized by water scarcity as well as lack of organic matter. Application of soil amendments with the use of saline water might help to obtain good production under these conditions.

Seed Spices

India is a leading producer of spices and condiments; and the seed spices have unique position being the commodity of economic importance. The varied agro climatic conditions provide suitable conditions for spices cultivation. Among spices, seed spices have unique position. They are mostly grown in arid and semi arid zones of India like Rajasthan and Gujarat. Seed spices as the commodity of economic significance, are important horticultural commodity and form integral part of the Indian agriculture. Seed spices are broadly categorized in two groups; major and minor seed spices. Major seed spice crops are cumin, coriander, fennel and fenugreek whereas ajwain, celery, nigella, dill, caraway and anise comes under minor seed spices. India is largest producer, consumer and exporter of seeds spices in the world. Cumin was recently in news due to its record export of all times high of 1093 crore. This situation arises due to Syrian crisis. Syria is second largest producer of cumin after India. This crisis pushed one of seed spice for more export due to slow global supplies from major competing countries like Syria, Turkey and Iran.

In India, seed spice fennel (*Foeniculum Vulgare* Mill.) is grown in Gujarat, Rajasthan, Madhya Pradesh, Haryana and Uttar Pradesh covering an area of 100 thousand ha with production of 143 thousand tonnes in the year 2012-13 (Indian Horticulture Database, 2013). Since the crop is widely grown in arid and semi-arid regions where soil and water often contain high concentration of salts, farmers resort to irrigate it with saline groundwater (Ashraf and Akhtar, 2004; Qasim *et al*., 2003). Though the farmers use saline water for irrigation but no systematic information is available on irrigation water salinity tolerance limits of this crop. In addition to this, there is growing concern about the adverse impacts of pesticides and chemical fertilizers on the environment, quality of food and safety of human and animal populations. As the people are becoming more quality conscious, the demand for organically grown spices is increasing in the global market. Although the benefits of organic fertilizers are widely documented (Enwall *et al*., 2005; Lal, 2004; Fliessbach *et al*., 2009; Pimental *et al*., 2005), but simultaneously it has also emerged that application of organic inputs may be at the cost of yield-loss over short periods (Maeder *et al*., 2002). However, Mbagwu (1992) advocated that use of organic fertilizers can be as effective as chemical fertilizers over longer periods of time. At present; there is limited information available on cultivation of seed spices using saline water; and role of organic fertilizers in mitigating the adverse effects of saline water. Therefore, this study was planned with the objectives (i) to assess the effect of saline water irrigations on the yield of fennel and (ii) to investigate the mitigation of adverse impacts of saline water through appropriate combinations of organic inputs under irrigation using low and high saline water for sustainable production of the crop.

Domestic Scenario

It is beauty of seed spices that at least one crop is grown in each state of India for seed or leafy vegetable purpose. In some states, they are grown on very marginal land for leafy vegetables while in others they are grown on a large scale for seed spice. Rajasthan and Gujarat have maximum are under cultivation and production of seed spices. Thus both states are known as Seed Spice Bowl. Rajasthan ranks first in coriander, fenugreek and ajwain production and second in cumin, fennel and dill. Gujarat stood first in cumin, dill and fennel production and second in fenugreek and ajwain. Punjab is largest producer of celery. UP and Bihar are major producer of nigella. MP, Assam, Odisha, Bihar and UP contribute significantly in coriander production. Haryana, West Bengal and Uttaranchal are othet fenugreek producing states.

Table 1. Area (ha) and production (t) of major seed spices in India

Spice	2013-14		2014-15		2015-16		2016-17	
	Area	Production	Area	Production	Area	Production	Area	Production
Coriander	516070	496240	604090	546800	624780	572990	672760	863530
Cumin	690080	445030	701560	372290	808230	503260	780920	500360
Fennel	94070	135930	46760	78570	76000	129350	89540	148560
Fenugreek	90500	110530	124710	134100	227960	248350	220670	310070

(Source : Spice Board of India)

Table 2. Major seed spice growing regions

Seed spice crop	Growing regions
Coriander	Rajasthan, Madhya Pradesh, Andhra Pradesh, Assam, Tamil Nadu, Gujarat, Karnataka, Uttar Pradesh, Bihar, Meghalaya, Uttrakhand
Cumin	Gujarat, Rajasthan, Madhya Pradesh
Fennel	Gujarat, Rajasthan, Madhya Pradesh, Haryana, Uttar Pradesh
Fenugreek	Rajasthan, Madhya Pradesh, Maharashtra, Haryana, Uttar Pradesh, Uttaranchal, Gujarat
Ajwain	Rajasthan, Andhra Pradesh, Maharashtra, Bihar
Dill	Rajasthan, Gujarat, Jammu and Kashmir, Uttar Pradesh, Odisha, Madhya Pradesh, Punjab
Caraway	Jammu and Kashmir, Hilly areas of HP
Celery	Punjab, Haryana, UP , Delhi
Nigella	UP, Bihar, Jharkhand, West Bengal
Aniseed	Punjab, J & K, AP

Role of Fertilizer Management

At a given level of salinity, growth and yields of crops are depressed more when crop nutrition is disturbed than when it is normal. The salt affected soils are often poor in most of the essential plant nutrients owing to lack of vegetation and low organic matter content. Nitrogen deficiency is widespread in saline soils and a large fraction of the applied nitrogen is lost in gaseous forms under high soil salinity. Availability of phosphorus increases up to a moderate level of salinity but thereafter it decreases. The accumulated salts in saline soils can affect the nutrient availability for plants in following ways: by changing the forms in which the nutrients are present in soils; by increasing the losses through leaching when the saline soils are leached heavily or as in nitrogen through denitrification or by precipitation in soils; through interactive effects of cations and anions; and through the effects of complementary (non-nutrient) ions on nutrient uptake.

Organic Inputs

The use of manures and fertilizers is very important in saline/sodic water irrigated soils. Application of the organic manures, besides adding plant nutrients, brings out improvement in the chemical, physical and biological properties of the soil. Increased crop growth resulting from the addition of manures tends to promote soil aggregation, reduces crust formation and causes rapid increase in the biological activity of the soil. Application of the FYM or compost or green manures also improved soil physical, chemical and biological properties. Amongst the several green manuring crops, dhaincha has been found to be the most efficacious in alkali soils. Field studies revealed that best results were obtained when rice was transplanted immediately after the burial of the dhaincha green manure crop. It was found that green manuring with dhaincha during summer produced rice yield as much as 80 kg N ha^{-1}. Subsequent studies showed that incorporation of 60 days old dhaincha turns about 60 kg N ha^{-1}.

FYM and other organic materials have not only the nutritive value, but play an important role in structural improvements. This further influences leaching of salts and reduce their accumulation in the root zone. The other advantages of these materials in saline water irrigated soils are in terms of reducing the volatilization losses and enhancing nitrogen-use efficiency and the retention of nutrients in organic forms for longer periods also guards against their leaching and other losses. Therefore, the addition of FYM and other organic/green manure should be made to the maximum possible extent. Experimental evidences at CSSRI, Karnal showed that at a given salinity level, increasing application of organic materials improved yields of all the field crops. However, when salinity of the irrigation water was higher, the percent response was reduced when referenced to yields where no organics were applied. It seems that addition of organic materials temporarily immobilize the NH4 - N and subsequently release the organically bound N to crops during the growth season. Increased responses to N fertilizers in the presence of organic materials suggest its role in reducing the volatilization losses and enhance the N-use efficiency under saline environment.

Tolerance of Seed Spices to Salinity/Sodicity

Coriander (*Coriandrum sativum*)

Soil sodicity delayed about one week in germination with the rise of ESP levels in coriander. Sodicity has more adverse effect on the formation of inflorescence than the vegetative growth. The crop could endure ESP 20 for seed and ESP 30 for biomass yields. Variety RCr-41 produced is fairly tolerant to higher sodicity. However, this cultivar is more susceptible to higher pH under calcareous environment. However, Hissar sugandh, CO-1 and CO-2 cultivars are fairly adoptive to such conditions. Coriander can tolerate salinity upto EC 4.0 dS m-1. However growth, flowering and yield of coriander reduce 50% when salinity exceeded 6.0 dSm-1 and do not adversely affects below the EC 4.0 dS m-1. The essential oil content of coriander increases from 0.30% to 84% with higher salinity. For the germination under saline environment Hisae Surbhi,

Sudha and Sadhana cultivars are more tolerant. However, Rajaendra Swathi, GCR-1 & 2 and RCR-20 are least tolerant. Based on the performance under throughout growing period, RCR-446, GCR-2 and CO-2 are more salinity tolerant cultivars (Aishwath *et al*, 2010).

Cumin (*Cuminum cyminum* L.)

Based on survey at farmer's field, cumin can be grown successfully up to EC 13.5 dS m^{-1}. However, sodicity causes adverse effect on cumin cultivation, when soil pH goes beyond 8.5. At high pH, absorption and translocation of micronutrients adversely affected leads to induction of chlorosis and morphological impairments. Among the seed spices cumin is highly tolerant to salinity from germination to overall growth period. Salinity does not affect the essential oil content marked an special characteristics of the crop. Among some of the cumin RZ-341 is the most salinity tolerant cultivar followed by GC-2, RZ-223, RZ-19, and RZ-209 with respect to seed germination. Seed germinates even up to EC 20 dS m^{-1} (Aishwath *et al*., 2010).

Fenugreek (*Trigonella foenumgraecum*)

After cumin, fenugreek can tolerate very high salinity with respect to germination. However, it cannot be grown at higher salinity as that of its germination. Moreover, this problem could be overcomes by supplementary use of Si as Na2SiO3, which decreases membrane permeability. Besides that inoculation of salt tolerant strains of rhizobia improves salt tolerance in fenugreek. Based on farmer's field survey, it can tolerate EC 2.0-3.0 dS m^{-1} depends on the types of salinity and plant part require for marketing. For foliage it can tolerate more salinity than for the seed purpose. Hissar Mukta is a highest salinity tolerant cultivar with respect to germination in a cluster of seventeen cultivars. Fenugreek crop is able to endure soil sodicity at germination stage but an adverse effect was noticed on emergence of branches plant-1 rather than plant height in cultivars namely, HM-346, RMt-1, Hissar Sonali and Kalyanpur Selection. Medium tolerance of sodicity observed in this crop and yield attributes were unaffected up to ESP 30. The variety Kalyanpur Selection produced greater biomass and seed yield than other genotypes up to ESP 30. The cation composition of plant revealed Na inclusion mechanism and showed narrow K/Na and Ca/Na ratio in the foliage indicating the potential of fenugreek crop to withstand medium level of sodicity. Under green house conditions, mitigates the negative effects of salinity on plant dry matter and chlorophyll content in fenugreek (Aishwath *et al*., 2011).

Dill (*Anethum graveolens* L.)

Dill can well perform with salinity EC 5 dSm-1 under heavy textured (saline black) soil and under light textured soil up to 12 dS m^{-1} (NaCl salinity). Up to a certain extent, salinity improves the growth, yield (foliage and oil) and essential oil content in dill. Salinity up to EC 4.0 dS m^{-1} hastens the seed germination also. Hence, mild saline areas are the potential opportunities for both yield and quality of dill cultivation. It is also a good tolerant to alkalinity (~ pH- 9.5 to ~ pH- 9.8). Among the dozens of cultivars, CSS-1 is comparatively more adoptive to higher soil pH. Flowering stage is most sensitive for higher pH as compared to seed yield, plant height, primary and secondary branches. It almost equally performs as fennel in calcareous.

Fennel (*Foeniculum vulgare* Mill.)

Fennel can be grown successfully on salt affected black soil with salinity of 8-10 dS m^{-1}. It also reported by some workers that threshold EC tolerance in fennel was 10 dS m-1 for trimmed shoots and 11 dS m^{-1} for untrimmed plants. Usually fennel can be grown on sodic soil having Exchangeable Sodium Per cent (ESP) 20. The variety HF-107 is most sodicity tolerant followed by Local BRS, NDF-9 and NDF-7. Therefore, the crop can tolerate medium level of sodicity up to ESP-30. Higher sodicity adversely affect the seed yield than foliage even low sodium and potassium leads to lower growth of crop. It also mobilizes calcium in sodic soil as well as phosphorus in calcareous and reclaims them could be boon for companion and subsequent crops. Consequently, this crop also reduces down the EC and pH of the saline and alkali soils, respectively. Highest salinity tolerance cultivars of fennel are GF-1 and RF-125 among the 13 cultivars with respect to seed germination. It is interesting to note that growing age of fennel improve the tolerance in plants than its juvenile and germination stage. Therefore, transplanting is one of the options for further advancement in salinity tolerance (Yadav *et al.*, 2013).

In American and European countries fennel can grown with saline water having salinity around EC_{iw} 3.8 dS m^{-1}. However, sweet fennel irrigated by 1000 ppm sea water gave a good result for growth and yield parameters. Under Indian conditions, fennel and dill can be cultivated profitably in the salt affected black soils by using saline water of EC 4.0 dS m^{-1}.Under arid conditions celery yield increased 10% in response to irrigation waters with EC_{iw} varied from 4.2 to 5.4 dS m^{-1}, but decreased 10% when EC_{iw} was with 6.2-8.0 dS m^{-1}. Celery and fenugreek have tremendous potential for cultivation with irrigation of underground saline waters having salinity up to 10 dS m^{-1} under calcareous soils of Haryana with alternate use of canal water. Nigella can tolerate salinity of irrigation water up to EC $_{iw}$ 4.0 dS m^{-1}. Under Hisar conditions, saline water having EC 4.0 dS m^{-1} can be used in fenugreek, while EC_{iw} 8.0 dS m^{-1} in fennel and coriander.

Table 3. Salinity/alkalinity tolerance limit in seed spices

Crops	EC dS m^{-1} (soil/water)	Remark
Coriander	4.0	Sensitive to higher pH in calcareous soil
Cumin	13.5	Sensitive to higher pH in calcareous soil
Fennel	8.0-10.0	Tolerance improves with age. Sensitive to very high pH in calcareous soil
Fenugreek	2.0-4.0	Seedling stage is more tolerant than the later.
Dill	5.0-12	Depends upon the soil texture and salinity type. Tolerant to high pH (9.8)
Celery	9.0-11.0	Bit sensitive to sodicity
Ajwain	6.0-8.0	Mild sensitive to high pH in calcareous soil. Medium tolerant to sodicity
Anise	6.0-8.0	This tolerance is for germination
Nigella	2.0-7.5	Depend upon the types of salinity. Mild sensitive to high pH in calcareous soil

(Source: Aishwath et al., 2015)

Coriander, Fennel and Fenugreek under Saline Water Irrigation in dryland condition

Averaged seed yield of fennel (ranged from 1.47 to 1.71 t ha^{-1}) in various treatments, the highest being in treatment T8 with 200% application on N basis. Most economical combination over the four years period however, was T_3, where farmyard manure + vermin-compost was used in 50:50 ratio on N basis with an average seed yield of 1.60 t/ha. It could fetch a net income of Rs. 123980 per ha. According to Edwards (1998), vermin-compost contains most of the plant nutrients such as; nitrate, phosphates, exchangeable calcium, soluble potassium, and microelements. Thus, application of vermin-compost helps in improving plant growth and development and is responsible for increased qualitative and quantitative yield of many crops. A cursory look at the results of four years revealed that saline water up to 8.5 dS m^{-1} can be used for irrigation of fennel with application of organic manures. Later helps in mitigating the adverse effect of saline water application and sustaining the productivity of high value crop as compared to application of inorganic fertilizers alone. It can be attributed to improved soil physical state especially in low saline RSC water and sustained release of macro and micro nutrients. Similar results were also reported by several workers (Bahadur *et al.*, 2006;

Gopinath *et al*., 2008; Bahadur *et al*., 2009; Jaipaul *et al*., 2011; Upadhyay *et al*., 2012). Results obtained by Phogat *et al.* (2010) also show that synergy of chemical amendments and organic inputs sustained vegetable production irrigated with high RSC waters. The results presented in this paper are of great importance in managing saline water in arid and semi-arid regions for cultivation of seed spices in general and fennel in particular.

The perusal of data from table 5, indicate that fennel was least sensitive to saline water irrigation as the decrease in yield from continuous use of low saline (4.6 dSm^{-1}) water for irrigation to alternate irrigations of low (4.6 dSm^{-1}) and high (8.7 dSm^{-1}) salinity water and further to regular irrigations with high salinity (8.7 dSm^{-1}) water was to the extent of 4.7 and 20% in seed yield, and about 2 and 15% in total biomass production, respectively. In comparison to above extent of decrease in fennel, the seed and biomass yield of coriander decreased about 6 and 27%, and 3 and 23%, respectively indicating that coriander was comparatively more sensitive to saline environment than fennel. We could not ascertain the saline water irrigation tolerance of fenugreek because of the extensive rabbit damage in the crop. As the salinity of irrigation water increased, there was decrease in vegetative as well as reproductive growth of fennel and coriander (Table 4). The decrease in vegetative growth i.e. height and branches was the maximum in fenugreek followed by coriander and minimum being in fennel.

Table 4. Vegetative growth of coriander, fennel and fenugreek under saline water irrigation

Crop / Mode of Irrigation	Fennel			Coriander			Fenugreek*		
	Height (cm)	Primary Branches (No.)	Umbels per plant	Height (cm)	Primary Branches (No.)	Umbels per plant	Height (cm)	Primary Branches (No.)	No. Sec. Branches
Low Saline	103	9	40	97	8	34	37	6	--
Alternate	98	8	37	94	7	31	33	6	--
High Saline	92	6	33	86	5	27	29	3	--
Mean	97.7	7.7	36.6	92.3	6.7	30.6	33	5	

(Source : Yadav et al., 2013)

However, reproductive growth *i.e* umbels and seed yield was more affected than vegetative growth. The deleterious effects of high salinity irrigation water were minimized when low and high salinity water was used in alternate irrigations (Table 5) and thus adverse impacts on growth can be checked to good extent. Similar results were also obtained by Mangal *et al.* (1986) and Abou El-Magd *et al.* (2008) on coriander and fennel. The harmful effects of saline water irrigation might be due to specific ions such as NaCl, $CaCl_2$ and Na_2SO_4 which inhibit the production of chlorophyll in green parts of the plants, high Na concentration also induce Ca and Mg deficiency and respiratory pathways in roots (Abel and Mackenzie, 1974; Chinnusamy *et al*., 2005).

Table 5. Seed and total biomass yields of coriander, fennel and fenugreek under different modes of saline water irrigation

Crop / Mode of Irrigation	Coriander ($kgha^{-1}$)		Fennel ($kgha^{-1}$)		*Fenugreek ($kgha^{-1}$)	
	Biomass	Seed Yield	Biomass	Seed Yield	Biomass	Seed Yield
Low Saline	1568	980	2017	1146	427	216
Alternate	1521	916	1984	1092	513	302
High Saline	1209	708	1708	914	398	189
LSD (p=0.05)	179	102	218	183	NA	NA
	For overall comparison of three crops: seed-198; biomass-337; irrigation water salinity levels: seed-243; biomass-376; Irrig x crop: seed- 217; biomass-351					

**Crop was damaged heavily by rabbits; NA- not analyzed for statistical comparisons*

Organic Input Management for Fennel under Saline Water Irrigation in Semi-arid Conditions

A field experiment was initiated during *kharif* 2008 with sesame-fennel crop rotation, fennel being cultivated during the *rabi* season at Bir Forest Farm, Hisar (29^{o} 10' N latitude and 75^{o} 44'E longitude at an altitude of 220 m above mean sea level). The study site is categorized as semi-arid with an average annual rainfall of about

450 mm. The total rainfall received during June to May during four years (2008-09 to 2011-12) varied from 399.2 mm to 918.8 mm, of which 75% was received during July to September. Only 10 to 15% of the total annual rainfall was received during the *rabi* seasons. The pan evaporation ranged from 1.2-10.3 mm day^{-1} during November 2008 to May 2012. The low temperatures in the area during December and January adversely affected the growth of the fennel but crop growth resumed afterwards with the rise in temperature. The soil of the experimental site is highly calcareous (Ustic Haplocambids) sandy loam with EC_e 0.80 – 0.86 dS m^{-1}, pH_s 8.2 – 8.5 and organic carbon 0.26%. The water quality of two tube wells available at the farm was analyzed at different intervals following standard methods (Jackson, 1973) to keep track of the temporal changes in the water quality. The average EC_{iw} of two tube wells was 1.9 dS m^{-1} and 8.6 dS m^{-1} and designated as low saline and high saline water, respectively. Periodic EC_{iw}, pH, RSC and SAR of low saline water were 1.9 dS m^{-1}, 8.4, 4.8 meq l^{-1} and 12.9 m mol l^{-1}; and of high saline water these values were 8.6 dS m^{-1} , 7.7, nil and 18.5 mmol l^{-1}, respectively.

The crop was sown in first week of November every year and harvested in last week of April to 3rd week of May of the next respective years in 3-4 plucking. Irrigations were applied commonly to all the treatments but depending upon the climatic conditions, numbers of irrigations varied from 5 – 7 during the four years of study. The fennel variety Hisar Swarup (HF-33) was cultivated for all the four seasons. The treatments composed of irrigations with two water qualities of water in main plots. In sub plots, 8 different treatments comprised of inorganic fertilizer in the recommended dose (60 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1}); inorganic fertilizer and organic manures in combination; and 6 combinations of organic inputs, viz., farmyard manure, vermicompost and non-edible Neem manure as shown in the following treatments:

T_1: 100% inorganic fertilizer which includes 60 kg N ha^{-1} through urea and 30 kg P_2O_5 ha^{-1} through single super phosphate;

T_2: 50% N through urea and P through SSP (inorganic) + 50% using organic inputs, for initial three years. This treatment was fully converted to organic inputs in the 4th year applied through FYM+VC+NM @ 8 t, 1.74 t and 1.60 t ha^{-1}, respectively;

T_3: 50% of N equivalent each using farmyard manure @ 6 t ha^{-1} + vermin-compost @ 1.3 t ha^{-1};

T_4: 50% of N equivalent each using farmyard manure @ 6 t ha^{-1} + non-edible Neem manure @ 1.2 t/ha;

T_5: 33.3% of N equivalent each using farmyard manure @ 4 t + vermicompost @ 0.87 t + non-edible Neem manure @ 0.8 t ha^{-1};

T_6: 100% N equivalent (200% of treatments 3) each using farmyard manure @ 12 t + vermin-compost @ 2.6 t ha^{-1};

T_7: 100% N equivalent (200% of treatments 4) each using farmyard manure @ 12 t + non-edible Neem manure @ 2.4 t ha^{-1};

T_8: 66.6% N equivalent (200% of treatments 5) each using farmyard manure @ 8 t + vermin-compost @ 1.74 t + non-edible Neem manure @ 1.60 t ha^{-1}.

Effect of Saline Water Irrigation on Growth of Fennel

Perusal of data on plant height showed that the average plant height (136.4 cm) was highest under low saline irrigation although it was not significantly different to high saline water during 2008-09 and 2010-11. The data show that fennel was able to tolerate high salinity to a great extent without much reduction in plant height. Number of umbels per plant ranged from 20.1 to 28.2 with an average of 23.2 with low saline and 22.7 with high saline water. No significant difference in number of umbels/plant was observed, however, though the highest number (30.1) of umbels/plant were recorded during first year under high saline water irrigation. Number of umbellets/umbel decreased from 21 to 19.2 during first three years although maximum (28.3) were recorded during fourth year under low saline water irrigation. Number of umbellets/umbels increased from 18 in first year to 27 in the fourth year under high saline water irrigation. It could be attributed to improved physical condition of soil under various organic inputs over the years. Significant difference in number of umbellets was observed during first and third years with higher average number of umbellets (22.4) recorded in low saline water irrigation. Similar results have been reported by Mangal *et al.* (1986) and Abou El-Magd *et al.* (2008).

Effect of Saline Water Irrigation on Yield of Fennel

Seed weight per umbel varied from 1.16-4.04 g and 1.27-3.81 g with low and high saline water, respectively with an average of 2.30 and 2.25 g, respectively (Table 6). Contrary to the expectation of large differences, only the small differences were recorded between two salinities of irrigation water. This might be due to several reasons, possibly higher RSC in low saline water and mitigation of the adverse effect of saline water irrigation by application of different organic inputs. Seed weight of 100 seeds did not differ significantly during the initial three years while significant differences were observed only in fourth year. Averaged data showed that maximum 100 seed weight was recorded under high saline water, may be due to presence of RSC in low saline irrigation water which might have adversely affected the development of seeds as compared to high saline water. Similarly, seed yield of fennel showed decreasing trend initially which got reversed during third and fourth years. Averaged seed yield showed that the higher yield of 1.57 t ha^{-1} was obtained under low saline water which was not much different than 1.56 t ha^{-1} with high saline water irrigation (Table 6). The reasons for such minor differences have been discussed previously in this section. Similar results were obtained by Mangal *et al.* (1986) and Abou El-Magd *et al.* (2008).

Table 6. Seed yield and yield parameters of fennel under saline water and organic input application

Treatments	Seed weight/umbel (g)					100 seed weight (g)					Seed yield (t/ha)				
	08-09	09-10	10-11	11-12	Av.	08-09	09-10	10-11	11-12	Av.	08-09	09-10	10-11	11-12	Av.
Salinity of irrigation water															
Low saline	2.46	1.54	1.16	4.04	2.30	0.90	0.55	0.72	0.79	0.74	1.50	1.26	1.50	2.03	1.57
High saline	2.26	1.64	1.27	3.81	2.25	0.90	0.63	0.77	0.76	0.77	1.40	0.85	1.87	2.13	1.56
LSD (p=0.05)	0.07	NS	NS	0.14	-	NS	NS	NS	0.01	-	NS	0.41	0.06	NS	-
Organic inputs															
T_1	2.20	1.31	1.10	3.40	2.00	0.90	0.54	0.75	0.79	0.75	1.37	0.97	1.53	1.78	1.41
T_2	1.95	1.45	1.27	3.37	2.01	0.89	0.56	0.71	0.79	0.74	1.17	1.01	1.55	2.16	1.47
T_3	2.32	1.59	0.94	3.92	2.19	0.87	0.62	0.74	0.78	0.75	1.44	1.20	1.65	2.10	1.60
T_4	2.20	1.53	1.32	4.02	2.27	0.88	0.64	0.78	0.76	0.77	1.34	1.11	1.61	2.17	1.56
T_5	2.23	1.58	1.25	4.11	2.29	0.85	0.60	0.75	0.77	0.74	1.55	1.17	1.63	2.01	1.59
T_6	2.55	1.84	1.25	4.09	2.43	0.90	0.57	0.74	0.75	0.74	1.44	0.88	1.97	1.97	1.57
T_7	2.47	1.69	1.29	4.06	2.38	0.93	0.57	0.74	0.78	0.76	1.60	1.05	1.56	2.17	1.60
T_8	2.95	1.74	1.29	4.40	2.60	0.97	0.60	0.75	0.77	0.77	1.63	1.03	1.98	2.21	1.71
LSD (p=0.05)	0.41	NS	NS	NS	-	NS	NS	NS	NS	-	0.03	NS	NS	NS	-

(Source : Meena RL et al., 2014)

Effect of Organic Inputs on Growth of Fennel

Application of organic inputs had significant effect on plant height of fennel during all the years. Application of inorganic fertilizers resulted in significantly lower plant heights of 114.3, 100 and 137.5 cm during first, second and fourth year, respectively. Among the treatments, application of farmyard manure, vermin-compost and neem manure (*Neem shakti*) in different combinations (T_3-T_8) resulted in increased plant height as compared to inorganic fertilizer alone (T_1) or combination of inorganic fertilizer + organic manures (T_2). Results also showed that effect of organic manures was quite discernible during the fourth year probably because of the fact that few years are required to improve and rejuvenate the soil fertility. Average plant height was 122.4 cm with application of inorganic fertilizer alone while higher values were obtained in all other treatments. The year-to-year variations in plant height might be due to climate variability, rainfall, impact of saline water irrigation and role of organic manures in mitigating its adverse effects. The role of organic manures in mitigating the adverse effect resulted in overall good plant growth. Average number of umbels/plant under organic manures application ranged from 21.1 to 24.1. The maximum number of umbels per plant ranging from 24.3 to 33.3 were recorded during first year and there was general decline in later years. Number of umbellets/umbel has significant variation only in the first year while remaining non-significant in the following years. Maximum umbellets were recorded during fourth year with average number of umbellets per umbel ranging from 19.8 to 23.5 (Table 6) Meena et al. (2014). Similar findings in plant height and yield of capsicum spice crop were also reported by Gopinath *et al*., 2008; Jaipaul *et al*., 2011.

Effect of Organic Inputs on Yield of Fennel

Perusal of the data presented in Table 6 showed that seed weight per umbel and seed yield with different organic input management options varied significantly during first year. Average seed weight per umbel ranged from 2.0 g with inorganic treatment to 2.6 g with organic manure treatment T_8. Highest seed weight per umbel was recorded during fourth year which ranged from 3.4 to 4.4g. Data on 100 seed weight showed that it differed non-significantly during all the years averaging 0.74 to 0.77g under different treatments.

In first year, the lowest seed yield (1.17 t ha^{-1}) of fennel was obtained with the application of inorganic+organic input combination in the ratio of 50:50 while highest 1.63 t ha^{-1}was obtained under treatment T_8 which was at par with the seed yield (1.44 t ha^{-1}) obtained in treatment T_3. The results of lower yield in treatment T_2 (50% inorganic+50% organic) are in line with the results available in literature on several crops, since the availability of nutrients applied through organic inputs needs time to build-up for its availability to the plants. As expected under field conditions, there are year to year variations in crop yield varying from 0.88 t ha^{-1}to 2.21 t ha^{-1}

(Meena et al., 2014). These can be attributed to initial soil conditions as salinity build-up take time within the season or over the years, variations in quality of irrigation water and rainfall and its distribution during the crop growth period.

Conclusion

Groundwater of poor quality is a general character of arid and semi-arid ecology where fennel crop is cultivated. Results of four years study reveal that cultivation of high value seed spices in general and fennel in particular is possible using saline water up to EC 8.5 dS m^{-1}without much yield reduction. The long-term adverse effect of saline water if any can be mitigated by application of organic inputs (farmyard manure, vermin-compost and neem manureThe organic inputs in various combination helps in improving the soil physico-chemical properties that mitigates the adverse effect of saline water including RSC, which is known to cause adverse effects on soil physical properties. Considering the cost and quality of organic inputs, a combination of 6 t ha^{-1} farmyard manure and 1.3 t ha^{-1} vermicompost seems to be a good combination to achieve the sustainable production of seed spice crops in saline environment.

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Impact of Land Use System on Soil Physico-chemical Properties and Effects on Salinity/Alkalinity Management

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Introduction

Soil salinity and sodicity are the main reasons for soil degradation in arid and semiarid regions worldwide (Gorji *et al*., 2017), adversely affecting the physical (Rasouli *et al*., 2013), chemical (Ferreras *et al*., 2006) and biological (Yuan *et al*., 2007) properties of soils and severely restrict the sustainable development of agriculture (Singh, 2015). Globally, salt-affected soils reach approximately 1 billion hectares, which represent approximately 7% of the extent of the Earth's continents or 20% of the world's irrigated lands (Qadir *et al*., 2006). However, the distribution and types of salt affected soils in different regions and countries are significantly different due to the diverse climates, natural environments and soil formation processes. Recent trends and future projections suggest that with the increasing demands for food and fibre from a rapidly growing population and the reductions in soil resources caused by soil degradation, the sustainable use of salt-affected soils will gain more and more attention (Qadir *et al*., 2006; Herrero and Castaneda, 2015).

As an extremely sensitive and fragile soil resource, salt-affected soils can be more easily influenced by land management practices than other soil types. Therefore, reasonable and effective management practices should be taken to prevent or improve soil salinity and sodicity during the utilization of salt-affected soils (Bennett *et al*., 2009). With intensive studies on the causes and processes of soil salinization and alkalization, several different physical, chemical and biological approaches, including the use of amendments, tillage, crop diversification, irrigation, mulching and revegetation have been used to ameliorate salt-affected soils for sustainable agriculture (Barrett-Lennard, 2002). Of these, revegetation has been used commonly due to its low cost and efficiency in ameliorating salt-affected soils (Barrett-Lennard, 2002; Jiang *et al*., 2010; Devkota *et al*., 2015). Different vegetations have diverse influences on changing soil moisture content and redistributing salts through plant-soil feed-backs due to their different abilities of using soil water and nutrients (Nosetto *et al*., 2008; He *et al*., 2014). Therefore, selecting suitable vegetation to restore degraded soils caused by soil salinization and alkalization is the essential prerequisite of sustainable agriculture in a specific region.

Salt-affected soils are impediments to agricultural production. These soils include saline, sodic, saline-sodic and acid- sulfate soils. Among them saline soils having high concentration of soluble salts, occupy approximately 3.1% (397 million hectare) of the world's land area (FAO, 1995). About 40-60% of world's salt-affected lands are saline and sodic in nature (Tanji, 1990). In India, saline and sodic soils account for approximately 2.95 and 3.79 million hectares, respectively and together constituted 6.74 million ha area in India (CSSRI, 2015). Crop growth and productivity are greatly affected by salinity and sodicity, resulting in annual losses of ` 230 billion in India alone (Sharma *et al.,* 2015). By 2050 the losses are likely to increase manifold with projected increase in salt-affected soils to 16.2 m ha. In India, to feed this huge population of the country, salt-affected soils should be reclaimed and brought under productive cultivation. Moreover, presently climate change coupled with soil salinity/sodicity will significantly affect the crop productivity in rainfed areas of dry semiarid regions.

One of the major drivers of several processes of environmental change is land use as it influences basic resources within the landscape, including the soil resources. Vast area of land can be rapidly deteriorated due to poor soil management, thereby often becoming a major threat to rural subsistence in many developing and developed countries. Conversely, impact of land use changes on soil can occur so unnoticed that land managers hardly contemplate initiating ameliorative measures (González *et al*., 2014). For efficient remediation or reclamation of disturbed or damaged soils, knowledge and understanding of soil properties and processes are essential. Soils provide multiple ecosystem services, allowing sustained food and fibre production, and delivering climate regulation, flood regulation, improved air and water quality, reducing soil erosion, and provide a reservoir for biodiversity (Smith *et al*., 2015).

All soils are subject to some degree of human disturbance, either directly through land-use and land management, or indirectly through responses to human-induced global change such as pollution and climate change. Human impacts on soils largely emerge from the need to meet the food, fibre, and fuel demands of a growing population including an increase in meat consumption as developing nations become wealthier, the production of biofuels, and increasing areas of urbanization. Reclamation of salt-affected soils through different means such as gypsum technology for sodic soil management, different tolerant tree/crop species for saline soil rehabilitation etc. has also resulted changes in land use. This has led to conversion of natural degraded land to managed land and intensification of agricultural and management practices such as increasing nutrient and water inputs and harvest frequency to increase the yields per hectare.

Soil physical properties as influenced by land uses

In 1978, the CSSRI had taken over the Gudha farm about 20 km away from Karnal in Panipat district to set up its experiments. So many experiments were conducted till 1992 and after that CSSRI had given back the land to the Panchayat. Till 2007, the farm was kept fallow and since 2008, rice-wheat cropping system has been followed by the farmers in those lands. Many reclamation technologies were tested during that time and standardized for farmers' use. The effect of those technologies on soil salinity parameters at present time in those areas is essential to understand what changes have been taken place during these times. In Gudha farm, bulk density (BD) of soil ranged from 1.59 to 1.64 Mg m^{-3}, lowest was observed at 0-20 cm soil depth under Eucalyptus (Table 1). Soil under Eucalyptus showed lowest BD at surface soil which might be due to higher leaf litter and bark accumulated at surface soil thereby increased SOC at surface soil (Datta et al., 2015). BD increased with depth, highest (1.80 Mg m^{-3}, at 20-40 cm) was observed under fallow land which might be due to compaction of soil. Soils under Eucalyptus also showed higher gravimetric (0.22 and 0.22 g water g^{-1} soil) and volumetric water (0.35 and 0.36 g cm^{-3}) at both the soil layers than the other land uses. Higher porosity (40%) was also observed at surface soil under Eucalyptus land use. Higher porosity in soils under Eucalyptus resulted in higher gravimetric as well as volumetric water content at surface soil. Datta *et al*. (2017) reported lowest BD (1.25 Mg m^{-3}) at 0-20 cm soil depth under Frass (*Tamarix articulata*) plantation trees compared to other land uses in saline soils of Bir Forest, Hisar (Table 1). Among the agroforestry systems Prosopis *(Prosopis Alba)*-Mustard showed lowest BD whereas Bael-mustard system recorded highest BD at both the soil depths (Table 1). In Sodic soil of Saraswati forest, at 0-20 cm soil depth, lowest BD (1.41Mg m^{-3}) was observed under Eucalyptus plantation. In another study Datta et al. (2015) also reported lowest BD (1.41Mg m^{-3}) under Eucalyptus plantation than others in a reclaimed sodic soil (Table 1). In another study by Mishra *et al*. (2014), lowest BD (1.36 Mg m^{-3}) was observed under *Casuarina* at 0-15 cm soil depth after 10 years of management practices. *Prosopis juliflora* recorded highest mean weight diameter (0.59 and 0.32mm) at both the soil depths, respectively. Highest water stable aggregates (97.3%) were observed under *Casuarina equisetifolia* at 0-15 cm soil depth (Mishra *et al*., 2014) (Table 2).

Table 1. Effect of different land uses on bulk density in saline, sodic and reclaimed sodicsoil (Mg m^{-3})

Land uses	0-20	20-40
Saline soil (Bir forest, Hisar, Haryana)		
Frass (*Tamarixarticulata*)	1.25	1.28
Desikikkar (*Acacianilotica)*	1.54	1.40
Prosopis *(Prosopis Alba)*-Mustard	1.32	1.39
Karonda (*Carrisacarandas*)-Mustard	1.65	1.63
Prosopis *(Prosopis Alba)-Aloevera*	1.64	1.57
Kainth*(Feronialimonia)*	1.50	1.46
Bael*(Aegle sp)*-Mustard	1.72	1.66
Aonla (*Emblicaofficinalis)*	1.64	1.65
Eucalytus (*Eucalyptus tereticornis*)	1.49	1.47
Grassland-pasture	1.66	1.68
Jowar-wheat	1.63	1.73
Mean	1.55	1.54
Sodic[* and # indicate land uses in Swarasati range, Kaithal and Gudda, Panipat, Haryana]		
Prosopis cineraria*	1.54	1.55
Jamun (*Litchi chinensis*)*	1.44	1.63
Eucalyptus*	1.41	1.56
*Prosopisjuliflora**	1.55	1.66
Grassland*	1.79	1.79
Eucalyptus# (Gudda, Panipat)	1.59	1.73
Fallow #	1.62	1.80

Rice-wheat farmers field#	1.64	1.75
Rice-wheat in Farm area#	1.64	1.75
Mean	1.58	1.69
Reclaimed sodic soil (Karnal, Haryana)		
Mango (*Mangiferaindica*)	1.57	1.61
Guava (*Psidiumguajava*)	1.45	1.58
Litchi (*Litchi chinensis*)	1.62	1.66
Jamun (*Syzygiumcumini*)	1.57	1.6
Eucalyptus (*Eucalyptus tereticornis*)	1.41	1.53
Prosopis (*Prosopis alba*)	1.49	1.64
Rice-wheat	1.44	1.73
Mean	1.51	1.62

Table 2. Changes in BD, MWD and WSA under different land uses in sodic soils (Mishra et al., 2014)

Land uses /soil depth	Bulk density (Mg m^{-3})		Mean weight diameter (mm)		Water stable aggregate (%)	
	0-15	15-30	0-15	15-30	0-15	15-30
Fallow	1.52a	1.48b	0.21c	0.17c	82.8b	85.5c
Prosopis juliflora L.	1.39b	1.45bc	0.59a	0.32a	95.3a	93.0a
Casuarina equisetifolia L.	1.36b	1.50b	0.54a	0.22b	97.3a	93.4a
Syzygium cuminii L.	1.40b	1.44c	0.42b	0.23b	95.7a	93.0a
Tamarindus indica L.	1.41b	1.43c	0.40b	0.25ab	94.2a	90.6b
Rice–wheat	1.44b	1.59a	0.47ab	0.22b	95.3a	94.0a

(Data under the same depth followed by the same letter are not significantly different at P = 0.05)

Effects on pH and EC

Land use types significantly influenced pH_2 and EC_2 irrespective of soil depth in Gudha farm (Datta *et al*., 2017). Soil pH_2 and EC_2 significantly increased with depth in rice-wheat system of farmer's field. Soil pH_2 ranged from 9.12 to 10.4, highest and lowest were observed at 140-160 and 0-20 cm soil depth, respectively. Soil pHs of saturation paste varied between 8.54 to 9.64, highest (9.64) and lowest (8.54) pHs were observed at 160-180 and 0-20 cmsoil depth, respectively. Highest EC_2 (2.74 dS m^{-1}) and EC_e (3.05 dS mm^{-1}) were observed at 120-140 and 0-20 cm soil depth, respectively. Under Eucalyptus system, pH_2 ranged from 8.74 to 9.58, lowest (8.74) and highest (9.58) were associated with 0-20 and 40-60 cm soil depth. Here with depth increment, pH_2 and pH_s increased upto 60 cm and then decreased at lower depths. Lower pH_2 was observed at lower depths compared with middle layers pH_2. Low pH_s (8.17) was observed at surface soil of 0-20 cm soil depth, EC_e also showed similar trend with EC_2. EC_2 and EC_e ranged from 0.99 to 1.58 and 2.34 to 3.57 dS m^{-1}. Soil pH_2 and pH_s ranged from 8.49 to 9.27 and 8.14 to 8.74, respectively in fallow land (Datta *et al*., 2017). Surface soil in fallow land (0-20 cm) showed lowest pH_2 and pH_s (8.49, 8.14); EC_2 and EC_e (0.77 and 2.0 dSm^{-1}). Among the land uses, rice-wheat cropping system inside the experimental farm showed lower $pH_{1:2}$ and pHs irrespective of soil depth. Surface soil rice-wheat showed lowest soil pH_2 (8.48) and pH_s (8.08) and with increment in soil depth both soil pH_2 and pH_s increased significantly and reached at highest at 180-200 cm soil depth pH_2 (9.16 and 8.61, respectively). Whereas, EC_2 ranged from 0.68 to 1.56 dSm^{-1}, highest and lowest were observed at 160-180 and 80-100 cm soil depth, respectively (Datta *et al*., 2017). In another study, Datta *et al*. (2015) reported that soil pH increased with depth in all the seven land uses. Minimum and maximum soil pH was associated with Litchi (6.81) at 0–0.2 m and Eucalyptus (9.52) at 1.5–2.0 m depth, respectively. In another study, lowest pH was observed under *Prosopis juliflora* and Rice-wheat cropping system at 0-15 cm soil depth after 10 years of management practices (Table 3).

Table 3. Changes in soil pH under different land uses in sodic soils (Mishra *et al*., 2014)

Land uses /soil depth	Soil pH	
	0-15	15-30
Fallow	10.3a	9.7c
Prosopis juliflora L.	9.2c	9.7c
Casuarina equisetifolia L.	9.8b	10.0b
Syzygium cuminii L.	9.8b	10.0b
Tamarindus indica L.	9.9b	10.1b
Rice–wheat	9.2c	10.4a

(Data under the same depth followed by the same letter are not significantly different at P = 0.05)

Effects on Cations: Sodium was the dominant among the analysed cations of soil saturation extract in all the land uses of Gudha farm irrespective of soil depth (Datta *et al.*, 2017). In rice-wheat system of farmers' field, Na^+ was lowest (28.2 meL^{-1}) at surface soil (0-20 cm) and consequently increase along soil depth around 60 meL^{-1}). In Eucalyptus, irrespective of soil depth Na^+ concentration in soil saturation extract ranged from 21.6 to 41.05 me $L^{-1}$and lowest was observed at surface layer (21.6 $meqL^{-1}$). Under fallow land Na^+ concentration ranged from 21.05 to 30.97 meL^{-1}, highest (30.97 meL^{-1}) and lowest (21.05 meL^{-1}) were associated with 100-120 and 0-20 cm soil depth. Concentration of Mg^{2+} (1.45-2.88 meL^{-1}) was dominant over Ca^{2+} (0.88-2.05 me L^{-1}) irrespective of soil depth.

Under rice-wheat cropping system inside the experimental farm Na^+ concentration ranged from 18.26 to 49.8 me L^{-1}; highest and lowest were observed at 180-200 and 60-80 cm soil depth. Soils at lower depths showed higher Na^+ concentration compared to upper soil depths. Whereas, other cations (K^+, Ca^{2+} and Mg^{2+}) were lower in range (Datta et al., 2017). Cations concentration under Eucalyptus in saline (Bir forest) and sodic soil (Bichia forest) were compared (Table 4). Significant variation in cation concentration was observed among the soil depth. Highest Na^+ (159 meq L^{-1}) concentration was observed at 0.56-0.94 m soil depth in saline soil whereas in sodic soil highest Na^+ (85.4 meq L^{-1}) concentration was found at 0.78-1.2 m soil depth (Table 4). Higher Ca^{2+}, Mg^{2+} and Na^+ concentration were observed in saline than sodic soil.

Effects on Anions and SAR: In rice-wheat system of farmers' field, carbonate concentration increased with depth and highest and lowest (5.34 and 0.87 me L^{-1}) was observed at 160- 180 cm soil depth. Further, bicarbonate concentration increased significantly with depth and highest (23.15 me L^{-1}) was observed at 80-100 cm soil depth. Chloride concentration ranged from 11.75 to 19.05 me L^{-1}, highest and lowest were observed at 120-140 and 60-80 cm soil depth, respectively. Sulfate concentration was lowest at surface (6.02 meq L^{-1}) and increased along soil depth. With depth increment, SARe increased significantly and highest (40.8) was observed at 180-200 cm soil depth. Lowest SARe (14.52) was observed at 0-20 cm soil depth. In Eucalyptus concentration of HCO_3^- varied from 6.74 to 15.1 me L^{-1}. At 0-20 cm soil depth, Cl^- concentration was 6.45 me L^{-1} and increased upto 60-80 cm and then decreased at lower soil depths. Sulfate concentration increased with depth and highest (20.31 me L^{-1}) was observed at 160-180 cm depth. Lowest SARe (15.9) was observed at 0-20 cm soil depth in soil under Eucalyptus. SAR increased with depth upto 100 cm soil depth and then decreased at lower depths. Highest SAR (34.8) was observed at 80-100 cm depth. Surface soil of fallow land showed a lower value of CO_3^{2-}(0.67 me L^{-1}) and HCO_3^- (5.8 me L^{-1}). HCO_3^- concentration increased along depth upto 120-140 cm of soil depth (12.3 me L^{-1}). Irrespective of soil depth sulphate concentration ranged from 7.47 to 11.11 me L^{-1}. SARe varied from 16.95 to 28.9, and lowest value of soil SARe observed at surface soil (16.95). Under rice-wheat cropping system inside the experimental farm, HCO_3^-(5.5 to 13.65 me L^{-1}), Cl^- (8.70 to 16.54 me L^{-1}) and SO_4^{2-} (6.8 to 10.54 me L^{-1}) were greater range. Soil SARe was greater at deep layer (31.5 to 36.5; 120 to 200 cm) compared to 80-120 cm of soil depth (12.87 to 15.57). Anions concentration under Eucalyptus in saline (Bir forest) and sodic soil (Bichia forest) were compared (Table 4). Significant variation in anion concentration was observed among the soil depth. Highest Cl^- (207 meq L^{-1}) concentration was observed at 0.56-0.94 m soil depth in saline soil whereas in sodic soil highest Cl^- (90 meq L^{-1}) concentration was found at 0.78-1.2 m soil depth (Table 4). Higher SO_4^{2-} and Cl^- concentration were observed in saline than sodic soil.

Table 4. Ionic composition in saturation extracts in *Eucalyptus tereticornis* under different soil horizons in salt affected soils

Depth (m)	Saline soil (Bir forest)				Depth (m)	Sodic soil (Bichian Range)			
	Ca^{2+}	Mg^{2+}	Na^+	SAR		Ca^{2+}	Mg^{2+}	Na^+	SAR
	meq L^{-1}			$mmol^{1/2}\ L^{-1/2}$		meq L^{-1}			$mmol^{1/2}\ L^{-1/2}$
0-0.24	2.0	2.0	6.5	4.6	0-0.14	9.0	10.0	3.04	1.0
0.24-0.56	15.0	7.0	28.3	8.5	0.14-0.32	4.0	1.0	3.26	2.1
0.56-0.94	46.0	7.0	159.1	30.9	0.32-0.78	2.0	2.0	53.48	37.8
0.94-1.18	51.0	17.0	113.7	19.5	0.78-1.2	0.5	0.5	85.43	120.8
1.19-1.67	106.0	30.0	58.5	7.1	1.2-1.58	0.5	0.5	47.61	67.3
					1.58-1.90	0.5	0.5	49.13	69.5
					1.90 +	0.5	0.5	35.43	50.1
Depth (m)	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Depth (m)	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
	me L^{-1}					me L^{-1}			
0-0.24	0.9	3.5	11.0	8.1	0-0.14	nd	3.5	18.0	15.3

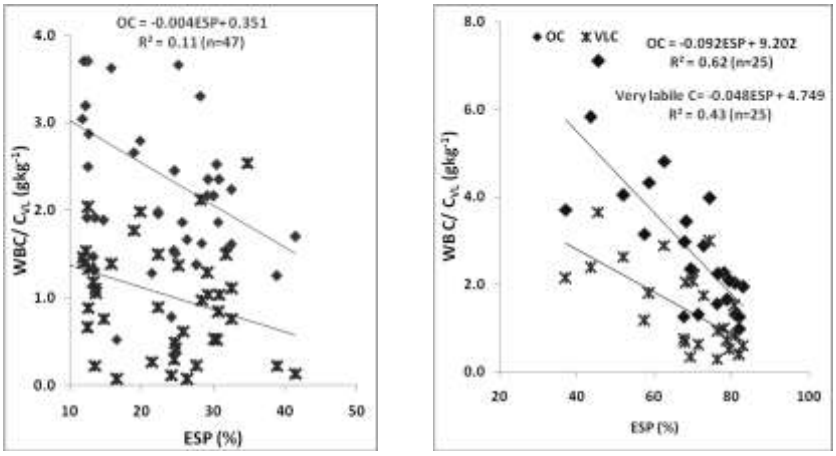
0.24-0.56	0.9	7.5	47.0	1.9	0.14-0.32	nd	9.0	20.0	12.4
0.56-0.94	0.9	5.5	207.0	24.4	0.32-0.78	nd	11.0	72.0	69.2
0.94-1.18	0.7	4.5	143.0	35.3	0.78-1.2	0.4	16.0	90.0	77.0
1.19-1.67	0.7	9.5	183.0	25.0	1.2-1.58	0.4	23.0	50.0	54.5
					1.58-1.90	0.2	23.0	48.0	54.9
					1.90 +	nd	9.0	32.0	36.7

(nd: not detected)

Effects on $CaCO_3$ and ESP

$CaCO_3$ content varied significantly depth wise and also among the land uses in salt affected soils. In reclaimed sodic soil, highest CaCO3 was observed under Litchi (374 Mg ha^{-1}) upto 2.0 m soil depth followed by Guava (306Mg ha^{-1}) and Eucalyptus (279 Mg ha^{-1}) whereas lowest was observed under Jamun (138 Mg ha^{-1}) (Table 6) (Datta et al., 2015). In saline soil, highest (268 Mg ha^{-1}) and lowest (5 Mg ha^{-1}) $CaCO_3$ was associated with Kainth and Grassland, respectively. In sodic soils, excessively higher CaCO3 was observed highest being associated with Jamun (5973 Mg ha^{-1}) upto 2.0 m soil depth. *Prosopis juliflora* recorded lowest (666 Mg ha^{-1}) CaCO3 among the land uses in sodic soils (Table 7).

Different land uses significantly influence ESP of soil. *Tamarix articulata* recorded lowest ESP (6.9%) at surface soil among the land uses in saline soils. In Sodic to Saline-sodic soil, pasture land showed lowest ESP (37%) than other land uses. Significant negative relation was observed between ESP and WB-C and very labile carbon both in saline and sodic soils irrespective of land uses (Fig. 1).



Saline soils   Sodic soils

Fig. 1. Relation among ESP *vs*. WBC and ESP *vs*. very labile C irrespective of land-uses in saline and sodic soils

Effects on SOC: Land uses significantly influence soil organic carbon through their inputs from above and below ground biomass in salt affected soils. In sodic soils Rice-wheat cropping system recorded highest SOC (4 g kg^{-1}) followed by *Casuarina* (3.59 g kg^{-1} at 0-15 cm soil depth) (Mishra *et al*., 2014) (Table 4). In reclaimed sodic soil, highest SOC storage (133 Mg C ha^{-1}) was observed in Guava land use (Datta et al., 2015). In saline soil highest SOC storage was observed in Tamarix (111 Mg C ha^{-1}) and in sodic soil, *Prosopis cineraria* stored highest SOC (175 Mg C ha^{-1}) upto 2.0 m soil depth (Table 7).

Table 5. Changes in soil organic carbon (g kg^{-1}) under different land uses in sodic soils (Mishra *et al*., 2014)

Land uses /soil depth	Soil organic C	
	0-15	15-30
Fallow	1.15c	2.29b
Prosopisjuliflora L.	3.4a	2.69a
Casuarina equisetifolia L.	3.59a	1.96c
Syzygiumciminii L.	3.01b	1.6d
Tamarindusindica L.	2.85b	1.48d
Rice–wheat	3.99b	0.95e

(data under the same depth followed by the same letter are not significantly different at P = 0.05)

Table 6. Changes in WBC and very labile C with soil salinity and sodicity in surface soil under different land uses

Category/ Properties	Normal to saline soil			
	ESP (%)	EC_e (dS m^{-1})	WBC (g kg^{-1})	Very labile C (g kg^{-1})
Frass (*Tamarix articulata*)	6.9	3.2	4.3	2.0
Kainth (*Feronia limonia*)	12.6	5.7	2.9	1.3
Eucalyptus (*Eucalyptus tereticornis*)	12.5	1.0	3.7	2.0
Grassland	12.0	1.0	3.7	1.4
Anola (*Emblica officinalis*)	11.0	3.2	8.8	5.2
Category/ Properties	Sodic to Saline-sodic soil			
Jamun	62.6	3.9	4.8	2.9
Eucalyptus	45.5	4.3	7.1	3.7
Maskat	74.3	5.6	4.0	3.0
Kikar	51.9	9.5	4.0	2.6
Pasture	37.1	2.0	3.7	2.1

Table 7. $CaCO_3$ and SOC-stock (Mgha^{-1}) in different land-uses upto 2.0 m soil depth in northwest India

Category	Land use	$CaCO_3$	Soil organic C
Reclaimed sodic soil (Datta *et al*., 2015)	Mango	162.1	87.4
	Guava	305.9	132.7
	Litchi	373.6	93.9
	Jamun	138.2	83.4
	Eucalyptus	278.6	118.9
	Prosopis	171.1	86.8
	R-W	210.4	95.4
	Mean	234.3	99.8
Saline soil (Datta *et al*., 2017)	Frass (Tamarix articulata)	102.9	111.4
	Kainth (Feronialimonia)	267.9	80.2
	Eucalyptus (Eucalyptus tereticornis)	87.3	99.4
	Grassland	53.3	76.2
	Karonda-Mustard	105.5	85.3
	Anola (Emblicaofficinalis)	182.8	94.7
	Bael	203.6	45.4
	Prosopis -Mustard	268.6	86.0
	Mean	159.0	84.8
Sodic soil (Datta *et al*., 2017)	Prosopis cineraria	3054.0	174.9
	Jamun	5972.8	96.0
	Eucalyp	3146.9	95.0
	Prosopis juliflora	666.0	88.9
	Grassland	3834.7	83.7
	Mean	3334.9	107.7

Conclusions

Different land uses has different potential to reclaim salt affected soils naturally. Eucalyptus with higher biomass as well as leaf and bark fall resulted highest decline in soil pH and higher SOC stocks in salt affected soils and therefore, recommended and popularized among the farmers because it not only helps to reclaim salt affected soils but simultaneously performs many ecosystem services in terms of soil carbon sequestration.

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Efficient Management of Micro-nutrients in Salt Affected Soils

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Introduction

Micronutrient deficiency frequently occurs in salt affected soils of the Indo-Gangetic plains of India. Deficiency is exhibited mainly in upland crops grown on these soils with coarse texture, high pH, high calcium carbonate content and poor retention of water and nutrients (Meena *et al.,* 2017). These soils are low in organic matter and hence contribution of soil organic matter to available pools of micronutrients (Zn, Cu, Mn and Fe) is limited. Additionally, the emphasis on increasing the crop production using of high yielding varieties along with intensive application of chemical fertilizers and limited use of organic manures has accentuated the depletion of micronutrients reserves in the soils (Sharma *et al.,* 2004). In India, a sizeable area has been suffering from various types of land degradation such as soil salinity and sodicity, soil erosion (wind and water), flooding, water logging, shallow depth of soils and sand dunes (Sidhu *et al.,* 1994). Salt-affected soils contain excess salts which impair their productivity. The degree of adverse affects depends upon the type and quality of salts, soil texture, type of crop, variety, stage of growth, cultural practices and environment. Development of salinity and water logging is a serious problem in arid and semi-arid regions of the world and is threatening the sustainability of irrigated agriculture (Chhabra, 2005). In India, 6.73 m ha areas have been characterized as salt affected soils. In general, these soils are alkaline in reaction with exchangeable sodium percentage (ESP) more than 50 and are thus, prone to deficiency of one or more micronutrients. Widespread Zn deficiency has been reported in saline-sodic soils and it was associated with high pH (Katyal and Sharma, 1979). The efforts are underway to ameliorate salt affected soils by applying inorganic and organic amendments with following certain agronomic practices (Meena *et al.*, 2014).

The process of transfer of scientific knowledge into farmer's practices requires a better understating of the existing and emerging micronutrient problems and the options available for their amelioration in crop plants without deteriorating soil quality and environment for increasing the farmer income.

In view of this, present article focuses on efficient micronutrient management options, prevailing information gaps, farmer's experiences about micronutrient problems and new research strategies to suggest suitable measures for correcting micronutrient deficiencies under intensively cultivated and salt affected areas.

Diagnosis of Micronutrient Disorders

Scientific knowledge generated for identifying the characteristic symptoms of visual deficiency under refined sand culture and field situations has been found very helpful in creating mass awareness among the farmers and extension agencies for diagnosing micronutrient disorders in plants more precisely (Katyal and Rattan, 2003). In case of marginal deficiency the critical limits (Table 1) established are also found useful in monitoring micronutrient disorders in crops and soils. Scientific knowledge for diagnosing multi micronutrients deficiencies more precisely are still lacking. Soil testing laboratories are also not well equipped to handle micronutrient analysis to precisely recommend need based fertilizer use.

Table 1. Critical limits in soil and plant tissue (fully developed youngest leaf) for micronutrient deficiencies in field crops

Element	Soil		Plant tissue
	Extractant	CL (mg kg^{-1})	CL (mg kg^{-1})
Zn	DTPA	0.6	10-20
Mn	DTPA	2.0	15-25
Fe	DTPA	2.5-4.5	50
Cu	DTPA	0.2	2-5
B	Hot water	0.5	5-30
Mo	Ammonium oxalate (pH 3.5)	0.2	0.03-0.15

Efficient Management Practices for Correcting Micronutrient Deficiencies in Fields

Amelioration of zinc deficiency

Sources of Zinc

- Among various inorganic sources, zinc sulphate hepta hydrate ($ZnSO_4.7H_2O$) containing 21-22% Zn is found the most efficient, commonly available, economically cheapest zinc source for correcting Zn deficiency in most of the crops and diverse alkaline soils as compared to sparingly soluble Zn sources, chelates and mixtures. Mono hydrated & hepta hydrated zinc sulphate containing (33 & 22% Zn) were found equally efficient for correcting zinc deficiency either through soil and foliar application.
- Synthetic Zn-EDTA chelates were found better than zinc sulphate in combating Zn deficiency in crops in non calcareous loamy sand soils but at par in calcareous and Aridisols soils. However, their high cost than zinc sulphate made it chetated fertilizers most uneconomical and less effective for common use (Singh, 2008).
- The efficiency of sparingly soluble Zn sources such as ZnO, $ZnCO_3$, zinc fritts in fine textured high Zn fixing soils was at par to highly soluble $ZnSO_4.7H_2O$, however, when sparingly soluble and soluble zinc sources were compared in coarse textured soils, it was soluble zinc sources which gave best performance.
- Micronutrient blended macronutrients sources such as zincated urea, zincated super and boronated super were found initially inferior to zinc sulphate or chelates in highly Zn or B deficient soils as they mismatched with the nutritional requirements of crops but long term effect of zincated urea, boronated super became as efficient as that of soluble sources in controlling hidden /emerging micronutrient deficiencies in several crops under salt affected soils.
- Zinc oxide was found effective for roots dipping and seed coating before transplanted crops than zinc sulphate (Singh, 2008). Zinc phosphate was found efficient source for seed coating to control hidden hunger and cheaper than ZnO. Zinc frits release Zn slowly in soil.

Rate of zinc application

- Amount of zinc required for alleviating zinc deficiency varied with severity of deficiency, soil types, nature of crops and cultivars. In majority of instances 5.5 kg zinc ha^{-1} was found to be ideal dose. Zinc deficiency can be best alleviated with the use of 11 kg Zn ha^{-1} to wheat, rice and maize; 5.5 kg Zn ha^{-1} to soybean, mustard, raya, sunflower and sugarcane and with 2.5kg Zn ha^{-1} to groundnut, ragi, gram, linseed, green gram, lentil etc (Singh, 2008).
- Alkali soils are generally deficient in zinc and calcium. Therefore, higher yields of rice, wheat, berseem and other crops in such soils can't be achieved unless the toxicity of Na/ deficiency Ca and Zn are corrected simultaneously. Use of 9-10 kg Zn ha^{-1} to highly alkaline soil and 4.5 kg Zn ha^{-1} in reclaimed alkali soils for rice-wheat/ mustard / barley was found optimum.
- Zinc requirement of crops in alkali soils is reduced substantially by 25-75% depending upon the levels of amendments added (25-100%GR) or reducing level of sodicities (Swarup, 1999).
- Fertilizer Zn requirement of crops was found to be doubled in coarse textured loamy sand with high pH soil than in fine textured loam or clayey soil for wheat and rice.

Frequency of zinc application

- Zinc leaves marked residual effect so it is not necessary to apply Zn to every crop. The residual effect of 11 kg Zn ha^{-1} added to soil persisted on four crops in calcareous and on six crops in non-calcareous soils.
- In sandy loam alkaline alluvial soil 5.5 kg Zn ha^{-1} for first four crops and repeat application of 5.5 and 2.75 kg ha^{-1} for next 8 and 12 crops, respectively gave the largest grain response and were found optimum.
- Under brackish water irrigation in a highly sodic soil (pH 10.4) amended with gypsum @ 50% of the gypsum requirement (GR) the residual effect of 22 kg Zn ha^{-1} could last for four crops of rice- wheat sequence and the fifth crop required repeat application of Zn.
- Alkali soil (pH 10.45) when irrigated with normal quality water, the yield with fresh application of 2.25 kg Zn ha^{-1} continuous to each crop was not different from a single initial application of 18 kg Zn ha^{-1} after the seventh crop, suggesting that residual effectiveness of Zn applied once had not diminished (Nayyar *et al.,* 2001).
- The beneficial effect of FYM alone or in combination of zinc was higher compared to Zn application.

Integrated nutrient management proved better than zinc alone (Meena *et al.,* 2018). Organic manures 12 t ha^{-1} FYM, 5 t ha^{-1} poultry manure and 2.5 t ha^{-1} of piggery manure were as efficient as 11.2 kg Zn ha^{-1} in meeting the Zn requirements of maize-wheat rotation. Also half or even less rates of these manures proved equally efficient or better when amended with 5.6 kg Zn/ha for maize-wheat rotation. Application of 12 kg Zn ha^{-1}, 8-16 t FYM ha^{-1} and 4 t FYM + 3 kg Zn ha^{-1} were found equally efficient for enhancing soybean-wheat productivity in Vertisols (Singh, 2008). Application of 12 kg Zn ha^{-1} left residual effect for 2-3 cropping cycles in medium to deep vertisols.

Methods of application

- Basal application of Zn to soil through broadcast and mixed or its band placement below the seed proved superior to top dressing, side dressing or band placement, foliar sprays or soaking or coating of seeds /seedling in Zn solution/slurry as well as transplanting Zn enriched nursery because of later led delayed cure of Zn deficiency than basal use.
- Foliar feeding of crops with application of 0.5 to 2.0% ZnSO4.7H2O solution is the supplement of soil application but it is not a substitute. In field crops it proved inferior in case of zinc and boron; however, in horticultural and plantation crops foliar feeding of crops with repeated foliar sprays of or boron generally excelled to their soil application.
- Seed coating of Zn materials like concentrated zinc Zn; Mn zinc phosphate was found good in correcting Zn deficiency in bold size seed crops in marginally deficient soils. But these are ZnO proved superior but inferior to soil application of Zn in highly Zn deficient soils. However, seed treatment to potato with ZnSO4.7H_2O solution proved equally effective as that of its foliar sprays or soil application.
- Dipping of rice seedlings in 2-4% ZnO slurry before transplanting proved less effective with other sources in combating Zn deficiency and could not catch up with the farmers because of certain limitations as that of zinc. Dipping of vegetable seedlings in ZnO suspension and sugarcane sets could not meet full Zn requirement of these crops.

Time of application

- Time of zinc application mainly depends upon its content in seed or severity of its deficiency. Best time of zinc addition is prior to sowing or transplanting of crops because maximum zinc absorption by plants takes place upto tillering or preflowering stages.
- Split application of zinc sulphate in rice is recommended as 50% at the time of sowing or transplanting and remaining 50% before or upto tillering stage.
- Basal application of zinc to soil is found the best. However, if it is missed, zinc deficiency can be corrected by top dressing of zinc upto 45 days. Seed coating with ZnO, Teprosyn zinc, zinc phosphate slurry successfully corrected deficiency in marginally deficient soils.
- Foliar sprays of 0.5% zinc sulphate two to three times at 7-10 days interval just after appearance of its deficiency can control zinc deficiency more efficient and effectively. If deficiency persists then continue more sprays.

Use of organic manures

- Fertilizer use efficiency zinc applied to soil seldom exceeds 5 percent. Organic manures were found to increase the efficiency of soil applied Zn (Fageria *et al.,* 2002).
- Among organic materials, poultry manure proved most effective and twice efficient to FYM/compost. Zinc use- efficiency increases twice on combined application of 10 t ha^{-1} of either FYM or compost with 2.5–5 kg Zn ha^{-1}. Poultry manure @ 5 t ha^{-1} alone was as much efficient as 25 kg zinc sulphate ha^{-1} > 10-15 t ha^{-1} FYM > 10-15 t ha^{-1} compost.
- IPNS options for applying 0, 4, 8 and 16 t FYM ha^{-1} in conjunction of 100, 50, 25 and 0 % of zinc requirements were found optimum for soybean–wheat, rice-wheat, maize- wheat and other cropping systems. When 8-10 t ha^{-1} FYM is added annually then micronutrient deficiencies does limit the crop productivity. Excessive use of organics mainly under organic farming may cause emergence of zinc, copper deficiencies in the growing crops.

Amelioration of Iron Deficiency

Sources of iron

- Iron deficiency or its chlorosis is a serious constraint to crops production in many upland alkaline, calcareous, coarse textured soils low in organic matter.

- A number of inorganic, synthetic and other sources available to combat iron chlorosis are ferrous sulphate (19-20.5%Fe), Fe-EDTA (9-12%Fe), Fe-EDDHA (10% Fe), pyrites, biotite and organic manures (FYM 0.15% Fe), poultry and piggary manure (0.16% Fe), sewage sludge are also used as sources of Fe to correct Fe chlorosis in crops.
- Application of Fe-EDTA or FeSO4.7H_2O was found equally efficient and effective in increasing rice yield when seeds were coated with 2% FeSO4.7H_2O solution/slurry. Among various sources, pyrites and biotite proved inferior to ferrous sulphate.
- Since iron applied to soil through inorganic Fe carriers is susceptible to transformation into unavailable forms, therefore its deficiency in crops is one of the most difficult micronutrient deficiencies to manage. Ferrous sulphate, Fe-EDTA and FYM, green manures are most commonly used to correct iron deficiency in most crops.

Iron chlorosis in nursery

- Iron chlorosis in rice seedlings can be effectively controlled by raising them under puddled nursery beds supplemented with requisite dose of FYM or compost. Ponding of water in nursery beds during dry spell is essential to mitigate Fe chlorosis.
- Foliar sprays of 1-2% $FeSO_4.7H_2O$ solution unutilized at weekly interval at early stage of deficiency are quite successful to control Fe chlorosis (Meena et al., 2016). Foliar sprays proved more effective than soil application of iron carriers. As soil application, pyrite proved better than $FeSO_4.7H_2O$ in alkaline calcareous coarse texture upland and saline-sodic soils.

Correction of iron deficiency using soil management

- Iron chlorosis in rice is encountered in upland soils or highly permeable coarse textured soils because of less mobilization of Fe^{2+} as the desired degree of reduction does not occur. So puddling markedly reduces the extent of Fe-chlorosis in rice.
- Iron chlorosis in rice, pearl millet, groundnut, soybean, sugarcane, citrus and horticultural crops is a serious problem. Foliar sprays of 1-2% un-eutralized ferrous sulphate three to four times efficiently correct the iron chlorosis. Soil application is inferior and less profitable than foliar sprays.

Use of organic manures

- Combination of green manure (GM) or organic manures with foliar spray of un-neutralized 1%$FeSO_4.7H_2O$solution is more beneficial in increasing crop yield than GM/ sprays.
- Green manuring, use of FYM and compost helped in mobilisation of inherent soil iron resource in available forms during its decomposition.

Method of application

- Iron deficiency can be corrected by application Fe sources to soil or foliar sprays. Foliar sprays of ferrous sulphate or chelates are found to be more effective and efficient than soil application in correcting Fe chlorosis in rice, wheat, soybean, groundnut, sugarcane, citrus and several other crops.
- Efficiency of ferrous sulphate increases with citric acid during foliar sprays soybean, groundnut, rice, sugarcane yield by 16-24%.

Optimum rate

- Fertilizer requirement for basal soil application of Fe is very high (50-150 kg $FeSO_4$) compared to 1-2% ferrous sulphate solution for foliar application and as such soil application uneconomical.
- Iron chalets are more efficient than inorganic sources in combating Fe deficiency but due to high cost of synthetic carriers farmers do not prefer using chelate except in cash crops.
- The dose of pyrite ranged from 5-10 qha^{-1} and that of $FeSO_4.7H_2O$ from 50-100 kgha^{-1} in soil. The efficiency of soil applied Fe could be enhanced when applied in conjoint with 10 t ha^{-1} organic wastes. The relative efficiency of iron source was: sewage-sludge >municipal waste >poultry manure >pressmud >FYM >$FeSO_4.7H_2O$. Sewage-sludge as a source of Fe was more efficient than poultry manure and other organic wastes.

Amelioration of manganese deficiency

Sources of manganese

- Manganese deficiency occurs sporadic. Its deficiency in wheat has emerged and is on the increase in Punjab as a result of the adoption of intensive cultivation of rice-wheat system in place of maize-wheat or groundnut -wheat system for a period of 7-10 years on highly permeable coarse-textured alkaline soils low in organic matter.
- Soils application of $MnSO_4.4H_2O$ proved 1.5 and 10 times more effective than Mn-frits and MnO_2, respectively in increasing the grain yield of wheat in sandy textured soils.

Method of application

- Both soil and foliar application of Mn significantly increased the yields, but the rates of soil applied Mn (40-50 kg ha^{-1}) are uneconomical than its foliar sprays due to more reversion of soil applied Mn to higher oxide in alkaline soils.

Rate of application

- Foliar sprays 3-4 times of 0.5-1.0% $MnSO_4$ solution (7.5-15 kg Mn ha^{-1}) are equally or more efficient than basal soil application of 25-75 kg Mn ha^{-1} to wheat in salt affected soils.

Time of application

- Foliar sprays of $MnSO_4$ solution one before and two after first irrigation gave maximum wheat yield response in alkaline sandy soils.

Tolerant cultivars

- Among large number of wheat cultivars the magnitude of response to Mn application decreased successively as the rating of the tolerance increased and there were no significant responses in the most tolerant categories.
- The tolerant cultivar HD 2329 needed only one foliar spray (1.6 kg Mn ha^{-1}) as compared to 2 to 3 sprays (3.2-4.8 kg Mn ha^{-1}) to moderate or least tolerant cultivars like HD 2329 so later is being sown on a large scale by the farmers on Mn-deficient soils.
- Durum wheat genotypes are more susceptible to Mn deficiency than aestivum wheat. Relative susceptibility of crops to Mn stress was in the order of oat > lentil > Lucerne > gobhi sarson > senji > maize fodder crops to the order of berseem > shaftal = metha.

Amelioration of Boron Deficiency

Sources of boron

- Borax, granubor & boric acid proved equally efficient in combating B deficiency in crops.

Method of application

- Basal soil application of B proved superior and corrected its deficiency more efficiently than to foliar sprays. Sprays controlled its deficiency in standing crops but less effectively.
- In case of hidden deficiency sprays of 0. 2% boric acid or borax at pre flowering or flower head formation stages enhanced te crop yields.
- Boron helps in pollination and seed formation so foliar sprays are helpful in better pollination, seed setting and yield even in few soils tested adequate in soil available B.

Rate of application

- Boron deficiency in crops grown in alkaline, calcareous or non-calcareous (coarse textured) soils can be corrected by its soil application more efficiently.
- Optimum dose of boron in calcareous soils of Pusa, Bihar and Junagarh (Gujarat) ranges between 1.5-2.0 kg B ha^{-1} and 1.0-1.5 kg B ha^{-1} in non-calcareous sandy, laterite soils. Maize, wheat groundnut, sugarcne, cotton, sunflower, safflower and various vegetable crops showed high B requirements than soybean, green gram and mustard & oilseeds.
- Maize, rice, wheat, sunflower, groundnut, cotton, cabbage, cauliflower need 1.5-2.0 kg B ha^{-1} in calcareous soils of North Bihar, West Gujarat, red and lateritic soils, 0.5 kg ha^{-1} to gram, pearl millet in sandy soils of western Haryana and 0.5 kg Zn ha^{-1} in soybean/wheat/mustard,/gram sequence in

swell- shrink soils of Central India. Sensitive crop needs two to three times more boron than tolerant crops in B deficient soils (Shukla *et al.,* 2014).

Frequency of application

- Boron leaves residual effect to the succeeding crops. Effect of 1.6 kg B ha^{-1} in calcareous soil persists on two to three crops in sequence.
- Application of more than 2.0 kg B ha^{-1} caused toxicity to maize, grain and other crops even in calcareous alkaline soils.

Copper deficiency

- Copper sulphate is mostly used carrier in soil and/or for foliar sprays. Application of 5 kg Cu ha^{-1} increases wheat grain yield in loamy sand salt affected soils.

Molybdenum deficiency

- Application of ammonium molybedate (54% Mo) and sodium molybdate (39% Mo) are common sources of Mo to rectify its deficiency in soils and crops.
- Vegetables, pulses, legume oilseed are more responsive to Mo than cereals. Crop need varied from 0.4-0.5 kg Mo ha^{-1} in Mo deficient red acid soils.
- Mixing of ammonium or sodium molybdate with phosphatic fertilizers proved very effective to increase Mo use efficiency.

Relative tolerance of crop species or cultivars

- Marked variations in the relative susceptibility of a number of varieties of rice, wheat, maize, chickpea, lentil, potato, pearl millet, finger millet, mustard and linseed for Zn; of rice, chickpea and lentil for Fe and of wheat, maize chickpea, pigeon pea lentil, sesame, mustard and linseed for B.
- In general, the varieties of rice, maize are more susceptible to Zn deficiency than wheat. Susceptible varieties being mostly dependent on readily available forms of native micronutrients in soil are more responsive to applied micronutrients than the tolerant one under stress condition.
- A number of pulses, oilseeds and cereals varieties have been found tolerant to B deficiency, which can safely be grown under B stress condition.
- Application of B to tolerant crops or cultivars has produced negative response.

Interactions with Micronutrients

Availability of micronutrients to plants is mainly controlled by soil pH, concentration in the soil solution, organic matter content, crop species and genotypes within species, salinity level and salt composition. Due to these factors and their interactions, micronutrient availability in salt affected soils is very complex. Grattan and Grieves (1999) reported that availability of micronutrients to plants growing on salt affected soils may increase, decrease, or have no effect. Zinc concentration in plant tops has been found to decrease with increasing sodicity (Mehrotra *et al.,* 1986) but not necessarily with increasing salinity. The majority of studies in the literature have shown salinity to increase Zn concentration in shoot tissue such as in dry bean (Doering *et al.,* 1984) and corn (Rahman *et al.,* 1993) but in other studies it was not affected (Izzo et al., 1991). Iron uptake in plants is also as inconsistent under salinity treatment as Mn and Zn. The increase in uptake of these micronutrients was associated with decrease in pH of the soil solution (Fageria, 1985). Very little information is available towards salinity effect on Cu and Mo uptake in crop plants. Salinity influence on Cu was also variable. High concentration of substrate Ca^{2+}, particularly under calcareous conditions, decreased B absorption and can induce a B deficiency (Gupta *et al.,* 1994). The decrease in B uptake with increasing calcium and sulfate ions is also reported (Grattan and Grieve, 1999).

Management Practices to Improve Nutrient Use Efficiency

Successful crop production on salt affected soils depends on soil, water, and plant management practices. Management practices which can improve crop yields and consequently nutrient use efficiency by crop plants grown on salt affected soils are use of soil amendments to reduce effect of salts, application of farmyard manures to create favorable plant growth environments, leaching salts from soil profile and planting salt tolerant crop species or genotypes within species (Fageria *et al.,* 2011). Addition of fertilizers, especially potassium may also help in reducing salinity effects and improving nutrient use efficiency. The maintenance of an internal positive turgor potential of plants exposed to saline conditions is an important factor for maintaining growth. This is accomplished by the uptake of ions, chiefly K^+, Na^+, and Cl^- as well as by synthesizing organic metabolites. Thus the application of high K^+ fertilization might enhance the capacity for osmotic adjustment of plants growing in saline habitats.

Micronutrient Sources in Fertilizer Control Order (FCO) for Farmer's Use

The deficiency of a micronutrient can be corrected through addition of chemical fertilizers (off farm inputs), organic manures/waste, recycling crop residues (on- farm inputs) and to some extent by cultivation of tolerant crops and their cultivars.

Table 2. Nutrient contents of fertilizers approved under FCO

Materials	Element/Forms	Content (%)
Zinc sulphate.	Zn	21.0
Manganese Sulphate*	Mn	30.5
Ammonium Molybdate	Mo	52.0
Borax (For soil application)	B	10.5
Solubor (Foliar spray)	B	19.0
Copper Sulphate*	Cu	24.0
Ferrous Sulphate*	Total Fe	19.5
	Ferrous & Ferric	19.0 & 0.50
Zinc Sulphate mono-hydrate	Zn	33.0
Zinc Phosphate $Zn_3(PO_4)_2.4H_2O$	Zn + P	19.5
Chelated Zn (EDTA form)	Zn	12.0
Chelated Fe (EDTA form)	Fe	12.0
Boronated super phosphate	$B+P_2O_5$	0.18 B + 16.0 P_2O_5
Zincated urea	Zn+N	2.0 Zn + 43.0 N

Several inorganic salts, synthetic chelates, natural organic complexes, mixtures are notified by the Government of India under FCO, 1985 as micronutrient fertilizers which vary considerably in their nutrient content, ameliorative efficiency, residual effect and for economic effectiveness for different soil-cropping systems (Table 2). Apart from the specifications of single micronutrients, some major nutrient fertilizers fortified with micronutrients have also been notified under FCO, 1985 such as boronated single super phosphate and zincated urea.The fortified fertilizers, which may have one or two major nutrients like N or N and P with a specific micronutrient may prove to have special advantage in areas of wide spread deficiency in the soils. Zinc phosphate was notified based its better performance to seed treatment.

Conclusion

Salt-affected soils in arid and semi-arid tracts of the India are prone to deficiency of micronutrients. A considerable scientific knowledge has been made available about the methods of diagnosis of micronutrient disorders and their management more efficiently. The deficiency of Zn is now declining due to regular zinc fertilization. Most of the farmers apply zinc and other micronutrient fertilizers through broadcast, basal, top dressing, band or seed/seedling coating and foliar sprays but use of zinc in rainfed crops is very less than irrigated crops. Multi-micronutrient mixtures are mainly used in sugarcane, grape, turmeric, roses, groundnut, vegetable, fruit and plantation crops. Chelates are efficient but farmers do not commonly use them as soil application due to higher cost. Soil application of zinc and boron and foliar sprays of iron and manganese are found more economical; hence their application is widely practiced by the farmers. Micronutrient toxicities through fertilizations are not reported except of boron. Use of manures and IPNS reduced the micronutrient fertilizer requirements of crops and enhances residual effect. The better partnership among scientists-industrialists-state governments and farmers are very much needed to curve micronutrient malnutrition, improve yield and quality of produce and sustain soil environment.

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Determination of Micronutrients in Salt Affected Soils and Estimation of Requirements for Crops-Practical

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The incidence of micronutrient deficiencies in plants is increasing under salt affected soils. Suitable test methods for the diagnosis and assessment of such deficiencies can be employed for delineation of soil fertility, for making practical recommendations and for monitoring the nutrient status of soils. The available micronutrients do not necessarily reflect their total content in problem soils. The availability of micronutrients in soils is related to their amount in various solid forms which is in equilibrium with that in the soil solution and the rate at which the solution phase is renewed. Soil tests attempt o measure those micronutrient form namely Zn, Cu, Mn, Bo and Fe in soils which are related to plant availability during a growing season. Practical suggestions are offered for ensuring accurate and reproducible analyses. Information on critical levels of available nutrients in soils is also provided.

Determination of Available Zinc, Copper, Manganese and Iron

Various studies have been conducted to find a suitable reagent for the simultaneous extraction of available. Lindsay and Norvell (1978) developed a method using DTPA (Diethylene Triamine Penta Acetic Acid) which was found useful for separating soils into deficient and non-deficient categories for Zn, Cu, Mn, and Fe by using atomic absorption spectrophotometer. This method has been adopted in all the laboratories engaged in the analysis of available Zn, Cu, Mn and Fe in soils of India.

Principle: Chelating agents offer great promise for assessing readily available micronutrient cations in soils. These agents combine with free metal ions in solution to form soluble complexes. DTPA offers a most favorable combination of stability constants for the simultaneous complexing of Zn, Cu, Mn, and Fe.

To avoid excessive dissolution of $CaCO_3$ can release occluded micronutrients (not available for plants), the extractant is buffered in a slightly alkaline pH range and in part by including soluble Ca^{2+}. Triethanolamine (TEA) is used as buffer because it burns cleanly during atomization and has a pka = 7.8. At the selected pH of 7.3, 3/4th of TEA is protonated and is present as $HTEA^{+}$. When the extractant is added to the soil, additional Ca^{2+} and some Mg^{2+} enter the solution, largely because the protonated TEA exchanges with Ca^{2+} and Mg^{2+} from soil exchange sites. This raises the concentration of ionic Ca^{2+} by two to three fold and aids in suppressing the dissolution of $CaCO_3$ in calcareous soils with a 2:1 solution to soil ratio. The capacity of DTPA to complex each of the micronutrient cations is 10 times its atomic weight and ranges from 550 to 650 ppm depending on the micronutrient cation.

Reagents, Standards and Standard Curve: Following reagents are required:

- DTPA = 0.0005M (formula weight 393.35),
- (ii) $CaCl_2.2HO_2$ = 0.01 M solution and
- TEA = 0.1 M solution.

Extracting Solution: For 1 L DTPA solution, dissolve 13.1 ml reagent grade TEA, 1.967 g DTPA (AR grade) and 1.47 g of $CaCl_2$ in 100 ml of glass distilled water. Allow sometime for the DTPA to dissolve and dilute to approximately 900 ml. Adjust the pH to 7.3 ±.05 with 1:1 HCI while stirring and dilute to 1 liter.

Standard Solutions

Zinc Standard Solution: Dissolve 0.439 g AR grade $ZnSO_4$. $7H_2O$ in 27 ml of glass distilled water in a beaker. Add 5 ml of 1:5 H_2SO_4. Transfer to a litre measuring flask and make volume to the mark to have a standard solution of 100 ug Zn/ml (l00 ppm). Transfer 10 ml of this standard solution to 100 ml volumetric flask and dilute to the mark with DTPA extracting solution to have a stock solution of 10 ug Zn/ml (10 ppm). For preparing working standards, transfer 1, 2, 4 and 5 ml of stock solution (10 ug Zn/ml) to a series of clean 100 ml volumetric flasks and dilute each to the mark with DTPA extracting solution.

Volume of stock Zn solution taken	0	1	2	4	6 ml
Concentration of Zn now in solution	0	0.1	0.2	0.4	0.6 ug/ml (ppm)

Iron Standard Solution: Dissolve 0.702 g of AR grade $(NH_4)_2SO4FeSO_4.6H_2O$ in 300 ml deionized or glass distilled water in a beaker. Add 5 ml of 1:5 H_2HO_4. Transfer to a liter measuring flask and make volume to the mark. This is a standard solution of 100 ug Fe/ml (ppm). To prepare working standards, transfer 1, 2, 4 and 6 ml of stock solution and dilute each to the mark with DTPA extracting solution.

Volume of stock Fe solution taken	0	1	2	4	6 ml
Concentration of Fe in solution	0	1	2	4	6 ug/ml (ppm)

Manganese Standard Solution: Dissolve 0.288 g potassium permanganate ($KMnO_4$) AR grade in 300 ml deionized water in a beaker. Add 20 ml concentrated H_2SO_4, warm to about 600^o C and add oxalic acid solution drop wise to make the solution color less. Cool and transfer to a 1 liter measuring flask and make volume to the mark. This solution contains 100 ug Mn/ml (100 ppm). To prepare working standards, transfer 1, 2, 4, 6 and 8 ml of the standard solution to a series of clean 100 ml volumetric flasks and dilute each to the mark with DTPA extracting solution.

Volume of stock Mn solution taken	0	1	2	4	8 ml
Concentration of Mn in solution	0	1	2	4	8 ug/ ml (ppm)

Copper Standard Solution: Dissolve 0.392 copper sulphate ($CuSO_4$.$5H_20$) of AR grade in 400 ml glass distilled water in a beaker. Transfer to a liter measuring flask and make volume to the mark with glass distilled water. This is a standard solution containing 100 ug Cu/ml. To prepare working standards, transfer 1, 2, 4 and 6 ml of stock solution to clean 100 ml volumetric flasks and dilute each to mark with DTPA extracting solution.

Volume of stock Cu solution taken :	0	1	2	4	6
Concentration of Cu in solution :	0	1	2	4	6 ug/ml (ppm)

Standard Curve and Calibration: Usually at least 3 to 4 standards and a blank of each micronutrient cation are used for drawing a calibration curve. The blank solution (0**ug/ml)** is used to zero the atomic absorption spectrophotometer. The standards are then analyzed with lowest concentration first, and the blank run between standards to ensure that the base line (zero point) has not changed. The concentration of the sample is read off directly on the instrument. After setting the instrument, aspirate the sample, read the concentration. Suppose it is C.

Concentration of element in soil : C x 2 ug/l or ppm

Extracting and Determination: Weigh 10 gram of air dried soil in a 125 ml conical flask or polypropylene bottle. Then add 20 ml of the DTPA extracting solution. Cork the bottles or flask and place them on a horizontal shaker. Shaker for two hours with speed of 120 cycles per minute. Filter the suspension through Whatman filter paper. Keep the filtrate in polypropylene bottles to be analyzed for Zn, Cu, Mn and Fe with AAS. Analyze the sample as described above under standard curve. Experimental condition such as shaking time, DTPA concentration, pH and temperature during shaking influence the amount of Zn, Cu, Mn and Fe extracted by DTPA. The suitable pH of extracting solution is 7.3, shaking time 2 hours and temperature during shaking 25^{o}C. The values of nutrient extracted will change if these precautions are not followed.

Analysis for Available Boron

Out of several methods devised to assess the level of available B in soil, the hot water soluble B method of Berger and Truog (1939) has been most widely accepted. Recent description of this method includes some changes (Koren and Bingham 1985), but the basic procedure remains the same. Throughout boron analysis, use of borosilicate glassware should be avoided even for storage of chemicals. Plastic containers or corning pyrex glassware should be used.

Reagents and Standard Solutions

Reagents

- **Buffer masking solution:** Dissolve 250 gm of ammonium acetate and 15 g of EDTA disodium salt in 400 ml of distilled water and slowly add 125 viol glacial acetic add and mix.
- **Ammethine-H reagent:** Dissolve 0.45 g of Azomethine-H in 100 ml of 1% L-ascorbic acid solution. Fresh reagent should be prepared each week and stored in a refrigerator.

Standard solution: To prepare the standard stock solution, dissolve 0.570 g boric add (H_3BO_3) AR grade in a liter of distilled water to obtain a stock solution of 100 ug B/ml. Take 5 ml of the stock solution in a 100 ml volumetric flask and dilute to the mark. This solution contains 5 ug B/ml.

Working Standards: To a series of 25 ml volumetric flasks, add 0.25, 0.5, 1, 2 and 4 ml of 5 ug B/ml solution and make the final volume to 25 ml.

Volume of stock solution taken	: 0, 0.25, 0.50, 1.0, 2.0, 4.0 ml.
Concentration of B in solution	: 0, 0.05, 0.10, 0.20, 0.40, 0.80 ug B/ml

Preparation of Standard Curve: To each volumetric flask containing working standards add 2 ml of buffer solution and mix add 2 ml of Azomethine-H reagent solution stir thoroughly and allow standing at room temperature for 30 minutes. Make the volume to 25 ml with distilled water and measure absorbance at 420 nm on Spectronic 20 or any other spectrophotometer.

Over a concentration range of 0.5 to 10 ug B/ml Azomethine-H solution forms a stable complex with H_3BO_3 at pH 5.1. Maximum absorbance occurs at 420 nm with little or no interference from a wide variety of salts. Plot the graph of concentration vs absorbance on a semi log paper, plotting concentration on X axis and absorbance on Y axis. Include distilled water for the 0.0 ug B/ml standard solution.

Extraction and Determination of Boron

A 25 gm soil sample, 50 ml of water and about 0.5g of activated charcoal is boiled for 5 minutes in a quartz flask and filtered immediately through Whatman filter paper No. 42. The 5 ml of the extract is taken in a 25 ml volumetric flask and 4 ml of buffer masking solution and 4 ml of Azomethine-H reagent solution is added. The colour is allowed to develop for 1 hour, and the volume is made to the mark. Intensity of colour is measured spectrosphotometrically at 420 nm, and the B concentration read off from standard curve described above.

Calculation

Boron (ppm) in soil sample = Concentration of B in sample (read from the standard curve x 10).

Accuracy of analysis: Difference of 3 to 4% is acceptable. Larger deviation indicates either a large error in one or more determination or presence of some underdetermined constituents. Some errors are practically unavoidable in analytical work. The analyst's skill and judgment play a large part in controlling the extent of such error.

Critical Limits of Available Micronutrients

Critical limits of soil Zn, Cu, Mn and Fe which separate deficient from non-deficient soils vary with the soil, crop and the extractant used. These variations are to some extent related to their differential sensivity to nutrient areas. Even for the same crop, critical limits are not universal for different soils since several factors modify availability of these micronutrients. Therefore, critical limits should be used with reference to a crop and established to match the local soil and environmental conditions. Notwithstanding these variations, the general critical limits of these micronutrients 0.6, 4.5, 0.2 and 2.0 mg/kg soil for Zn, Fe, Cu and Mn, respectively.

Estimation of Micronutrient Requirements for Crops

The probability of getting economic response to micronutrient fertilizer application in soils below the critical limit is quite high while in soils having the nutrient above the critical limit, such a probability is quite low. Critical limit is the level of soil available nutrient above which that nutrient is no longer a primary limiting factor. The critical level varies depending on the soil types, crops and varieties, soil test methods used and seasonal variation. Also, in this approach the quantification of fertilizer dose for individual situation is not possible. Therefore, this concept is more suitable for micronutrient fertilizer recommendations.

Example: Zinc is categorized in very low (0.4 ppm), low (0.4-0.6 ppm), medium (0.6-1.2 ppm) and high (> 1.2ppm). The zinc will be applied in soil, 1.5 times, 1.25 times, general recommendation and no application of zinc in soil under very low, low, medium and high category soil test value, respectively.

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Multi-enterprise Farming System for Livelihood Security in Reclaimed Alkali Soils

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Introdution

In the context of growing threats to global food security due to changing climate in the world's agricultural regions, the effectiveness of integrated farming systems at mitigating the risk of crop failure bears significant relevance. Smallholders practice diverse crop–livestock farming systems in many parts of the tropics, particularly Asia and Africa, which integrate different enterprises on the farm; crops provide food for consumption and feed to livestock, and livestock provide milk and manure to fertilize the soil. The synergies between highly diversified but integrated cropping and livestock systems offer real opportunities for raising productivity and increasing resource use efficiency (Herrero *et al.*, 2010). Out of total 129.22 million land holders in the country, 64.8% are marginal holders who own less than 1 ha and 18.5 % families are small farmers owing between 1-2 hectares of land. The Indo-Gangetic Plains (IGP) of South Asia is characterized by lowest per capita availability of land, inequitable agrarian structure and resource poor farmers (Singh *et al.,* 2011).Continuity of Rice-wheat system in IGP of India has raised serious concerns on degradation of soil health and shrinking fresh water resources. Integration of various farm enterprises in the form of integrated farming system may offer sustainable solutions to these problems, especially for the increasing number of small holders in the region. To improve the agricultural productivity and profitability per unit area, a study on integrated farming system was carried out at ICAR-Central Soil Salinity Research Institute (CSSRI) Karnal, India in reclaimed sodic soils. This pilot study explored the synergies of integration of different possible components of farming systems and evaluated their role to enhance the availability of and access to food, and increase household incomes and employment of smallholders in salt affected areas.

Methodology

At ICAR-CSSRI Karnal, out of the total 2.0 hectare study area (average land holding in the region); 1.0 hectare was allocated tograin crops and 0.2 hectare to each of fodder, vegetables, horticulture, fish pond and livestock+ poultry with biogas plant and compost pits.The allocations of different crops/agricultural enterprises adopted in the integrated farming system at Karnal are described in Table 1. Fruit trees like guava, banana, papaya, crane berry (karaunda),and Indian gooseberry (aonla) were planted on pond dykes and understory inter-spaces between these plants were used for raising seasonal vegetables round the year.

Table 1. Different crop/agricultural enterprise rotations followed within each production system

Crop components		Horticulture		Subsidiary components	
Grain production	Fodder	Vegetables	Fruit trees	Livestock / Poultry	Fisheries
Area in hectare					
(1.0)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Rice-Wheat- 0.2 Rice-Wheat-Moong bean- 0.2 Maize-Wheat-Moong bean- 0.2 WinterMaize-Soybean- 0.2 Pigeonpea-Mustard-Fodder maize- 0.2	Sorghum-Berseem	Cabbage-Tomato-Khira- 0.1 Bottlegourd-Cauliflower/Potato-Onion-Okra- 0.1	Guava + Papaya + Banana	3 Buffaloes+ 2 Cows+ 120 Birds	Catla Rohu Mirgal Common carp Grass carp

Each component was evaluated at the field and farm level for its profitability, sustainability and resource use efficiency in comparison to prevalent rice-wheat system for respective years of studies.

Results and Discussion

At ICAR-CSSRI, Karnal, the productivity in different components of integrated farming system was worked out on the basis of marketable produce from 2007-08 to 2013-14. It represents the yields of individual components in terms of grain, green fodder, green vegetable and fresh fruit in the case of grain crops, fodder crops, vegetables and fruits, respectively (Table 2). In food-grain production, the highest system productivity in terms of rice equivalent yield (REY) was recorded with rice-wheat-moongbean cropping system (12.2 t ha^{-1}) followed by rice-wheat (11.1 t ha^{-1}) and maize-wheat-moongbean (7.0 t ha^{-1}). However, the lowest rice equivalent yield (3.7 t ha^{-1}) was recorded in winter maize-soybean cropping system with low net returns of ₹9815/- because of foggy weather conditions which resulted in frequent attack of diseases (mildew, blights and rusts) during flowering to ripening of soybean. Under grain production components, rice-wheat and maize-wheat-moongbean cropping systems were comparable with each other in terms of production and profitability.

The average net income from crop and subsidiary components together was ₹348595/-, out of which ₹72020/- came from crop (including fodder), ₹35880/- from vegetables and fruits and ₹195650/- from subsidiary components from an area of 2.0 ha, which was substantially higher than conventional rice-wheat cropping system (₹302250/-). Among all the systems, fruits and fisheries production were found more remunerative with a B:C ratio of more than 4, whereas, vegetable production system generated lowest B:C ratio (1.9) due to involvement of higher input cost and labor in this system.

Table 2. Rice equivalent yields (REY) and income generated by various components from their respective area (2007-08 to 2013-14) at CSSRI, Karnal

Component	Area (ha)	Rice equivalent yield (t/ha)	Gross Income ₹	Expenditure ₹	Net Income ₹	B:C Ratio
Rice-Wheat	0.2	11.1	49075	18850	30225	2.6
Rice-Wheat-Moong	0.2	12.2	54145	19630	34515	2.8
Maize-Wheat-Moong	0.2	7.0	31135	11700	19435	2.7
WinterMaize-Soybean	0.2	3.7	16250	6435	9815	2.5
Pigeonpea-Mustard-maize	0.2	4.3	19175	8710	10465	2.2
Fodder	0.2	4.4	19305	6695	12610	2.9
Vegetables	0.2	6.4	28210	14625	13585	1.9
Fruit trees	0.2	6.6	29315	7020	22295	4.2
Livestock	0.2	67.7	299130	134550	164580	2.2
Fisheries	0.2	9.3	41015	9945	31070	4.1
Enterprise Mix Diversification	2	13.3	586755	238160	348595	2.5

The greatest advantage of adopting integrated farming system is round the year income and employment for the farm family. The gross annual income from integrated agriculture system was Rs. 7.9 Lakhs, whereas income from Rice- Wheat system was Rs. 7.3 Lakhs.

The higher net return from integrated multi-enterprise agriculture system comes from synergistic effect among various enterprises resulting in reduced overall costs of production. These observations are consistent with the findings of earlier studies (Chan *et al.*, 1998). The reduced net returns variability and income was due to extended trade-offs among various agricultural enterprises.

Recycling of Resources

The resources were recycled within the system to increase water, nutrient and energy use efficiency through diversified agriculture options. The animal, fishery and poultry components were getting the feed and fodder from the crop components. Whatever dung was produced by the animals was used in different ways. Major part of it used for composting that was applied in fruits and vegetables cultivated on pond dykes. Some part of it was used for biogas generation to meet the daily energy requirement of kitchen and remaining part of it used in fish pond as 'feed' for fishes. Nutrient rich pond water was used for irrigating the crops around the pond and in the crop field during summers. Banana leaves, over matured fruits and vegetables were also used as fish feed. All the resources were recycled within the system. Feed concentrates for the animals also made from ‘D’ grade grains from the crop component. Animal feed prepared at site to reduce the cost of inputs and to ensure the quality of the feed. The schematic trade-off that has taken place in the integrated farming system is depicted in fig. 1.

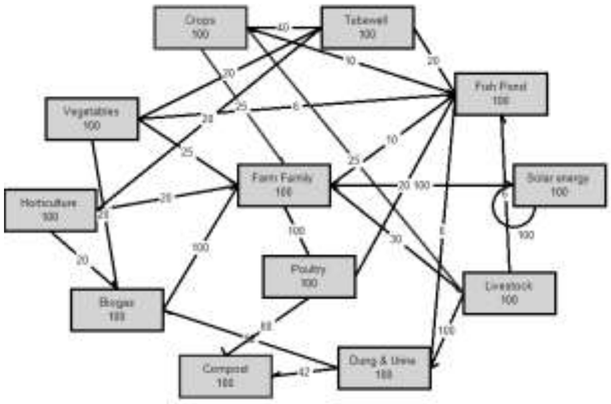

Fig. 1. A Generalized Diagram with Tradeoffs in Integrated Farming System

About 3.85 tons of cow dung per month was obtained from the five to six animals during the study period. Out of which, 52% was used for generating biogas, 42% for composting, 2% for vermin-composting and 4% was added in the fish pond as fish feed. The cooking gas generated from the bio-gas plant (2 $M^3 day^{-1}$) was sufficient to meet cooking requirement of a family of 5-6 persons. The dung used in biogas plant, after production of biogas was also added into the compost pits. The biogas slurry was rich in NPK (1.0-2.0, 0.7-1.0 and 0.8-1.2 %) and better than the Farm Yard Manure (0.5, 0.2 and 0.5 %) respectively. A major part of urine of animals was added directly into the fish pond. The farm wastes were better recycled for productive purpose in the integrated system. In this study, the D-grade grains of the different crops formed >60 per cent of the cattle feed and the feed cost could be reduced by >75% by substituting rice grain, maize, oil cakes of crop components. Recycling of organic wastes (over ripened vegetables, banana leaves, rotten fruits etc.) animal shed flush and duck droppings for fish culture serves the dual purpose of cleaning the environment and providing economic benefits. The anchored straw of rice in rice-wheat cropping system was incorporated in to the soil and the moong straw was left in the soil in maize-wheat-moong cropping system to improve the soil fertility. In vegetable and horticulture system all the plant/crop residues were incorporated in to the soil. The nutrient rich pond water was also recycled and applied to the fodder components of the system for fast growth of the fodder crop and also to meet the nutritional requirement of the crops.

Conclusion

The Integrated farming system can be an efficient and remunerative alternative to rice-wheat/rice-rice cropping system for small holders of salt affected areas in IGP.This diversification of system may help to gain confidence of small and marginal farmers in agriculture by increasing productivity, profitability and sustainability and ultimately their livelihood security.

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Integrated Nutrient Management Issues in Sodic and Reclaimed Sodic Soils

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Introduction

Soil is a complex system which is made up of multi-components and is multifunctional with definite operating limits and a characteristic spatial configuration (Kibblewhite *et al.,* 2008). It is an important and essential component for agricultural production and environmental quality at global level (Glanz, 1995). Deterioration of soil fertility is a major threat to sustainable development of agriculture and is also a major indicator of soil quality. Soil quality is an integrative indicator of environmental quality, (NRC, 1993; Monreal *et al.,* 1998), food security (Lal, 1999), and economic viability (Hillel, 1991), and hence it is an unignorably aspect by any consideration. A soil with proper availability and discharge of water, good biological activity and plenty of nutrient supply is regarded as that of good health. Sustenance of good soil quality is challenging yet necessary in the present scenario of intensive agriculture and fast economic development (Doran and Parkin, 1996). With the growing food demand, no doubt, intensive agriculture has increased the food production yet, at the same time, it has led to nutrient imbalance, particularly micronutrients, unnecessary fertilization to warrant economic losses, soil pollution, water quality deterioration and declined soil health in general. Intensive agriculture has caused second generation problems with the mining of 10 million tons nutrient per year leaving soil in condition of nutrient deficiency, decreased carbon accumulation and impaired soil health. With increasing population leading to increased load on limited resources, the naturally occurring processes that endure life on earth are the most affected, e.g. soil biological processes, and biota in soil and water bodies. (Costanza *et al.,* 1992; Postel, 1994).In reference to crop production, such processes are highly sensitive to frequency and intensity of agricultural interventions that have significant effect on soil physico-chemical properties and ultimately the soil health.

Components of healthy soils

Among the various components of soil, soil organic matter is defined as the most important component of soil. It is plant litter, debris and humus on which microorganisms flourish. A soil rich in organic matter gives sufficient substrate to soil organisms to act upon. Soil microorganisms are responsible for organic matter decomposition and mineralization of nutrients contained in it. This is also a nature-provided way to remove all toxins and wastes from an ecosystem. However, the decomposition is dependent on various other factors such as soil moisture, temperature, pH and quality of the substrate material of which the organic matter is made up (Lavelle *et al.,* 1997). A soil rich in humus, mainly humic acid and fulvic acid, is congenially supportive to healthy plant growth and virtuous nutritional quality of the harvest (Pettit, 2006). Soil organic matter has significant effect on soil pH and thus the soil structure. The soil structure results from the balance between compaction (by machine and soil weight) and buildup of soil aggregates by compaction or any other fauna and climate mediated processes, and breaking of aggregates due to tillage activities (Roger-Estrade *et al.,* 2000). The size and distribution pattern of soil aggregates decides and regulates the transport and diffusion mechanism of gases (Powlson *et al.,* 2001). Microbial decomposers and other detrivores together regulate the rate of microbiological decomposition. They ensure release of nutrients and also have great influence on soil microbial population (Coleman and Hendrix, 2000). Soil pH and amount of natural organic matter accumulated/incorporated at a given time are main governing factors for the continually occurring decomposition process.

Characteristics of Salt Affected Soils

The main sources of salt deposition/accumulation in soils are weathering, runoff water and accession.However, in India, the problem of salt-affected land is generally irrigation-induced, thus covering a large area over naturally occurring salt-affected soils. Sal-affected soils are either saline or sodic in nature. Saline soils refer to the soils having electrical conductivity more than 4 dSm^{-1}, whereas sodic soils are characterized by high exchangeable sodium percentage above 15. Based on FAO/UNESCO Soil Map of the World, a total of 831 Mha covering about 7-8% of the surface areais suffering from this problem (FAO/AGL, 2000). It is estimated that in India about 6.75 Mha of land is barren or less productive due to being salt-affected out of which 3.79 Mha is sodic and 2.96 Mha is saline (Mandal *et al.,* 2010).This area is expected to increase due to canal irrigation that enhances the waterlogging and salinity of soil. Out of total affected area, 1.37 Mha land is spread over in Central Indo-Gangetic Plain (Uttar Pradesh).Besides geogenic development, salt-affected soils also result from changes in water balance with salt accumulation at surface or within the soil profile following the erosion and exposing it to the atmosphere (West *et al*., 1994).

Sodic soils have abundance of sodium carbonate, bicarbonate and sulphate, which stimulatevarious kinds of processes in these soils.The soils usually show poor hydro-physical properties. Sodicity generates structural constraints in the soil that causeslaking and dispersion when the soil is wet and excessive hardness on drying. In the soil profile the level of native soil organic matter is very less due to its high solubility, decomposability and accessibility within the soil system (Tisdall and Oades, 1982). As an adverse effect of soil poor physical and chemical conditions, the organic carbon remains ≤ $1gmkg^{-1}$. Presence of high sodium on exchangeable sites directly affects the plant growth (Gupta and Abrol, 1990). Presence of salts in the soil solution raises the osmotic potential of it and makes the water physiologically unavailable to the plants. This may further cause deficiency of several essential nutrients. At high pH, nitrogen volatilization also takes place at higher rates (Gupta and Abrol, 1990; Grattan and Grieve, 1999),whilepresence of chloride limits the uptake of nitrate (Grattan and Grieve, 1999). All these activities cumulatively affect the plant growth and yield by affecting its physiological and biochemical functions (Lauchli and Epstein, 1990; Rengasamy *et al*., 2003). However, the nature and severity depends on several other factors like topography, hydrology, drainage, land use and climatic conditions (Yadav, 2011). High sodicity causes high dispersion of soil as clay particles move apart and weaken the aggregate structure. This leadsto soil structural collapse and closing of soil pores resulting in hard surface crusts. Presence of hard pan of calcium carbonate in the deeper root zone also restricts downward movement of both water and roots. These soils are characterized with high bulk density and very poor hydraulic conductivity. Sodicity reduce the productive potential of arable lands to nearly one third of their capacity all over the world.However, the severity of the problem is dependent on several other factors as well.

Rice-wheat systems

Rice- wheat (RW) cultivation is a common and established cropping practice in India. The cultivation techniques used for RW system are very old. They cause deterioration of soil structure and influence the soil water relations. These cultivation practices leave the soil with poor physical condition for crop growth by limiting root development and its distribution (Sur *et al.*, 1981; Boparai *et al*., 1992; Oussible *et al*., 1992). Rice is cultivated through wet cultivation method. Puddling activity done during this method reduces the water holding and transmission capacity of soil (Bhagat *et al*., 2003). Also flooding is maintained in field which causes loss of essential nutrients and decreases their availability to the plants due to the creation of anaerobic conditions. Flooding significantly affect the soil pH. Also the process of nitrification-denitrification and phosphorous availability get influenced by the water stagnation particularly in oxisols, vertisols and alluvial soils (Singh, 2009). Iron and manganese toxicities with zinc are very common due to the prolonged submergence of soil (Neue and Lantin 1994; Savithri *et al*., 1999; Singh, 2009). Decrease in zinc availability is an unescapable disorder of wetland rice which is very common in soils with high pH, high organic matter, and high available P or Si content, high Mg - Ca ratio apart from the soils with low level of zinc (Ponamperuma and Deturck, 1993). Wheat sowing is a general practice after rice harvest which is commonly done by deep tilling of soil. Rice soil takes much time to attain the desired moisture level for tillage and sowing. This is the main reason for delay in wheat planting. Preparation of field for wheat sowing requires much time and energy and if the seed is not planted within the desired tilth, it results in weak seedling growth and poorcrop stand (Kumar *et al.,* 2012). Delayed planting of wheat is also responsible for low productivity of wheat. Wheat germination, seedling development, crop establishment and grain development are crucially temperature dependent processes (Jame and Cutforth, 2004). Thus, late sown wheat tends to face temperature variations at different growth stages and get adversely affected. Shortening of the phyllochron interval (Cao and Moss, 1994) and terminal heat stress during grain filling of wheat (Bashir *et al*., 2010; Farooq *et al*., 2011) are the common effects of temperature on wheat growth and its productivity. RW cropping system is highly nutrient exhaustive and continuous cultivation causes depleted fertility of inherent soil by causing deficiency of several essential nutrients (Zia *et al*., 1997).

Increasing demand of food and fiber has forced the farmers to over-explore the natural resource of soil. For this, application of fertilizers is a widespread practice to increase the yield in India. Traditionally recommended dose of nitrogen (N), phosphorous (P) and potassium (K) are trial based and vary from field to field (Moody and Aitken, 1996). Injudicious use of NPK fertilizers is detrimental to soil health (Carpenter *et al*., 1998) because it does not increase the nutrient uptake by plants (Smaling and Braun, 1996). However, it contributes the low use efficiency of the excessively applied fertilizers and other associated factors of leaching, evaporation and volatilization of nutrients (Tilman, 1998; Gyaneshwar *et al*., 2002; Kennedy *et al*., 2004). Chemical fertilizers affect the salt solubility of soil and affect itspH of soil and soil structure by affecting soil aggregates. Variation in soil pH also influences the biological properties of soil that are ecologically important to maintain soil fertility. Alteration in soil health significantly alters the ecosystem capability of restoration of the damage. Sustainable development, is thus, the need of today's scenario that causes no or minimum damage to natural resources.

Integrated Nutrient Management (INM) for sustainable crop production

Integrated Nutrient Management is a soil test based practice in which all sources of nutrients namely inorganic (chemical fertilizer), organic and bio-fertilizers are combined so that good quality crops with maximum yield can be grown. Maintaining a healthy and fertile soil is of key importance in INM.

Problems with unbalanced fertilizer usage:

- Soils receiving only inorganic fertilizers show declined productivity because of deficiency of secondary and micro-nutrients.
- The physical condition of the soil is deteriorated.
- Problem of poor fertilizer nitrogen use efficiency is also increases.
- A considerable portion of applied fertilizer is lost to atmosphere by volatilization or to ground water by leaching.
- Excess nitrogen use causes groundwater and environmental pollution and is destroying the ozone layer through N_2O production.
- Further, higher fertilizer application than required also increases cost and reduces the profit.
- The partial factor productivity of fertilizers during the last three and half decades has showed a declining trend from 48 kg food grains/kg NPK fertilizer in 1970-71 to 10 kg food grains/kg NPK fertilizer applied in 2007-08. It means more and more fertilizers need to be used for per unit production.
- Crops growing under reduced or excessive supply of plant nutrients, in poorly structured soils, with insufficient moisture content will be stressed and it makes plants susceptible to pests and diseases.

Benefits of INM

- It enhances the availability of applied and native soil nutrients and therefore provides balanced nutrition to the crops.
- Improves the Physical, Chemical and biological functioning of soil.
- Improves and sustains soil fertility and productivity.
- Minimizes the deterioration of soil, water & ecosystem.
- Reducing nutrient losses to ground, surface water bodies and atmosphere.
- Reduces cost by eliminating the excess use of inorganic fertilizers.
- Contributes to better pest management, thus reducing use and cost of pesticides and producing better quality and less risky food to consume.

Components of INM

- Inorganic fertilizers.
- Compost and vermicompost
- Manures
- Green manure
- Crop residue and Zero tillage/reduced tillage
- Crop rotation and inter cropping

Conclusion

Soil ecosystem provides range of services to human-beings. But over exploitation of the related natural resources is causing depletion in the fertility and health aspects of soil. Conventional practices of tillage and irrigation are having deteriorating effects on soil structure and health. Shifting towards zero-tillage and conservation-tillage has been found to have favorable effects on aggregate stability, soil organic matter content and moisture conservation. These practices also decrease fluctuation in soil temperature, reduce the risks of soil erosion and enhance the activities of living organisms of soil. Basic idea behind this is to maintain the balance between output and input in soil ecosystem. Continuous use of inorganic fertilizers may cause decline in soil health and crop yields. Integrating nutrient management plan is an economically and ecologically friendly program that uses organic fertilizers like compost and other organic manures with inorganic fertilizers in an integrated manner to sustain high productivity. Computation of nutrient budget to decide the quantity of fertilizer to be applied has come up as an economically and ecologically successful strategy in reducing fertilizer loss. Assessment of soil quality for finding the area of nutrient deficiency needs to be adopted on priority basis. This would serve as an indicator of soil health when planning for integrated and sustainable land management. Targeted, efficient and adequate application of fertilizers is necessary to maximize their potential of influencing crop yield and minimizing the environmental pollution. All these plans need to be supported through proper policies, processes and responsible bodies for implementing them practically.

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Role of Soil Microbes in Salinity Management along with Laboratory Estimation Procedures-Practical

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Introduction

Soil salinity is one of the serious agricultural problems that cause osmotic stress in crops and leads to reduction in growth and productivity in arid and semiarid regions. Excess of salt present in the soil adversely affect the plant metabolism through osmotic inhibition of water uptake by roots or ion toxicity. Salinity consequences in enhanced uptake of Na^+, and eventually reduced Ca^{2+} and K^+ uptake, however low Na^+ and high K^+ or Ca^{2+} are required for physiological functions of plants while excess Na^+ cause metabolic disorders. Enhanced uptake and accumulation of Cl^- may disrupt photosynthetic function of plants by inhibiting of nitrate reductase activity. Since, the accumulation of salts increases in the intercellular space of cell which further leads to dehydration and death (Abrol *et al*., 1988).

Soil microbes are reported several times to have the potential to mitigate abiotic stresses. Plant-microbial interactions are an integral part of the ecosystem. Microbes play an important role in the survival of plants as they modulate local and systemic mechanisms in response to the defence in adverse conditions. The potential of beneficial microbes residing in the rhizosphere is an alternative strategy to ameliorate stress tolerance in plants. The beneficial effects of Plant growth-promoting microbes (PGPM) involve enhancement of water and nutrient uptake, enhancement of systemic resistance that promote growth and development (Kumar and Verma, 2017). PGPM secrets indole-3- acetic acid and 1-aminocyclopropane-1-carboxylic acid deaminase biosynthesis, and other extracellular metabolites act as signaling molecules and elicit stress responsive pathways (Sadeghi *et al.*, 2012). PGPMs also control the osmotic balance and ion homeostasis through the modulation of phytohormones, gene expression, protein function, and metabolites synthesis in plants. These phenomenon results in the production of antioxidants, osmolyte accumulation, and proton transport machinery, salt compartmentalization, and nutrient content which finally reduce the osmotic stress and ion toxicity in plants.

Plant Growth Promoting Microbes (PGPM) and their Mechanism to Ameliorate Salt Stress

Plant growth promoting microbes are the group of microbes that are found in the rhizosphere/ root surfaces or in association with roots which provide benefits to the plants. PGPM have the potential improve the plant growth directly and/or indirectly. The direct mechanisms of plant growth promotion is to provide growth promoting metabolites that are synthesized by PGPMs s and facilitate the uptake of plant nutrients that are present in soil in unavailable form . They directly enhance plant growth by several mechanisms that includes fixing atmospheric nitrogen and transfer them to plants, solubilization of complex minerals such as phosphorus, production of siderophores that chelate iron and make it available to plants, and synthesis of phytohormones (IAA and gibberellic acid) and growth regulators (cytokinins and ethylene). The indirect mechanisms are PGPR helps in preventing deleterious effects of phytopathogens by production of antagonistic compounds like siderophores and cyanides. They also have the ability to synthesize antibiotics, anti-fungal metabolites and cell wall-lysing enzymes, which suppress the growth of pathogens (Klopper *et al*., 1980; 1989). In addition to facilitating plant growth, PGPM has also been reported to protect plants from the deleterious effects of abiotic stresses like drought, salinity, and heavy metals. It has also been observed that plants inoculated with PGPM having different growth promoting properties are more resistant to the deleterious effect of biotic and abiotic stresses.

Several studies was carried out on various crops like wheat, rice, maize, barley, canola and lettuce indicated that PGPM ameliorated deleterious effects of salt stress and enhanced the growth of crops (Li *et al.*, 2017; Cardinale *et al*., 2015; Rojas-Tapias *et al.*, 2012). Under stress conditions, the plant hormone ethylene endogenously regulates plant homoeostasis and results in reduced root and shoot growth. In the presence of ACC deaminase producing microbes, plant ACC is sequestered and degraded by bacterial cells to supply nitrogen and energy to plants (Safari *et al.*, 2018). Hence, by removing ACC, the bacteria reduce the deleterious effect of ethylene, ameliorating stress and promoting plant growth. Inoculation of plant with ACC deaminase containing PGPR has also resulted in enhanced chlorophyll contents of maize as well as lettuce

(Saleem *et al.,* 2007). Another PGPR strain, *Achromobacter piechaudii* ARV8 which produced 1-aminocyclo propane-1-carboxylate (ACC) deaminase, conferred IST against salinity in pepper and tomato (Mayak *et al.*, 2004).

Production of indole acetic acid, and gibberellins by PGPM, results in increased root length, root surface area and number of root tips, leading to an enhanced uptake of nutrients thereby improving plant health under stress conditions. Plant growth promoting microbes have been found to improve growth of wheat, tomato, pepper, canola, bean and lettuce under saline conditions (Li *et al.*, 2017).

Some PGPR strains produce cytokinin and antioxidants, which result in abscisic acid (ABA) accumulation and degradation of reactive oxygen species. High activities of antioxidant enzymes are linked with oxidative stress tolerance. Chen et al., 2007 correlated proline accumulation with salt tolerance in plants. Increased production of proline along with decreased electrolyte leakage, maintenance of relative water content of leaves and selective uptake of K ions resulted in salt tolerance in *Zea mays* coinoculated with Rhizobium and Pseudomonas. Yao *et al.*, 2010 also reported that inoculation with *P. putida* promoted cotton growth and germination under conditions of salt stress

Microbes secrete exopolysaccharides (EPS) that bind soil particles to form microaggregates and macroaggregates. Plant roots and fungal hyphae adjust in these pores between microaggregates and thus stabilize macroaggregates. It has been reported that plants treated with EPS producing bacteria display increased resistance to salt stress due to improved soil structure. EPS can also bind to cations including Na^+ thus making it unavailable to plants under saline conditions (Upadhyay *et al*., 2011).

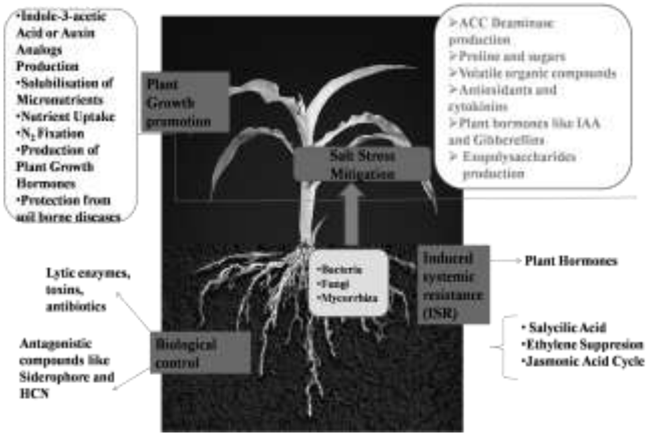

Fig. 1. Mechanism of the plant growth promoting microbes

Isolation of Plant Growth Promoting Microbes from the Rhizosphere by Serial Dilution Method

The rhizospheric soil samples should be mixed thoroughly to make a composite soil. 10 g of dry and highly pulvirised soil sample should be suspended in 90 ml of sterile distilled water considered as a stock solution then transferring 1 ml of soil suspension into 9 ml sterile distilled water with the help of a sterile pipette to yield 10 dilutions. Similarly, a series up 1 to 10 dilutions should be prepared under aseptic condition.

Bacteria will be isolated on nutrient agar, Actinomycetes on actinomycetes isolation agar while fungi on Potato dextrose agar. Then 0.1 ml soil suspension should be introduced into sterilized agar media in Petri dishes and it should be spread thoroughly on the media incubated at 37°C for 24-48 hours and for each dilution the plates should be taken in triplicates.

After incubation period, visual morphological characterization of the bacterial colonies isolated on the agar petri plates will be observed on the basis of colour, shape, size, and elevation etc. of the bacterial colonies. Similar results will be observed for actinomycetes and fungi. Colonies exhibiting prolific growth are selected for further streaking on fresh agar plates for purification and multiplication of the isolates should be done by streak plate methods.

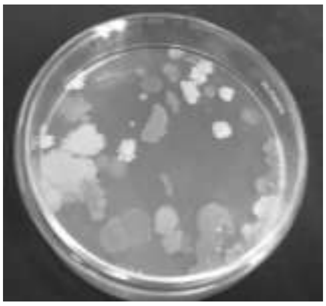

Fig. 2. Bacterial colonies on nutrient agar medium

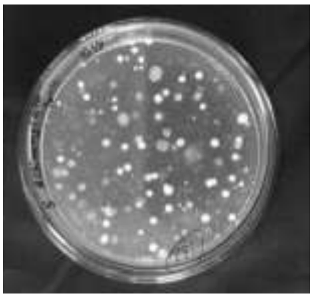

Fig. 3. Actinomycetes colonies on actinomycetes isolation agar

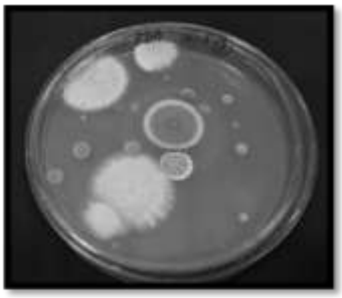

Fig. 4. Fungal colonies on potato dextrose agar medium

Estimation of Plant Growth Promoting Activities

Phosphate Solubilization

Principle: Phosphorus solubilizing microbes has been reported to dissolve the insoluble phosphates by the production of inorganic or organic acids and/or by decreasing the pH. Any microorganism that acidifies its external medium will show some level of phosphorous solubilizing activity. Phosphorus solubilizing activity is determined by the ability of microbes to release external metabolites such as organic acids, through which their hydroxyl and carboxyl groups chelate the cation bound to phosphate, then the latter being converted to soluble forms. Phosphate solubilization takes place through various microbial processes and mechanisms such as organic acid production and proton extrusion (Chen *et al.*, 2008).

Methodology: Phosphate solubilization activity should be screened on Pikovskaya's agar medium. This medium is a selective media. Microbial culture should be inoculated on the centre of plate containing Pikovskaya's agar media by inoculation loop under aseptic conditions. These petri plates should be incubated at 30±2°C for 5 days. The clear zone develops around the microbial colonies shows positive phosphate solubilization activity of the microbes.

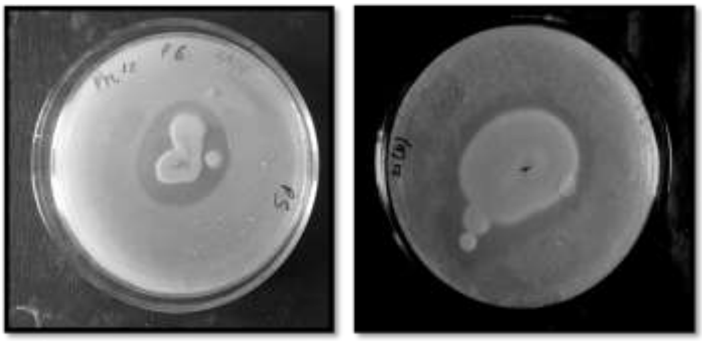

Fig. 5. Fungi Showing Positive Phosphorus Solubilizing Activity

Zinc solubilisation

Principle: Zinc is one of the most essential micronutrient required in various metabolic processes of plants. The deficiency of zinc adversely affects the growth and development of plants. Zinc-solubilizing microorganisms have the potential to solubilize the zinc present in the unavailable form and make it available to plants (Kamran *et al*., 2017).

Methodology: For the estimation of Zn solubilizing ability, the microbes should grow on modified Pikovskaya medium. These microbes were checked based on the formation of halo zones. Incubate the inoculated plates for one week at 37°C

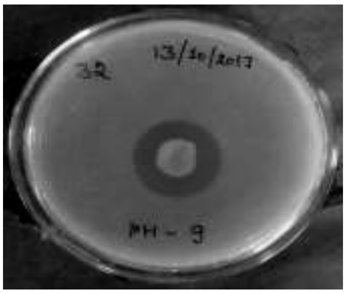

Fig. 6. Bacteria Showing Zinc Solubilising Activity

ACC Deaminase Activity

Principle: Ethylene is a plant growth regulator which is responsible for various physiological processes in plants. It is also act as a stress hormone because their synthesis in plants increases under stress conditions. Ethylene decreases seed germination and root development and eventually stops the plant growth. Under salinity stress, levels of 1-aminocyclopropane-1-carboxylate (ACC) increase in the plants which leading to increase in concentration of ethylene which damages the plant cells. Many microbes have the characteristics of producing ACC deaminase enzymes which can convert ACC into α-ketobutyrate and ammonium, thereby lowering levels of ethylene and protect the plants from salinity stress and enhance the plant growth (Kruasuwan and Thamchaipenet, 2018).

Methodology: The test bacteria should be grown in a rich medium and then transferred to minimal medium with ACC as sole source of nitrogen. Bacterial cells were grown to mid- up to late log phase in 15 ml Trypton Soy Broth. Cultures were incubated over night in a shaking water bath at 200 rpm at 30°C. Bacterial cell mass was then harvested by centrifugation at 8000 g for 10 min at 4°C. The supernatant was then removed and the cells were washed with 5 ml Dworkin and Foster salts medium. Again centrifugation process for 10 min at 8000 g at 4°C and then the cells should be suspended in 7.5 ml of DF medium. Just before to incubation, the frozen 0.5 M ACC solution should be thawed and an aliquot of 45 µl should be added to the cell suspension to obtain a final ACC concentration to 3.0 mM. The bacterial cells should be then again incubated in shaking water bath to enhance the activity of ACC deaminase. The cells should be then harvested by centrifugation as mentioned above and were washed twice in 5 ml of 0.1 mM Tris-HCl at pH 7.6 so as to ensure that the pellet is free of the bacterial growth medium. The bacterial cells should be suspended in1.0 ml of 0.1 M Tris-HCl and transferred to 1.5 ml microcentrifuge tubes and centrifuged at 16,000 g for 5 min. The supernatant of the tube should be then discarded and pellet should be suspended in 600 µl of 0.1 M Tris-HCl pH 8.5. Thirty micro-liters of toluene should be added to the suspended cells and vortexed at highest speed for 30 s. 200 µL of the toluenized cell suspension should be then placed in 1.5 ml micro-centrifuge tubes. 20 µl of 0.5 M ACC should be then added to the suspension, briefly vortexed and then incubated at 30°C for 15 min. Following the addition of 1 ml of 0.56 M HCl, the mixture should be vortexed and then centrifuged for 5 min at 16,000 rpm. One ml of the supernatant was then vortexed with 800 µl of 0.56 M HCl. Then, 300 µl of 2, 4- dinitrophenylhydrazine reagent should be added to the glass tube; the content should be vortexed and incubated at 30°C for 30 min. Two ml of 2 N NaOH should be added and then absorbance should be taken at 540 nm. Production of ACC deaminase can be calculated as the amount of α-ketobutyrate produced when the enzyme cleaves ACC.

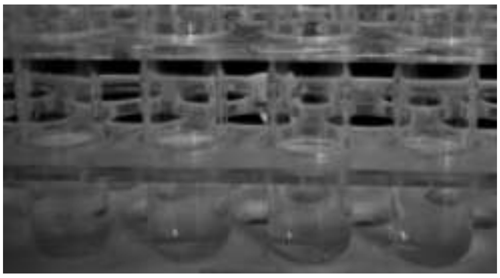

Fig. 7. Yellow Colour Demonstrating ACC Deaminase Activity

Production of Indoleacetic Acid (IAA)

Principle: Plant growth promoting microbes produces plant growth regulators like auxin, gibberellins, ethylene etc and they exhibits a variety of properties which are responsible for influencing plant growth. Indole Acetic Acid is the form of most physiologically active plant auxins. IAA is the end-product of L-tryptophan metabolism of many plant growth promoting microbes. The production of IAA leads to promotion of plant growth and development of roots. Due to this property PGPM helps the rapid establishments of roots and facilitate the elongation of primary roots and proliferation of lateral and adventitious roots. Hence PGPM increases the ability of seedlings to establish in the soil and also helps them to obtain water and nutrients (Loper and Schroth, 1986).

Methodology: Nutrient broth (NB) containing 0.1% DL-tryptophan should be prepared. This medium should be inoculated with microbial cultures and incubate it at 28±2°C for 3-4 days. The cultures should be centrifuged at 10,000 rpm for 10 min at 4°C. The supernatant (2 ml) should be mixed with two drops of orthophosphoric acid and 4ml of the Salkowski reagent (50 ml of 35% percholoricacid, 1ml 0.5M $FeCl_3$ solution). Development of pink colour indicates IAA production.

Fig. 8. Pink Coloured Tubes Indicate Positive IAA Production

Siderophore Production

Principle: Siderophores are the low molecular weight iron-binding compounds which are produced by PGPMs and have the high affinity to bind ferric ion. The bound iron is absorbed by microbes. Genus Pseudomonas has been known to generally produce fluorescent, yellow-green, water soluble siderophores. The characteristic of siderophores production has been linked with the disease suppression potential of PGPMs. Siderophores have a very strong affinity for ferric ions and they are secreted under low iron conditions. The ferric siderophore complex can be utilized via receptors in the outer cell membrane of microbes. Siderophores functions as a biocontrol agent by depriving the pathogens from iron nutrition, resulting in the increased yield of crop (Ngamau *et al*., 2014).

Methodology: Screening for the production of siderophore is done on petriplates. The tertiary complex Chrome Azural S (CAS) / Fe hexadecyltrimethyl ammonium bromide act as an indicator in this test. To prepare one liter of blue/green agar, 60.5 mg of CAS is dissolved in 50 ml of distilled water and mixed with 10ml of iron (III) solution (1mM $FeCl_3.6H_2O$ in 10mM HCl). While constantly stirring, this solution should be slowly added to 72.9 mg of hexadecyltrimethyl ammonium bromide (HDTMA) dissolved in 40ml of water. The resultant dark blue/green solution should be added in nutrient agar to make Chrome Azural S (CAS). Inoculation should be done on CAS agar and these plates should be incubated at 30°C for 48–72 hr. Development of yellow–orange halo zones around the growth is considered as positive for siderophore production.

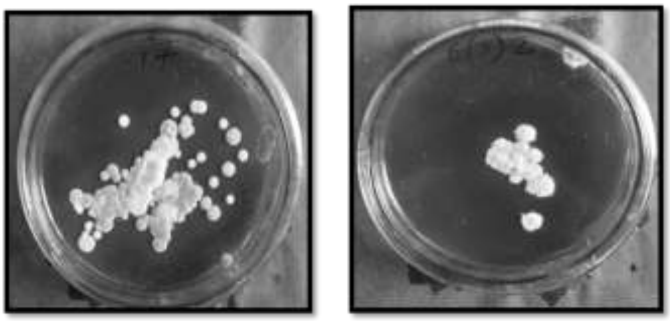

Fig. 9. Fungi Showing Positive Results for Siderophore Production

Production of Ammonia

Principle: Ammonia production is one of the most important traits of PGPMs which benefits the crops. Ammonia production by microbes leads to increase in pH and causing the alkaline conditions pH 9-9.5in the soil. The change in pH suppresses the growth of pathogenic fungi and other pathogens. It also upset inhibits germination of spores of many pathogenic fungi (Agbodjato *et al*., 2015).

Methodology: For the test of ammonia production, Bacterial isolates should be grown in peptone water. Freshly grown cultures should be inoculated in 10ml peptone water in each tube and incubated for 48–72 hr at 30°C. After the incubation, Nessler's reagent (0.5 ml) should be added in each tube. Development of faint yellow to dark brown colour indicates the positive test for ammonia production.

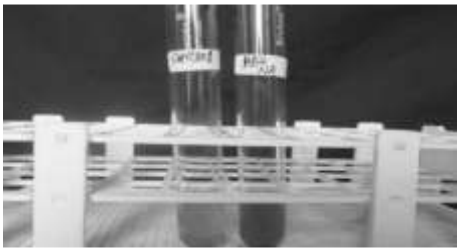

Fig. 10. Results Demonstrating the Positive Result of Ammonia Production

HCN Production Activity

Principle: Many PGPMs releases HCN which inhibits the electron transport and the energy supply to the cell are disrupted which leads to the death of the pathogens. It also inhibits functioning of many enzymes and receptors by reversible mechanism of inhibition. It is also known to inhibit the functions of cytochrome oxidase. HCN is produced by many PGPMs and is reported to play an important role in biological control of the pathogens (Agbodjato *et al.*, 2015).

Methodology: Nutrient agar plates supplemented with glycine should be prepared. These plates should be inoculated with microbial cultures. A whatman filter paper soaked in 2% w/v sodium carbonate in 0.5% (w/v) picric acid solution was placed inside the lid of the petriplate. Then plates should be covered with parafilm and incubated at 30^{o}C for 2 days. A change in the colour of filter paper from yellow to reddish brown is considered to be an indicator of HCN production.

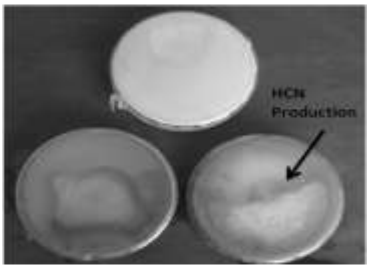

Fig. 11. Brown petri plates demonstrating positive HCN production

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Impact of Climate Change on Crop Water Demand and Fresh Groundwater Resources

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Introduction

The climate of a region is described as long term weather condition such as temperature, rainfall, relative humidity, wind velocity etc. Climate Change is referred as an altered state of the climate that can be identified by change in the mean and/or variability of its properties that persist for an extended period, typically decades or longer (Bates *et al. 2008*). The increased concentration of green house gases in atmosphere has significant effect on altered global and regional climate. There is growing evidence that climate is changing in India also. It is predicted that the global mean surface temperature would increased by 1.4 to 5.8° C by 2100 under different emission scenarios (IPCC, 2007). Changes in climate are expected to alter India's hydro-climatic regime over the 21st century. The projected alteration in climate may cause the redistribution of water resources in time and space. Spatial and temporal changes in temperature and precipitation may modify the water balance of an aquifer. The changing frequency of droughts or heavy precipitation can also be expected to impact on water levels in aquifers. Droughts result in declining water levels not only because of reduction in rainfall, but also due to increased evaporation and a reduction in infiltration that may accompany the development of dry top soils. Paradoxically, extreme precipitation events may lead to less recharge to groundwater in upland areas because more of the precipitation is lost as runoff. Aside from the influence of climate, recharge to aquifers is very much dependent on the characteristics of the aquifer media and the properties of the overlying soils. Urban built-up areas are also expanded rapidly, replacing either forest or agricultural land (i.e., replacing vegetation with concrete and bitumen) thereby reducing groundwater recharge (Scanlon *et al., 2002*).

India is the largest groundwater user in the world, with an estimated usage of around 230 km^3 per year, more than a quarter of the global total. With more than 60 percent of irrigated agriculture and 85 percent of drinking water supplies dependent on it, groundwater is a vital resource for rural areas in India (Clifton *et al.,* 2010). Over last few decades, the demand of water for agricultural, household, recreational, industrial, and environmental use is rapidly increasing. India's population is predicted to reach 1.4 billion in another 15 years with an annual growth rate of 1.3 percent. Additionally, there is unprecedented urbanization in India which itself is greatly energy and water intensive. Agricultural demand for irrigation is already the single largest draw on India's water, yet estimates by the Ministry of Water Resources indicate that by the year 2050 irrigation needs will rise by 56 percent. At the same time, India's drinking water demand will double and India will also have to increase water supplies to industries fivefold and supply 16 times more water for energy.

Study site

The study area was Karnal which have fresh groundwater aquifer, where rice-wheat cropping system is prevailing. The groundwater table in this region is declining at alarming rate. The study area covers an area of 2520 km^2. About 70% of net irrigated area is covered through groundwater. The analysis of long term groundwater table data of Karnal reveals an average decline of 0.24m per year. However, in the last decades (2000- 2010), there was steep decline (0.88m/ year) in groundwater table (Bhaskar *et al.,* 2014).

Projection of future climate

The projected change in climatic parameters in future for Karnal was derived from coupled model inter-comparison project 5 (CMIP5), GCM model's coarse resolution projection using Hybrid-Delta (HD) ensemble method. Daily temperature and precipitation were derived for historical (1981-2010, base period) and future time periods of 2040-2069 (2050s, mid century), 2070-2099 (2080s**,** end century**).** The projected and observed monthly minimum and maximum temperature and rainfall for RCP 4.5 were compared statistically (Table 1). It was found that model projected reasonably close values for minimum and maximum temperature with the index of agreement of 0.95 between observed and predicted values. However, index of agreement between observed and predicted value of rainfall was found to be 0.75.

Table 1. Performance indices for validation of projected climatic parameter

Parameters	RMSE	Model Efficiency	Index of agreement
Temperature (max)	2.91	0.83	0.95
Temperature (min)	1.88	0.94	0.98
Precipitation	8.43	0.10	0.75

The projected change in mean annual minimum and maximum temperature and precipitation for different representative pathways is presented in fig.1. It can be observed from the figure that increases in temperature and rainfall is expected in coming future and that change will stabilized by the end of the century. The climate data for base period (1981-2010) and future time periods of 2040-2069 (2050s, mid century), 2070-2099 (2080s, end century) are averaged monthly for 30 years. The change in mean annual minimum (T_{min}) and maximum (T_{max}) temperature of Karnal is projected to be 1.8-2.9 ^{0}C and 1.9-3.2 ^{0}C, respectively. (Fig 1 a & b) in mid and end century under different RCPs. The change in annual precipitation of Karnal in mid and end century under different RCPs is projected as 85 -117mm (Fig. 2). However, the maximum change in monthly maximum and minimum temperature was found during the period of January to May.

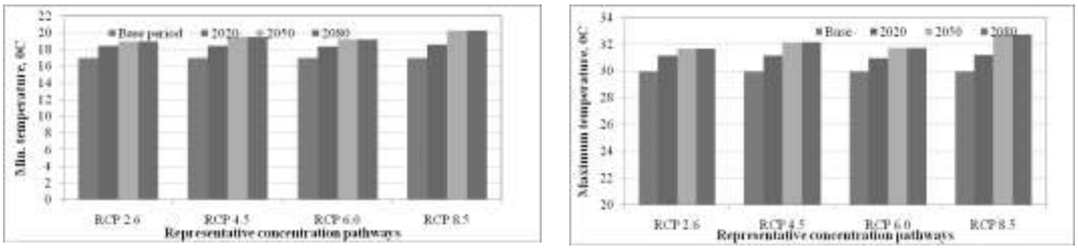

Fig. 1. Mean annual a) minimum temperature and b) maximum temperature in base period (1980-2010), 2020, 2050 and 2080

Modeling the impact of climate change on crop water demand

To assess the impact of changing climate on crop water demand, projected daily T_{max}, T_{min} and precipitation under RCP 4.5 were used as input data in CROPWAT computer program and computed future crop water requirement. The model was run with different dates of transplanting of rice to find out the appropriate time for rice transplanting to utilize maximum precipitation and pump minimum groundwater for irrigation. The estimated crop evapotranspiration, effective rainfall and irrigation requirement are given in table 2. Table 2 shows that shifting date of transplanting of rice from 25th June towards 05 July would help in reducing irrigation demand by 70-75 mm and subsequently groundwater draft also in coming future.

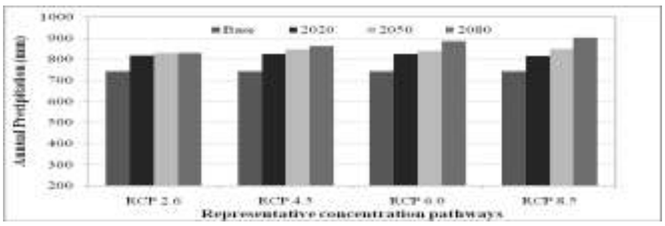

Fig. 2. Mean annual precipitation in base period (1980-2010), 2020, 2050 and 2080

Table 2. Crop evapotranspiration (ETc), effective rainfall (ER) and irrigation requirement (IR) of transplanted rice as affected by date of transplanting under changing climatic scenario (RCP 4.5)

Period	Date of transplanting								
	15 June			25 June			05 July		
	ET_c (mm)	ER (mm)	IR (mm)	ET_c (mm)	ER (mm)	IR (mm)	ET_c (mm)	ER (mm)	IR (mm)
Base period	591.7	516.4	800.4	560.8	420.3	840.2	559.4	461.6	797.3
2020	590.1	526.4	800.6	567.3	498.2	770.3	558.6	507.3	726.9
2050	599.7	537.1	800.8	577	542.2	700.5	568.3	517.6	727.1
2080	600.4	570.6	800.8	577.1	495.0	770.6	568.1	518.4	727.2

The crop evapotranspiration (ETc), effective rainfall (ER) and irrigation requirement (IR) of wheat for the base period, 2020, 2050 and 2080 for climatic scenario of RCP 4.5 are presented in table 3. It is clear from the table that ETc will increase slightly in coming future for the date of sowing of wheat of 15 November. However, irrigation requirement would not change in 2050. In 2080, irrigation requirement is expected to be decreased as compare to 2020. Table 3 also indicates that date of sowing has significant impact on crop water requirement and irrigation demand. Delay in sowing of wheat from 15 November towards 05 December will result in increased irrigation demand for wheat production.

Table 3. Crop evapotranspiration (ETc), effective rainfall (ER) and irrigation requirement (IR) of wheat as affected by date of transplanting under changing climatic scenario (RCP4.5)

Period	Date of transplanting								
	15 June			25 June			05 July		
	ET_c (mm)	ER (mm)	IR (mm)	ET_c (mm)	ER (mm)	IR (mm)	ET_c (mm)	ER (mm)	IR (mm)
Base period	433.5	118.9	371.4	471.3	123.1	371.4	514.3	126.6	464.3
2020	451.5	120.9	371.4	490.5	130.2	371.4	534.5	136.9	464.6
2050	467.0	121.4	371.4	506.8	126.9	464.3	551.7	133.9	464.3
2080	465.4	124.1	342.9	505.2	129.5	400.0	550.2	136.1	457.1

Impact of changing climate on groundwater fluctuation

The scenario for studying impact of rice-wheat cropping system on groundwater resources under changing climate was generated. The whole cultivable and non cultivable land use of Karnal was taken as one hydrological unit for this study. The different land uses such as cropped area, forest land, residential area, water bodies including canal network and other land (barren, pasture and waste land) were considered to represent whole district for calculation of different water balance components. The recharge component (return flow) and draft (groundwater pumping) were estimated separately for different land uses with the help of different models/relationship and GEC 1997 methodology of estimating groundwater resources. The fluctuation in ground water table was calculated by considering specific yield of aquifer as 0.12 and total study area as 0.246 M ha. The annual decline in water table was estimated by using deficit in groundwater recharge over draft and specific yield. Since, prevailing date of transplanting of rice and sowing of wheat is 15 June and 15 November, respectively, in this region, therefore these dates were taken for estimation of return flow and ground water draft form cultivated land.

The observed average groundwater table depth 15.47 m of 2010 was taken as the base line for projecting water table depth by next year using annual groundwater fluctuation. The observed groundwater table depth was taken from year book of CGWB. From the results (Fig 3) it was estimated that by the end of early century (2001-2039) , groundwater table will reach to 37 m, 52 meter by the end of mid-century (2040-2069) and 73 meter by the end of the century (2070-2099), respectively.

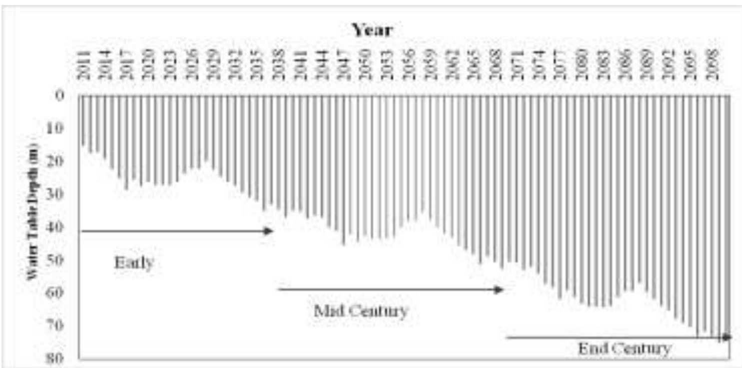

Fig. 3. Estimated groundwater table in Karnal under prevailing climatic scenario of RCP 4.5

Conclusions

The projected change in temperature and rainfall of Karnal under different pathways (RCPs 2.6, 4.5, 6.0 and 8.5) indicates slight increase in value of these parameters till mid of the century (2050) and thereafter it will be stabilized under RCPs 2.6, 4.5 and 6.0, while it will remain increasing in RCPs 8.5. The shifting of transplanting date of rice from 15^{th} June towards 05 July would help in reducing irrigation demand by 70-75 mm in coming future (2070-99), if changes in climate occur as projected under RCP 4.5. For the same RCP 4.5, it was estimated that by the end of early century (2001-2039), groundwater table of Karnal will reach to 52 meter by the end of mid-century (2040-2069) and 73 meter by the end of end-century (2070-2099), respectively.

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Government Policies for Increasing Agricultural Productivity and Livelihood Security of Farmers in India

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Introduction

Agriculture continues to remain the mainstay of Indian economy with half of population depending upon it for their livelihood. Agricultural production is showing upward swing with 275 MT in cereals and 300MT in horticulture production with an escalating rank in world agriculture (among top producers in wheat, rice, pulses, sugarcane and cotton*etc*). It is the highest producer of milk and second highest producer of fruits and vegetables. In 2013, India's contribution was 25% to the world's pulses production, 22% to the rice production and 13% to the wheat production. It contributes to 17.5% of the GDP (at current prices in 2015-16). But when it comes to per unit production *i.e.,* productivity, contribution to national economy (GDP), growth rate, increase in farmers income *etc,* progress is still dismal. This very paradox of being the most dependant and still most underdeveloped sector brings agriculture to the forefront of policy consideration.

In practice agricultural production and farmers income is viewed as the obvious causal relationship but in depth contemplation hints towards absence of this phenomena some times as marketing facility and presence of remunerative price in market is the sine qua non of normal profit. So, the paradigm shift in policy focus towards livelihood and income security in the lieu of agricultural production oriented plans were necessary to make agriculture "a way of livelihood not the way of living" only.

However, the past experience of Indian agricultural policies have been production centered keeping food security as main goal but, with the opening up of world market, attitude change of farmers, and visibility of scope of business in agriculture *etc.,* provoked policy makers to plan for productivity, efficiency and income enhancement altogether. The ambitious target of doubling farmer's income by 2022 shows the level of commitment that present day policy makers put forward towards enhancing livelihood security of producers. Policies to enhance productivity and livelihood security can be classified from many fronts. Those plans, projects or programs directly or indirectly contributing to farm productivity, efficiency of input, input cost reduction, post harvest loss reduction, more revenue generation, employment generation *etc,* can ensure livelihood security of farmers. So, the present policy outlook of government is trying to combine both livelihood security and agricultural productivity with the object of sustained income generation and growth to suffice livelihood demand coupled with food security. And, in this regard, the government policy action comprises of two spheres of formulations to attain comprehensive objective of sustained agricultural productivity and livelihood security. These spheres are:

Policies for Achieving Economic Empowerment - Doubling Farmers Income

In spite of the huge progress and development of agricultural sector the majority of the farmers are now caught within the vortex of low income trap. The income of an average agricultural household in the course of July 2012 to June 2013 was as low as Rs.6,426 to meet its usual month-to-month consumption expenditure of Rs.6,223. As many as 22.50 per cent of the farmers are living below legit poverty line. Soil salinity, problem soil, alkalinity are major challenges that have become concern.The depleting water table is another challenge for sustainable production practice. Local weather condition is establishing to challenge the farmer's ability to undertake coping and adaptation measures and indicating the path for precision and climate controlled production process. Technological stagnation in adoption of modern practice is also creating hindrance in the flight of agriculture from subsistence based to profit based enterprise. Briefly, to align agricultural development in the line of sustainability is a quite pronounced challenge now and profitable agrarian venture is a major concern to make it available for the farming community of the country.

It can be contemplated that, the solution for this present agrarian distress lies in higher and steady income appropriations. It is in this context, that the Hon'ble Prime Minister's vision of doubling farmers' income on 28th February, 2016 is a direction towards it.

The strategies for it has been developed by considering sustainability of production, monetisation of farmers' produce , re-strengthening of extension services and recognizing agriculture as an enterprise and enabling it to operate as such, by addressing various structural weaknesses.

The seven point strategy suggested includes:

- Focus on Irrigation along with adequate resource building
- Increase Production through Improved Seeds, Planting Materials, Organic Farming and Soil Health Card
- Strengthening warehousing and cold chain facilities to curb post-harvest losses
- Value addition through food processing
- Overcoming deficiencies in agriculture marketing through e-NAM.
- Work on institutional loan to reduce risk and growth of agriculture sector.
- Allied activities of agriculture like Dairy development, Poultry, Beekeeping, Fisheries, Agro-forestry and Integrated Farming System

Policies for Achieving Food Security

According to the findings of study of Centre for Study of Developing Societies (CSDS) (2018), 76 per cent of the farmers revealed their willingness to quit farming. There were also concerns about slowdown in the yield of major crops. Despite the occurrence of some degree of diversification from field crops to horticulture, the amount of income generated from field crops still matters for improving the income of farmers' households. When the total cost is taken into consideration, the profitability from the cultivation of paddy appears to be very low or even negative in a few states. Out of 18 states, the real net income has increased in only seven states. Further, profitability from the cultivation of wheat turns out to be quite low in similar context. As compared to farm business income, net income has shown a declining trend in most states. Even in the agriculturally advanced states such as Punjab and Haryana, profitability from wheat cultivation has, by and large, declined during the recent period. The decline in net income was largely due to an increase in the total cost, while the production may not be market-led, productivity remains almost stagnant. It was observed that, income from crop cultivation reveals a mixed picture across states. The net income from the cultivation of many crops has declined and turned out to be negative in many states. In spite of the fact that, by and large, the per hectare real value of output increased for most crops during the period 2004-05 to 2013-14, but the rise in input cost was much higher than the increase in the value of the output which resulted in lowered net income from the cultivation of most crops. In this context, it is important to have a look on the dynamics in farm profitability in the context of input use efficiency and input costs and examine the underlying factors responsible for varying input efficiencies.

The first sphere of management is input management. The soil health card scheme (SHC) is the driver for assisting farmers about nutrient management and reduced and judicious fertilization which in turn will provide input cost efficacy in the production process. From 2014-15, nearly 12 crores soil health card have been issued in the country. To ensure the quality fertilizers to farmers at affordable rates, the budget 2016-17 announced opening up of 2000 model fertilizer retail shops over a period of 3 years. Direct benefit transfer schemes in fertilizers and neem coated urea policy are another leap towards availing dual objective of ensuring farmers benefit through the scheme and reducing burden on the exchequer. Pradhan MantriKrishiSinchayeeYojana (PMKSY) with the motto "harkhetkopani" is another plan for end to end solution in irrigation supply chain *viz.*, water sources, distribution network and farm level application. Enhancing water use efficiency is another facet of this program to ensure sustainable water use plan. Achieving the convergence in the investment in both public and private partners at field level is also a scope of this policy to ensure a permanent and lasting solution for the frequent drought problems. The another most important factor in the production process is credit as it provides for new technology and production practice adoption. The KCC scheme (1998-99) is the flagship program in this regard which encompasses all categories of farmers viz. marginal, small and large farmers along with share croppers and oral lessee and tenant farmers. To ensure the adoption of new and modern technology and practice, the GOI launched Submission on Agricultural Mechanisation (SMAM) in 2014-15 under which financial assistance as cost subsidy @ 25-50% is provided for the individual ownership of the farm machinery. Promoting custom hiring centres to help easy access to specialised machineries is also a subsidiary of this policy.

The second sphere in managing the production plan is unifying it with production strategy related policy. So, this input support policies are again converged under production management policy where the production oriented support and input use and availability is ensured under large policy head like National Food Security Mission (NFSM), Bringing Green Revolution to Eastern India (BGREI), National Mission on Oilseeds and Oilpalm (NMOOP), Mission for Integrated Development of Horticulture (MIDH) etc. The broad targets of these policies are to stimulate the production of cereals, pulses, vegetables and fruits through area expansion and productivity enhancement in a sustainable manner. Besides it, these policies also aims towards promoting good agricultural practices with respect to plant protection strategies and techniques.

Policies for Post-Production Management

Attaining the objective of postproduction management of agricultural produce for ensuring better prices, sustained prices and heightened profits is a priority of the government. The major policy breakthrough in this respect is eNAM (National Agriculture Market). With the aim to abridge the information gap and improved price mechanism and delivery the eNAM program is a major policy driver to ensure profitability gain for farmers. The integrated market network of 585 markets across the states and 22000 Grameen Rural Markets will establish the backbone of effective marketing practice for agricultural product in the country. The government announcement in budget 2018-19 announced the broad based procurement operation strengthened for major crops. The 10-25% rise in absolute amount of price support from 2014-15 to 2017-18 is another step forward for achieving the goal of livelihood support. The Pradhan MantriKisan SAMPADA Yojana with the object of creation modern infrastructure with efficient supply chain management from farm gate to retail outlet is a big boost to the growth of food processing sector. The cold chain management scheme and agro processing clusters are also the policy initiatives for enhancing value chain of agricultural product.

Risk Management Policies

The major policy initiative for risk management and mitigation in agriculture is Pradhan MantriFasalBimaYojana (PMFBY). Under this scheme, the premium rates are kept low and the balance premium will be equally shared by central state governments. The coverage in terms of both crops and insured farmers under this scheme is quite impressive and the use of sophisticated technology is a complement of this scheme.

Conclusion

To support increasing productivity, the policies must equally focus on secondary and tertiary sector linked to agriculture as horizontal expansion has a limit but vertical expansion through value addition, manufacturing is all together a bonus and limitless. This way livelihood options can be broadened. The policies related to skill enhancement of existing workforce and those who are interested in agricultural endeavours are again need of the hour. Programmes like Attracting and Retaining Youth in Agriculture, Agri Clinic and Agri Business Scheme and institutions like Agriculture Skill Council of India (ASCI) are flagships in this regard and must be implemented, reviewed and converged based on thorough analysis. The support services like extension, information, subsidies, credit *etc* are again very necessary to sustain livelihood options. There is the need to build a system such that all farmers are able to access credit – need to liberalise such that all farmers can get short-medium-long term credit. The investment for agriculture, such as rural roads, rail, power, and other area is the primary responsibility of the government. The main challenge before researchers and policy makers is to make policies which can accelerate agriculture growth rate making it at par with industry and service sector while not stepping out of the ground where marginal and small farmers struggle just to secure a decent income.

Salinity Induced Stressors in South-western Punjab: Farmers' Knowledge and Adaptation Strategies

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Introduction

The introduction of modern technology and methods of cultivation during 1970s in Punjab has resulted green revolution and thus contributed to secure food security of India. The new technologies have provided numerous socio-economic gains to the State in the form of increase in both production and productivity, and irrigation coverage up to 95 per cent of the total cropped area in Punjab (Rangi and Sidhu, 1998). Due to imbalance use of inputs including faulty irrigation practices, ecological fragility and related agricultural risks increased in Punjab in past 40 years. Introduction of new agricultural technologies that demand more water, chemical fertilizers, agro-chemicals and energy increased sharply in the State. Faulty cropping systems and irrigation practices in canal command areas gave the birth to the problem of waterlogging, while in other areas water depletion, soil degradation and health problems in many parts of Punjab (Swaminathan, 2004; Singh, 2013). Poor water management leading to land degradation in irrigated areas through waterlogging and salinity. Due to the unplanned canal irrigation system, inadequate drainage and over irrigation seepage, the problem of waterlogging becomes an important ecological stressor in the South-Western part of Punjab.

Using simple and generic technology to overcome problem of salinity although does not solve the problem, farmers of South-western Punjab have been suggested to use good quality irrigation water and adapt various biotic, mechanical and chemical reclamation measures to minimize the salinity impact (Kielen, 1996). The ecological stress caused by salinity (both secondary salinization and natural salinity) after combining with socio-economic, institutional, policy and climatic factors make farmers and food production systems more vulnerable in South-western Punjab (Singh, 2013). A number of measures and technologies are developed by various scientific institutions related mainly to change in the quantity, frequency and ratio of application of canal and tube-well water, and crop and variety choice, application of chemical amendments, installation of sub-surface drainage system (SSD) and agroforestry models, but those have least benefited farmers. Despite relatively higher adaptive capacity (O'Brien *et al.,* 2004), farmers of this area have further become vulnerable due to climate change. In order to study how these stressors are being perceived by farmers and what do they adapt to cope-up such stressors, a study was conducted in selected villages of South-western Punjab.

Research Methodology

This study followed qualitative and semi-quantitative approaches. In order to complete the objectives, five villages from Fazilka (Abohar and Baluana) district of Punjab were sampled. From each village, 15 farmers and thus a total of 75 were sampled randomly for conducting the study. The villages were sampled in a manner that they were located nearby the canals (the agricultural fields 0.5 km to 2.0 km away).

The purpose of combining these two approaches of data collection was to elucidate nexus and in-depth understanding of issues and practices, and their process at individual levels (Ward *et al*., 2017; Stringer *et al*., 2018). Data pertaining to this study were collected using transect walk, key informant interviews, FGD (focus group discussion), event ecology and sampling of soil and water. Samples of soil and water were analyzed in laboratory to find out the EC and pH related stresses. Other than agroecosystems variables- which may act as stressors (soil and water EC, pH and water level), we collected data relating to socioeconomic, institutional and policy constraints. Closed and open-ended questions were formulated in interview schedule and pilot tested in the non-sampled areas to increase reliability. Data were entered into spread sheet and analyzed qualitatively, except the soils and water data quantitatively to draw the inference from study.

Results

1. Soil and water related stressors

Results indicated that out of total, 85% farmers were small and marginal with less access of technologies required to cope-up the salinity/sodicity and waterlogging stressors. There were three production systems namely kinnow-wheat/berseem (40-50 t/ha in 20-25 year trees) followed by rice-wheat (38-45 q/ha rice; 35-40 q/ha wheat) and cotton-wheat. Rising water table (Dhani-Latkan 5-6, Alamgarh 2-4, Saidawali 0-7, Bhawalwasi

1.0-1.5 and 4.0-4.5, Kera Kheda 3-4 and 5-6 feets have become a major stressor and causing severe harm to commercial kinnow orchards. The drains made for draining salty water are against the slope, and thus does not carry salty water, as reported by farmers. Rather it has become itself a stress as expressed by more than 90% farmers. Due to increasing water table, the cotton-wheat system is affected adversely. The salinity problem started after 1986 from Datta-Kheda area.

In general, according to analysis the soils were found saline-sodic (mean pH ranged from 8.02 to 10.12 and mean EC_2 ranged from 0.28 to 2.68) (Table 1). Due to increasing water table and salt load in soils, now the rice-wheat production system is also turning into waste lands. In few of the villages, EC of ground water was 3.37 to 9.67 dS/m and in some villages, shallow water tables (~2 feet below surface) have caused severe decline in orchards prompting the farmers (>60%) to replace kinnow orchards with rice and wheat crops where soil and water salinity seems to be low or marginal. Farmers' experienced (89.75%) salinity as first stressor followed by diseases compounded with climate and ecological factors those led in declining kinnow orchards.

Table 1. Soil pH and EC patterns in different production systems of studied villages (per unit total samples 8)

Villages	System	Soil pH range	Soil EC_2 range	Soil pH		Soil EC_2	
				Mean	SD	Mean	SD
Dhani Latkan (site-1)	Kinnow (declining)	8.17-8.65	0.21-0.38	8.49	0.20	0.28	0.06
	Kinnow based (healthy)	8.17-8.69	0.52-1.0	8.41	0.21	0.78	0.18
	Cotton-wheat	8.47-8.81	0.58-2.55	8.59	0.16	1.39	0.79
Site-2	Kinnow based (declining)	8.54-8.95	0.23-1.53	8.72	0.15	0.98	0.55
	Kinnow based (healthy)	7.88-8.70	0.30-1.58	8.58	0.20	1.29	0.39
	Kinnow based (declining)	8.31-8.87	0.74-1.07	8.60	0.21	0.95	0.13
	Rice-wheat	8.95-9.43	1.05-2.53	9.16	0.18	1.68	0.55
Site-3	Rice-wheat	7.96-9.19	0.55-1.70	8.82	0.48	0.80	0.44
	Cotton-wheat	8.31-9.00	0.91-2.52	8.68	030	1.91	0.51
Saidawali	Rice-wheat	8.13-9.03	0.48-1.43	8.61	0.37	0.72	0.35
	Kinnow-1	8.13-8.87	0.49-1.36	8.36	0.23	0.94	0.32
	Kinnow-1	8.15-8.78	0.50-1.86	8.41	0.20	1.05	0.54
	Cotton-wheat-1	8.25-8.72	0.40-3.20	8.51	0.18	1.51	0.99
	Cotton-wheat-2	8.53-9.75	1.66-3.00	8.97	0.59	2.27	0.56
Bhawalwasi	Barren land	8.98-9.90	1.14-5.09	9.51	0.40	2.68	1.86
	Kinnow (declining)	7.80-8.22	0.45-2.92	8.02	0.16	1.65	0.98
	Rice-wheat	9.99-10.28	2.10-3.24	10.12	0.12	2.63	0.51
Bhawalwasi	Cotton-wheat	8.83-8.55	0.72-1.77	8.44	0.09	1.16	0.45
Kera-Kheda	Kinnow (declining)	7.78-8.29	0.34-5.44	8.08	0.20	1.58	2.14
	Cotton-wheat	7.82-8.30	2.18-3.60	8.07	0.18	2.93	0.55

Farmers use water from diverse resources which have different range of EC and RSC (Table 2). Minimum EC of tube-well water being used for irrigation was 0.76 while maximum of 5.26 with mean value 2.59. Sometimes farmers in compulsion also use water from SSD drain which carries saline water, and this had EC 2.57 to 3.98 with mean value 3.49. These together increases the salt load in soil, however, in between farmers use canal water for irrigation that helps to minimize the salinity impact. Though, canal water was not easily available to some of the farmers. Overall, the salinity of water (*Choa*) of land having increased watertable varied from EC 3.77 to 3.85 with mean value 3.8.

Table 2. EC and RSC of water resources being used for agriculture in study areas

Water resources	Minimum		Maximum		Mean	
	EC_{iw}	RSC	EC_{iw}	RSC	EC_{iw}	RSC
Tube well (n=6)	0.76	0.46	5.26	28.06	2.59	11.94
SSD drainage Nala (biggest exposure during intense rains) (n=3)	2.57	3.22	3.98	5.06	3.49	4.14
Waterlogged soils (Choa water) (n=6)	3.77	23	3.85	25.3	3.81	24.15
Pond water (used for pisciculture) (n=2)	2.68	7.1	3.24	8.4	2.96	7.75

2. Compunding stressors

Ecological stressor (salinity) was found highly perceived with mean score 38.6% and CV 8.0%. This was further compounded by climate variability (mean score 34.48) stressor. Policy and institutional (means score 27.19 with CV 14.0%), and socio-cultural stressors (mean score 25.85 with CV 9.0%) further compounded the salinity risks. Economic and labour related stressors were also observed as aggravating factors as perceived by farmers impacting their crop production systems. Farmers experienced climate is changing from dry to semi-dry and act as driver in waterlogging. In recent past, the rainfall has increased from 20-25 cm to 30-35 cm annually. Frequency of rains increased and thus affected management practices of wheat, rice, kinnow and cotton crops. Anomalies in seasonal cycles are being noticed by farmers as they reported that "*earlier we were wearing sweater during October last week, now wearing in the second to third week of December*" (Mr. Rajesh Kumar, a farmer of Dhani-Latkan village, 2015). They are experiencing day temperature more and sudden declining in the night temperature. Such abrupt changes in temperature leads the fruit drops in kinnow crop and flowering anomalies in it. For example, if winter is delayed, the flowers in kinnow will be late till the end of March. Under such condition if the April temperature is suddenly increased (upto 40^{o} C) then the fruit setting gets adversely affected. Such compounding impact of climate has affected kinoow fruit production in last 15 years, together with unstable market prices.

In rice-wheat production system, farmers are also facing threats from various stressors. These include increasing water table caused by the seepage from canal, inappropriate drains system and poor coordination between various institutions working on agricultural development. Non-availability of appropriate technologies, disintegration of joint family into the nuclear one, fragmentation of landholdings and migration of farmers to cities for gainful livelihoods were observed to be compounding socio-economic factors leading farmers' at risks. Other management practices in crops cannot be ignored which are drivers in leading livelihood risks. For example, due to erratic rainfall, the efficacy of insecticides after spray get reduced and thus led loss of crop due to insect-pests attack, and increased cost of cultivation. During 2015, farmers have used 9-10 spray in cotton (sown away where salinity is marginal and water table is below) against the white fly with leaf curl virus (hot and humid environments favoured) but could not save their crop.

3. Knowledge status of farmers about soil salinity hazards

The interaction of human being with their surrounding ecosystem and environments evolve a variety of knowledge and ultimately form a particular perception which shapes the management practices. It is important to understand not only the scientific knowledge but also to learn what farmers know about his/her local ecology. Such understanding helps to devise better programmes and policies in managing stressful landscapes and farming system. Keeping this in view, we asked the farmers to narrate how they understand about soil and water salinity so that their ways of management practices can be explored. It was found that majority over 59.0 per cent farmers had partial knowledge about the understanding of soil and water salinity. Farmers define such lands based the soil, plant and crop indicators, however, about 27.0% farmers had full knowledge. Remaining had either least (9.46%) or no knowledge (4.05%) about soil and water salinity. Those who were higher in age and experience of doing agriculture in saline environments could demonstrate greater narration on salinity knowledge.

4. Adaptation strategies for salinity induced stressor

It is evident from Table 3 that due to salinity stress most of the farmers (32.43%) have switched over autonomously from kinnow and cotton-wheat to rice-wheat system to avoid salinity led crop failure risks. This took place exclusively in low lying to moderately higher landscapes. This strategy was relatively more adaptive among medium and small farmers. About 19.0 per cent of same group of farmers started integrated adaptations with rice-wheat (low lying areas) and cotton-wheat (upper landscape, BT & Deshi cotton) to marginalize the risks of salinity as well as climate variability. Diversification of varieties (hybrid in cotton and rice, and improved varieties in coarse grain rice, and Pusa 1121, Pusa 1509, and somewhere CSR-30, etc.) was another set of autonomous adaptation strategies hybridized with formal knowledge among more than 14.0 per cent farmers. This was predominant particularly in the landscapes where salinity varies from marginal to higher level. Some farmers (5-6%) are willing to adapt lentil where salinity is very nominal.

Table 3. Adaptation strategies among the farmers

Planned adaptations with autonomous decision (Thorn *et al*., 2015)*	Percentage	Remarks on salinity and social-ecological systems
Cotton-wheat	13.51	Upper landscape (where kinnow is replaced) where salinity is less and market is an opportunity for cotton (more among medium and large farmers)
Varietal diversity (hybrid in cotton and rice, and improved varieties such as Pusa 1121, Pusa 1509, and somewhere CSR-30, etc.)	14.86	Low lying areas where salinity is high (more among medium and small farmers)
Rice-wheat, and kinnow	6.75	Rice-wheat low lying areas, kinnow at upper landscape where water table is below 5 feets (more among large farmers)
Rice-wheat, and fish culture	5.40	In low lying areas where water logging is a problem and salinity is high (more among large and medium farmers)
Rice-wheat/cotton-wheat (BT & *Deshi* to avoid climate and salinity risks)	18.91	Low lying and upper landscape (more among small and medium farmers)
Rice-wheat	32.43	Exclusively at low lying areas to moderate landscape by replacing kinnow and cotton (more among small and medium farmers)
Rice, and Kinnow-cotton at far places	8.10	In low lying areas, and upper landscape for initial 2-3 years (more among large farmers)

Other than CSR-30, farmers face larger yield penalty (30-50%) in particularly Basmati rice varieties, although, area under CSR-30 was very less. About 13% farmers have started adapting cotton-wheat by replacing kinnow orchards where surface water table is <4.0 feet and marginal salinity (0.5 to 3.27 dS/m).

In order to cope-up with declining kinnow orchard caused by salinity, diseases and insect pests, farmers have increased plant density (15x15 feets as compared to 20x20 feets which was earlier). As management issue, some farmers uses over dose of urea at every two months. Now cotton cultivation is minimized upto 40-60 per cent as reported by farmers. Results indicated that about 30-40% small and marginal farmers who are facing secondary salinization and some of their land have become totally barren, adapted to become beneficiaries in MAGNREGA and PDS like schemes through which they secure their livelihoods. Those having joint family system (28.5%) migrated to cities for gainful wages/jobs to spread their livelihood risks.

After learning on multiple stressors, it was felt necessary to try some of salt tolerant rice and wheat varieties to enable farmers for their decision making on adoption of alternative strategies in crops. Therefore, a total of 35 FLDs (5 on CSR-43 rice, 9 on CSR 36 rice, 9 on CSR-30 Basmati rice, and 12 on KRL-210 wheat varieties) were conducted as an intervention to motivate farmers about making adaptations of such varieties against soil and water salinity. The mean pH of soils where FLDs of salt tolerant rice varieties were conducted was found to be 9.22 with EC value 1.69. Results indicated that the yield of CSR-43 varied between 5.0 to 7.4 t/h, whereas the yield of CSR-36 could yield 5.5 to 7.2 t/ha in same soil and water environments. The yield performance of CSR-30 was recorded between 2.0 to 2.9 t/ha. The wheat variety KRL-210 was intervened on farmers' field in Malot area affected by saline-sodic soils. Perception of these farmers about the performance KRL-210 on 15 parameters indicated that this variety was good against salinity tolerance, climate variability, tolerance to waterlogging, lodging behavior and pod shattering attributes. This variety could yield 5.73 t/ha at the soil salinity level of 4.03 dS m^-1 as compared to local variety which provided 4.5 to 4.8 t/ha yields.

Conclusions

From foregoing study, they key results indicated that human-environment systems are interwoven and therefore they cannot be seen in isolations. Problems of soil and water can have direct and indirect interrelations with socio-economic and policy factors (Stringer *et al.,* 2017), although, they are beyond the control of local community who are already exposed to salinity and other stressors. There could be lower level of farmers' adaptive capacity to recover the lowering threshold limits of social-ecological system exposed to salinity stressors (Reynolds *et al.,* 2007). The differences in perception about local issues such as in our case of salinity-which are influenced by not only the secondary salinization, but also the other socio-economic, political, and climatic factors between local farmers and policy planners, may eventually lead to develop the maladaptive practices (Stringer *et al.,* 2017). So there is need of close tie between various stakeholders to evolve the hybrid knowledge which are tuned with local conditions, and are integrated at local and regional level of planning and community driven knowledge development on salinity management (Reynolds *et al.,* 2007; Stringer *et al.,* 2017).

It can be concluded that water level below ground level has risen; causing water quality and affecting crops (cotton, kinnow and wheat). Further, farmers perceive salinity (ecological stress) is compounded with climate, socioeconomic and policy stressors affecting their crop cultivation/livelihoods. Largely, farmers had partial knowledge about the attributes of soil and water salinity which directly affect the management practices at local level. Overall, adaptation strategy was autonomous in nature such as changes in cropping systems (rice-wheat from kinnow-wheat/cotton), local contingency measures, and in some case combination of both. Adaptation strategies are now becoming more of location specific and vary with socio-economic scale (small, marginal and large farmers). Large farmers are still trying to take risks with Kinnow-cotton (initial 3 years) in areas where water is more than 5 feets below the ground level, while small and medium farmers remain with rice-wheat system to avoid current and future livelihood risks. Some insights can be taken from the farmers' autonomous adaptation strategies (landscape based adaptations, contingency measures in cropping system, etc.) to make planned adaptations more inclusive. The key concerns on salinity management are now changing from science and policy *for* the farmers to *with* the farmers. So era of *top-bottom* science and policy planning has now least relevance in view of global policies such as UNCCD (1994), SDGs (2015) (NITI Ayog 2017) and Climate Agreement Paris (UN, 2016). There is strong need to increase coordination and collaborations between the agencies and stakeholders in order to reach more mutual understanding and strong knowledge development to adapt salinity induced stressors in India, as learned elsewhere also (Stringer et al., 2014).

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Socio-Economic Impact Analysis of Technologies for Reclamation and Management of Sodic and Waterlogged Saline Soils

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Introduction

Soil sodicity and salinity have direct impact on growth and development of agricultural economy. The consequences of degrading land resources due to salinity and sodicity are witnessed at farm level, regional level and national level. At the farm level adverse effects are (i) threat to the sustainability of land resources and (ii) decrease farm production by (a) decline in resource productivity, (b) abandon crop production and (c) cut-back in resource use. Studies have shown that the yield and income effects of salt affected soils are quite high. The land degradation severely affects the production of important crops like rice, wheat, cotton, sugarcane, groundnut, etc. At the regional level, consequences are (i) displacement of labour from agriculture, (ii) widen income disparities and (iii) affect the sustainability of secondary and tertiary sectors. At the national level, consequences are (i) decline in agricultural production, (ii) affect gross domestic product, (iii) bring down export potential of important crops and (iv) increase import bill.

Sustainable agricultural development and food security is one of the key challenges for India. Around 60% of the India's population is depending on agriculture for their livelihood support. The vast majority of Indian farmers are smallholders and farm size is decreasing further due to population growth. Similarly, the quality of the land is deteriorating due to soil erosion, increasing water scarcity, adverse impacts of climate change and accumulation of toxic elements in soil and water. The total area under degraded and wastelands in the country stands at 114.01 M ha. The extent of area under water erosion is 23.62 M ha, and under wind erosion is 8.89 M ha. Chemical degradation comprises salinization/alkalization and acidification. Area under salt-affected soils is 6.73 M ha and under acid soils is 16.03 M ha. Many more areas with good quality aquifers are endangered with contamination as a consequence of excessive withdrawals of groundwater.
The brief description of agro-physical, socio-economical and environmental impact of soil salinity and sodicity are as follows.

Impact on Crop Production

- Various degrees of salinity and sodicity can cause serious and severe decline in soil productivity and crop yields (Table 1).
- To overcome reduction in yield farmers increase inputs such as seeds, fertilizers, etc.
- In salt-affected soils, response to any input is low: e.g., crop yield response to fertilizer application is less as salinity is a limiting factor.
- Less possibility for alternative land use: e.g., farmers are forced to cultivate only salt-tolerant crops, which might not always be high-income cash crops.
- Salinity and sodicity reduce efficient use of water (i.e. crop yield per unit water) causing reduction in return from capital investment and labour inputs.
- Salt-affected soils are more fragile with greater risk and always subjected to other forms of degradation: e.g., salinity and sodicity reduce land green cover and soil becoming subject to other degradation processes such as wind and water erosion.
- In salt-affected soil environment, saline watertable can enhance salinity of fresh waters in rivers and other water sources through seepage.
- The rehabilitation programmes require high investment cost in reclamation of salt-affected soils as compared to other types of degraded lands, in general.

Impact on Socio-Economic Conditions

- Abandonment of the land where severe salinity and sodicity degradation occurred which increased the number of landless farmers.
- Low food security due to low food production and supply.

- Reduce labour use efficiency: e.g., reclamation of salt-affected soils needs more labour, crop yield declines and input requirement reduces which ultimately would reduce labour use efficiency in these soils. Reclamation programmes and improved farming systems often involve high costs being capital investment of the Government.
- Lower farm income of resource poor small farmers: e.g., as a consequence of salinity and sodicity farmers force to work on land of others or migrate to outside the area in search of other sources of livelihood.

Table 1. Grain yield of major crops under various environments (t/ha)

Crop	Normal soils	Salt affected soils	Waterlogged soils
Rice	3.99	2.18 (45)	2.30 (42)
Wheat	2.59	1.57 (40)	1.85 (38)
Cotton	1.63	0.61 (63)	0.37 (77)
Sugarcane	63.68	33.02 (48)	24.74 (61)

Figures in parentheses indicate percentage loss over normal soils.

Impact on Environment

Most studies of long-term experiments provide information only about biophysical impacts of sodicity and salinity at the site of the experiment. There are also off-site environmental impacts of salinity development. These may be at least as important as those on-site. Chemical effects contribute because nutrients are leached from the soil during leaching processes of salt-affected soils and contaminate water supplies. Biological effects because of the loss of organic matter, which weaken the strength of soil aggregates, increase the loss of nutrients in run-off, and increase carbon dioxide and methane released to the atmosphere. Nutrient losses by leaching are most often observed where nitrogenous fertilizers are being used injudiciously and where organic manures are concentrated and the effluent arising is allowed to reach streams or rivers.

Washing of soil nutrients, organic matter and even nutrient rich topsails in to streams and rivers is a serious cause of eutrophication. The nutrients and organic matter cause a proliferation of water borne organisms, which use oxygen in the water and deplete it, at the expense of fish. Until now there have been few studies in which a comprehensive attempt has been made to quantify fully the off-site effects of salt-affected soil development on environment. Where irrigation systems are established it is necessary that proper attention be given to inclusion of adequate drainage systems to dispose of the saline drainage waters so that salinization does not become an environmental hazard.

Production and monetary losses from salt-affected soils in India

Every year India losses about 16.84 million tones of foodgrains production from salt-affected soils in the country. In terms of monetary losses the country is losing about Rs. 230196 million. The major affected states are Uttar Pradesh and Gujarat. These states together contributes to 74 per cent of production losses and 79 per cent of monetary losses in the country (Table 2).

Table 2. Production and Monetary Losses in various states from salt-affected soils in India

States	Gross Salt-affected Area (ha)	Production loss (mt)	Production loss (%)	Monetary loss (Rs. in million)	Monetary loss (%)
Haryana	455568	0.719	4.27	7791	3.38
Punjab	301723	0.144	0.85	975	0.42
Uttar Pradesh	2573242	7.695	45.69	81291	35.31
Madhya Pradesh	239271	0.032	0.19	882	0.38
Andhra Pradesh	626893	0.501	2.98	7308	3.17
Karnataka	147387	0.016	0.09	309	0.13
Kerala	17131	0.004	0.02	71	0.03
Tamil Nadu	394527	0.147	0.87	1378	0.60
Gujarat	4129376	4.832	28.69	100635	43.72

Maharashtra	986265	0.923	5.48	4987	2.17
Rajasthan	561756	0.190	1.13	4032	1.75
Bihar	282723	0.554	3.29	5594	2.43
Odisha	273275	0.197	1.17	2658	1.15
West Bengal	591521	0.890	5.29	12286	5.34
Total	11580658	16.844	100.00	230196	100.00

(Source: Sharma et al., 2015)

Production and monetary losses from sodic soils

Crop production and monetary losses in different states due to sodicity are presented in Table 2a. The analysis revealed that the total production losses due to sodicity in India is about 11.183 million tones where as the monetary losses accounts to Rs. 150174.91 million. Among the states, Uttar Pradesh (67.56%) contributed higher production losses followed by Gujarat (18.85%), Haryana (5.37%) and Bihar (4.48%) as presented in Table 3. In terms of monetary value, Uttar Pradesh contributed the highest monetary losses of Rs.80753 million followed by Gujarat (Rs.51497.59 million), Haryana (Rs.6555 million) and Bihar (Rs.5066 million). The major sodicity affected states like Uttar Pradesh, Gujarat, Haryana and Bihar together contributes about 96 per cent production as well as monetary losses in the country.

Table 2a. Statewise production and monetary losses due to sodicity in India

States	Production loss (mt)	Production loss (%)	Monetary loss (Rs. in million)	Monetary loss (%)
Haryana	0.600	5.37	6555.04	4.36
Punjab	0.144	1.29	975.27	0.65
Uttar Pradesh	7.555	67.56	80753.71	53.77
Madhya Pradesh	0.032	0.29	882.00	0.59
Andhra Pradesh	0.102	0.91	2640.15	1.76
Karnataka	0.015	0.14	301.40	0.20
Tamil Nadu	0.103	0.92	1067.41	0.71
Gujarat	2.107	18.85	51497.59	34.29
Maharashtra	0.001	0.01	36.62	0.02
Rajasthan	0.021	0.19	399.61	0.27
Bihar	0.501	4.48	5066.13	3.37
Total	11.183	100	150174.91	100

(Source: Sharma et al., 2015)

Production and monetary losses from saline soils

Production monetary losses from different states due to salinity are presented in Table 2b. The analysis indicated that due to salinity, about 5.661 million tones of production losses and Rs. 80021.31 millions of monetary losses occurs in the country. Among different states, Gujarat suffered the highest production losses of 2.725 million tones and Rs. 48137.83 millions of monetary losses. The production losses and monetary losses in Gujarat were 48.13% and 61.41% respectively. Next stands the Maharashtra, West Bengal and Andhra Pradesh with the respective production losses of 16.27%, 15.73% and 7.05% and monetary losses of 6.19%, 15.35% and 5.83%.

Table 2b. Statewise production and monetary losses due to salinity in India

States	Production loss (mt)	Production loss (%)	Monetary loss (Rs. in million)	Monetary loss (%)
Haryana	0.118	2.09	1236.46	1.55
Punjab	0.000	0	0.00	0
Uttar Pradesh	0.141	2.49	536.80	0.67
Madhya Pradesh	0.000	0	0.00	0
Andhra Pradesh	0.399	7.05	4668.03	5.83

Karnataka	0.000	0	7.76	0.01
Kerala	0.004	0.07	71.25	0.09
Tamil Nadu	0.044	0.78	310.19	0.39
Gujarat	2.725	48.13	49137.83	61.41
Maharashtra	0.921	16.27	4950.00	6.19
Rajasthan	0.168	2.97	3632.17	4.54
Bihar	0.052	0.93	527.50	0.66
Odisha	0.197	3.48	2657.59	3.32
West Bengal	0.890	15.73	12285.73	15.35
Total	5.661	100.00	80021.31	100.00

(Source: Sharma et al., 2015)

Reclamation cost of salt-affected soils in India

Investment components for sodic land reclamation: In India, gypsum is the major source of soil amendment used to reclaim sodic soils. The use of other amendments like phosphogypsum, press mud, acid wash and molasses is limited (Chhabra *et al*. 1980). The investment depends on the quantity of gypsum required for reclamation, which depends on the amount of exchangeable sodium to be replaced, which in turn is governed by the amount of absorbed sodium in the soil, sodicity tolerance and rooting depth of the crop to be raised.

Gypsum is an important amendment used for sodic soil reclamation and a study has shown that 10–15 Mg of gypsum containing 70 % hydrated calcium sulphate ($CaSO4 . 2H_2O$) is sufficient to reclaim 15 cm surface sodic soil of one hectare land (Abrol and Bhumbla 1979). The actual quantity of gypsum required is calculated on the basis of laboratory tests carried out on the surface soil (0–15 cm). The capital investment of Rs. 76,284 is needed to reclaim one hectare sodic land (Table 3). The gypsum and its application cost is the major item (57.29 %) followed by tube well and its installation (19.66 %) and land development costs (16.26 %) in the total reclamation cost. The irrigation and flushing of salts are the other cost items (6.80 %) in the total investment cost. This indicates that a large amount of capital is required to reclaim salt-affected soils and it may not be possible for the resource-poor marginal and small farmers to bear this cost. Experiences in Haryana and Punjab revealed that there was negligible response for land reclamation without subsidy on gypsum (Joshi and Agnihotri 1982; Tripathi 2009). In order to encourage farmers for reclaiming the sodic land, the government provides subsidy on soil amendments ranging from 50 to 90% through different antipoverty programmes. Investment on land reclamation involves medium to long gestation periods.

Table 3. Capital required for sodic land reclamation

Particulars	Investment (Rs. ha^{-1})	Share in total cost (%)
Land Development	12400	16.26
Tubewell and itsinstallation	15000	19.66
Gypsum and its application	43700	57.29
Irrigation and flushing	5148	6.80
Total	76284	100

(Source: Thimmappa et al., 2017)

Investment components for saline land reclamation: The cost of preparation of DPR in case of medium textured alluvial soils with pumped outlet with 67 m spacing, and heavy soils with gravity outlet with 30 m spacing was 2,500 each and its cost share was 3.7 and 2.2% of the total cost, respectively (Table 4). The cost of drainage materials including structures and pump set for medium textured soils with pumped outlet was Rs.37,226 (50.9%) whereas the cost of drainage installation including filter wrapping, dewatering and supervision charges was Rs.27,453 (37.5%). Similarly, for heavy textured soils including Vertisols with gravity outlet, the cost of drainage materials including structures and outlet pipe Rs.60,550 (54.2%) whereas the cost of drainage installation including filter wrapping, dewatering and supervision charges was Rs.40,766 (36.5%). It is observed that the cost of drainage materials in case of medium textured soils with pumped outlet, and heavy soils with gravity outlet is higher by 13.4% and 17.7% than that of installation, respectively. It is also observed that cost of drainage materials in medium textured soils with pumped outlet is lower by 13,324 (higher by 3.3%) than that of heavy textured soils with gravity outlet. Similarly, installation cost in medium textured soils is lower by Rs.13,313 (higher by 1.0%) than that of heavy textured soils. The higher material and installation cost in heavy textured soils including Vertisols is mainly due to installation of larger length of lateral drain pipes than that in medium textured soils.

Table 4. Cost comparison of SSD components for heavy and medium textured soils

SSD Component	Cost (ha-1)	
	Medium texture soils (67 m spacing with pumped outlet)	Heavy texture soils (30 m spacing with gravity outlet)
DPR	2,500 (3.7)	2,500 (2.2)
Pipes and fittings	21,750 (29.7)	41,989 (37.6)
Filters/envelopes	8,334 (11.4)	14,776 (13.2)
Structures	7,142 (9.8)	3,785 (3.4)
Installation cost	22,953 (31.4)	36,766 (33.0)
Dewatering	500 (0.7)	0 (0.0)
Supervision charges	4,000 (5.4)	4,000 (3.5)
Contingencies	3,431 (4.7)	5,352 (4.8)
Farmer's training	750 (1.0)	750 (0.7)
M&E	2,000 (2.7)	2,000 (1.8)
Total	73,000 (100.0)	111,500 (100.0)

Note: Figures in parenthesis show the share (%) of the total cost; (Source: Bundela et al., 2016)

Financial Appraisal of Land Reclamation Projects

The financial appraisal of salinity and sodicity management projects is aimed to find out whether the project is economically reasonable and able to provide justified return on the investment made on it. The financial feasibility involves detail analysis of the capital requirement for installation of the systems, annual operational and maintenance cost of the project and benefits generated by the project. In the land reclamation projects, the initial investment is made once for installation of the system whereas the returns obtained from the project is spread over several years in future.

The financial appraisal of project mainly includes costs and benefits analyses for estimation of economic parameters. The cost-benefit analysis is a decision-making tool for investment choice with respect of total costs and total benefits. It helps in comparing the cost and benefit of alternative technologies. Nevertheless, all the costs and benefits are difficult to quantify in financial terms because a new technology may have negative and positive side effects on the life quality of society and accordingly required to be accounted for the assessment. When side effects of a technology are accounted both direct and indirect benefits and costs, it is called social cost-benefit analysis. Generally, for the financial feasibility we consider only tangible direct benefits and costs viewing the simplicity of estimation procedure.

There are many tools and measures to evaluate the feasibility of the land reclamation technologies. Some important cost-benefit analysis measures are described here which are used widely to find out the financial and commercial viability of the technologies.

1. Pay Back Period
2. Net Present Worth
3. Benefit-Cost Ratio
4. Internal Rate of Return.

Pay Back Period (PBP): The pay back period measures the number of years a project will take for the net undiscounted benefits to repay the investment. If the pay out period is longer than some arbitrary limit (say five years) the project is rejected. If shorter, it is accepted. Thus, the pay back is the time period for an investment to generate sufficient incremental cash to recover its initial capital outlay in full. The following formula is used to calculate the pay back period, if the cash flows are uniform.

$$P = \frac{I}{E}$$

Where,

P = Number of years required for pay back the investment,
I = Initial capital investment, and
E = Annual net earning (benefits).

If the cash flow is not uniform per year the payback period is determined by calculating the cumulative proceeds in successive years until the total is equal to the original outlay. It is computed to supplement the other measures used to judge the desirability of the projects. The shorter pay back period provides the greater profitability of the project.

The pay out period criterion is justified for the individual's point of view in the short run but for aggregate purposes such as a nation as a whole, some times it misleads the results. The crucial draw back of this measure is that it rejects all projects whose benefits take long time to materialize and favours only good short-term prospects. There is no reason to believe that all quick yielding projects are superior projects.

Net Present Worth (NPW): The waiting has a cost and the longer you wait the larger the cost. If money and other assets are more productive, as reflected in the higher discount rate, the waiting is costlier. This raises the question as to which interest rate should be used in project appraisal. Generally the discount rate should reflect the cost of capital to the investor. The net present worth method is based on three important features of the present value.

1. The present value is always less than the nominal value that occurs in the future.
2. The longer the delay, the less is the present value.
3. The highest the interest rate, the lower the present values.

In the estimation of NPW, the return achieved at different future dates is made commensurable by assigning to them equivalent present values. This is an expression of net revenues from the crop production discounted to a common time point for ensuring costs and returns comparability, which occur at different periods of time. The NPW can be calculated by taking the difference between present worth of benefits and present worth of cost. The positive values of NPW reflect viability of the project whereas negative NPW indicates economic loss in the project. Once future benefits and costs have been expressed in terms of present values, we add them to find out the NPW of the project. General formula used for estimation of NWP is:

$$NPW = \sum_{t=1}^{n} \frac{Bt - Ct}{(1+i)^t}$$

Where,

Bt = Benefit received each year,
C = Cost incurred each year,
t = Time in years (with present difference as 0),
n = Number in years of the project duration, and
i = Rate of interest for discounting the cost or benefit.

Benefit-Cost Ratio (BCR): Benefit-cost ratio is the most popular criterion in social project appraisals. It is calculated by dividing the total discounted benefits by total discounted costs. The projects with the highest ratios are given higher ranking. It is the ratio of present worth of benefit and present worth of cost expected at different points of time for a particular project. The project is accepted if the BCR is above 1. The ratio more than 1 reflect economic viability of the project whereas less than 1 indicating loss in taking up the project. The BCR can be calculated with the help of the following formula.

$$BCR = \frac{\sum_{t=1}^{n} \frac{Bt}{(1+i)^t}}{\sum_{t=1}^{n} \frac{Ct}{(1+i)^t}}$$

The benefit-cost ratio is a ratio of present worth of benefits (PVB) to Present worth of costs (PVC) of a technology under assessment. In other words, it is return to one rupee invested on the project. Therefore, at the economic feasibility level of the project the BCR should be more than unity.

Internal Rate of Return (IRR): The internal rate of return is used to find out the rate of return, which a project is likely to earn over its useful life. This measure is practically used for all economic and financial analyses of projects by the international financing agencies. When the internal rate of return is used in economic analysis, it is called internal economic rate of return (ERR) whereas on the financial analysis it is called internal rate of return (IRR). The IRR is the discount rate at which the NPW is equal to zero. In calculating the NPW, we independently chose a discount rate based on the opportunity cost of capital and then found the differences between discounted benefits and costs. The IRR calculation reverses the procedure as we use for NPW. Instead of selecting the discount rate, we set the NPW at zero and try to solve for the discount rate, which finally gives results. Since higher discount rates reduce the present value of future cash flows, the higher the discount rate, the lower the NPW. The process of finding the IRR involves trial and error method. An arbitrary discount rate is used to find NPW. If the result is positive a higher rate is used to find the NPW, if negative a lower rate is used and the process is repeated until the NPW is reduced to zero. At this discount rate, benefit-cost ratio is equal to one. The IRR is compared with the minimum acceptable rate of return and if it is either higher than or equal to the minimum acceptable rate of return, then the technology is assessed to be desirable. Suppose, IRR is 18% this means that a discount rate of 18% the project just breaks even, i.e., it will earn back all the capital and operating costs extended upon it and pay 18% for the use of money in the mean time.

The internal rate of return or discounted cash flow rate of return is the marginal efficiency of capital or discounted cash flow of the investment on a project. It is the rate at which the discounted cash flows are equal to the investment outlay of the enterprises. So IRR is that rate of interest, which applies to expenditures incurred at different times for finding compounded sums equal to, revenues compounded at the same time. The rate of discount, which makes Net Present Worth of the investment exactly equal to zero, is known as internal rate of return of a project. Thus IRR is that rate of discount, which makes present value of benefits zero.

The IRR is a trial and error solution in which we choose a discount rate at random. The investment is considered to be desirable if the IRR is higher than the cost of capital in a project. If NPW >0, we choose a higher discount rate (accept the project viability) and NPW<0, we choose lower discount rate (reject the proposal). The rate of discount at which the NPW is equal to 0 is the actual IRR and at this stage the procedure is completed. The IRR can be expressed in algebraic form as:

$$IRR = \sum_{t=1}^{n} \frac{Bt - Ct}{(1+i)^t} = 0$$

In the estimation of IRR, the first step is to discount the cash flow at the cost of capital. If the NPW is negative, we know the project cannot pay such a high rate of interest. It means that we have chosen a high discount rate. Now, choose a discount rate (lower rate), which will give a positive NPW. If in the first step, NPW is positive we should choose a new discount rate (higher), which will decrease the NPW and make it negative. The real IRR lies between these two rates, and we can successively narrow down the limits. The easier and widely adopted method employed for estimation of true IRR is the interpolation formula. The interpolation formula is as follows.

$$IRR = \text{Lower discount rate} + \begin{array}{c}\text{Difference between}\\ \text{the two discount rates}\end{array} \times \frac{\text{NPW at lower discount rate}}{\text{Difference between NPW's at the two discount rates}}$$

It is very important to note that interpolation should not be carried out between a wider spread of discount rates (not more than five per cent). Since interpolation is a higher linear algebraic technique and the changes in IRR, NPW do not follow this pattern. In reality, the IRR rectified by actual verification and by narrowing down the limits between the two discount rates.

Economic feasibility of reclamation of salt-affected soils in India

The economic feasibility analysis assumed 12% opportunity cost of capital assuming the life periods of 20 years (Table 5). The benefit-cost ratio of land reclamation was 2.47 and 1.95 respectively for sodic and saline land reclamation. The internal rate of return was 67 per cent for sodic soils and 27.5 per cent for saline soils. The payback period was 3 and 4 years respectively for sodic and saline soils years. Several past studies also have highlighted the economic feasibilities of investment in rehabilitation and management of sodicity-affected lands (Joshi and Singh 1990; Tripathi, 2011).

Table 5. Economic feasibility of sodic and saline land reclamation

Indicators	Sodic land *(Thimmappa et. al., 2017)*	Saline land *(Raju et. al., 2016)*
Benefit-Cost Ratio	2.47	1.95
Internal Rate of Return (%)	67	27.5
Payback Period (Years)	3	4

Conclusion

Salt-affected soils cause enormous production and monetary losses in India, which can affect the food security and economy over the years. The different technologies include biological reclamation approaches, reclamation of sodic soils by amelioration with chemical amendments and waterlogged saline soil reclamation using sub-surface drainage technology. Several impact studies on restoration of salt-affected soils indicated a significant improvement in socio-economic conditions and livelihood security of resource-poor farmers living in this region. Hence, India needs to reclaim large tracks of salt-affected lands on priority to achieve long-term objectives of providing food and livelihood security to resource-poor farmers.

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Notes to Remember

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