SIGNIFICANT TECHNOLOGIES ALONG WITH IMPACT BASED ON 50 YEARS OF SALINITY RESEARCH

under

ICAR-AICRP on Management of Salt Affected Soils & Use of Saline Water in Agriculture

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Compiled and Edited

by

M.J. Kaledhonkar and B.L. Meena

Project Coordinating Unit
ICAR-All India Coordinated Research Project
Management of Salt Affected Soils and Use of Saline Water in Agriculture

ICAR-CENTRAL SOIL SALINITY RESEARCH INSTITUTE, KARNAL-132001, HARYANA

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FOREWORD

The genesis of salt affected soils and poor quality groundwater is natural process and it is influenced by parent material, mineralogy, topography and human activities. Inefficient irrigation water management including canal network losses is leading to the waterlogging and soil salinity/sodicity while use of poor quality waters for crop production, without due consideration to leaching requirement of soil, is responsible for soil salinization and sodification in semi-arid and arid regions. Further, hydrological imbalance of coastal aquifers with sea water induces sea water intrusion. Thus, the problems of salt affected soils and poor quality waters are observed in wide range agro-ecological regions in Indian subcontinent. 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 and sodicity at the national level is 17 million tonnes (M t), accounting for the annual monetary loss of ₹ 23,000 Crores at prevailing Minimum Support Prices (MSP) of different crops during 2015.

The ICAR-Central Soil Salinity Research Institute was established at Karnal (Haryana) in 1969. Since then, the Institute has made significant contributions towards the understanding of management of saline and alkali environments. The All Indian Coordinated Research Project on Salt Affected Soils and Use Saline Water in Agriculture, established on 14th April 1972, is our active partner in fine tuning of reclamation technologies, delineation of salt affected soils and poor quality waters and screening of newly developed varieties. The AICRP is completing 50 years of its salinity research under different agro-climatic region in 2022 and this is the time for introspection. This AICRP provided national guidelines for use saline and alkali water for irrigation purpose in 1992 and ground water quality map of the country in 1994. At present, 10 centres of the AICRP are involved in developing location specific technologies to address irrigation induced soil salinity and sodicity problems. Some of the important technologies can be listed as conjunctive use of saline/sodic water and good quality water, use of drip for saline/sodic waters, amelioration of alkali waters, subsurface drainage and controlled drainage, skimming of fresh water layer from coastal aquifer, low cost recharge structure for poor quality semi-arid regions, distillery spent wash for reclamation of alkali soil and water, drip with mulching on waterlogged saline soils, reclamation of abandoned aqua ponds, integrated farming system (IFS) models, screening and identification of crop genotypes/ varieties for salt tolerance, etc. It is also important to mention that AICRP has undertaken work of revision of ground water quality map at national level. On occasion of 50 years, AICRP has compiled "Significant Technologies along with Impact based on 50 Years of Salinity Research". This is an appreciable work by Project Coordinating Unit and all the Cooperating Centres of the AICRP. This publication can be useful to researchers, planners, managers, state land reclamation boards, farmers, entrepreneurs in achieving the goals under Land Degradation Neutrality (LDN) particularly for salt affected eco-systems in different states in changing climate. I wish all success in future plans.

Date: 6-10-2022

(PC Sharma)

CONTENTS

1. INTRODUCTION OF AICRP ON MANAGEMENT OF SALT AFFECTED SOILS AND USE OF SALINE WATER IN AGRICULTURE (AICRP on SAS&USW), ICAR-CSSRI, KARNAL

1.1 Background

The All India Coordinated Project on Use of Saline Water in Agriculture was first sanctioned during the IVth Five Year Plan under the aegis of Indian Council of Agricultural Research, New Delhi at four research centres namely Agra, Bapatla, Dharwad and Nagpur to undertake researches on saline water use for semi–arid areas with light textured soils, arid areas of black soils region, coastal areas and on the utilization of sewage water respectively. It was started on 14-04-1972. During the Fifth Five Year plan, the work of the project continued at the above four centres. In the Sixth Five Year Plan, four centres namely Kanpur, Indore, Jobner and Pali earlier associated with AICRP on Water Management and Soil Salinity were transferred to this Project whereas the Nagpur Centre was dissociated. As the mandate of the Kanpur and Indore centres included reclamation and management of heavy textured alkali soils of alluvial and black soil regions, the Project was redesignated as All India Coordinated Research Project on Management of Salt Affected Soils and Use of Saline Water in Agriculture. Two of its Centres located at Dharwad and Jobner were shifted to Gangavati (w.e.f. 01.04.1989) and Bikaner (w.e.f. 01.04.1990) respectively to work right at the locations having large chunks of land afflicted with salinity problems. During the Seventh Plan, Project continued at the above locations. During Eighth Five Year Plan, two new centres at Hisar and Tiruchirappalli were added. These Centres started functioning from 1 January 1995 and 1997 respectively. Further, during Twelfth Five Year Plan, four new Volunteer centres namely Bathinda, Port Blair, Panvel and Vyttila were added to this AICRP. These four centres started functioning from 2014. Details of the centres are given in Table 1.1.

Table 1.1 Details of AICRP on SAS&USW centres

Location	**Climate**	**Year of start**	**Ecology**	**Irrigation command**	**College / University**
Main cooperating centres (Ongoing)					
Agra	Semi-arid	1972	Inland AER 4 (Northern plain, hot semi-arid region)	Agra canal	R.B.S. College, Agra, UP
Baptala	Semi-arid	1972	Coastal/Inland AER 18 (Eastern coastal plain, hot sub-humid to semi-arid region)	NSP & Krishana	Acharya N.G. Ranga Agril. University, Guntur, Aandhra Pradesh
Bikaner	Arid	1980	Inland AER 2 (Western plain, hot arid region)	IGNP	Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan

Gangavathi	Semi-arid	1972	Inland AER 3 (Hot Arid Eco-region with Red and Black Soils)	Tunga Bhadra Project	University of Agricultural Sciences, Raichur, Karnataka
Hisar	Arid	1996	Inland AER 2 (Western plain, hot arid region)	Bhakra canal	CCS Haryana Agricultural University, Hisar, Haryana
Tiruchirapalli	Semi-arid	1995	Coastal/Inland AER 8 (Eastern Ghats and Tamil Nadu uplands and Deccan plateau, hot semi-arid region)	East Kattalai canal/tank	Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu
Kanpur	Semi-arid	1980	Gangetic plain of Uttar Pradesh	Canal network of Ganga	CSAUA&T, Kanpur, UP
Volunteer Centres (Ongoing)					
Bathinda	Semi-arid	2014	Inland AER 2 (Western Plains, Hot arid)	Rajasthan canal	Punjab Agricultural University, Ludhiana, Punjab
Indore*	Semi-arid	1980	Inland AER 5 (Central highland region)	Omkeshwar	Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh
Panvel	Humid	2014	Coastal/Inland AER 19 (Western Ghats and Coastal Plain, hot humid-per humid)	Rajnala Karjat	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri, Maharashtra
Vytilla (Kochi)	Humid	2014	Coastal (Low-lying Polders) AER 19 (Western Ghats and Coastal Plain, hot humid-per humid)	----	Kerala Agricultural University, Thrissur, Kerala

*Indore centre was main centre till 31 March 2020 and it was converted to Volunteer centre from 1-04-2020.

Closed centres:

Location	Climate	Year of start	Ecology	Irrigation command	College / University
Main cooperating centres					
Kanpur	Semi-arid	1980	Gangetic plain of Uttar Pradesh	Canal network of Ganga	CSAUA&T, Kanpur, UP

Volunteer Centres					
Port Blair	Humid	2014	Coastal/ Island ecology	----	CIARI, Port Blair, &N Islands

As per recommendations of QRT (2011-2017) of ICAR-CSSRI, Karnal, Indore centre was converted from main cooperating centre to volunteer centre on 1-04-2020. The Kanpur and Port Blair centre were closed on 31 March 2020. The volunteer centre has been proposed at Dr. PDKV, Akola in SFC document of the scheme for period 2021-2026. During 2017-2020 Plan, Project continued with an outlay of Rs. 2522.18 lakh at these centres with the Coordinating Unit at Central Soil Salinity Research Institute, Karnal. The ICAR share was of Rs. 1980.60 Lakh while state share was of Rs. 541.58 Lakh. The year wise actual allocation in terms of ICAR share for financial year 2017-18, 2018-19 and 2019-20 was Rs. 615.00 Lakhs, Rs. 649.67 Lakhs, Rs. 527.03 Lakhs, respectively. Annual allocation for 2020-21 and 2021-22 was Rs. 560.70 Lakhs and Rs. 479.17 Lakhs, respectively.

1.2 Existing and Proposed Mandate for the AICRP

Name of the scheme (Present):

"AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture"
ICAR-Central Soil Salinity Research Institute, Karnal, Haryana- 132001

Proposed:
In the NRM Division meeting dated 18 Nov. 2019, the issue of revision of the title of AICRP was discussed and the following title was finalized.

"AICRP on Management of Saline Water & Associated Salinization in Agriculture"
ICAR-Central Soil Salinity Research Institute, Karnal, Haryana- 132001

Objectives of the scheme (Present):
Survey and characterization of the salt affected soils and ground water quality in major irrigation commands.

- Evaluate the effects of poor quality waters on soils and crops and plants.
- Develop standards/guidelines for assessing the quality of irrigation waters.
- Develop management practices for utilization of waters having high salinity/alkalinity and toxic ions.
- Develop and test technologies for the conjunctive use of poor quality waters in different agro-ecological zones/major irrigation commands.
- Develop alternate land use strategies for salt-affected soils
- Screen crop cultivars and tree species appropriate to saline/alkali soil conditions.

Proposed:

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

1.3 Mandates of Cooperating Centres

Centre wise mandate (as finalized in Annual Review Meeting 04-05 June 2018)

In view of scientific staff position reduction from 37 to 16 during SFC 2017-20, research prioritization exercise was done during Annual Review Meeting of the scheme held at ICAR- CSSRI, Karnal during 04-05 June 2018. After discussion with all concerned including ICAR nominated experts, priority areas for each centre was finalized. Priority research areas of the centres, which will continue during 2021-2026 are provided below (Table 1.2).

Table 1.2. Research priorities for different centres

SN	Centre	Priority Areas for Research
	Main Cooperating Centres	
1	Agra	• Survey and mapping of groundwater quality • Use of poor quality water use including waste water • Screening for salt tolerance • Survey and mapping of Salt Affected Soils (with ICAR-CSSRI)
2	Bapatla	• Survey and mapping of groundwater quality of AP • Conjunctive use of fresh and saline water with emphasis on *doruvu* technology upscaling • Reclamation and management of irrigation induced salinization (including sodification). • Alternate land use
3	Bikaner	• Survey and mapping for ground water quality of Rajasthan • Use of saline water through micro irrigation for vegetables/field/horticultural crops etc.
4	Gangavathi	• Reclamation and management of irrigation induced salinization (including sodification). • Subsurface drainage including controlled drainage • Micro irrigation in drainage areas/ shallow water areas/ poor quality area • Map of SAS of TBT command area
5	Hisar	• Ground water quality mapping of Haryana • Micro irrigation for saline water use along fertility treatments • Screening for salt tolerance
6	Tiruchira-ppalli	• Ground water survey and mapping for groundwater quality in coastal TN • Reclamation and management of alkali water and irrigation induced sodification • Rain water harvesting based conjunctive use • Screening of crops and varities for sodicity tolerance
	Volunteer Centres	
7	Bathinda	• Ground water quality mapping of South West Punjab • Land Shaping Technology for waterlogged saline soils (in collaboration with CIFE Rohtak Centre and CSSRI fishery scientist)
8	Indore	• Control of Resodification in Sodic Vertisols • Revised/Updated map of ground water quality and SAS in MP

		• Irrigation water management for sodic Vertisols • Alternate land use • Updated map of SAS in Madhya Pradesh (with ICAR-CSSRI)
9	Panvel	• Survey and mapping of ground water quality of Konkan region • Rainwater harvesting based IFS models • Increasing cropping inetnsity during rabi season (Establishment of vegetable crops during the Rabi season through management practices)
10	Vytilla	• Mapping of groundwater quality/ SAS in the coastal Kerala • Integrated farming system including management of acid sulphate soils

In case of approval, the proposed centre at Dr. PDKV Akola will work on management of dry land salinity.

1.4 Staff Position

Sanctioned staff positions at centres as per the SFC 2021-26 of AICRP on SAS&USW are provided in Table 1.3

Table 1.3 Sanctioned staff positions at the cooperating centres as per SFC 2021-26 proposals

Category	Agra		Bapatla		Bikaner		Gangavathi		Hisar		Tiruchirappalli		Total	
	San	Filled	San	Filled	San	Filled	San	Filled	San	Filled	San	Filled	San	Filled
Scientific	2	2	2	2	2	2	2	2	2	2	2	2	12	12
Technical	2	2	2	2	2	1	2	2	2	2	2	2	12	11
Admini-strative	1	1	0	0	0	0	0	0	0	0	0	0	01	01
Supporting	1	1	0	0	0	0	0	0	0	0	0	0	01	01
Total	**6**	**6**	**4**	**4**	**4**	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**26**	**25**

San. = Sanctioned

1.5 Important Technological Mile Stones

The important technological mile stones in the journey of 50 years of AICRP on SAS&USW are given in Table 1.4 and Table 1.5.

Table 1.4 Technological Milestones in the Journey of 50 Years

Sr. No.	**Period**	**Important milestones of AICRP on SAS&USW**
1	1972 -1992	Experiments on use of saline water and alkali water under different agro-climatic regions and understanding their effects on soil properties, crop growth and yields. The estimation of irrigation water quality parameters at 90, 75 and 50% yield level.
2	1992	National guidelines for use saline and alkali water for irrigation purpose
3	1972-1994	Survey of irrigation water, characterization and mapping of groundwater on basis of groundwater quality classification provided by CSSRI, Karnal
4	1994	National Groundwater quality map for irrigation purpose (1^{st} Edition)
5	1972-2021	Screening of around 30 crops (cereals, pulses, oil seeds, fibre crop and vegetables) for salinity/ sodicity tolerance under saline/ alkali water use
6	2019	Issue of Indian Standard (IS 11624 : 2019) for Quality of Irrigation Water —

		Guidelines (*First Revision)*
7	2019	Soil Salinity map for Tunga Bhadra Project Command in Karnataka
8	2020	Groundwater quality for irrigation purpose for state of Madhya Pradesh
9	2000-2021	Groundwater quality survey, characterization at 1: 50000 scale for 165districts of country for preparation of revised groundwater quality map
10	2021	Revision of Groundwater quality map of India for irrigation (Initiated)

Table 1.5 Technological milestones by centres in chronological order during journey of 50 years

Sr. No.	Period	Technologies	Centre
1	**1972 -1992**	Experiments on use of saline water and alkali water under different agro-climatic regions and understanding their effects on soil properties, crop growth and yields. The estimation of irrigation water quality parameters at 90, 75 and 50% yield level. Survey of irrigation water, characterization and mapping of groundwater on basis of groundwater quality classification provided by CSSRI, Karnal National guidelines for use saline and alkali water for irrigation purpose	All centres
2	**1990-1995**	National Groundwater quality map for irrigation purpose (1st Edition)	All centres
		Conjunctive use of saline water/ alkali groundwater using amendment for crop production	Agra
		Tree species such as A.*nilotica*, D.*sissoo* and C.*equisetifolia* were found efficient in intercepting canal seepage when grown parallel to distributaries/canals. (Gangavathi)	Gangavathi
		Fruit species such as wood apple, jamun, pomegranate and sapota have been found promising under saline waterlogged conditions of TBP area	Gangavathi
		Use of RSC water along with gypsum for crop production in Mahendragarh, Rewari and parts of Gurugram districts	Hisar
		Rehabilitation of alkali Vertisols suitable trees and planting techniques (*Azadirachta indica* and *Accacia nilotica,* the tree species along with native check plant *Prosopis juliflora* are helpful in reclamation of sodic Vertisols. A successful crop production can be taken up after removal of tree species (10-12 years) under rainfed situations in Madhya Pradesh	Indore
		Sapota and Ber were found to be sodicity tolerant fruit plants on sodic Vertisols of Madhya Pradesh	Indore
3	**1995-2000**	Sprinkler irrigation for wheat and mustard with saline water	Agra
		Reclamation of alkali soils and water through use of gypsum / phospogypsum/ green manuring & spent wash, Pressmud in Andhra Pradesh	Bapatla
		Interceptor drain for control of waterlogging on sloppy lands in TBP command of Karnataka	Gangavathi

		Conjunctive use of saline and canal water in cotton-wheat and Bajara-Mustard rotation in Haryana	Hisar
		Raised and Sunken bed (1:1) technology for Rainfed sodic Vertisols The system helped in water (50%), soil (95%), nutrients (90%) conservation and improved crop production and the system is economically viable in Madhya Pradesh	Indore
		Babchi, sadabahar and lemon grass were found suitable for cultivation sodic Vertisols up to ESP 30. Ashwagandh was found to very sensitive to sodic condition as it could not survive even at ESP 20 in Madhya Pradesh	Indore
		Reclamation of alkali soils through gypsum in Gangetic plains of Uttar Pradesh	Kanpur
		Reclamation of alkali water through gypsum bed in Gangetic plains of Uttar Pradesh	Kanpur
4	**2000-2005**	Low cost technology for dilution of ground water aquifer through rain water recharge at farmer's field	Agra
		Neutralization of RSC groundwater through gypsum bed	Bikaner
		Foliar sprays of $FeSO_4$ and Citric acid for iron deficiency for groundnut in parts of Rajasthan (Bikaner)-2 Lakh ha	Bikaner
		Subsurface drainage system for reclamation of waterlogged saline Vertisols in Tungbhardra Project (TBP) command, Karnataka	Gangavathi
		Gypsum bed for reclamation of alkali ground water in Tamil Nadu	Tiruchirapalli
5	**2005-2010**	Skimming well (Modified Doruvu) technology for extraction of good quality groundwater in coastal region of AP	Bapatla
		Sub-surface drainage technology for waterlogged saline soils in Andhra Pradesh	Bapatla
		Micro irrigation for use of saline water in vegetables in Andhra Pradesh	Bapatla
		Vegetable production under drip fertigation with marginally saline water in Sodic Vertisols of Madhya Pradesh	Indore
		T*amarindus indica, Bambusa bamboo*, *Lueceana leucocephala, Acacia leaucophloea, and Azardiracta indica* are suitable for agroforestry in rainfed sodic soils in Tamil Nadu	Tiruchirapalli
		Reclamation of sodic soils using Distillery Spent Wash (DSW) in Tamil Nadu	Tiruchirapalli
6	**2010-2015**	Ber cultivation with saline water using drip irrigation (ECiw= 8 dS/m)	Bikaner
		Land and rain water management with gypsum for cultivation of sodic Vertisols in rainfed situations.	Gangavathi
		Rhodes, para and grazing guinea forage grasses could be grown in saline Vertisols of ECe up to 4-8 dS/m in TBP command of Karnataka	Gangavathi
		Cabbage, cauliflower and brinjal can be successfully grown in sodic Vertisols up to ESP 45 (Madhya Pradesh)	Indore
		Sodic soil reclamation using phospo-gypsum technology (Tamil	Tiruchirapalli

		Nadu)	
		Use of treated distillery effluent either as pre-plant application or along with irrigation water at 1:20 dilution (four times per year) along with 75% N & P fertilisers (omitting K) gave higher sugarcane yield (Tamil Nadu)	Tiruchirapalli
7	**2015-2020**	Use of drip for growing vegetables with saline water in Agra region of Uttar Pradesh	Agra
		Growing of vegetables in shadenet with saline water using micro-irrigation in Coastal Andhra Pradesh	Bapatla
		Reclamation of abandoned Aqua ponds in coastal Andhra Pradesh	Bapatla
		Mole drain for control of waterlogged heavy soils Godavari district in Andhra Pradesh	Bapatla
		Conjunctive use of canal water with natural drain water and ground water in delta region of Andhra Pradesh	Bapatla
		Identification of salinity tolerant fodder crops such Sweet sudan grass, COFS-29 (fodder jowar), Fodder sorghum (panthchari-6), Hedge lucerne, Lucerne,), Stylo-Stylosanthus (Irrigation by 7.1 dS/m)	Bapatla
		Saline groundwater through drip for groundnut, wheat, pearl-millet, Isabgoal, Cumin in arid region of Rajasthan	Bikaner
		Laser land leveling and Direct Seeded Rice (DSR) to enhance water productivity in TBP command area in Karnataka	Gangavathi
		Controlled Subsurface drainage for waterlogged saline Vertisols in (TBP) Command to save irrigation water and nitrogen fertilizers in TBP command area in Karnataka	Gangavathi
		Drip irrigation for sugarcane and drip with mulch for cotton on saline Vertisols for sugarcane in TBP command area in Karnataka	Gangavathi
		Drip N Fertigation with saline water for Tomato and Onion	Hisar
		Spent wash @ 5.0 cm and spent wash vermi-compost for reclamation of sodic Vertisols of Madhya Pradesh	Indore
		Application of Raw Spent Wash @ 2.5 lakh L per ha along with lagoon sludge @ 5 t/ha helps in reclamation of sodic Vertisols and successful crop production (Madhya Pradesh)	Indore
		Reclamation of alkali soils through City Waste and Poultry Manure in Gangetic plains of Uttar Pradesh	Kanpur
		Conjunctive use of canal and sodic water for rice based cropping systems in Cauvery delta of Tamil Nadu	Tiruchirapalli
		Integrated Farming System in salt affected soil areas of Tamil Nadu	Tiruchirapalli
		Drip irrigation to grow vegetables in alkali soil using amended alkali water through gypsum bed in Tamil Nadu	Tiruchirapalli
		Integrated Farming System (IFS) for coastal areas of Maharashtra	Panvel
		Drip with rice straw mulching for vegetable crops (Brinjal, Tomato Chili) during rabi season on coastal saline soils of	Panvel

		Maharashtra	
		Alternate land management system for waterlogged and saline soils in A&N Islands	Port Blair
		Identification of four most promising zinc solubilizing isolates (SM2, 1D, CHI, NW1)	Port Blair
		Rice-prawn integration- *Pokkali* lands of Kerala	Vytilla
8	2020 Onwards (Ongoing/ Proposed)	• Rain water harvesting and conjunctive water use in sodic groundwater areas of Tamil Nadu	Tiruchirapalli
		• Integration of preventive and reclamation approaches for managing waterlogged saline soils in Tunga Bhadra Project Command in Karnataka	Gangavathi
		• Establishment of rabi vegetable crops in rice fallow in coastal kokan areas of Maharashtra	Panvel
		• Up-scaling of Doruvu technology in coastal Andhra Pradesh	Bapatla
		• Improving groundwater quality through recharge in saline groundwater areas and use of improved water through drip for higher productivity in Agra and Mathura region of Uttar Pradesh	Agra Centre
		• Compilation data base of groundwater quality at national level with the help of NBSS&LUP, Nagpur.	PC Unit & all centres
		• Use of different sources of gypsum (marine and mineral) to address irrigation induced sodification	Tiruchirapalli
		• Development of horticulture based agri-horti system with saline water irrigation in arid region	Bikaner

2. GROUNDWATER QUALITY GUIDELINES FOR IRRIGATION PURPOSE

The ground water surveys in India indicate that different states use poor quality ground waters in the range of 32 to 84% of the total ground water development. Groundwater of arid regions is largely saline and in semi-arid regions it is sodic in nature. These groundwater resources are used solely or in conjunction with canal water for irrigation purpose. Indiscriminate use of the poor quality waters for irrigation deteriorates productivity of soils through salinity, sodicity and other toxicity effects. In addition to reduced productivity, it deteriorates the quality of produce and also limits the choice of cultivable crops. The spatial distribution of saline and alkali waters in India is given in Fig. 2.1.

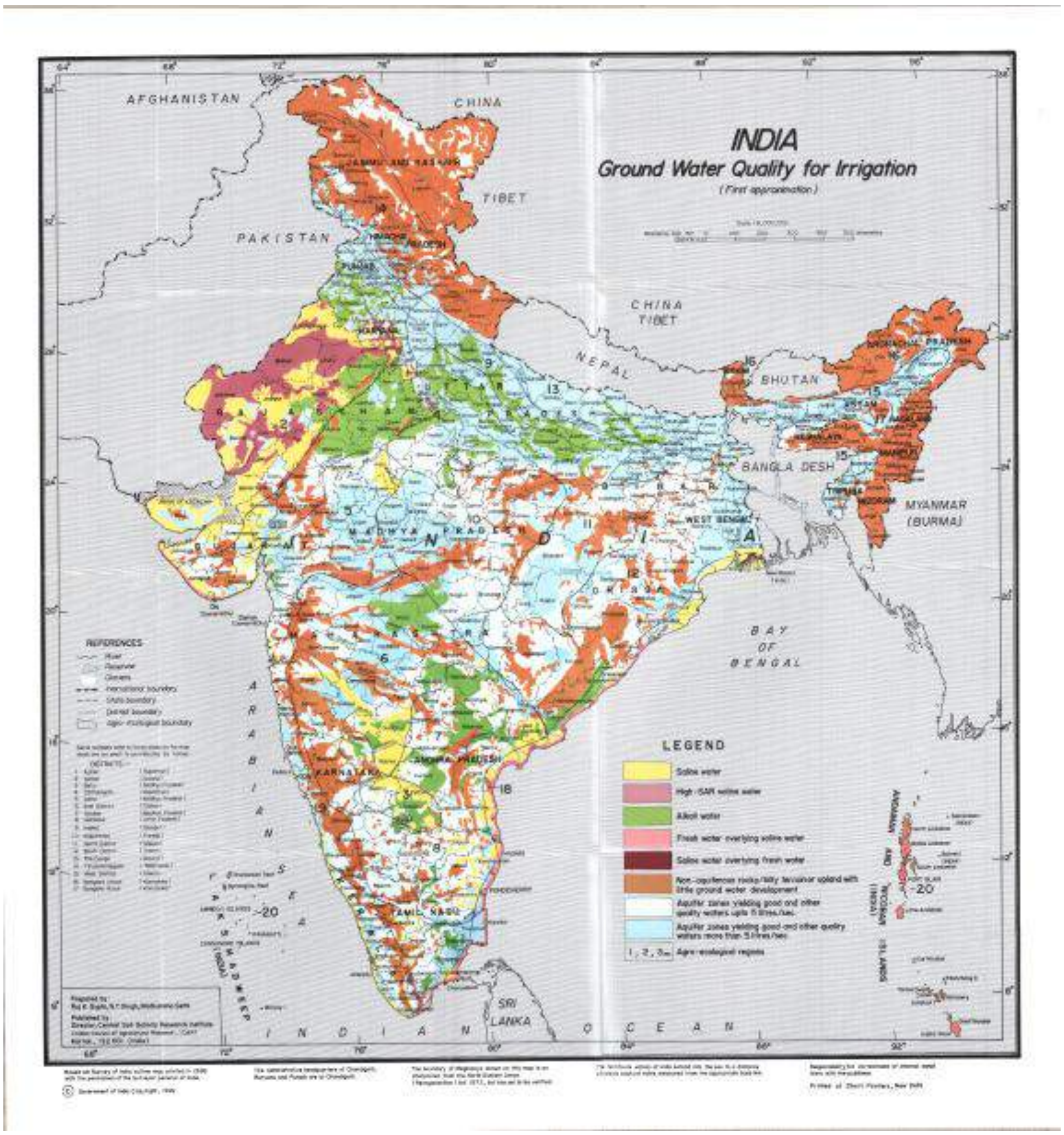

Fig. 2.1 Distribution of saline and alkali waters in India (Source: Gupta, et al. 1994)

Poor quality alkali water zones occur in parts of Agra, Mathura, Aligarh, Mainpuri, Etah, Ballia and several districts of U.P. and parts of Haryana, Punjab and Rajastan. Low to medium RSC waters occupy about 47% area of Punjab. Highly alkali waters are found in Parts of Amritsar, Southern Ludhiana, Ropar, Patiala, Ferozpur, Bhatinda, Faridkot and Sangrur districts covering 25% of total area of the state. In Haryana, alkali waters are found in Bhiwani, Mahendragarh, Gurgaon, Kaithal, Kurukshetra, Ambala, Karnal and Panipat districts covering almost 21% of the total area of the state. Saline area occupies another 36% area in Haryana. In parts of Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu poor quality sodic and saline waters are observed in the pockets. Many of these areas have black cotton soils. In east coast, areas between Krishna and Godavari rivers have brackish ground waters. In coastal areas of Sunderban Delta, the groundwater is saline. The poor quality use in different states is provided below (Table 2.1).

Table 2.1 Percentage use of poor quality waters in different states

Sr. No.	Name of State	Percentage
1	Andhra Pradesh	32
2	Gujarat	30
3	Haryana	62
4	Karnataka	38
5	Madhya Pradesh	25
6	Rajasthan	84
7	Uttar Pradesh	47

On the basis of hydro-geochemistry, chemical constituents of groundwater also vary. The groundwater in the country can be classified as i) Bicarbonate type; ii) Bicarbonate-chloride type; iii) Chloride-Bicarbonate type; iv) Sulphate-chloride type; v) Chloride-Sulphate type and vi) Chloride type. The first three types of groundwater belong to alkali type while remaining three types of groundwater belong to saline groundwater. Some predictions about use of poor quality water in various states indicate that total area underlain with the saline ground water (EC>4 dS m^{-1}) is 193438 km^2 with the annual replenishable recharge of 11765 million m^3 yr^{-1}, leaving aside minor patches (CGWB 1997).

2.1 Classification of Saline and Alkali Water for Irrigation

Irrigation water is classified based on electrical conductivity (EC), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC). However, from management point of view, the groundwater in different agro-ecological regions can be grouped into three classes *i.e.* (a) good, (b) saline and (c) alkali/sodic. Depending on the degree of restriction, each of the two poor quality water classes has been further grouped into three homogenous subgroups (Table 2.2) and groundwater quality map of India for irrigation purpose showing distribution of different groundwater classes is shown in Fig. 2.1.

Table 2.2 Classification of poor quality ground water

Water Quality	ECiw (dS m^{-1})	SARiw $(mmol^{-1})^{1/2}$	RSC (meq l^{-1})
a. Good	<2	<10	<2.5
b. Saline			
i. Marginally saline	2-4	< 10	<2.5
ii. Saline	>4	< 10	<2.5
iii. High-SAR saline	>4	>10	<2.5
c. Alkali			
Marginal alkali	<4	<10	2.5-4.0
ii. Alkali	<4	<10	>4.0
iii. Highly alkali	Variable	>10	>4.0

2.2 Water Quality Guidelines for Management of Saline and Alkali Groundwater

Based on field experience and results from different saline and alkali water use experiments, CSSRI, Karnal in consultation with Scientists from HAU, Hisar and PAU, Ludhiana prepared some guidelines for efficient utilization of saline and alkali water. It has been established that the success with poor quality water irrigation can only be achieved if factors such as rainfall, climate, depth to water table and water quality, soils and crops are integrated with appropriate crop and irrigation management practices (Minhas and Gupta 1992). The available management options mainly include the irrigation, crop, chemical and other cultural practices but there seems to be no single management measure to control salinity and sodicity of irrigated soil, but several practices interact and should be considered in an integrated manner. The guidelines for use of saline groundwater are given in Table 2.3 while guidelines for use of alkali water are given in Table 2.4.

Table 2.3. Guidelines for use of saline water (RSC < 2.5 meq/l)

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

Note: S, ST and T denote sensitive, semi-tolerant and tolerant crops

These guidelines emphasize on long- term influence of water quality on crop production, soil conditions and farm management with assumption that all rainwater received in field is being conserved for leaching and de-adsorption of Na^+ from upper root zone.

Table 2.4 Alkali groundwater with RSC > 2.5 meq l^{-1} and ECiw < 4.0dSm^{-1}

Soil texture (% clay)	**Upper limits of SAR (m mol L-1)$^{1/2}$**	**RSC meq L^{-1}**	**Remarks**
Fine (>30)	10	2.5-3.5	Limits pertain to kharif fallow – rabi crop rotation when annual rainfall is 350 –550 mm
Moderately fine (20-30)	10	3.5-5.0	When water has Na < 75%, Ca+Mg >25% or rainfall >550mm, the upper limit of RSC becomes safe
Moderately coarse (10-20)	15	5.0-7.5	For double cropping, RSC neutralization with gypsum is essential based on quantity of water used during rabi season. Grow low water requiring crops during kharif.
Coarse (<10)	20	7.5-10.0	

Special considerations

- Gypsum application is necessary for sensitive crops if saline water (SAR > 20 and / or Mg: Ca ratio > 3 and rich in silica) induces water stagnation in rainy season.
- Fallowing in rainy season under high salinity (SAR > 20) is helpful for low rainfall areas.
- Fertilization with additional phosphorus is beneficial especially when C1:SO_4 ratio in waters is > 2.0.
- Canal water should be used preferably at early growth stages including pre-sowing irrigation in conjunctive use mode.
- Putting 20% extra seed rate and a quick post-sowing irrigation (within 2-3 days) will help in better germination.
- Accumulation of B, F, NO3, Fe, Si, Se and heavy metals beyond critical limits with irrigation is toxic.
- Expert advice prior to use of such water is essential.

Textural criteria should be applicable for all soil layers down to at least 1.5 m depth. In areas, where ground water table reaches within 1.5 m at any time of the year or a hard subsoil layer is present in the root zone, the limits of the next finer textural class should be used.

2.3 Management Technologies for Use of Saline Groundwater

Some of management options have been described as below.

- Selection of semi-tolerant to tolerant crops and crops with low water requirements
- Use of crop cultivars having tolerance to salinity (Table 2.5)
- Proper selection of crop sequence

- Avoiding saline water use during initial growth stages
- Micro- Irrigation (Drip and Sprinkler) Drip experiments at Bikaner, Hisar, Gangavathi centres of AICRP have shown that saline water can be effectively for vegetable and field crops reducing effect of salinity (i.e. osmotic stress) as well as reducing fertilizer requirement (Biennial Report, 2016-18; Singh et al. 2018)

Some important suggestions for management of conjunctive water use of saline and canal or good quality water are listed below:

- Analysis of saline water to evaluate its use potential
- Selection of crops/ crop varieties that can produce satisfactory yields with saline water irrigation
- Selection of tree species/ medicinal plants in adverse condition
- Pre-sowing irrigation by good quality water so that germination and seedling emergence is not affected
- Adequate leaching of accumulated salts
- Alternating the area/ area switching i.e. irrigate the selected area with saline water for 3-4 years and then switch to next area
- Improved cultural and nutrient management practices

Table 2.5 Promising cultivars for saline environment

Crop	Cultivars
Wheat	Raj 2325, Raj 2560, Raj 3077, WH 157
P. millet	MH269, 331, 427, HHB-60
Mustard	Pusa Bold, CS 52, CS54, CS56, CS58, CS60
Cotton	DHY 286, CPD 404, G 17060, GA, JK276-10-5, GDH 9, G. Cot-23
Safflower	HUS 305, A-1, Bhima
Sorghum	SPV-475, 881, 678, 669, CSH 11
Barley	Ratna, RL345, RD103, 137, K169

Nutrient management for saline water irrigation

- Additional doses of nitrogenous fertilizers are recommended to compensate for volatilization losses occurring under saline environments
- Soils irrigated with chloride rich waters respond to higher phosphate application, because the chloride ions reduce availability of soil phosphorus to plants. The requirement of the crop for phosphoric fertilizers is, therefore, enhanced and nearly 50 per cent more phosphorus than the recommended dose under normal conditions should be added, provided the soil tests low in available P.
- For sulphate rich waters, no additional application of phosphate fertilizers is required and the dose recommended under normal conditions may be applied.
- For micro-nutrients such as zinc, the recommended doses based on soil test values should be applied.
- Farmyard manure (FYM): FYM and other organic materials have not only the nutritive value, but play an important role in structural improvements, which 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.

Guidelines for Arid regions of Rajasthan

- Nitrate content of irrigation water up to 80 ppm has no adverse effect on yield of wheat. Further the adverse effect of nitrate in irrigation waters can be mitigated by application of potash.
- If two sources of good and saline water are available, mixing of these waters for surface irrigation should be done in such a way that EC of mixed water does not exceed beyond 3.75 dSm^{-1} for ground nut and 5.0 dSm^{-1} for wheat for sustainable production in light textured soil of Bikaner district.
- Seed soaking and two sprays of K_2SO_4 (200 ppm) at 45 and 60 DAS were found promising in mitigating adverse effect of salinity of irrigation water and increasing crop yields under drip system for wheat and groundnut. In isabgol also, two sprays of two sprays of K2SO4 (200 ppm) proved effective.
- In moderately saline irrigation water, the salt tolerance of crops could be increased by adding 25% extra fertilizer nutrient than the recommended dose along with 5 t/ha of FYM.

- Cactus varieties are being grown with drip as fodder crop and nutritional status of cactus as fodder is being evaluated.

2.4 Use of Drip for Saline Water Irrigation

Now days, drip is being adopted as suitable irrigation method for saline water irrigation in arid soils of Rajasthan, sandy loam soils of Haryana, coastal sandy soils of Andhra Pradesh and saline Vertisols of Karnataka. Arid soils with coarse texture are highly permeable and infiltration rates of such soils remain so high that irrigation by surface method remains highly inefficient and sometimes practically impossible on larger areas. Under such situations, sprinklers and drip systems are preferred on large scale (Singh *et al.*, 2018). Saline water through sprinkler can be injurious to foliar parts of crops. Drip can be a better option with optimal emitter discharge and optimal irrigation scheduling. Drip experiments at Bikaner have proved that that saline water can be effectively for field crops reducing effect of salinity (i.e. osmotic stress) as well as reducing fertilizer requirement (AICRP on SAS&USW, 2017, 2019). Important aspects of drip irrigation are discussed in following subsections with help of experimental data from different AICRP centres.

Effect of irrigation water salinity on crop yields under drip irrigation

Crop yield is generally affected by irrigation water salinity. In case of drip, irrigation water of higher salinity can be used. However, threshold salinity value for irrigation water (i.e. salinity of irrigation water beyond which crop yield will start declining) depends on salinity tolerance of crop. Data showing effect of irrigation water salinity on crop yield in case of four field crops under drip system at Bikaner (Kaledhonkar et al. 2020) are given in Table 2.6.

Table 2.6 Effect of irrigation water salinity on yields (qha^{-1}) of different crops at Bikaner

Particular	Groundnut Pod yield	Wheat grain yield	Pearl-millet grain yield	Isabgol seed yield
BAW (0.25 dS/)	31.35	27.27	13.75	8.78
4 dS/m	30.65	26.86	13.10	8.45
8 dS/m	12.75	26.03	10.74	5.15
12 dS/m	6.38	11.07	-	-
S Em (±)	0.26	0.09	0.26	0.106
CD (0.05)	0.73	0.25	0.73	0.303

BAW: Best Available Water

On basis of four years pooled analysis, it was observed that different treatments had significant effect on pod yield of groundnut. Increase in EC_{iw} beyond 4 dS/m caused significant reduction in pod yield. Application of irrigation water of EC_{iw} of 8 and 12 dS/m caused significant reduction of 61.09 and 81.49 per cent, respectively as compared to BAW. In case of wheat pooled data of three years, it was observed that different treatments had significant effect on yields of wheat. Increase in EC_{iw} beyond 8 dS/m caused significantly drastic reduction in grain yield. As compared to EC_{iw} 4 dS/m, EC^{iw} 8 and 12 dS/m caused reduction of 3.04 and 56.69 per cent. Three years pooled data of pearl millet indicated that increase in the EC_{iw} beyond 4 dS/m caused significant reduction in the grain yield. As compared to BAW and EC_{iw} of 4 dS/m, the EC_{iw} of 8 dS/m showed significant reduction of 29.31 and 22.94 per cent respectively. Experimental data of two years indicated that different treatments had significant effect on seed yield of isabgol. Increase in EC_{iw} beyond 4 dS/m caused significant reduction in the seed yield. EC_{iw} of 8 dS/m showed significant reduction of 41.34 and 39.0 per cent over BAW and EC_{iw} 4.0 dS/m, respectively. It is also true that threshold irrigation water salinity in case of drip remains higher than surface irrigation.

Some guidelines for use of saline water through drip system in state of Rajasthan

- ✓ Ber cultivation with saline water using drip was established successfully. Saline irrigation water (up to 8.0 dS/m) was used through drip without any significant reduction in yield.
- ✓ Better yields of tomato and bottle gourd were recorded with water having ECiw up to 3.0 dSm^{-1} in sandy soils under drip irrigation system.
- ✓ Most of the vegetables can successfully be grown upto 3 dS/m salinity of irrigation water if water is applied through drip irrigation without any reduction in yields.
- ✓ Performance of wheat varieties (Raj 3077, Raj 4188, KRL 210 and KRL 213) was evaluated under drip using varying levels of salinity of irrigation water (BAW, 4 dS/m, 8 dS/m and 12 dS/m). Variety Raj 3077 established its superiority over rest of the other varieties at all the levels of ECiw. Increase in the levels of ECiw beyond 4 dS/m caused significant reduction in the yield of all the four varieties tested, yet, magnitude of reduction was less in KRL 210 and KRL 213.
- ✓ Drip geometry of 60 cm x 30 cm (lateral x emitters) have been found suitable for irrigation with saline water in groundnut, wheat and isabgol. Irrigation at 0.8 PE of saline water under drip was found optimum for groundnut. Yield of ground nut was not affected up to 4 dS/m of irrigation water salinity under drip. The wheat yield was slightly reduced at 8 dS/m. However, wheat yield was drastically reduced above 8 dS/m. Isabgol can be grown successfully with ECiw of 4 dS/m under drip.

- ✓ Four varieties of cluster bean namely, RGC 1066, RGC 936, RGC 1017 and RGC 1003 and were evaluated under three levels of irrigation water salinity viz. BAW, 4 dS/m and 8 dS/m under drip with saline water irrigation. Results pooled over two years showed that up to ECiw of 4 dS/m there was no significant reduction in the grain of cluster bean, however, ECiw of 8 dS/m caused significant reduction of 37.9 and 34.9 per cent in grain yield, respectively, over BAW and ECiw of 4 dS/m. Variety RGC 1066 established its superiority in grain yield over RGC 936, RGC 1017 and RGC 1003, respectively.

Some guidelines for use of saline water through sprinkler system in state of Rajasthan

- ✓ ECiw values for 50% yield reduction in wheat, mustard, cluster bean and groundnut crops were found to be 5.9, 5.0, 2.9 and 2.7 dSm-1, respectively, under sprinkler irrigation in light textured soils
- ✓ Irrigation water with salinity more than 2.5 dS/m is not suitable for groundnut cultivation under sprinkler irrigation

Guidelines for use of saline water through drip system in coastal Andhra

Different vegetable crops were grown on coastal saline soils with drip system at Bapatla centre and irrigation water salinity at 90, 75 and 50% yield levels were worked out (Table 2.7). The selection of suitable vegetable crop can be done depending irrigation water salinity. Also economics of crop can be worked to know feasibility of its growing at particular salinity (AICRP on SAS&USW, 2017).

Table 2.7 Effect irrigation water salinity crop yield at coastal soils of Bapatla

Crop	Yield levels (%)		
	90	75	50
	Irrigation Water salinity (dS/m)		
Okra	1.3	4.3	9.3
Cluster Bean	2.0	4.2	5.9
Capsicum	1.2	3.1	6.3
Cabbage	1.3	2.5	5.0
Cauliflower	1.7	2.9	5.4
Drumstick	1.2	1.8	3.1
Chrysanthemum	1.5	3.1	5.8
Marygold	1.4	2.9	5.5
Tulasi	3.0	6.0	11.0
Chilly	3.8	6.0	8.5

Effect of irrigation water application level and spacing of lateral drip lines on crop yield at Bikaner

In case of all four drip irrigation experiments at Bikaner, water requirement was worked out on basis of Potential Evaporation (PE). Data on combined effect of PE (Potential Evaporation) x drip geometry on grain yield (q/ha) of wheat (pooled data of 3 years) and groundnut (pooled data of 4 years) are given in Table 2.8 and Table 2.9 as examples. On basis of yield performance, it was observed that PE 1.0 and PE 0.8 were at par while there was significant yield reduction in case of PE 0.6 in wheat and groundnut.

Also it was observed that drip geometry 60x30 cm was superior to 90 x30 cm for both crops. Thus, water requirement at 0.8 PE and drip of geometry of 60x30 cm are suitable for arid region of Rajasthan for field crops. Similar results were obtained in case of pearl millet- isabgol experiments (Kaledhonkar et al. 2020).

Table 2.8 Combined effects of treatments (PE x drip geometry) on grain yield (q/ha) of wheat (Pooled of 3 years) at Bikaner

PE levels	Drip geometry	
	60 x 30 cm	90 x 30cm
PE 0.6	23.51	16.83
PE 0.8	26.44	21.47
PE 1.0	26.96	21.63
	S Em (±)	CD (0.05)
Drip geometry at same level of PE	0.30	0.85
PE at same level of Drip geometry	0.26	0.71

Table 2.9 Combined effects of treatments (PE x drip geometry) on pod yield and straw yield of groundnut (pooled of 3 years) at Bikaner

PE levels	Pod yield (q/ha)	
	60 x 30 cm	90 x 30cm
PE 0.6	18.21	14.30
PE 0.8	25.03	19.02
PE 1.0	25.91	19.21
	S Em (±)	CD (0.05)
Drip geometry at same level of PE	0.36	1.00
PE at same level of EC_{iw}	0.31	0.87

Effect of irrigation water application level and method of irrigation on sugarcane yield at Gangavathi (Saline Vertisols)

Performance of subsurface drip irrigation for surgarcane crop was evaluated on saline Vertisols at Gangavathi. The changes in soil physico-chemical properties, growth and yield of salt tolerant sugarcane were monitored during 2013-14 to 2016-17 at Agricultural Research Station, Gangavathi. The experiment had three replications with main treatments (method of irrigation) *viz.,* surface drip, subsurface drip and furrow irrigation (control) and sub treatments (irrigation levels) viz., 0.8, 1.0 and 1.2 ET. A sugarcane variety Co-91010 (Dhanush), known as salt tolerant, was procured from Mudhol was planted (single eye bud sets) during Feb-2014 in paired row system (0.6 m x1.20 m x0.6 m). Depth to the water table was monitored through nine observation wells which was within 1.5 m from the surface. Results revealed that subsurface drip gave, significantly higher cane yield (129.7 t ha^{-1}) among irrigation methods and it was par with surface drip (i.e. 123.3 t ha^{-1}). In case of furrow irrigation, it was (103.2 tha^{-1}). Among irrigation levels, 1.2 ET irrigation level gave significantly higher yield of 122.6 tha^{-1}. It was followed by 1.0 ET level (120.4 tha^{-1}) and lowest yield was recorded in case of 08 ET (113.3 t ha^{-1}). The sugarcane, being water loving crop, responded to 1.2 ET (AICRP on SAS&USW, 2018).

Choices of crops and their cultivars

Since crops differ in their tolerance to salinity, selection of crops and cropping sequences for saline soils or saline water irrigation assumes significance in the overall management of saline environment (Kaledhonkar *et al.*, 2019). The crops can be classified into tolerant and sensitive groups as per their tolerance to salinity. Highly tolerant crops are barley, rice (transplanted), cotton, sugar beet, turnip and safflower. Medium tolerant crops are spinach, sugar cane Indian mustard, rice (direct seeded), wheat, pearl-millet and oats. Under medium sensitive category, crops are radish, cow pea, cabbage, cauliflower cucumber, tomato and sorghum while lentil, chickpea, beans, pea, carrot and onion are under highly sensitive. The promising cultivars of important crops are given in Table 2.5.

The wheat yields of different varieties at different salinity levels are plotted in Fig. 2.2. It is important to note that there is in general reduction in the grain yield due to increase in the salinity of irrigation water (Gulati *et al.*, 2018). However, at different irrigation water salinity levels, different wheat varieties performed differently.

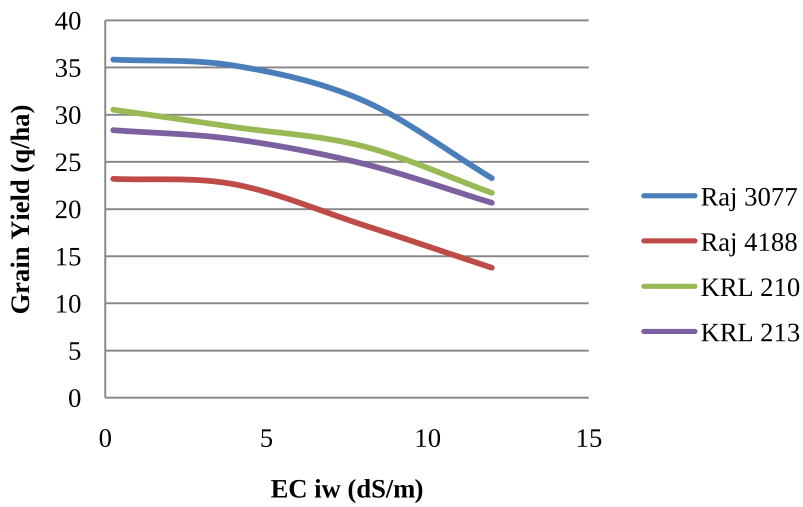

Fig. 2.2 Effect of irrigation water salinity on wheat yield on basis of pooled data

The rates yield reduction for different wheat varieties at different irrigation water salinities are provided in Table 2.10.

Table 2.10 Rate of yield reduction (%) of wheat as influenced by irrigation water salinity

Variety	EC iw (dS/m)		
	4	8	12
Raj 3077	1.78	10.50	26.15
Raj 4188	2.46	19.04	24.73
KRL 210	6.05	7.07	18.56
KRL 213	3.38	9.48	16.74

Rate of yield reduction was lowest as 1.78 at 4 dS/m for Raj 3077, as 7.07 at 8 dS/m for KRL 210, and 16.74 at 12 dS/m for KRL 213. Despite the abilities of different wheat varieties to perform better at different irrigation water salinity, Raj 3077 has performed better, in terms of yield, for all saline waters as shown in Fig. 2.2.

Efficient utilization of fertilisers through drip

Bikaner Experiment: Additional doses of nitrogenous fertilizers are recommended to compensate for volatilization losses occurring under saline environments. However, results in Table 2.11 indicated that it was possible to get optimum yield at 100% RDF (Recommended Dose of Fertiliser) with drip and 125% RDF did not give significant yield enhancement. Thus, drip fertigation along with saline water irrigation ensured efficient utilization of fertilisers in arid sandy soils (Kaledhonkar et al. 2020).

Table 2.11 Combined effect of treatments (ECiw x fertility levels) on yield at Bikaner

Treatments	Isabgol Seed yield (q/ha)			Pearl millet Grain yield (q/ha)		
	% 75RDF	% 100RDF	% 125RDF	% 75RDF	% 100RDF	% 125RDF
BAW	8.14	9.04	9.18	11.04	14.99	15.23
4dS/m	7.37	8.91	9.08	10.48	14.22	14.59
8dS/m	3.40	5.92	6.14	9.82	10.89	11.53
S Em ((±	0.18			0.44		
CD ((0.05	0.52			1.26		

Hisar Experiment: An experiment on nitrogen ferti-irrgation through in case of brinjal crop at Hisar gave slightly different results. The main treatments were quality of the irrigation water such as Canal water EC_{iw} = 0.3 dS/m, Saline water EC_{iw} = 2.5 dS/m and Saline water EC_{iw} = 5.0 dS/m. Sub treatments were related to nitrogen fertigation and three levels of nitrogen doses such as 75% of RDN and RDN 125% of RDN were adopted. The experiment was laid out in 2.0 x 2.0 m plot as per the following plan. The spacing between plant to plant and row to row was kept as 45 cm. The data on yield of brinjal under nitrogen and salinity levels with drip irrigation (Table 2.12) revealed that under drip irrigation with 75% of RDN of nitrogen application, the reduction in yield of brinjal were 12.94 and 28.71 % when irrigated with saline water of 2.5 and 5.0 dS/m, respectively, as compared to the yield reduction in yields recorded in canal water irrigation. Under drip irrigation in RDN application, the reduction in yield of brinjal were 10.51 and 24.39% when irrigated with 2.5 and 5.0 dS/m, respectively, as compared to the yield recorded in canal water irrigation. Under drip irrigation in 125% recommended dose of nitrogen application, the reduction in yield of brinjal obtained 8.98 and 20.25% when irrigated with saline water of 2.5 and 5.0 dS/m, respectively as compared to the yield recorded in canal water irrigation. Significant reduction in yield was recorded at ECiw 5.0 dS/m as compared to the canal water irrigation. Significantly highest yield (269.60 q/ha) of brinjal was recorded with the application of 125% RDN and canal water irrigation. In this experiment, yield losses reduced with additional application of Nitrogen through drip (AICRP on SAS&USW, 2022).

Table 2.12 Effect of nitrogen fertigation under different saline water in drip irrigation system brinjal fruit yield (q/ha)

Nitrogen Level	Canal(0.3 dS/m)	2.5 dS/m	5.0 dS/m	Mean
75% RDN	237.90	207.10	169.60	204.90
RDN	257.90	230.80	195.00	227.90
125% RDN	269.60	245.40	215.00	243.30
Mean	255.10	227.80	193.20	
CD (p=0.05)	Nitrogen (N) = 2.56, Salinity level (S) =10.30, N x S = NS			

Drip along with conservation agriculture to control waterlogging and soil salinity of moderately waterlogged Saline Vertisols of TBP command

The experiment to study response of drip fertigation and conservation agriculture practices on cotton yield was conducted at Agricultural Research Station, Gangavathi during *Kharif* 2013-2016 (Halidoddi, et al. 2018). The initial soil salinity values of the experimental field ranged from 5.30 dSm^{-1} to 7.0 dS m^{-1}and 5.27 dS m^{-1}to 9.24 ddS m^{-1}at 0-15 and 15-30 cm, respectively. Also depth to the water table within the field ranged from 0.56 to 1.13 m. The main treatments were without mulch and with mulch and sub treatments were fertigation with 50 % recommended dose of fertilizers (RDF), 75 % RDF, 100 % RDF and 125 % RDF. Irrigation water was of good quality but soil was waterlogged saline. The mulch treatment gave significantly higher number of bolls (33.2) per plant and higher single boll weight (5.74 g boll-1) when compared to without mulch treatment. Among fertilizer treatments, 125% RDF gave significantly higher number of bolls(34) per plant and higher single boll weight (6.0 g boll^{-1}) and it was at par with 100 % RDF (32.0 and 5.54 g boll$_{-1}$), followed by 75 % RDF (31.3 and 5.53 g boll^{-1}) and the lowest in case of 50 % RDF (29.3 and 5.03 g boll^{-1}) treatment. The third year study revealed that 125% RDF gave significantly higher seed cotton yield (27.3 q ha^{-1}) compared to 50 % RDF (24.13 q ha^{-1}) but it was at par with 75% (25.37 q ha^{-1}) and 100% RDF (26.0 q ha^{-1}). In the case of conservation practices, mulch treatment gave significantly higher seed cotton yield (27.9 q ha^{-1}) compared to without-mulch treatment (23.5 q ha^{-1}) (Table 2.13). The interaction effects between main and sub plots were non-significant. The use of conservation agriculture along with drip in the irrigation command can economize the use of irrigation water further. The problems of water shortage as well as waterlogging can be simultaneously addressed ensuring better soil health and crop productivity.

Table 2.13. Seed cotton yield as influenced by different fertigation levels and mulching

Fertilizer level	Cotton Yield (q/ha)		Mean
	Without mulch	With mulch	
	M1	M2	
S1 (50% REDF)	22.5	25.8	24.13
S2 (75% RDF)	22.7	28.0	25.37
S3 (100% RDF)	23.7	28.3	26.00
S4 (125% RDF)	25.3	29.3	27.30
Mean	23.5	27.9	
	SE m +	CD (0.05)	
M	0.23	1.01	
S	0.95	2.08	
M x S	1.35	NS	

(a) (b)

View of cotton experimental plot (a) with mulch and b) without mulch treatment

Similar concept can be used in arid regions. However, availability of crop residue is limiting factor in arid region. Plastic mulch can be suitable option and it needs testing under field conditions prevalent in arid climate.

Application of bio-regulators/ antioxidants for reducing salinity stress at Bikaner

Foliar sprays/ seed soaking with different chemicals viz., Thio-urea, potassium sulphate, Ascorbic acid, benzyl adenine have been found effective in mitigating adverse effect of saline irrigation water. In experiments at Bikaner with groundnut, wheat and isabgol using increasing levels of irrigation water salinity from best available water (0.25 dS/m) to as high as 12 dS/m, it has been found that seed soaking + two sprays of K_2SO_4 (200 ppm) at 45 and 60 days after sowing was found most effective treatment in increasing the yields of groundnut and wheat. In isabgol also, two sprays of two sprays of K_2SO_4 (200 ppm) proved effective. Amongst tested bio regulators K_2SO_4 (200 ppm) was found significantly superior with yield increase of 16.2 per cent in groundnut and 21.4 per cent in isabgol.

Root zone salinity balance under saline irrigation through drip

Long-term sustainability of saline water irrigation through drip under arid region is possible, if salts added through irrigation water are leached from root zone by rainwater during next monsoon season. The data of soil ECe at wheat harvest, as influenced by different levels of irrigation water salinity, in different soil layers up to 45 cm depth and at lateral distances of 0, 15 and 30 cm from the drippers are provided in Table 2.14 as an example.

The maximum salinity was observed at 30 cm distance from drippers due to ECiw of 12 dS m^{-1} while minimum salinity was found just below the dripper at 30-45 cm depth for BAW (ECiw 0.25 dS m^{-1}). At different lateral distances from dripper (i.e. 0, 15 and 30 cm) highest salinity was observed in 0-15 cm layer compared to below layers of 15-30 and 30-45 cm for all irrigation water salinity levels. Also soil salinity increased with lateral distance of 0 to 30 cm from dripper. Thus salt concentration in soil profile increased with increase in lateral as well as vertical distances from the drippers. Thus, it can be inferred that salts were pushed out or leached away from the active root zone of the plant providing better growth conditions. Despite of low application rate, the drip irrigation has ability to push salts at outer boundaries of wetted soil mass.

Table 14. Salinity (ECe) build-up in the soil profile after harvest of wheat under saline water through drip irrigation at Bikaner

Distance from dripper (cm)	**Soil depth** (cm)	Salinity (ECe), dS/m			
		ECiw levels (dS/m)			
		0.25	4.0	8.0	**12**
0	0-15	0.18	0.39	0.48	0.56
	15-30	0.14	0.32	0.44	0.48
	30-45	0.11	0.26	0.38	0.45
15	0-15	0.23	0.42	0.55	0.62
	15-30	0.21	0.34	0.52	0.57
	30-45	0.19	0.30	0.41	0.53
30	0-15	0.26	0.44	0.58	0.71
	15-30	0.24	0.37	0.56	0.66
	30-45	0.22	0.32	0.50	0.63

Leaching requirement for coarse textured soils was worked out as 0.5 to 0.6 cm of water /cm of soil to leach 80% of salts. Thus water requirement to leach 60 cm of root zone came as 30 to 36 cm (CSSRI, 2004). The soil texture at experimental site was sand with sand as 89.1%, silt as 2.84% and clay as 5.68%. It can be treated as very coarse as the maximum soil salinity (ECe) of 0.71 dS/m was developed with irrigation water salinity as 12 dS/m. The farmers also grow moong bean and cluster bean as rainfed crops during monsoon season or keep the land fallow. The annual rainfall the region is of 295.4 mm and it may help in leaching most the salts accumulated in root zone due to very coarse nature of soil and long-term sustainability of saline water irrigation through drip appeared as feasible. This logic is more or less valid for other regions also.

Economic feasibility with saline water irrigation through drip at Bikaner

The benefit cost ratios for different crops grown with saline water through drip at Bikaner are provided in Table 2.15 to show concept of economic feasibility.

Table 2.15 Benefit Cost ratio for saline water irrigation through drip at Bikaner

Particular	Groundnut	Wheat	Pearl-millet	Isabgol
Range for irrigation water salinity (dS/m)	0.25 to 12	0.25 to 12	0.25 to 8	0.25 to 8
Range for B/C ratio	0.46 to 2.38	1.44 to 2.36	1.46 to 1.84	1.63 to 2.79

The data in Table 2.15 indicated that B/C ratio for all four field crops remained above 1 in case of saline water irrigation through drip (Kaledhonkar et al. 2020). Thus, saline water irrigation through drip is economically feasible option in arid regions. Similar results have been obtained at other centres also.

Crop diversification options for arid region with drip irrigation in Rajasthan

Due to unfavourable climatic conditions and saline groundwater, crop diversification options in arid regions are very limited. Agriculture in western Rajasthan is facing challenges such as extremely high summer temperature, low relative humidity, strong winds rapidly depleting ground water sources and highly saline ground water for irrigation. Farmers have to rely on use of brackish water for irrigation. Perennial irrigation from brackish water without proper management practices results in salt build up in soil. Use of drip and salt tolerant crops are increasingly important. Improved verities of Ber (Gola, Seb, Umran) have made a big impact in arid and semi arid regions. Ber could be raised successfully with poor quality water. Most of the farmers are taking Ber crop as rainfed which leads to poor and uneconomic yields. On basis field experiment during 2002 to 2012, it was observed that saline water having EC of 8.0 ds/m can be effectively used through drip for Ber cultivation economically. The economical yield from ber plantation is expected from 4th year onwards. The Benefit Cost ratio during 5th year was 2.00, it reached to 3.04 during 6th year and became 6.48 during 10th year. The ber plantation may give economic yield up to 25 years. Thus, farmers can have benefit cost ratio approximately of 6.00 for 15 years. These results indicate that ber with drip is important crop diversification option in arid region of Rajasthan. The drip irrigation can be effectively used to grow horticultural crops on salt affected soils or with saline water in other agro-climatic regions also.

2.5 Management Technologies for Use of Alkali Groundwater

Water quality researches over past few decades have enabled development of technological options to cope up with the problems of alkali water use. The adverse effect of residual sodium carbonate (RSC) in irrigation water can be reduced by soil application of gypsum or passing of RSC waters through gypsum bed. Possibilities have now emerged to safely use the water otherwise designated unfit. These options are as below:

- Appropriate irrigation scheduling and conjunctive use options with canal water; rain water management and leaching strategies to maintain a high level of soil moisture and low level of salts and exchangeable sodium in the rhizosphere.
- Use of land management practices to increase the uniformity of water distribution, infiltration and salt leaching besides the optimal use of chemical amendments like agricultural grade gypsum and acidic pyrite at proper time and mode of their application with judicious use of organic materials and chemical fertilizers. The gypsum can be directly applied before rice crop in soil top layer or can be used in gypsum bed for passing sodic groundwater.
- In case of irrigation by sodic waters, the conjunctive use strategy should either minimize the precipitation of calcium or maximize the dissolution of precipitated calcium. This is particularly relevant to the areas, where canal water supplies are either un-assured or less than required, and farmers often pump sodic groundwater for crop production. For the efficient use of waters of different qualities, good quality waters can be used for sensitive crops and sodic waters for tolerant crops. The most appropriate practice, however, can be the conjunctive use of these waters by: i) blending in supply network, making appropriate water quality available for each crop irrespective of soil conditions; ii) alternate use of sodic and canal water according to availability and crop needs; and iii) switching these water sources during the growing season according to critical stages of crop growth. The blending of sodic water and canal water is done in such proportion so that final RSC is maintained below the threshold limit of the crop to be grown. The alternate use is preferable and has operational advantages.

- Selection of crops (Table 2.16) cropping patterns and crop varieties (Table 2.17) that produce satisfactory yields under the existing or predicted conditions of sodicity.

Table 2.16 Relative tolerance to alkalinity/ sodicity of soils

ESP	Crops
10-15	Safflower, Mash, Peas, Lentil, Pigeon-pea, Urd-bean, Banana
16-20	Bengal gram, Soybean, Papaya, Maize, Citrus
20-25	Groundnut, Cowpea, Onion, Pearl-millet, Guava, Bel, Grapes
25-30	Linseed, Garlic, Guar, Palmarosa, Lemon grass, Sorghum, Cotton
30-50	Mustard, Wheat, Sunflower, Ber, Karonda, Phalsa, Vetiver, Sorghum, Berseem
50-60	Barley, Sesbania, Paragrass, Rhoades grass
60-71	Rice, Sugarbeat, Karnal grass

Table 2.17 ICAR-CSSRI recommended crop varieties for cultivation in alkali soils

Crop	pH	Varieties
Rice	9.8-10.2	CSR 10
	9.4-9.8	CSR 10, CSR 13, CSR23, CSR 27, CSR 36, CSR43, CSR46, CSR56, CSR 60
	<9.4	Basmati CSR30
Wheat	9.2 - 9.3	KRL-1-4, KRL-19, WH 157, Raj. 3077, KRL210, KRL213, KRL 283
Mustard	Up to 9.3	Pusa bold, Varuna, Kranti, CS52, CS54, CS56, CS58, CS60
Barley	Up to 9.3	CSB 1, CSB 2, CSB 3, DL 200, DL 348. Ratna, BH 97, AZAD
Chickpea	Up to 9.0	Karnal Chana 1

The other guidelines pertinent to selecting crops suitable for alkali water are:

- Fields should be kept fallow during *kharif* in low rainfall areas (< 400 mm) where good quality water is not available. However, only tolerant and semi-tolerant crops like barley, wheat and mustard should be grown during rabi.
- Jower-wheat, guar-wheat, pearl millet-wheat and cotton-wheat rotations can be successfully grown in areas having rainfall > 400 mm/annum provided that sowing of kharif crops is done with rain or good quality water and only 2 to 3 sodic water irrigations can be applied to kharif crops.
- In rice-wheat belt of alluvial plains having rainfall ≥600 mm, rice-wheat, rice-mustard, sorghum mustard, and *dhainacha* (GM)-wheat rotations can be successfully practiced with gypsum application.
- Sodic water should not be used for summer crops in the months of April to June.
- Conjunctive use of canal and sodic water for rice based cropping systems at Tiruchirappalli showed that:

- ✓ During shortage or limited supply of canal water, conjunctive use of canal and alkali water in 1:1 cyclic mode for rice and alkali water alone for greengram or vegetables can be recommended for alkaline environment of Cauvery irrigation command area.
- ✓ For amending alkali water gypsum bed method proved to be superior.
- ✓ Continuous use of alkali water for rice and greengram or vegetables resulted in yield decline of 25% in rice and 37% in greengram and 20% in brinjal with increased ESP of 25-34.
- ✓ Greengram (Pusa bold or VBN(GG) 2) or brinjal (Co2) can be recommended as follow-up after rice with alkali water irrigation for higher profitability.
- ✓ The change in chemical properties of soil viz., pH and ESP due to use of canal + alkali water was observed to be better than use of alkali water alone for both crops.

- Some important guidelines for use high RSC alkali groundwater in Rajasthan

  - ✓ Studies on mitigating adverse effect of high RSC water revealed that for sustainable production of pearl-millet-wheat crop rotation in sandy coarse textured soils under sprinkler system with water having RSC around 10.0 me/l gypsum @ equivalent to 5.0 mel^{-1} RSC neutralization of each irrigation with FYM @10t/ ha should be added in soil treated water. It was found that RSC of water treated through gypsum tank could be neutralized by 2.0 to 2.0 mq/q. Additional gypsum as per requirement should be added before sowing. Further a periodical monitoring of GR of soil is necessary while using high RSC water for irrigation.
  - ✓ Application of gypsum @ 50% GR every third year has been recommended for using high RSC waters. Mustard should be preferred over wheat.
  - ✓ Soil application of gypsum @ 50 % GR and equivalent to partial neutralization upto 4.0 meL-1 of high RSC water is recommended for pearl millet, mustard and cluster bean. Barley can tolerate RSC up to 8.0 meL-1. Addition of gypsum reduced the alkalinity of soil and prevented its further degradation with the use of high RSC water in Sikar district.
  - ✓ For the use of high RSC water in calcareous soils, mixing of pyrite @ 50 % GR in soil twenty days before sowing or two sprays of 2 % FeSO4 + 0.1 % Citric acid at 30 and 40 days after sowing are recommended for higher yields of mustard and cluster bean.
  - ✓ Adverse effect of high RSC water (7.5 meL^{-1}) under sprinkler irrigation can be reduced if 5.0 t ha^{-1} FYM and gypsum @ 50 % GR is applied to soil.
  - ✓ About 2.5 me/litre RSC of water can be neutralized by passing high RSC water through gypsum tank.

Nutrient management for alkali water irrigation

Since sodic waters cause a rise in soil pH that leads to greater nitrogen losses through volatilization and denitrification, extra nitrogen may have to be added to meet the requirement of the crops. Similarly, the availability of zinc and iron is also low due to their precipitation as hydroxides and carbonates. Some other beneficial tips as regards fertilizer use are.

- Application of 25% extra nitrogen is needed as compared to the normal conditions.
- Zinc sulphate @ 25 kg ha should be added, particularly to the *rabi* crop.
- Phosphorus, potassium and other limiting nutrients may also be applied on the basis of soil values.

- Some sodic waters may be rich in nutrients like nitrogen, potassium and sulphur such waters should be analyzed and the fertilizer dose of concerned nutrient reduced accordingly as per their composition in such water.

2.6 Policy Issues related to Sustainable Development of Saline Water Resources

- Conservation of available fresh water resources and make the judicious use of fresh water along with saline/ sodic water
- Exploitation of full potential of surface/ canal water system by improving the overall efficiency or promoting secondary reservoirs and micro-irrigation
- Exploitation of fresh groundwater in coastal areas should be kept within permissible limit to avoid seawater intrusion
- Improvement in groundwater potential of aquifers through recharge
- Development of institutional support for participation, development and optimal utilization of poor quality ground waters
- Demand management through pricing
- Diversification of agriculture in poor quality groundwater areas
- Incentives for water saving and adoption of improved technologies
- Awareness and capacity building
- Involvement of women and children in water management
- Educating farmers about water scarcity, judicious use of water and side effects/ losses due to salinity/ sodicity
- Need to create an environment for sustainability of system: Use of green manuring, FYM, salinity/ sodicity tolerant crop varieties, conservation agricultural practices are to be promoted
- Alternate options to sodic soil/ sodic water amendments like gypsum, pyrite, Municipality Solid Waste (MSW)
- Use of Growth Promoter such as CSR-Bio
- Legislative measures for groundwater pumping, residue burning, conservation agriculture, green manuring, etc.

2.7 Indian Standard- IS 11624:2019

The BIS (Bureau of Indian Standards) has issued the Indian Standard- IS 11624:2019 on basis of work of AICRP on SAS&USW, ICAR- Central Soil Salinity Research Institute, Karnal, Indian Institute of Water Management, Bhubaneshwar & Water Technology Centre, IARI, New Delhi. The IS 11624:2019 is provided in attached **Annexure No. 1.**

2.8 Revision of Groundwater Quality Map at National Level

Earlier map of groundwater quality, released in 1994, was at 1:2,50,000 scale. The revision of groundwater quality map of India has been undertaken at 1: 50,000 scale. Different centres of AICRP have completed groundwater survey and chemical analysis of groundwater samples and characterization of samples for 168 districts. The Agra, Bapatla, Bikaner, Hisar, Gangavathi, Indore, Kanpur, Tiruchirappalli, Bathinda, Panvel, Port Blair and Vytilla have completed 12, 9, 11, 17, 27, 51, 04, 12, 04, 05, 02 and 14 districts, respectively. The groundwater quality data have already been handed over to ICAR-NBSS&LUP, Nagpur for preparation revised map of groundwater quality of India for irrigation purpose.

Groundwater quality for irrigation purpose for Madhya Pradesh (Indore)

A new Ground water quality map for irrigation purpose for Madhya Pradesh has been prepared by Indore centre. The EC, pH, SAR and saline / alkali water categories were used to prepare the map. Data available with the AICRP on Management of Salt Affected Soils and Use of saline water in agriculture and data procured from Central Ground Water Board, New Delhi were used in GIS & RS software (ArcMap GIS software 9.3.1) as shown in Fig. 2.3

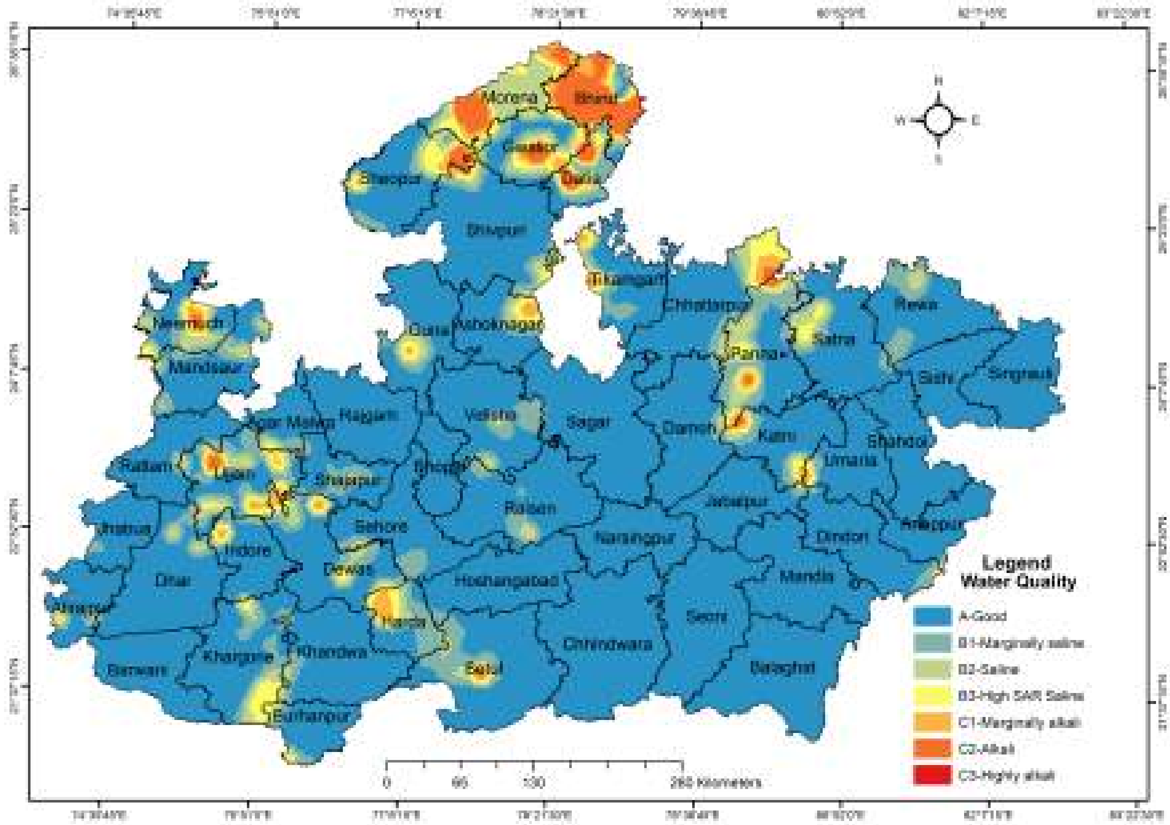

Fig. 2.3 Groundwater quality for irrigation purpose for state of Madhya Pradesh

In the whole state, 6483 ground water samples were used to generate maps. In whole Madhya Pradesh, 87.3% samples were good (A), 7.7 % saline (B) and 5.0 % alkali (C) water. Out of eleven agro climatic zone of Madhya Pradesh, seven have the good quality water in more than 90% water samples. The Chhatisgarh Plains, Northern Hills Zone of Chhattisgarh, Central Narmada Valley, Satpura Plateau and Jhabua Hills agro-climatic zones have good quality water in more than 95% samples. The ground water samples of Gird zone and Bundelkhand Zone have poor quality water in respect of alkali water category and represented 20.5% and 12.2% samples. On the other hand the ground water of Malwa Plateau has 12.0% saline and 2.5% alkali in nature. Similarly, Nimar Valley area of the agro-climatic zone depicted 14.2% saline and 0.4% alkali water.

Groundwater quality map for Kerala for irrigation purpose (Vytilla)

The groundwater quality map of Kerala for irrigation purpose, based on groundwater quality data from 14 districts (namely Thiruvananthapuram, Ernakulam, Kasargod, Kannur, Kozhikode, Malappuram, Thrissur, Kottayam, Kollam, Alappuzha, Pathanamthitta, Palakkad, Wayanad and Idukki districts) was prepared as per CSSRI's groundwater quality guidelines. Out of 351 samples of ground water analyzed, 296 were in good category, four each in marginally saline and saline category, respectively. Twenty eight samples were marginally alkaline and two samples were highly alkaline in nature. As a whole in Kerala, 84.33, 1.14, 1.14, 2.28, 1.42 and 0.85% fall under good, marginally saline, saline, high SAR saline, marginally alkaline and high alkali category of ground water quality (Fig. 2.4).

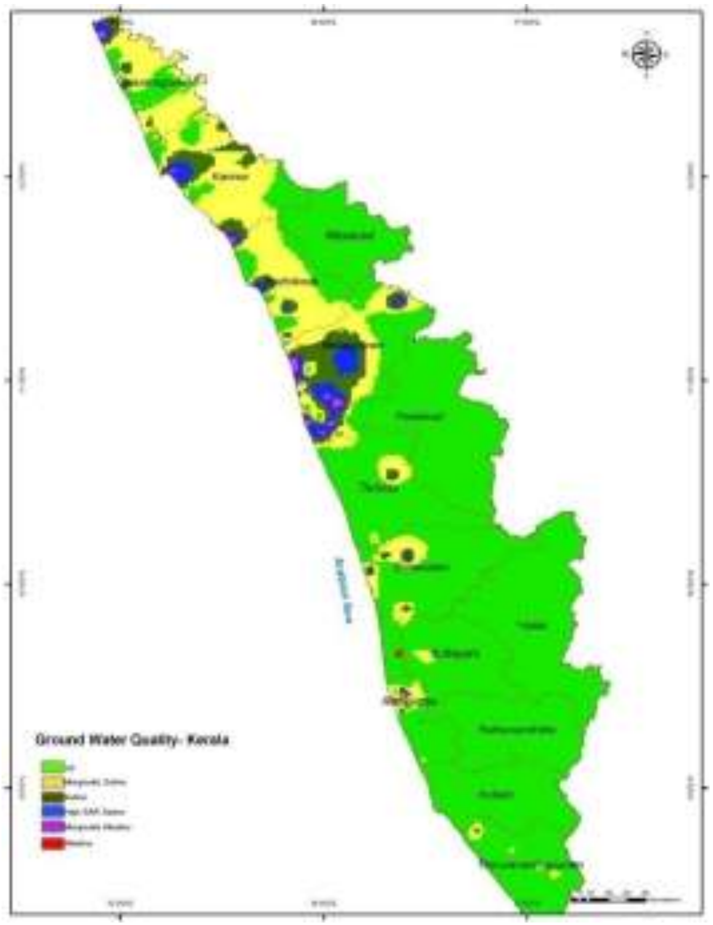

Fig. 2.4 Groundwater quality map for Kerala

2.9 Mapping of Irrigation Induced Salinity / Sodicity in TBP Command, Karanataka (Gangavathi)

The northeastern part of Karnataka comprising Raichur, Koppal, and Bellary districts traditionally suffered from water shortages, being rain shadow region. Therefore, planners at the national level thought of construction of reservoir across Tungabhadra River at village Munirabad (Mallapur). The planning of this reservoir was done prior to the independence of India but it was commissioned in 1953. Violation of cropping pattern in the command areas, by introducing paddy crop, resulted in waterlogging and soil salinity problems on large scale. In view of this background, an assessment and mapping of soil salinity in the command was undertaken by AICRP on Salt Affected Soils and Use of Saline Water in Agriculture, Gangavathi, Karnataka.

The results of survey showed that at surface soil (0-15 cm) $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varied from 10.76 to 5.72, 10.23 to 4.86, 31.0 to 0.10 (dS/m) and 75.0 to 0.14 (dS/m), respectively, with an average of 8.09, 7.58, 2.11, and 5.06 respectively. Among cations, average Na content (40.57 meq/L) was more than Ca+Mg (13.06 meq/L) followed by K. In case of anions, average Cl^- content was more (36.21 meq/L) than HCO_3^- (12.02 meq/L) followed SO_4^{2-}. Nearly 20 per cent of surface samples had ECe > 4.0 dS/m reflecting that these soils are saline. With respect to area (Fig. 2.5), about 23.62% (85692 ha) and 14.36 % (52097 ha) of the TBP command area had ECe 2.0-4.0 dS m^{-1} and 4.0-8.0 dS m^{-1} ,respectively. However, nearly 50% of the area had ECe < 2.0 dS m^{-1}. In about 80% (281892 ha) of the command area, the SARe was < 13 and 7% (25577 ha) of the command area had SARe in the range of 13-20. Soil pHs in the range of 7.50 – 8.50 was in about 269992 ha (74%) of the command.

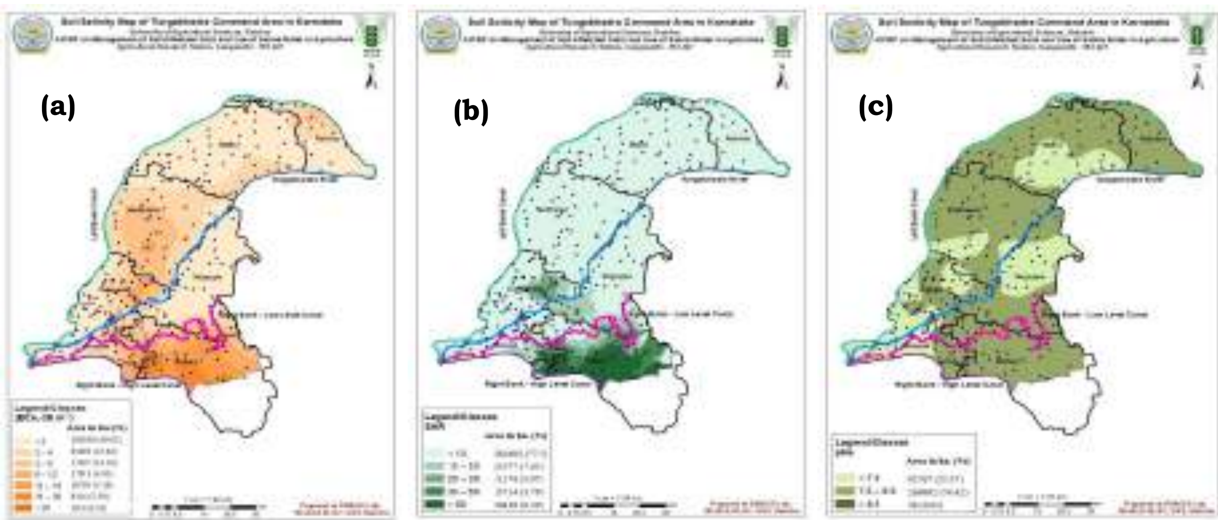

Fig.2.5 Maps showing per cent area under different categories of ECe (a), SARe (b) and pH (c) in TBP command area

The per cent of samples with >1 $(CO_3+HCO_3)/(Cl+SO_4)$ and $(Na/(Cl+SO_4)$ ratios were to the extent of nearly 12.5 and 45.5 respectively indicating that the soils could be sodic or developing into sodic. Accordingly, nearly 23.7 per cent of surface samples had SARe >13. Sub-surface (15-30 cm) soils had pH(1:2.5), pHs, EC(1:2.5) and ECe varying from 10.6 to 4.76, 10.3 to 5.45, 19.9 to 0.08 (dS/m), and 35.0 to 0.23 (dS/m) respectively with an average of 8.20, 7.74, 1.45 dS/m and 3.19 dS/m respectively (Table 20). Similar to surface soils, average Na content (27.0 meq/L) was more than Ca+Mg (9.10 meq/L) followed by K. In case of anions, average Cl^- content was more (21.9 meq/L) than HCO_3^- (9.00 meq/L) followed by SO_4^{2-}. Nearly 15 per cent of samples were considered to be saline as the ECe of these samples was >4.0 dS/m. The overall mean of the $(CO_3+HCO_3)/(Cl+SO_4)$ was less than 1 whereas Na/(Cl+SO4) was >1. However, about 16 and 49.5 percent of these samples had values more than 1 indicating that these samples could be considered as salt affected soil in particular sodic or developing into sodicity. About 23 per cent of samples analyzed had SARe >13.

3. RECLAMATION AND MANAGEMENT OF SALT AFFECTED SOILS UNDER DIFFERENT AGRO-ECOLOGICAL REGIONS

In India, 6.73 million ha (M ha) area has been characterized as salt affected by ICAR-CSSRI, out of which 3.77 M ha is alkali and the remaining 2.96 M ha is saline, threatening livelihood security of farming community. The distribution of alkali affected area among different states reveals that it is a serious problem across 11 states in India. Uttar Pradesh having the largest alkali area of 1.35 M ha accounts for 35.75 per cent of total alkali affected area followed by Gujarat (14.36%), Maharashtra (11.21%), Tamil Nadu (9.41%), Haryana (4.86%) and Punjab (4.02%). These six states are having about 80% of the total alkali lands of India. Extent of saline lands in India is estimated as 2.95 million ha (M ha). This estimate does not segregate soil salinity associated with subsurface water logging and soil salinity due to irrigation by saline groundwater. State wise distribution of saline soils in India reveals that soil salinity is a serious problem across 13 states of the country with Gujarat having largest area of 1.68 M ha (i.e. 56.84% of total saline soils) followed by West Bengal (14.92%), Rajasthan (6.61%) and Maharashtra (6.23%) (Sharma et al., 2015).

India loses 11.18 million tonnes (Mt) of cereals, oilseeds, pulses and cash crops from 3.77 M ha alkali affected area, which is equivalent to the monetary loss of ₹ 1,50,000 million (₹ 15,000 Crores) as per estimates. Similarly, crop production loss due to salinity at the national level is 5.66 million tonnes (Mt), accounting for the annual monetary loss of ₹ 80,000 million (₹ 8,000 Crores), at prevailing MSP of different crops during 2015 (Sharma et.al. 2015). Over the past few decades, chemical amelioration of alkali soils in Indo-Gangetic regions of Punjab, Haryana and Uttar Pradesh has been well standardized. With the support of World Bank, European Union and other developmental agencies, India has reclaimed 1.95 M ha of alkali lands. Across states, Punjab has reclaimed largest area (0.79 M ha), followed by Uttar Pradesh (0.73 M ha), Haryana (0.35 M ha) and other states (0.70 M ha) (Sharma et al. 2016b).

Also in case of waterlogged saline soils, number of pilot scale manually laid subsurface drainage (SSD) projects, undertaken by ICAR-CSSRI during 1980s, have slowly paved the way for mechanically installed large projects in the states of Haryana, Rajasthan, Maharashtra, Karnataka, Gujarat, Punjab and Andhra Pradesh. Implementation of large mechanically installed subsurface drainage projects has increased exponentially during the past 10 years with provision of Government funding under schemes like CADA, RKVY and others. So far, about 66,500 ha waterlogged saline soils have been reclaimed with SSD in India resulting in significant increase in cropping intensity and crop yields improving the socio-economic status of the farmers (Sharma et al. 2016a).

The technological packages for reclamation of alkali, saline & waterlogged saline soils and sustainable use of saline and alkali waters for irrigation including nutrient management issues are discussed in this paper on basis of experimental results from ICAR-CSSRI and centres of AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture.

3.1 Reclamation and Management of Alkali Soils

Reclamation of alkali soils requires the removal of exchangeable sodium and its replacement by calcium. It is accomplished by the application of gypsum or any other chemical amendment including several industrial wastes such as phospho-gypsum, distillery spent wash (DSW) or using organics. The details of technological packages including nutrient management issues are given below.

Reclamation through gypsum

The reclamation process is initiated by proper land levelling providing strong bunds on all sides of the farm to control ingress of water from the adjoining un-reclaimed areas. The on-farm development works including farm layout with irrigation and drainage channels should be completed by early summer before the on-set of rains. Although the amount of amendment to be applied, is based on soil analysis, as a thumb rule, 12-15 tonnes of gypsum per hectare (50% of gypsum requirement (GR) of 0-15 cm soil as per soil analysis) is sufficient enough to reclaim upper 15 cm soil layer of a highly deteriorated soil (pH as high as 10.7) for successfully growing rice-wheat crops in rotation. The dose can be reduced to half, if 10-15 t/ha FYM is applied along with gypsum or salt tolerant rice and wheat varieties are used in the first 3 years of cultivation. The amendment is uniformly spread in the whole field and thoroughly mixed within 10 cm top soil layer, followed by ponding of irrigation/ rain water for about 7-10 days to promote leaching and create conducive environment for ionic reactions at soil exchange complex. After disappearance of excess water, land is properly cultivated and fertilized. As far as possible, reclamation should start with rice as the first crop. Rice is transplanted with puddling, ensuring 3 to 4 seedlings per hill and maintaining 15 to 20 cm distance between the hills. Seedlings, raised in normal/ good soil nursery should be preferred for use. The normal crop management practices should be followed. Submerged condition is to be maintained during rice crop. Wheat or *berseem* is the best option to continue the reclamation process during *rabi* season. Recommended crop varieties should be planted at the appropriate time. It is desirable to go in for a green-manure crop during summer. It improves soil physical conditions and also saves about 60-70 kg/ha of nitrogen in the following rice crop. Light and frequent irrigations to wheat crop, keeping total quantity of irrigation water same, are recommended to avoid stagnation of standing water (Sharma et al. 2016b). Gypsum technology has been successfully tested and promoted by AICRP centres such as Indore, Tiruchirapalli, Kanpur, Gangavathi and Bapatla to reclaim alkali soils in respective states. Efficient, balanced and integrated nutrient management is an integral part of reclamation of alkali lands. Therefore, to sustain productivity during and after reclamation the following recommendations should be practiced.

These soils are highly deficient in organic matter and nitrogen. During the first few years after reclamation, crops are fertilized with about 25% more nitrogen compared to recommended dose for normal soil. Split application of nitrogen through urea (1/3rd as basal, 1/3rd each at 21 and 45 days crop growth) should be given. In rice, basal dose of urea should be applied under pre-submerged conditions to reduce ammonia volatilization losses and to enhance Nitrogen use efficiency. Alkaline soils suffer from Zn and Fe deficiency because of inherently poor supply power of these nutrients due to their low solubility (Meena et al. 2017). Farmyard manure, organic residues and green manures help in increasing the productivity. It is extremely important to integrate use of organic resources along with chemical amendments. Initially, alkali soils are high in available phosphorus. However, both rice and wheat require phosphorus fertilization @ 22 kg P/ha after 4-5 years to sustain productivity and to maintain soil fertility as available phosphorus in soil reduces to critical soil test value of 12 kg/ha (Sharma et al. 2016b).

Reclamation through distillery spent wash

Experiences from AICRP centre at Gangavathi (Karnataka) suggested that use of distillery spent wash, highly acidic by-product of alcohol industry with pH 3.7 and EC 36.1 dSm^{-1}, was beneficial in reducing soil pH from 8.82 to 7.66; ESP from 21.3 to 10.6; bulk density from1.33 to 1.05 Mgm^{-3} in case of alkali soil of Vertisols nature while significantly increasing organic carbon. Grain yield increase was to the extent of 26% over control (Biennial Report 2014-16). Experimental results from Indore centre revealed that ESP of sodic Verisols (fine smectitic hyperthermic family of typic heplusterts- sodic phase) reduced from 38.4 to 16.5 after one time application of Lagoon Sludge (LS) @ 5 t ha^{-1} +Raw Spent Wash (RSW) @ 2.5 lakh litre ha^{-1}. Significant improvement in all the parameters was observed due to application of LS 5 t ha^{-1} + RSW @ 2.5 lakh litre ha^{-1} as compared to gypsum @ 75 % GR (Gypsum Requirement) as well as LS @ 10 t ha^{-1} and Press Mud (PM) @ 5 t ha^{-1} application. Highest plant height (90.8 cm), tillers per plant (8.2), length of ear head (7.43 cm), grain (3.49 t ha^{-1}) and straw (4.72 t ha^{-1}) yield was recorded in case of LS 5 t ha^{-1} + RSW @ 2.5 lakh L ha^{-1} applications (Biennial Report 2016-18). Also it was observed that use of distillery spent wash (DSW) at rate of 5 lakhs litres per ha on highly alkali soil of sandy clay loam texture at Tiruchirapalli in Tamil Nadu, with soil pHs as 11.2 and ESP as 42, was beneficial. Post reclamation soil pH_s and ESP were 8.46 and 17.2. The rice grain yield obtained in control plot was 1.5 t ha^{-1} whereas in DSW reclaimed field, rice grain yield was 4.5 t ha^{-1} (Biennial Report 2014-16).

An experiment to evaluate long-term effects of pre-plant application of PME (Post Methanated distillery Effluent) at different rates (control and 1.25, 2.5, 3.75, 5.0 lakh litres ha^{-1}) along with different combinations of N, P and K on the changes in soil physico-chemical properties, fertility status, exchangeable cations, and cane yield was initiated during 2002 at cane farm of Tiruchirapalli centre. The experiment continued for 12 years. The PME was applied to soil and it was thoroughly mixed and allowed for natural oxidation. Different combinations of NPK fertilizers *viz.,* N alone, NP, NK, PK, NPK and control (without NPK) were imposed as subplot treatments. The results revealed that the application of PME significantly increased the yield of sugarcane. An increased cane yield of 52.1, 64.3, 76.4 and 84.8 per cent were recorded in 1.25, 2.5, 3.75 and 5.0 lakh lit ha^{-1} of PME applied treatments, respectively over control. The cane yield of sugarcane remarkably increased due to the application of inorganic fertilizers. Though significant response was observed for N and P fertilizers, differences between applications of N & NK and NP & NPK fertilizers were not significant indicating that the supply of K through PME was sufficient. The effect of inter relation was revealed that PME application @ 1.25 lakh litres ha^{-1} together with NP fertilizer is the most suitable dose of harvesting appreciable yield of sugarcane. The graded doses of PME along with NP significantly increased the soil available nutrients, organic carbon content besides reducing ESP and improving soil physical properties. Instead of soil application of PME, it can be applied along with irrigation. Hence, it was concluded that application of PME either as pre plant application @ 1.25 lakh litrers per ha or along with irrigation water at 1:20 dilution (four times per year) along with 75% N & P fertilisers (omitting K) is optimum for getting higher sugarcane yield besides improving the soil fertility without affecting the groundwater quality in sandy loam soils (Biennial Report 2014-16).

Reclamation through organics

Effect of green manuring on soil health and nutrient availability is well appreciated (Meena et al. 2018b). Results of long-term experiment imitated during 2005 at Indore centre showed positive effect of organic/green manuring on soil properties and crop yield on an alkali (sodic) Vertisols. Four treatments (i.e. control, FYM @ 10 t ha^{-1}, sunhemp and dhaincha as green manuring crops) were tested at four soil ESP levels (25, 35, 45 and 50 ± 2) achieved through one time gypsum application. The lowest average ESP values (23.54 in 2016-17 and 22.62 in 2017-18) were recorded under incorporation of dhaincha followed by sunhemp (26.70 in 2016-17 and 25.90 in 2017-18). The maximum yield of paddy (3.71 & 3.96 t ha^{-1}) and wheat (3.47 & 3.68 t ha^{-1}) was recorded at soil ESP of 25; however, the lowest yields were recorded at soil ESP of 50. Among various treatments incorporation of dhaincha gave highest yield and lowest was observed in control plot for both the crops. Green manuring helped in reducing soil ESP nd improving soil physical properties and soil fertility (Biennial Report 2016-18).

Reclamation through city compost and poultry manure

Addition of organic amendments to soil helps to supply of essential nutrients (N, P, K and others secondary and micronutrients); to improve soil physical and chemical properties and to enhance microbial populations and activities (Dotaniya et al. 2016). Application of urban waste such as sewage sludge and municipal solid waste compost in conjunction with gypsum can be an option for reducing soil sodicity. Initial results of experiments at ICAR-CCSRI has proved that Municipal Solid Waste (MSW) and Sewage Sludge can be effectively used reclamation sodic soils either in conjunction with gypsum or alone. There was reduction of pH and enhancement in yield. The micronutrients such as Fe, Mn, Zn and Cu were more in organic amended plots compared to control. Concentrations of heavy metals (Cd, Cr, Pb and Ni) in soil and leachate samples were below the permissible limits. Pathogen tests revealed safer application of compost and sewage sludge in sodic soil reclamation. If industrial waste is not mixed domestic city waste, then city compost can be important material for reclamation as well as nutrient supplement for sodic soils (Annual Report 2018).

The Kanpur centre (2020) studied of efficacy of organic amendments for sustainable crop production under rice-wheat cropping system in sodic soil. The maximum yield of rice grain (42.37 q/ha) and straw (50.89 q/ha) was obtained from 25%GR + Poultry manure @ 3t/ha treatment followed by 25%GR + GM @5 t/ha + Microbial culture and 25%GR + City Waste Manure @5 t/ha while minimum yield was received from control plot. The average grain and straw yield of rice varied from 24.48-42.37 and 29.48-50.89 q/ha respectively. Similarly, the maximum yield of grain (36.78 q/ha) and straw (44.73 q/ha) was obtained from 25%GR + Poultry manure @3t/ha treatment followed by 25%GR + GM @5 t/ha + Microbial culture and 25%GR + City Waste Manure @5 t/ha while minimum yield was received from control plot. The improvement of soil properties was observed with the application of different treatments over control plot. The average grain and straw yield of wheat varied from 19.59-36.78 and 24.13-44.73 q/ha respectively. The maximum beneficial changes in pH, electrical conductivity, exchangeable sodium percentage (ESP) and organic carbon (OC) were recorded in 50%GR treated plot followed by 25%GR + Poultry manure @3t/ha and 25%GR + GM @5 t/ha + Microbial culture than other treatments.

3.2 Reclamation and Management for Waterlogged Saline Soils

The waterlogged saline soils can be reclaimed by subsurface drainage (SSD) technology developed and standardized by ICAR-CSSRI, Karnal in collaboration with The Netherlands through field experimentation under different agro-climatic conditions. The system consists of a network of perforated corrugated/smooth PVC pipes for laterals and collectors, respectively. These pipes are covered with gravel/ synthetic filter to prevent clogging and are installed manually or by laser controlled trencher machines mechanically at a desired design spacing and depth below soil surface. Such a drainage network helps in maintaining water table below the root zone depth and drains excess water and salts out of the affected area through gravity or pumped outlet. In case of pumped outlet, provision of a sump to collect and to pump drainage water is required. Thus, system works naturally under gravity outlet while requires additional cost of pumping under pumped outlet. The depth and spacing of the drainage system are decided on the basis of drainage coefficient (depth of water in mm that is to be drained from drainage area per day) worked out considering rainfall, irrigation, crop rotation, soil texture, hydro-geology, soil salinity and outfall conditions. Based upon overall experience of CSSRI, design parameters of subsurface drainage have been finalized for different regions (Table 3.1) as explained by Bundela et al. (2016). In addition to above, the recommended values of minimum slope of drain pipes are 0.10 to 0.05 % for drain pipes of 100 to 150 mm diameter. In large scale drainage projects undertaken under Governmental schemes in alluvial soils of Haryana, the recommended drain parameters are 66 m (along field boundary/ *kila* line) drain spacing and 1.5 m average lateral depth. In case of heavy texture soils/Vertisols of peninsular India, 30 m drain spacing and 1.2 m average depth are common. In waterlogged saline soils reclaimed through subsurface drainage in different states, the crop yields increase significantly, more than 50% for paddy and more than 100% in wheat and cotton. Results also suggest 40% improvement in cropping intensity leading to 2- 3 fold increase in farmers' income (Sharma et al. 2016a).

Table 3.1. Design parameters of Subsurface Drainage for different regions of India

Drainage coefficient (mm/d)			Drainage depth (D_d)		Drain spacing (D_s)	
Climate	Range	Optimal	Outlet type	D_d (m)	Soil texture	D_s (m)
Arid	1-2	1	Gravity	0.9-1.2	Light	100-150
Semi arid	1-3	2	Pumped	1.2-1.8	Medium	50-100
Sub Humid	2-5	3			Heavy	30-50

Average loss of nitrogen through drainage effluent can be controlled by adoption of controlled subsurface drainage system once reclamation leaching is completed. Average loss of nitrogen through drainage effluent from subsurface drainage system with 40, 50 and 60 m spacing was 1.87 vs. 0.63, 5.95 vs. 2.64 and 4.30 and 2.68 kg/ha under conventional and controlled subsurface drainage system on Saline Vertisols in Tunga Bhadra Project in Karnataka as shown in Fig. 1 (Biennial Report 2016-18).

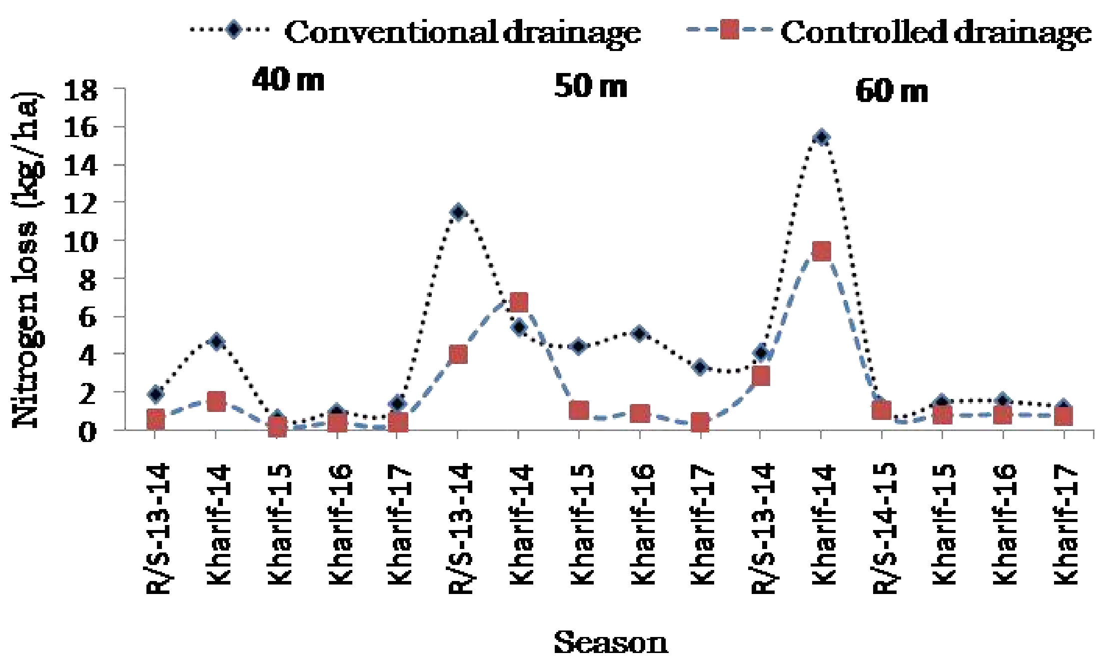

Fig.3.1 Nitrogen loss (drainage events) for conventional and controlled drainage system

Additional doses of nitrogenous fertilizers are recommended to compensate for volatilization losses occurring under saline environments. The deficiency of micro-nutrients such as Zn is observed. Application of Zn at rate of 20-35 kg ha^{-1} is recommended for saline soils. FYM and other organic materials have not only the nutritive value, but play an important role in structural improvements, which further influences leaching of salts and reduce their accumulation in the root zone. Seed soaking with 0.05M Fe-EDTA solution for 12 h prior to sowing was effective in alleviating Fe deficiency in aerobically-grown rice on the calcareous soil (Meena et al. 2013). Application of zinc sulphate at rate of 25 to 35 kg per hectare to pearl millet- mustard cropping sequence for first few years is recommended and then it should be applied on soil test basis and foliar application of 1% iron sulphate at twice at the interval of 15 days was more effective to reduce Fe deficiency in crops (Meena et al. 2018a). Therefore, the addition of FYM and other organic/green manure should be made to the maximum possible extent.

3.3 Reclamation Saline Soils

Saline soils having deep water table can be reclaimed though leaching. The amount of water required to leach down the salts depends upon the amount of salts in the soil, the type of salts present, soil texture, desired status of the salts in root zone and the depth of reclamation. The desired status of the salts in the root zone depends largely on the salt tolerance of the crop to be grown. The depth of land reclamation is decided on the basis of land use. While for shallow rooted crops, it could be 60 cm, for deep-rooted crops and trees it could be around 2.0 m. For diversified cropping, the depth of reclamation varies from 1 to 1.5 m (Gupta and Gupta, 2003). Usually; thumb rules are applied to decide the amount of water required for leaching (Table 3.2). Nutrient management options of saline soils are similar to waterlogged saline soils.

Table 3.2 Leaching requirements of soils for one time reclamation

Soil Type	Leaching requirement (cm cm^{-1} of soil depth)	Water requirement to leach 60 cm of soil profile (cm)
Coarse textured	0.5 – 0.6	30-36
Medium textures	0.6 – 0.8	36-48
Heavy textured	0.8 – 1.0	48-60

Note: The above requirement is to leach down 80% of the salts initially present

3.4 Integrated Farming System (IFS) Models for Waterlogged Alkali and Saline Soils

The IFS models are being developed and tested at different centres (Kerala, Panvel, Vyttila, Tiruchirapalli, Port Blair) of AICRP and at its regional research stations of ICAR-CSSRI (Lucknow and Canning Town). These models are applicable to water logged saline and waterlogged alkali soils. Basically water and salt balance of small portion of landscape is corrected through land modifications and nutrient recycling is ensured through different components such as field crops, vegetables, horticultural crops, fish, dairy animals and poultry, etc. These models reduce fertilizer requirement due to nutrient recycling and enhance land and water productivity values of overall system. The benefit cost ratio for such models range from 1.44 to 2.5 depending of components (Biennial Report 2014-16).

3.5 Conclusions

The reclamation process of alkali soil was initiated from Punjab and Haryana in 1970s, which was later extended to Uttar Pradesh with World Bank aided project, with technological package developed by

ICAR-CSSRI. The execution of the projects was done by the land reclamation corporations of the respective states and other government departments. Around 1.95 M ha alkali land has been reclaimed adding 15 -16 M t of food grains to national food basket. The gypsum technology is well tested and validated under agro-climatic conditions of the country. The alkali reclamation activities also took place in state of Madhya Pradesh, Tamil Nadu and Andhra Pradesh due to location specific technologies of respective AICRP centres. Reclamation of entire alkali affected area would further add around 12 M t of food grains to the national pool. On the basis of large scale reclamation projects for alkali soils and waterlogged saline soils, it has been observed that reclamation activities are economically viable, environmentally friendly and socially acceptable. However, these soils suffer from deficiencies of one or more nutrients and role of nutrient management becomes very important. Alkali soils are highly deficient in organic matter and nitrogen. Hence crops are fertilized with about 25% more nitrogen compared to recommended dose for normal soil during first few years of reclamation. Split application of nitrogen through urea (1/3rd as basal, 1/3rd each at 21 and 45 days crop growth) is preferred. In rice, basal dose of urea should be applied under pre-submerged conditions to reduce ammonia volatilization losses and to enhance nitrogen use efficiency. Also alkaline soils suffer from Zn and Fe deficiency because of inherently poor supply power of these nutrients due to their low solubility. It is extremely important to integrate use of organic resources along with chemical amendments. Initially, alkali soils are high in available phosphorus. However, both rice and wheat require phosphorus fertilization @ 22 kg P/ha after 4-5 years to sustain productivity and to maintain soil fertility as available phosphorus in soil reduces to critical soil test value of 12 kg/ha.

Subsurface drainage is a technically and financially viable technology for the amelioration of waterlogged saline soils in the irrigation commands of India. Nonetheless, Socio- economic issues, farmers' participation, post- reclamation pumping, organizational set up in states and training of technical personnel is vital for long-term success. Considering the extent of waterlogged saline soils, procurement of new machinery, enhanced Government funding through CADA and RKVY and outsourcing of subsurface drainage projects in PPP mode can speed up large scale implementation of reclamation projects. Additional doses of nitrogenous fertilizers are recommended to compensate for volatilization losses occurring under saline environments. The deficiency of micro-nutrients such as Zn is observed. Application of Zn at rate of 20-35 kg ha^{-1} is recommended for saline soils. FYM and other organic materials have not only the nutritive value, but play an important role in structural improvements, which further influences leaching of salts and reduce their accumulation in the root zone. Experimental results have shown that conservation agriculture practices such as incorporation of crop residues improve soil health and enhance availability of major and micro nutrients in case of salt affected soils. Use of microbes for improving availability of micro nutrients might be effective approach in near future. Integrated nutrient management coupled with nutrient recycling and practices to improve their use efficiencies can be more sustainable approach for sustaining crop production on alkali and saline environments.

4. SIGNIFICANT TECHNOLOGIES HAVING IMPACT BASED ON 50 YEARS OF RESEARCH

The ICAR-Central Soil Salinity Research Institute was established at Karnal (Haryana) in 1969. Since then, the Institute has made significant contributions towards the understanding of management of saline and alkali environments. The All Indian Coordinated Research Project on Salt Affected Soils and Use Saline Water in Agriculture, established on 14th April 1972, is our active partner in fine tuning of reclamation technologies, delineation of salt affected soils and poor quality waters and screening of newly developed varieties. The AICRP is completing 50 years of its salinity research under different agro-climatic region in 2022 and on this occasion, important technologies having impact are compiled below.

Uttar Pradesh

4.1 Technologies for Management of Poor Groundwater Quality Groundwater (Agra)

Problem:

The Agra centre of the AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture (SAS&USW), located in RBS College, has conducted a comprehensive survey for mapping of groundwater quality in 8 districts, namely Agra, Mathura, Aligarh, Etah, Firozabad, Mainpuri and Etawah in the state of Uttar Pradesh and Bharatpur in the state of Rajasthan. In general good, saline and alkali ground water in different districts vary from 17 to 78%, 3.6 to 63% and 16 to 60%, respectively. Further, it is observed that good quality groundwater is dominated in Etah, Mainpuri and Etawah district. Alkali groundwater is dominated in Aligarh and Firozabad district while saline ground water is dominated in Agra, Mathura and Bharatpur district. With very limited amount of good quality canal water for irrigation the region, farmers are compelled to use poor quality groundwater for irrigation purpose. Indiscriminate use of such waters in long-term deteriorates soil quality, adversely affects crop yields and limits choices of crops. Therefore, suitability of groundwater for irrigation purpose on basis of quality parameters, tolerance of crop for salinity/ alkalinity, soil texture and rainfall is to be planned for sustainable management of poor quality groundwater for irrigation in long-term.

Technology

Water quality problem	Strategy for management
Alkalinity	❖ Ameliorating through Gypsum using rain water conservation through bunding/ leveling, RSC management with gypsum, Dhaincha Green Manuring, Use of FYM
Medium Saline	❖ Standard Agro-technique
High Saline	❖ Conjunctive use of low salinity with high salinity water ❖ Improved crop establishment through post-sowing irrigation with sprinklers/surface methods ❖ Pearl millet-Wheat/Barley with post sowing sprinkler irrigation ❖ Fallow *kharif* – and *Rabi* Barley/Mustard sowing in carried over moisture from monsoon rain with appropriate conservation practices followed saline irrigation ❖ Dhaincha GM/Sorghum Fodder ❖ Groundwater recharge and the use of groundwater with improved quality
Saline and alkaline	❖ Crop and fertilizer management

Relative sensitivity of various crop growth stages

Relative sensitivity of various crop growth stages of different crops to saline/ alkaline water irrigation were indentified through field experimentation.

Crop	Relative sensitivity
Mustard	Pre sowing > Flower initiation > Secondary Branching
Wheat	Pre Sowing > Flowering > Milking > Crop root initiation > Jointing
Barley	Crown root initiation > Pre Sowing > Flowering/ Booting >Jointing
Safflower	Pre sowing > Rosette > Flower initiation > Main head opening

Conjunctive use strategies for various cropping sequences with saline water

Conjunctive use strategies for various cropping sequences with saline water were developed through field experimentation (Table 4.1).

Table 4.1 Conjunctive use strategies for various cropping sequences at Agra

Crop rotation	Crop	Year	EC_{iw} (dS/m)	Suitable mode	Relative yield compared to yield by canal water
Urd-potato-green gram	Urd	4	6	2CW:1SW	92
	Potato	4	6	2CW:1SW	97
	Moong	4	6	No mode	Crop failed
Soybean-cabbage-sorghum (F)	Soybean	1	6	2CW:1SW	88
	Cabbage	2	6	2CW:1SW	88
	Sorghum (F)	1	6	2CW:1SW	94
Cluster bean-pea-green gram	Cluster bean	2	6	2CW:1SW	87
	Pea	2	6	2CW:1SW	88
	Green gram	4	6	No mode	Crop failed
Cotton-wheat	Cotton	4	12	1CW:1SW	75
				2CW:2SW	79
	Wheat	4	12	1CW:1SW	97
				2CW:2SW	95
Pearl millet-mustard	Pearl millet	2	Rain fed	Rain fed	
	Mustard	2	12	1CW:1SW	95
Mustard-sunflower-green manuring	Sunflower	4	8	2CW:1SW	82

Conjunctive use of canal and saline/ alkali waters under different cyclic, mixing, seasonal cyclic, long-term annual cyclic modes were tried and best options were identified under limited canal water supply condition. Technologies for use of poor quality groundwater such as RSC management with gypsum, conjunctive use of low and high salinity water for irrigation, post sowing sprinkler irrigation, dhaincha green manuring, sowing of crops in rain conserved moisture and irrigation with saline water with crop and fertilizer management were demonstrated through ORP in Agra/ Bharatpur region resulting in 10-20% increase in yield and improving farmers' net income. Low cost recharge structures were installed around 20 farmers' fields by Agra centre to improve groundwater availability and quality.

Benefits

- Different conjunctive use modes developed for different crops considering availability of good quality water and salinity tolerance of crop are effective in controlling yield reduction despite of use of poor quality groundwater.

Impacts:

- The technologies have been demonstrated on fields of 500 farmers.
- Farmers are adopting technologies from own investments and extent of technologies is around 20,000 ha in Agra and Bharatpur region of Uttar Pradesh and Rajasthan, respectively.
- The technologies of the centre are being advocated by Agricultural development Officer and extension workers on different platforms. However there is no financial support from any state government scheme yet.

4.2 Low Cost Groundwater Recharge Technology for Poor Quality Groundwater Areas in Agra and Bharatpur Regions (Agra)

Problem

Agra – Bharatpur region in the states of Uttar Pradesh and Rajasthan are having poor quality groundwater aquifers. Shallow aquifers are relatively more saline (10-15 dS/m) relative to deeper aquifers (2-6 dS/m). The resource poor farmers of the region who cannot afford to drill deep bores are contented with exploiting the saline aquifers to give on 1-2 life saving irrigation (s) to mustard. In this region, 60% of groundwater is poor quality.

Low Cost Groundwater Recharge Technology

To overcome of use poor quality for irrigation, AICRP on SAS&USW, Agra centre developed low cost recharge structure for dilution of poor quality ground water in aquifers using harvested rain water. The structure consists of tank of size (2m × 1.8m × 1.5m) filled with gravel and harvested rainwater is put into aquifer through bore well generally used for pumping. The diluted ground water is again pumped to irrigate mustard/wheat crops to get better yields.

Rain water recharge and growing of mustard with diluted groundwater

Benefits

This technology of diluting saline ground water through artificial recharge has been designed and demonstrated on 8 farmers' fields in Odhara village of Bharatpur district during *Rabi* of year (2014-15 and 2015-16) for growing mustard varieties of CS-52 and CS-54 and wheat varieties of Raj 4120. Improvement in groundwater quality at groundwater recharge sites is given in Table 4.2.

Table 4.2 EC_{iw} (dS/m) during different irrigations at rain water recharging sites of farmer's fields

Name of farmer with recharge structure	Initial (ECiw)	Pre-sowing irrigation	Groundwater quality of pumped water			
			during 1st irrigation	during 2nd irrigation	during 3rd irrigation	during 4th irrigation
Mr. Lal Hans	10.9	RCM	4.6	5.3	9.7	10.4
Mr. Ram Bharosi	15.0	RCM	6.3	8.2	11.1	-
Mr. Jagan Singh	12.6	5.2	8.6	10.5	-	-
Mr. Mukesh Kumar	13.8	RCM	6.5	10.4	11.3	12.9
Mr. Dinesh Chand	11.0	RCM	5.8	8.7	9.6	-
Mr. Roop Singh	23.5	8.6	11.5	15.3	-	-
Mr. Birendra Singh	19.9	7.9	10.4	13.5	-	-
Mr. Subhash Chand	10.0	6.9	8.7	9.5	-	-

RCM = Rain Conserved Moisture

Impact:

- The increase in yield was varied from 11 to 18 per cent in mustard and 6 to 11 per cent in wheat crop, over the yield of farmer's field.
- Low cost recharge structures were installed around 20 farmers' fields by Agra centre to improve groundwater availability and quality.
- Potential areas for the technology are Agra district and Bharatpur, Deeg, Roopvas, Nadvai, Bayana blocks of Bharatpur district of Rajasthan. Farmers are adopting the technology by their own investment.

4.3 Low Tunnel Technology for Off -season Vegetable Crops (Agra)

Problem

Establishment of vegetables during winter season is a problem in Agra region. Hence vegetable sowing is delayed.

Technology

Low plastic tunnel is simple technology and it helps establishment of vegetable crop in winter season.

Low Plastic Tunnel Technology

Benefits:

- 30% irrigation water saving
- Early fruiting in low tunnel as compared to traditional farming.
- 35-40% increase in yield

Impact

- 100 farmers growing vegetables have adopted the technology.

4.4 Post Sowing Sprinkler Irrigation by Poor Quality Water (Agra)

Problem:

In case of pre sowing irrigation by saline water, germination percentage of mustard gets affected.

Technology

Dry sowing of mustard and post sowing irrigation by sprinkler with poor quality ground water.

Benefits:

- Good germination due to low soil salinity.
- 10-12% increase in yield
- Useful for Mustard and Dhaincha

Impact

- The technology has been adopted by farmers on 175 ha in Bharatpur district of Rajasthan.

Rajasthan

4.5 Drip Irrigation for Saline Water Irrigation in Parts of Rajasthan (Bikaner)

Problem

Out of total 342.26 lakh ha area of Rajastan, 106.02 lakh ha area (about 31% of Rajasthan) comes under saline ground water. Out of this 88.68 lakh ha area falls in western districts viz. Sriganganagar, Barmer, Bikaner, Churu and Jaisalmer. Saline groundwater is only source of irrigation water and it has to be judiciously used.

Technology

The Bikaner centre provided a design of drip with lateral spacing of 60 cm and emitter spacing 30 cm. This design is applicable for field crops like groundnut, wheat, isabgol, pearl-millet crops.

Benefits

- ✓ Saline irrigation water with salinity up to 4 dS/m can be used for ground nut, pearl-millet, isabgol without yield reduction and 8 dS/m of irrigation water can be used for wheat without yield reduction with 100% recommended dose of fertilisers.
- ✓ Less irrigation water is used.
- ✓ Crop faces low water and salinity stress.
- ✓ Benefit Cost ratio for different wheat varieties at different irrigation water salinities with drip system are given below as an examples.

Variety	Benefit Cost ratio			
	Irrigation water salinity			
	BAW	4 dS m^{-1}	8 dS m^{-1}	12 dS m^{-1}
Raj 3077	2.36	2.26	2.04	1.57
Raj 4188	1.68	1.59	1.37	1.07
KRL 210	2.06	1.98	1.77	1.46
KRL 213	2.01	1.96	1.75	1.44

- ✓ Thus, combination of drip irrigation and wheat variety (Raj 3077) has proved effective in ensuring higher benefit cost ratio (>2) and higher water productivity (>= 0.75 kg/m^3) for wheat crop. This approach may ensure long-term sustainability of crop production in arid climatic condition. This is also true for other crops.

The benefit cost ratios for different crops grown with saline water through drip are provided in Table below.

Benefit Cost ratio for saline water irrigation through drip

Particular	Groundnut	Wheat	Pearl-millet	Isabgol
Range for irrigation water salinity (dS/m)	0.25 to 12	0.25 to 12	0.25 to 8	0.25 to 8
Range for B/C ratio	0.46 to 2.38	1.44 to 2.36	1.46 to 1.84	1.63 to 2.79

The above Table indicated that B/C ratio for all four field crops remained above 1 in case of saline water irrigation through drip. Thus, saline water irrigation through drip is economically feasible option in arid regions.

Impact:

Total 2 Lakh ha area is under drip in Rajastan. Out of it, 32,000 ha area is in saline ground water areas of Sriganganagar, Barmer, Bikaner, Churu and Jaisalmer. Thus drip is saving irrigation water, reducing salt load to root zone and preventing yield loss.

4.6 Economic of Ber cultivation/production with saline water using drip irrigation (Bikaner)

Problem

Agriculture in western Rajasthan is faced with challenges such as extremely high summer temperature, low relative humidity, strong winds rapidly depleting ground water sources and highly saline ground water for irrigation. Farmers have to rely on use of brackish water for irrigation. Perennial irrigation from brackish water without proper management practices has resulted in salt build up in soil. Improved varieties of Ber (Gola, Seb, Umran) have made a big impact in arid and semi arid regions. It provides reasonable income to farmers even during drought years. The underground water quality limits cultivation of most of the crop. Ber could be raised successfully with poor quality water. Most of the farmers are taking Ber crop as rainfed which leads to poor and uneconomic yields. Therefore, providing irrigation to Ber may increase its productivity.

Technology

Drip system to irrigate ber plantation (at 8m x 8m spacing) with saline irrigation water (ECiw 8 dS/m). Intercropping in interspaces between two rows of ber plants by rainfed crops like cluster bean, moong etc. for first four years.

Benefits

- ✓ Intercropping till 4 years gave some benefits to farmers.
- ✓ Net returns from the ber plantation became positive 5th year onwards upto life of plantation of 25 years (Table 4.3).
- ✓ On basis of results obtained it was inferred that saline water of EC 8 ds/m can be used economically for ber cultivation under drip irrigation.
- ✓ Irrigation water application is done at 0.6 PE (Potential Evaporation) for ber crop.

Table 4.3 Net return from the ber cultivation using saline water through drip

S.N.	Particulars	Year									
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th to 25th
I	Benefit										
(1)	Yield(kg/plant)	0	0	0	0	25	35	50	70	70	75
(2)	Yield(kg/ha)	0	0	0	0	3900	5460	7800	10920	10920	11700
(3)	Inter Cropping* Income	20000	20000	20000	18000	-	-	-	-	-	-
	Total	20,000	20,000	20,000	18,000	58,500	81,900	1,17,000	163,800	1,63,800	1,75,500
II	Cost										
(1)	Capital Cost	28155	16640	19590	22360	26680	-	-	-	-	-
(2)	Maintenance Cost	0	0	0	0	0	18680	20550	22600	24800	27000
III	**Net Benefit**	**-8,155**	**3,360**	**410**	**-4,360**	**31,810**	**63,220**	**96,450**	**1,41,200**	**1,3900**	**1,48,000**

Impact

- ✓ Farmers who have water of high salinity groundwater, which is economically unsuitable for cultivation of most of the crops, are coming forward for cultivation of ber using drip irrigation. Some of the farmers have planted the crop and installed drip system. Centre is providing all technical information to farmers as and when required.
- ✓ Potential areas, for this technology, are arid districts of Rajasthan.

4.7 Foliar sprays of $FeSO_4$ and Citric acid for iron deficiency in parts of Rajasthan (Bikaner)

Problem

Deficiency of Fe is found in crops grown in salt affected areas.

Technology

Sprays of 2% FeSO4 + 0.1 % Citric acid at 30 and 40 days after sowing are recommended for higher yields of groundnut, moth bean and cluster bean.

Benefits

- ✓ Increase in yield under different crops was observed 20 to 34% (Cluster bean around 25%, Mustard 30 to 34%, Ground nut 20 to 25%).

Impact:

- ✓ The technology of the AICRP centre is recommended by SKRAU, Bikaner and around 2 Lakh ha area under different crops is benefitted because of the technology to recover iron deficiency.

Haryana

4.8 Conjunctive Water Use of Canal and Saline Groundwater (Hisar Centre)

Problem

Conjunctive use of canal and saline water is done to overcome shortage of good quality canal water. In general crops are sensitive to irrigation water salinity at initial stage. However they are tolerant to later stage. The canal and saline water can be blended together or can be used alternately as per their availability. There will be some yield penalty with use of saline water. The yield penalty depends on amount of saline water used during crop period in proportion to good quality canal water and the stage of crop growth when the saline water is used.

Technology

In case of use of conjunctive use of canal and saline water for cotton crop, highest seed cotton yield (2.76 t/ha) was recorded in all canal irrigation followed by 2 canal water (CW): 1 saline water (SW) cyclic irrigation. The lowest yield (1.98 t/ha) was obtained under all saline water irrigation. The relative yields of wheat were 96.8, 87.2, 82.2, 81.5, 77.1, 68.8 and 65.8% in 2CW:1SW, 1CW:1SW, 1SW:1CW, 1CW:RTS (rest with saline), 1SW:RTC (rest with canal), 2SW:1CW, and SW treatments, respectively, as compared to the yield recorded in canal irrigation. The relative yield percentage may vary slightly depending amount of rainfall during crop growing period.

Benefits

- ✓ Different conjunctive use modes developed for different crops considering availability of good quality water and salinity tolerance of crop are effective in controlling yield reduction despite of use of poor quality groundwater. Further use of saline groundwater prevents rise of water table in poor quality groundwater region.

Impact

- ✓ The conjunctive use technology is being adopted in Sirsa, Fatehabad and Hisar districts in cotton-wheat rotation by farmers.
- ✓ It is also adopted for Bajara- Mustard crop rotation in Hisar, Bhiwani, Palwal, Rewari Mahendragarh districts and parts of Jind and Gurugram districts of Haryana.

4.9 Application of Gypsum and Zn in Case of Use of RSC Groundwater for Irrigation (Hisar)

Problem:

In Mahendragarh, Rewari and parts of Gurugram districts of Haryana, RSC waters are found. These waters adversely affect soil physical properties and crop yield. Also deficiency of Zn is observed in RSC water area.

Technology

In case of RSC water irrigation, soil application of gypsum at rate of (0, 25, 50, 75 and 100% neutralization of RSC) was done at village Adalpur and village Bhurjat in Mahendragarh district. At Adalpur, mean wheat yield increased by 96.6, 118.5, 165.12 and 225.84% in G25, G50, G75 and G100 treatments as compared to control. The application of Zn (25, 50 and 75 kg/ha) resulted in 26.2, 45.4 and 60.4% increase in yield, respectively, as compared to control.

At Bhurjat, mean wheat yield increased by 43.0, 107.1, 149.7 and 209.1% in G25, G50, G75 and G100 treatments, respectively, as compared to control irrigated with sodic water having RSC 9.6 meq/l. The application of ZnSO4.7H2O (25, 50 and 75 kg/ha) resulted in 9.3, 17.9 and 22.5% yield increase as compared to control.

Soil application of gypsum and Zinc are effective in controlling adverse effects of RSC waters and well accepted in Mahendragarh, Rewari and parts of Gurugram.

Benefits

- ✓ Neutralization of RSC waters by gypsum is helping in reducing its adverse effects on soil properties and improving crop yields. Application of ZnSO4.7H2O helps in improving crop yield.

Impact:

- ✓ Farmers are applying gypsum to soil and are using sprinkler irrigation. The government of Haryana is giving subsidy to farmers on gypsum application. The extent of technology is in Mahendragarh, Rewari and parts of Gurugram districts of Haryana.
- ✓ Farmers are applying gypsum to soil and are using sprinkler irrigation. The technology is adopted RSC water areas of Sardar Shahar, parts of Bikaner, Churu, Jaiselmer, Jodhpur districts.

Madhya Pradesh

4.10 Long-term application of organic/ green manures in rice-wheat rotation on sodic Vertisols of Madhya Pradesh (Indore)

Problem

Availability of gypsum for reclamation of sodic soil is limited. The organic/ green manuring can be used for reclamation of sodic soils.

Technology

Various green manuring crops were cultivated in gypsum-treated plots in rice-wheat rotation having four levels of initial ESP ((25, 35, 45 and 50) ± 2) and four organic/ green manures such as Control, FYM @ 10 t/ha,

Dhaincha and Sunhemp. Application of gypsum was done once only for creation of different ESP levels and that to before sowing of green manuring crop at initiation of long-term experiment. The green manure crops were cultivated and buried in soil at the age of 45 days well before the sowing of the *kharif* crop (Paddy). Incorporation of green manures/ FYM significantly decreased the ESP at all the levels (Table 4.4). The lowest average ESP (23.54) was recorded under incorporation of Dhaincha followed by Sunhemp (26.70). However the pH_s and EC_e of soil did not change significantly. Range of mean pH_s was 8.20 to 8.27 while mean EC_e ranged from 2.08 to 2.16 dS/m.

Table 4.4 ESP as influenced by application of green manures/ FYM after harvest of wheat

Green manures	Initial ESP Level				**Mean of final ESP**
	25±2	**35±2**	**45±2**	**50±2**	
Final ESP Level after 12 years					
Control	22.69	31.59	39.88	43.95	34.53
FYM @ 10 t ha^{-1}	18.48	25.95	34.51	39.33	29.57
Sunhemp	17.46	23.85	32.07	33.42	26.70
Dhaincha	14.95	21.54	27.92	29.76	23.54
Mean	18.39	25.73	33.59	36.62	
	ESP	**FYM/GM**	**ESP x FYM/GM**	**FYM/GM x ESP**	
CD 5 %	**0.64**	**0.58**	**1.18**	**1.16**	

Benefits

- ✓ Incorporation of green manure significantly enhanced the paddy yield (grain and straw) over control by reducing soil ESP (Fig. 4.1). Maximum grain and straw yield of paddy was recorded in case of dhaincha (3.71 and 8.68 t ha^{-1}) followed by sunhemp (3.42 and 7.55 t ha^{-1}) at soil ESP of 25±2 in the 12^{th} year of experiment, while, lowest yield (2.62 and 5.40 t ha^{-1}) was observed in control plot.

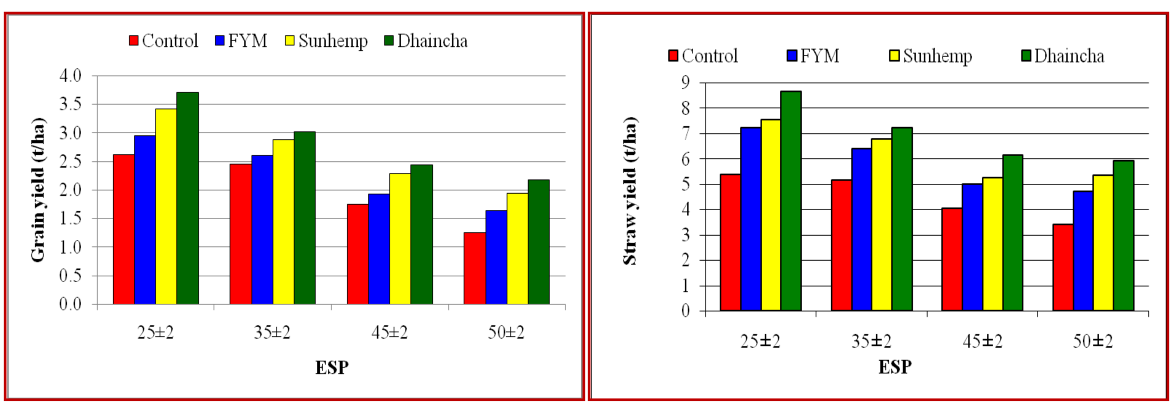

Fig 4.1 Effect of incorporation of green manures/ FYM on grain and straw yield of paddy

- ✓ Incorporation of green manure significantly increased the wheat grain and straw yield over control due to reduction in ESP (Fig. 4.2). Highest grain and straw yield of wheat in the 12th year of experiment was noticed with dhaincha (3.47 and 4.71 t ha^{-1}) followed by sunhemp (3.21and 4.30 t ha^{-1}) at soil ESP of 25±2. Lowest grain and straw yield was observed in control plot.

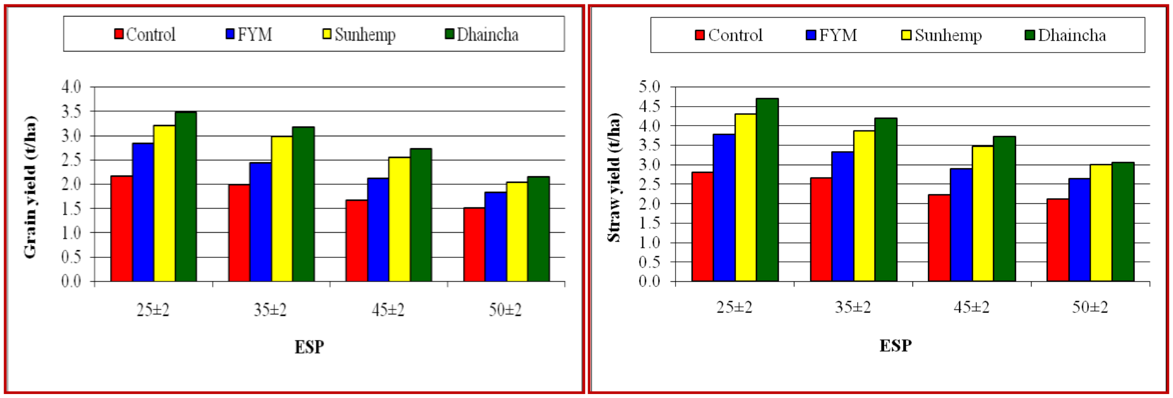

Fig 4.2 Effect of incorporation of green manures/ FYM on grain and straw yield of wheat

Impact

- ✓ Long-term application of green manures / FYM in sodic Vertisols of Madhya Pradesh has positive effect on soil properties and crop yields in case of rice-wheat crop rotation.
- ✓ The technology can be adopted in the areas where there is scarcity of the gypsum.

4.11 Spent Wash for Reclamation of Sodic Vertiosl Soils in Madhya Pradesh (Indore)

Problem

According to the estimates an area of 2.42 lakh ha is affected by soil salinity/ sodicity in Madhya Pradesh. Out of which about 33,898 ha is under black soil region. In the Malwa and Nimar region of Madhya Pradesh (agro- climatic region MP-10 and MP-11) approximately 22,643 ha was found to have salt problems (Anonymous, 1973). Whereas, in the Sheopur district 11,255 ha land was affected due to secondary salinization through canal irrigation. Area delineated through Remote Sensing in 9 districts (Bhind, Datia, Gwalior, Morena, Sheopur, Mandsaur, Neemuch, Hoshangabad and Dhar) of M.P. is about 1.35 lakh ha.

Reclamation of alkali soils takes place through physical and hydro-technical, chemical and biological ameliorations. The chemical amelioration in basically gypsum based viable technology for reclamation of these soils. This is high inputs chemical method in practice for improvement of sodic soils, but in this direction to reduce cost input on such soils the use of acid containing or producing waste materials generated by certain industries can be utilized for reclaiming of such soils. The use of such material as reclaiming agent will not be only eco-friendly but also sustainable for agricultural lands.

In India there are about 257 distilleries, which generate 40.72 million-kilo litres of spent wash annually. Disposal of such a huge quantity on land poses severe problem of soil, water and environmental pollution. Spent wash is acidic in nature and contained Ca, Mg, K and S and organic carbon and some other micronutrients in high amount. Being an organic material it improves physical condition of soils and it can be utilized as an amendment for reclaiming sodic soil with other organic materials. Owing to the high cost of reclamation, use of such locally available waste may economize the amendment cost. Its huge quantities pose a problem of disposal because of its high BOD & COD. In this experiment, the spent wash had been tested along with other organic amendments in rice and wheat crop grown on sodic soils.

Technology

Soil application of 5.0 cm (5 lakh liters per hectare) of spent wash for reclamation of sodic Vertisols. Physico-chemical properties of spent wash are given below.

Organic amendment	pH (1:4)	EC (dSm^{-1})	Ca	Mg	Na	K	S
Spent wash	4.80	13.42	1580 mg/L	962 mg/L	440 mg/L	8900 mg/L	1280 mg/L

Benefits

- ✓ Spent wash was applied @ of 5 lakh L per ha in paddy-wheat cropping sequence for 5 years. The soil ESP decreased from 38.8 to 17.
- ✓ Application of 5.0 cm (5 lakh liters per hectare) spent wash was found effective to increase the yield of paddy (16.6 to 39.5 %) and wheat (19.6 to 37.0 %) over application of gypsum @ 75 % GR.
- ✓ The soybean crop in *Kharif* was grown first time in the plots reclaimed after 5 years of experimentation without any treatment in the year 2009-10. 21.4 q/ha seed yield was obtained. There was 49.6 % increase in seed yield over recommended dose of gypsum (75 % GR).
- ✓ Benefit Cost ratio was 2.38.

Response of crops to reclamation of Sodic Vertisols by Spent Wash

Impact/ Constraints

The technology is spent wash for reclamation of sodic Vertisols is successful. However, clearance from Central Pollution Control Board for such use is required. Also farmers need transport arrangement for carrying Spent Wash in huge quantities from sugar factories to fields.

4.12 Raised and Sunken Bed for Sodic Vertisols under Rainfed Condition (Indore)

Problem

The reclamation and economic utilization of sodic Vertisols is quite difficult due to their poor hydraulic conductivity, swell-shrink nature, inadequacy of irrigation facilities, high bulk density, high water dispersible clay and low production potential. Survival of crops and crop productivity under these conditions suffer heavily on both the accounts i.e. water stress at one time and temporary water logging at the other time. The reclamation needs ample amount of water for efficient chemical reactions and leaching of reaction products below the root zone. In view of limited water availability, the effective depth of reclamation remains a limiting factor for growth even if all the recommended management practices and technologies are adopted during reclamation. Under these circumstances, farmers are unwilling to invest on rehabilitation of such black alkali soils for crop production. The *in-situ* and *ex-situ* rainwater harvesting could provide sufficient water for reclamation and crop production in black alkali soils.

Technology

Raised and sunken beds were prepared as per design provided below. The design was prepared considering annual precipitation of the area as 730 mm (Fig. 4.3)

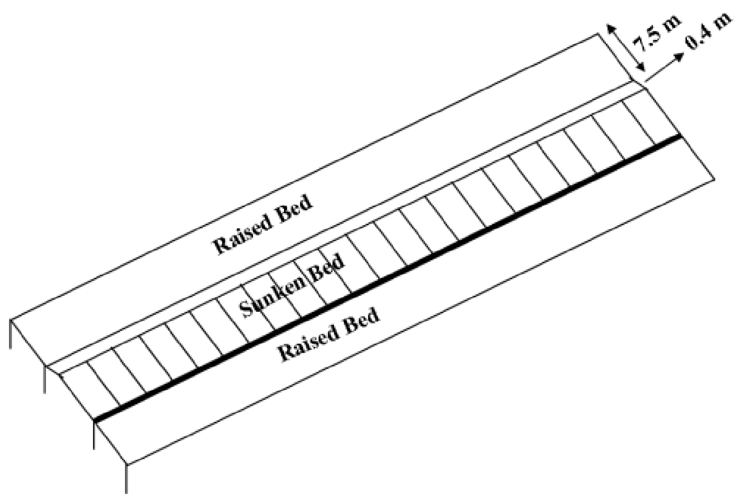

Fig. 4.3 Schematic Diagram of Raised –Sunken Bed system

Excess runoff from sunken beds was stored in storage tank of 30m x 25 m and 3.5 m depth. This size of the tank was worked as 7.5 % of cultivated land (Fig. 4.4)

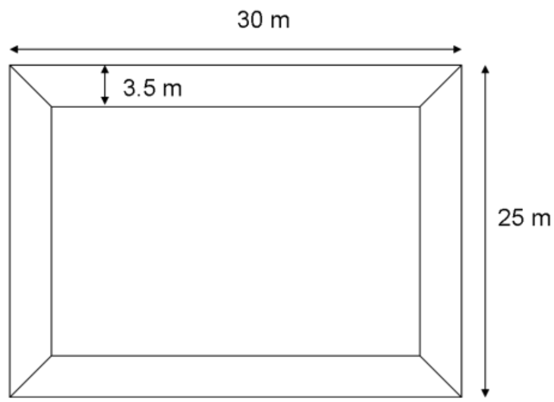

Fig. 4.4 Schematic Diagram of Tank

The gypsum was added to the soil of raised and sunken bed (ECe- 3.5 dS m^{-1}, pH-8.6, ESP-65 and CEC 40 c mol (p^{+}) kg^{-1}) @ 26 t ha^{-1}, which works out at 75 % of GR of the 0-20 cm layer.

Cotton was planted on raised beds while paddy was grown in sunken beds. All the recommended agronomic practices were followed. The water stored after a first rain was safely disposed off from the field (sunken bed) to storage tank to avoid any salt injury to the crop.

Sodic Vertisol

Raised-Sunken Bed System

Crops under Raised and Sunken Bed System

Repeat application of gypsum after 4-5 years would be essentially required to get optimum yields under rain fed conditions.

Benefits

- ✓ The net profit of ₹ 44,529 was obtained due to adoption of raised and sunken bed system by investing ₹ 56750 with the benefit cost ratio 1.78 considering the period of 5 years of experimentation.
- ✓ Rainwater could be effectively utilized for reclamation as well as for crop production during *Kharif* season, if the technology of raised and sunken bed system along with small storage tank is adopted.
- ✓

Impacts/ Constraints

- ✓ The technology is useful for sodic soils where irrigation facilities are meager.
- ✓ The farmers can adopt the technology if they get financial support either from state or from central govt.

Andhra Pradesh

4.13 Reclamation of Abandoned Aqua (Shrimp) Ponds in Coastal Andhra Pradesh (Bapatla)

Problem

Aquaculture is the most promising sector in Andhra Pradesh (AP). The state is the largest producer of shrimp in the country with a production of 51,081 MT from 0.35 lakh ha and productivity of 1.45 $MTha^{-1}yr^{-1}$ (Andhra Pradesh Fishery Policy, 2015). More than 90 per cent of the shrimp farmers' holdings in AP are small with an area of less than 2 ha. The main factors for shifting from conventional farming to aquaculture remained high economic returns from aquaculture and climate change issues like erratic and uneven distribution of rainfall associated with conventional farming. As it is mainly brackish water aquaculture, farmers fill dug out ponds by sea or creek water having salinity from 15-25 dS m^{-1}. The potential areas for brackish water aquaculture are estuaries in deltas of rivers like Nagavali, Vamsadhara, Godavari, Krishna and Penna on coast of Bay of Bengal. Brackish water aquaculture had two major setbacks in past. It suffered from viral disease and white spot disease during 1994 and 1995-96, respectively, incurring huge losses to farmers. Lack of sufficient technical know-how despite of huge investment and frequent outbreak of diseases forced some of farmers to stop aquaculture permanently. It is highly unfortunate to them that their productive agriculture lands have become salt affected, severely affected by chloride and sodium and have become alkaline (Soil ECe ranges from 3.0 to 25.0 dS/m and pH ranges from 7.5-9.5). Such farmers want lands to be reclaimed so that rice cultivation can be taken up for their livelihood.

Technology

The AICRP on SAS&USW, Bapatla centre developed technological package to reclaim abandoned aqua ponds. It includes the management of all types of physical and chemical disturbances of soils such as soil pH, EC and soil available nutrients to improve the crop productivity. Major components of the package are: i) Land leveling, ii) Application of gypsum for alkali soil, iii) Providing adequate drainage for removal of excess water and leachable salts, iii) *In situ* incorporation of *dhaincha* at 50% flowering stage, iv) Selection of salt tolerant crops, v) Transplanting the age old seedlings, vi) Increase in plant density, vii) 50% extra recommended dose of nitrogen and viii) Basal application of $ZnSO_4$. The recommended doses of N, P_2O_5, K_2O and $ZnSO_4$ fertilizers for rice are 180- 40- 40 and 50 kg ha^{-1} are also given.

Benefits

The technology was demonstrated on farmers' fields in three different villages *viz.,* Adavuladeevi, Gokarnamatam and Ganapavaram of Guntur district with rice varieties of NLR 145 and MTU 2716.

- Application of package to abandoned aqua ponds result in reduction in soil pH and soil salinity (ECe). Green manuring also has positive effect in reduction in pH along with gypsum.
- The mean grain yield of paddy in reclaimed aqua ponds ranged from 4250 to 5380 kg ha^{-1} compared to the non-reclaimed fields (3348 to 4150 kg/ha). The increase in yield was varied from 12 to 43 per cent over the control (Fig. 4.5).


Aqua ponds before reclamation


Paddy crop after reclamation

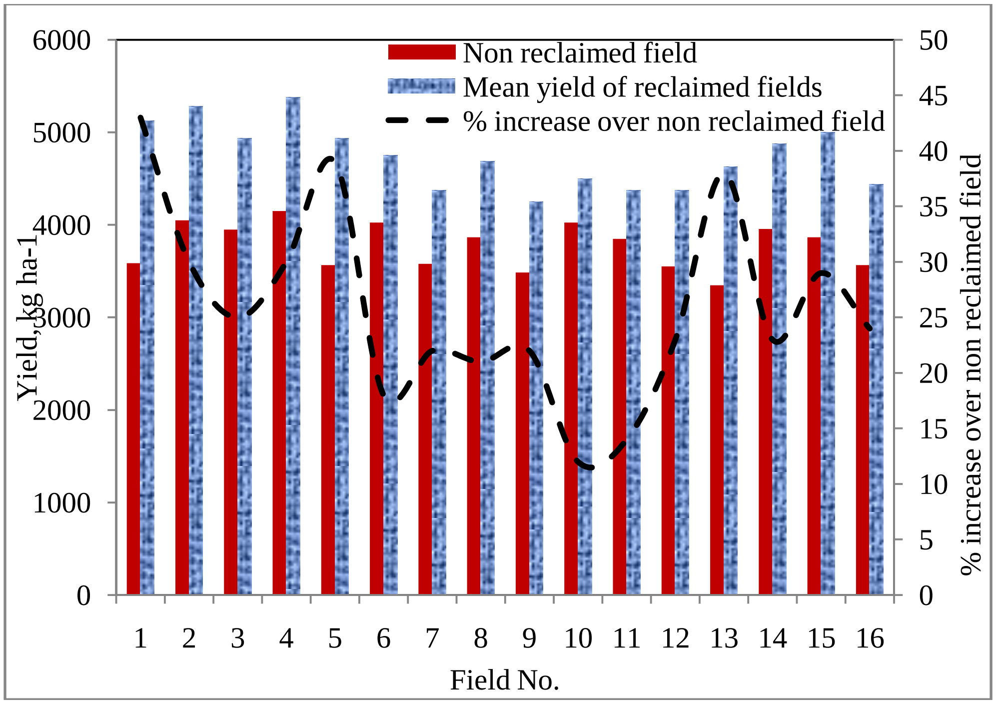

Fig 4.5 Increase in yield of rice in reclaimed abandoned aqua ponds

Impact

- The package has helped in reducing soil pH and soil salinity considerably in case of abandoned aqua ponds. The increase in rice yield was varied from 12 to 43 per cent over the control. Small and marginal farmers in coastal Andhra Pradesh who have stopped shrimp farming due to outbreak of diseases are adopting the technology for their livelihood security.
- The technology and package of practices for reclamation of abandoned aqua ponds is being transferred to other affected regions in Guntur district of coastal Andhra Pradesh.

4.14 Skimming of Fresh Water Floating on Saline Water (*Doruvu Technology*) in Coastal Andhra Pradesh (Bapatla)

Problem

Most of the coastal zone areas have shallow fresh water layers followed by saline waters at a depth below 6-10 m. These are tapped through traditional doruvu's (Dug out Conical pits) which fetches inferior quality irrigation water, occupies more space, more evaporation losses and high labour usage, resulting in degradation of soil and lesser productivity as given in figure below.

Traditional Doruvu technique

New Skimming well technology

Technology for efficient use of fresh water floating over saline ground water in coastal sands (Skimming well Technology) comprises installation radial corrugated perforated pipes and sump at centre for skimming of fresh water without disturbing underlain saline groundwater in coastal areas. Skimming well technology is designed with intention to extract/ skim freshwater layer floating over saline water aquifer. This is generally designed for irrigation or drinking water purpose. Rate of pumping of groundwater is a crucial decision, because unregulated pumping often results in up-coning phenomena, ultimately increasing salinity of pumped groundwater. Regulated pumping is carefully implemented such that relatively less saline water is skimmed from saline water aquifer beneath the fresh water layer in the coastal aquifer.

	
Construction of new Doruvu technique	**Functioning of new Doruvu technique**

Benefits

- ✓ After installation of skimming well, the water table depth varied from 1.39 to 2.04 m at Bapatla and surrounding coastal areas and E.C. of skimmed water is found to be 0.16 to 0.54 dS m^{-1}
- ✓ The studies have revealed that the improved fresh water skimming techniques have promising future prospects for sustaining crop production and potable water supply along the coastal belts.
- ✓ Cost of Construction of skimming well is Rs. 60,000.00 per well.
- ✓ The farmers are still reaping the highest benefits under skimming well as indicated by the values of NPW, B.C.R and IRR i.e. 52629, 2.01 and 33 per cent for the life of 25 years.

Impacts

- ✓ Around 250 skimming wells were installed covering an area of 500 ha in the coastal areas of Prakasam, Guntur and West Godavari districts of Andhra Pradesh covering twenty five villages including
- ✓ The technology can be applicable in an area of about 1.74 lakh ha. of coastal sandy soils and 35000 such skimming wells are possible to install in Andhra Pradesh.
- ✓ Feasible areas also exist in coastal sands of Tamilnadu, Orissa and West Bengal.

4.15 Sub Surface Drainage (SSD) System for the Control of Salinity and Waterlogging (Bapatla)

Problem

- ✓ Excess water in the crop root zone soil is injurious to plant growth. This causes water logging in irrigated regions may also result in excess soil salinity.
- ✓ This can be solved through subsurface pipe drainage systems which enables more rapid water table drawdown. Artificial drainage is essential on poorly drained agricultural fields to provide optimum air and salt environments in the root zone. Drainage is complementary to irrigation and is viewed as an essential component of irrigated agriculture.

Subsurface Drainage Technology (SSD)

- ✓ In this, trenches are dug to predetermined depth. Corrugated perforated PVC pipes are wrapped with the suitable envelope materials like Nylon and Geo-textile materials to avoid sedimentation of silt, are used for laying the laterals at a designed spacing and depths with a longitudinal slope. Then the trenches are backfilled with the spoil. The downstream ends of the laterals are normally connected to a collector drain. The required diameter of the pipe collectors increases with the area drained. Buried pipe drains are generally installed deeper in arid regions than in humid regions in order to control salinity.

Installation of SSD system

Operation of SSD System

Benefits

- ✓ This technology adoption has proved to reclaim waterlogged saline soils within a span of 3-7 years depending on the intensity of the problem and most suitable spacing is 30 m.
- ✓ The system removed 24.6 tons of salts per hectare/annum.

- ✓ The paddy yields increased by 322%.

Effect of SSD on crop yield

Impact

- ✓ The cost of construction is about Rs. 1,00,000/- per hectare. The B.C. ratio is found to be 1.24 and internal rate of return 39.07 per cent.
- ✓ In Andhra Pradesh 3.35 lakh ha area is waterlogged saline. These areas can be treated with subsurface drainage technology.

4.16 Reclamation Technologies for Black Alkali Soils (Bapatla)

Problem

In Andhra Pradesh, the problem of alkali soils exists to the extent of 3,85,110 ha. The ill effects of the alkali soils are high exchangeable sodium (ESP) on soil particles leading to poor physical condition and resulting in low yields. The soils with pH upto 9.5 and E.Ce < 4.0 dS m^{-1} are treated as alkali soils.

Technology

- ✓ These are reclaimed with gypsum application as per soil tests based recommendations. It is also suggested that the dhiancha crop is to be in-situ incorporated at 50% flowering stage.
- ✓ FYM application should be accompanied by the gypsum application. To mitigate the adverse affect of alkalinity, application of FYM without gypsum will not have much use.
- ✓ Gypsum should be applied @ 500 kg/ha for each crop especially where RSC waters are used for irrigation. It varies with the type of soil.
- ✓ Application of 25 percent extra nitrogen is needed as compared to the normal condition.
- ✓ Zinc sulphate @ 25 kg ha^{-1} should be added particularly to the rabi crops grown with alkali water.

Alkali Soil – Before Reclamation

Gypsum Application

Incorporation of Dhaincha

Crop growth in reclaimed Alkali Soil

Benefits

- ✓ There is reduction soil ph and soil ESP and improvement in soil infiltration.
- ✓ Adoption of this technology increases the paddy yields by 12-27%.

Impact

- ✓ Gypsum technology for reclamation of alkali soils has been transferred to an area of 200 ha by SWS, Bapatla alone.
- ✓ Technology has been further transferred to ATMA (Agricultural Technology Mission Agency) KVK, DAATTC and NGO's of A.P.

Karnataka

<u>Tunga Bhadra Project (TBP) Command</u>

4.17 Conventional Sub Surface Drainage (SSD) and Controlled SSD for Saline Vertisols in Tunga Bhadra Project (TBP) Command, Karnataka (Gangavathi)

Problem

Tunga Bhadra Project (TBP) Command area in Karnataka is mainly associated with soil salinity, soil erosion and shortage of irrigation water, particularly during *Kharif* season due to rice cultivation. Horizontal subsurface drainage system developed by centre is helping in controlling water table, reducing soil salinity and improving crop yields. Conventional subsurface drainage system installed at spacing of 30-50 m and depth of 1.00 to 1.50 m is effective in reducing soil salinity and improving groundwater quality and increasing crop yields. However, operation of conventional SSD is also important for tail end farmers in Tunga Bhadra Project (TBP) command of Karnataka who grow paddy with limited canal water supply. Excessive drainage of paddy fields by conventional subsurface system creates irrigation water shortage during crucial growth stages of paddy along with excessive leaching of nitrogen fertilizer (Fig. 1a). As a result, farmers used to block outlets of lateral drains of the system (Fig.1.b).

Technology

To address this problem, AICRP on SAS&USW, Gangawathi designed a small device made up of PVC pipes which was fitted with outlet of lateral drain as shown in the plate below.

a) Conventional Subsurface Drainage
b) Conventional Drainage with blocking of lateral by farmer
c) Controlled Subsurface Drainage

Comparison of conventional drainage and controlled drainage

In general, faster reclamation of waterlogged saline soil was observed under conventional drainage. However, controlled drainage saved about 17.5% irrigation water (104 cm vs 126 cm) and 52.5% nitrogen (5.32 kg/ha vs. 11.20 kg/ha) as compared to conventional drainage. It was observed that paddy yields improved over the years (26 to 34 per cent) irrespective of drainage systems. However, slightly higher yield (51.4 q/ha) was recorded under conventional drainage over controlled drainage (48.3 q/ha). The slight increase in yield under conventional drainage may be compensated because of saving on account of irrigation water and nitrogen fertiliser. Further, prevention of surface water bodies from pollution was non-tangible benefit and was also important considering environmental protection.

Benefits

The subsurface drainage is provided with device to maintain watertable, reduce drainage volume and prevent loss of nitrogen fertilizer. Further centre has developed controlled drainage system which saves irrigation water up to 17 and nitrogen loss up to 50%.

Impact:

- ✓ Around 20,000 ha was put under subsurface drainage system under TBP command of Karnataka to reclaim waterlogged saline lands reducing waterlogging and soil salinity and increasing crop productivity. During 2017-20, subsurface drainage system has been installed on 13,670 ha in Upper Krishna Project and TBP Command while 4000 ha has been installed in Ghataprabha and Malprabha commands.

- ✓ The Conventional SSD is necessary for reclamation of around 1 lakh waterlogged saline soils in the TBP command of Karnataka. The conventional drainage system may be converted to controlled drainage system once the reclamation leaching is completed after 3-4 years. It will save lot irrigation water and fertilizers.

4.18 DSR on Laser Levelled Fields in TBP Command (Gangavathi)

Problem

Rice is an important crop of Tunga Bhadra Project (TBP) command area cultivated under Puddled-Transplanted Rice (PTR). Poor water management in the command has resulted in the development of waterlogging and soil salinity in over 25% of the command area. Tungabhadra command area in Karnataka is mainly associated with soil salinity, soil erosion and shortage of irrigation water, particularly during *Kharif* season. Soil moisture cannot be distributed uniformly due improper leveling.

Technology

Laser Land Leveler is used for leveling of land and DSR (Direct Seeded Rice) is adopted on laser leveled fields.. A field experiment on Direct Seeded Rice (DSR), Puddled-Transplanted Rice (PTR) with and without laser leveling was conducted on Vertisols at Agricultural Research Station (ARS), Gangavathi, Karnataka. Results of experiment revealed that the total irrigation water applied was 23.2 and 18.1% less under DSR with and without laser leveling, respectively, compared to traditional transplanting without laser leveling. Significantly higher paddy yield was recorded under PTR in laser leveled land (5833 kg ha^{-1}) compared to PTR in traditional leveled land (5056 kg ha^{-1}). Similarly yield under DSR with traditional leveled land was 4893 kg ha^{-1} while it was 5682 kg ha^{-1} under DSR with laser leveled land. Water production efficiency was higher under PTR in laser leveled land (0.51 kg m^{-3}) compared to PTR in traditional leveled land (0.40 kg m^{-3}). The DSR laser leveled land gave highest value of 0.58 kg m^{-3} while DSR in traditional leveled land it was 0.47 kg m^{-3}.

Benefits

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



Impact:

- ✓ The B:C ratio was also significantly higher under DSR in laser leveled land (3.11) as compared to DSR in traditional leveled land (2.87), PTR in laser leveled land (2.66) and PTR under traditional leveled land (2.44). As per 2018 appraisal, the DSR technology has been adopted in about 27,000 ha area in Raichur, Koppal and Bellary districts of TBP command saving 20-25% irrigation water, 50% seed, 25-30% fertilizers and saving on labour and energy. Additional income is estimated at Rs. 15000 ha^{-1} $season^{-1}$ with adoption of DSR technology.

Tamil Nadu

4.19 Sodic Soil Reclamation Using Gypsum (Tiruchirapalli)

Problem

The State of Tamil Nadu has sodic soils in different districts. The pH and ECe and ESP of the soil where gypsum technology was demonstrated were 10.1, 1.78 dS/m and 42. The farmers were not able to grow crops due to high sodicity. It was affecting crops adversely and 75% of crop was getting dry before flowering.

Technology

The Gypsum Requirement (GR) of the soil was 16 t/ha and 50% GR was recommended (8 t ha^{-1}). Soil application of gypsum was done and first crop was rice. Standing water was maintained for dissolution of gypsum. The rice variety was TRY 3 was grown.

Benefits

- ✓ The results of the Post harvest soil sample analysis revealed that the pH of the soil reduced from 10.1 to 8.7. ESP reduced from 42 (initial) to 15.3 and pH was reduced from 10.1 to 8.48. The crop yield increased substantially to 4.67 t/ha.
- ✓ Benefit cost ratio for control plot was 0.85 while it was 1.56 for gypsum treated soil during first year and 2.07 during second year.

Reclamation of sodic soil by gypsum application

Impact

- ✓ Around 1000 ha sodic soil has been treated and the productivity of erstwhile sodic area has gone up.
- ✓ Potential area for application of technology is Lalkudi Block of Tiruchirapalli District and Viralimalai Blocks of Pudukottai District.

4.20 Reclamation of sodic soils using Distillery Spent Wash in Tamil Nadu (Tiruchirapalli)

Problem

In state of Tamil Nadu, highly sodic soils are found. The pH of such soils is around 11.2 ; EC was 1.7; ESP 42. The soil was highly sodic and sandy clay loam in texture. The Gypsum requirement at 50% GR was 9.5 t / ha.

Technology

Soil application of Distillery Spent Wash (DSW) is done @ 5 lakhs litres per ha. The DSW is bye product of sugar cane industry. It is acidic in nature and its pH is 3.7 and EC is 31.6 dS/m. Available N, P and K are 5850, 210, and 14700 mg/litre. The Ca, Mg, S and Na concentrations are 6377, 3600, 2250 and 385 mg/l. The BOD and COD are 38500 and 96500 mg/l. After complete mixing and agricultural operations, rice crop is taken as first crop.

Soil application of spent wash for reclamation of alkali soil

Benefits

- ✓ DSW application reduces soil pH and ESP of soil. It improves soil physical properties. It also provides essential nutrients.
- ✓ In case of high sodic soil, soil pH ws reduced from 11.2 to 8.46 and ESP was reduced from 42 to 17.2.
- ✓ The rice yield was 4.5 tons per hectare compared to 1.5 t/ha in the control plot.
- ✓ Benefit cost ratio in DSW reclaimed field was 1.56 and it was 052 in control plot.

Impact

The DSW technology can be easily adopted in Thiruchirapalli, Perambalur, Ariyalur districts and Viralimalai block of Pudukottai district. However, restriction by Central Pollution Control Board (CPCB) on use distillery spent wash for agricultural operation is important limitation. Permission from CPCB is necessary for use of DSW for reclamation of sodic soil in different states.

4.21 Amelioration of alkali/ RSC waters through gypsum bed/ DSW and its use through drip for growing crops in Tamil Nadu (Tiruchirapalli)

Problem

The RSC waters are found in the state of Tamil Nadu. The pH of alkali irrigation water remains around 8.96. EC and RSC of alkali irrigation water were 1.62 dS m^{-1} and 7.6 meq L^{-1}. The use of RSC waters for irrigation promotes sodification. Therefore, amelioration of RSC water is essential.

Technology

Amelioration of RSC water by gypsum: Agriculture grade gypsum (70 percent purity) @ 12 kg/ha per cm (i.e. 12 kg/100 m^3) is required for neutralization of 1 meq/l RSC. Depending on volume of irrigation water requirement of gypsum can be estimated. As irrigation water is to be applied through drip system, plastic tank can be used for store RSC water and treat it gypsum. Gypsum bed amelioration of RSC water reduced the irrigation water pH from 8.96 to 8.20 and RSC from 7.6 to 3.4 meq L^{-1}.

Amelioration of RSC water by DSW: The DSW is used to treat RSC water. The DSW is mixed with RSC water in ratio of 1: 250. It can reduce pH of irrigation water from 8.96 to 6.95 with complete neutralization of RSC.

Ameliorated RSC water is used through drip for irrigation.

	
Gypsum bed for treating RSC water	**Application of treated water through drip system**

Benefits

- ✓ Treating of alkali water by amendments and applying treated water through drip irrigation system can increase the cotton and vegetable yield significantly under alkali environment in the state of Tamil Nadu. It is most suitable for vegetable cultivation.

Impact

- ✓ 100 gypsum beds were constructed by farmers for reclamation of alkali water in state of Tamil Nadu in RSC water areas.

4.22 Integrated Farming System (IFS) on Sodic Soils of Tamil Nadu (Tiruchirapalli Centre)

Problem

Soil and groundwater in the area are not good. Farmer is getting normal rice yield during Kharif season by utilizing the canal water. But he could not cultivate any second crop due to poor quality groundwater (Highly sodic RSC 6.8; SAR 9.0; EC 1.8).

Technology

Surplus canal water is stored in the pond for Integrated Farming System (IFS). It includes poultry and fisheries along with the crop component and helps to improve water and land productivity.


Benefits

- ✓ The farmer is getting the income throughout the year.
- ✓ He is effectively utilizing the resource from his farm.
- ✓ Now he is getting the additional income of Rs. 75,000 (net profit) per year and smoothly running his family.
- ✓ Cost per unit: Rs. 52,000 per year including cost on capital investment, and Interest on capital.
- ✓ B: C ratio 1.44
- ✓

Impact

- ✓ The techology is working well at experimental farm. However, government support is necessary for its propogation.

Coastal Maharashtra

4.23 IFS for coastal waterlogged area of Konkan (Panvel Centre)

Problem

The coastal areas of Maharashtra suffer from the twin problem of salinity and waterlogging. IFS controls waterlogging. The IFS is necessary to improve water and land productivity.

Technology

- ✓ IFS components are fish pond, paddy field, vegetables, poultry, vermin-compost, ornamental fish raring and horticultural crops.

IFS model by Panvel centre

Benefits

- ✓ Total yield and profitability for 1 hectare area with IFS components revealed B:C ratio 1.99 at vashi farm location

Impact

- ✓ Farmers in Konkan area are adopting IFS model to improve income and increase land and water productivity.

Kerala

4.24 Rice-prawn integration on Pokkali fields in Kerala (Vytlla)

Problem

The polders in Kerala are located below mean sea level and connected with sea. The soils of polders are in acid sulphate in nature. Due to sea water connection, polders become saline-acidic. Such soils are not suitable for normal agricultural cultivation. Only Pokkali rice is grown on such soils. In the coastal area of Kerala, acid saline soils are dominated, which are very in productivity and profitability.

Technology

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

Rice prawn cultivation on Pokkali lands of Kerala

Benefits

- ✓ Farmer got an average yield of 2-3 t for rice and 400 kg/ha for prawn without applying chemical fertilizer and organic manure.
- ✓ Farmer also got additional income from the coconut palm and the vegetables.
- ✓ The B:C ratios for rice, prawn and rice-prawn integration system were 1.3, 3.5 and 2.02 respectively.

Impact

- ✓ Rice-prawn system is adopted by farmers of Pokkalli areas of Kerala.

Andaman & Nikobar Islands

4.25 Land shaping for controlling waterlogging and salinity in A & N islands (Port Blair)

Problem

The coastal areas of Andmans suffer from the twin problem of salinity and waterlogging. Alternate land management system is developed for such areas. Water from the pond was drained to leach salts during first year and from second year onwards rainwater has been harvested and stored for fish and horticulture crops.

Technology

Alternate land management system is developed for waterlogged and saline soils. Water from the pond was drained to leach salts and from second year onwards rainwater has been harvested and stored. The coastal areas of Andmans suffer from the twin problem of salinity and waterlogging. Sea water inundation during high tide makes life and livelihood very difficult as in the case of Padmaspahad village of South Andaman.

Benefits

- ✓ After making the system it was left for one full monsoon season to facilitate leaching of salts and other toxic substances from the raised dykes. Water from the pond was drained and from second year onwards rainwater has been harvested and stored. With in a year the salinity has comedown to less than 1.5 dSm^{-1} from the initial value of 4.6 dSm^{-1} and the pH has improved to 6.4.

IFS model for A&N Islands

- ✓ Encouraged by the favourable soil conditions banana ws grown all around the dikes as boundary plantation and in the remaining area seasonal vegetables viz. bhendi, brinjal, chilies, cucumber, beans, bottle gourd and amaranthus throughout the year.
- ✓ Polyculture of Indian Major Carps was practised in the pond with the production of 520 kg/year. The water harvested during rainy season was used for irrigating the vegetables while the surrounding land is dry and saline. The dykes also effectively prevented entry of saline sea water into the system.
- ✓ Banana cultivation gave her a net return of Rs. 18,000/- and veetable Rs.10,000 in one year after meeting her home consumption. Thus from an area of just more than 1 biga land she earned a net income of around Rs.80,000/- after meeting the food requirements of her family.
- ✓ Cost (Rs.) 45,000 - 60,000 /2000 m^2 area (one unit as per the landscape). On an average, B:C ratio of 1.8 in the first year and 2.0 - 2.5 from second year onwards.

Impact

- ✓ Technology has been accepted by the farmers for cultivating the coastal lowlands. This is included as a method of rainwater harvesting to prove irrigation and utilization of waterlogged saline areas and lowlands under Prime Minister Krishi Sinchaye Yojana and RKVY in A& N Islands.
- ✓ Technology has potential throughout the coastal, waterlogged areas of Andaman Islands, East and west coastal regions of India where waterlogging and salinity are problems.

5. SCREENING OF CROPS AND CROP VARIETIES FOR SALINITY/ SODICITY TOLERANCE

As far as convergence framework for consolidation of outcomes and saving of public resources is concerned, centres of this AICRP provide valuable help for screening of crop varieties developed by crop institutes for salinity and sodicitty (alkalinity) tolerance. Table 5.1 provides details of screening activities undertaken by different centres.

Table. 5.1 Screening for salinity/ sodicity by different centres

S. No.	Name of crop	Developers of varieties of crop	Centres of AICRP on SAS&USW involved in Screening
1	Mustard	ICAR-CSSRI, Karnal, Haryana	Hisar, Agra, Bikaner, Bapatla, Kanpur
		ICAR-DRMR, Bharatpur, Rajasthan	
2	Rice	ICAR-CSSRI, Karnal, Haryana	Tiruchirapalli, Panvel, Vytilla, Gangavathi
		ICAR-IIRR, Hyderabad	
		Tamil Nadu Rice Res. Institute, TNAU & AD Agri. College & Res. Institute, Tiruchirapalli, TNAU	
3	Wheat, Barley Oat	ICAR-CSSRI, Karnal, Haryana	Hisar, Bikaner
		ICAR-IIWBR, Karnal	
		State Universities	
4	Lentil	ICAR-IPRI, Kanpur, Uttar Pradesh, IARI, New Delhi	Agra, Hisar
5	Safflower, Sunflower,Castor	ICAR-IIOR Hyderabad, TNAU, Coimbatore	Gangavathi, Tiruchirapalli
6	Cotton	ICAR-CICR Nagpur Cotton Research Station, Srivilliputhur, TNAU Rasi Seeds Pvt. Ltd., Tamil Nadu	Gangavati, Hisar, Tiruchirapalli
7	Sorghum, Pearl-millet, Sweet Sorghum	ICRISAT, Hyderabad State Universities, UCC : University of Cap Coast, Ghana	Gangavathi, Hisar, Tiruchirapalli
8	Tomato, Spinach, Methi, Cauliflower, Cabbage, Chilies, Garlic	CSAUA&T, Kalyanpur, Kanpur	Kanpur, Tiruchirapalli
9	Ragi	AD Agri. College & Res. Institute, Tiruchirapalli, TNAU	Tiruchirapalli
10	Green gram	IARI, New Delhi, Pulses Research Station, Vamban, TNAU	Tiruchirapalli
11	Maize	TNAU, Coimbatore	Tiruchirapalli
12	Sesame	TNAU, Coimbatore	Tiruchirapalli
13	Okra	MKV, Parbhani, Maharashtra, IIHR, Bangalore, TNAU, Coimbatore	Tiruchirapalli
14	Brinjal	TNAU, Coimbatore	Tiruchirapalli

5.1 Important Screening Findings by Centres

Agra

- Tolerance of several vegetable crops viz., capsicum and okra for salinity of irrigation water was tested under drip and surface irrigation system. For the same yield levels of capsicum, saline water of 8 dS/m could be used under drip irrigation as compared to 4 dS/m with surface irrigation.
- Effects saline water irrigation on yields of non-conventional crops such as Tulasi, sesame, month bean, isabgol, fennel and fenugreek were assessed and relative yields at different irrigation water salinity (ECiw 4, 6 and 8 dS/m) were recorded.

Bapatla

- Screening of various vegetable crops (tomato, brinjal, okra, cluster bean, bitter gaurd, chillies, capsicum root crops like radish, carrot and leafy vegetables like spinach/palak) upto 6 dS/m revealed the salinity tolerance in the order of clusterbean >tomato>raddish>carrot> brinjal>okra>bitter guard>chillies >palak > capsicum.

Bikaner

- Ber cultivation with saline water using drip was established successfully. Saline irrigation water (up to 8.0 dS/m) was used through drip without any significant reduction in yield.
- Most of the vegetables can successfully be grown upto 3 dS/m salinity of irrigation water if water is applied through drip irrigation without any reduction in yields. It was found that even yields increased at 3.0 dS/m salinity of water.
- Irrigation water with salinity more than 2.5 dS/m is not suitable for groundnut cultivation under sprinkler irrigation.
- Yield of ground nut was not affected up to 4 dS/m of irrigation water salinity under drip. The wheat yield was slightly reduced at 8 dS/m. However, wheat yield was drastically reduced above 8 dS/m. Isabgol can be grown successfully with ECiw of 4 dS/m under drip.

Gangavathi

- Tree species such as C. equisetifolia, D.sissoo, Glyricidia and A.auriculiformis have been found promising under saline waterlogged conditions of Tunga Bhadra Project (TBP) command area.
- Fruit species such as wood apple, jamun, pomegranate and sapota have been found promising under saline waterlogged conditions of TBP area.
- On saline soils, cotton and wheat can be successfully grown up to 5-7 dS/m and safflower 4-5 dS/m. Brinjal can be grown in saline (ECe: 4-6 dS/m) vertisols. Ridgeguard can be grown in saline (ECe: 4-6 dS/m) vertisols. Beet root can be successfully grown on saline soils with ECe up to 6-8 dS/m without any yield reduction.
- Tree species such as A.nilotica, D.sissoo and C.equisetifolia were found efficient in intercepting canal seepage when grown parallel to distributaries/canals. Such tree plantations control water logging and salinity in low-lying area.

- Salt-tolerant crops such as cotton, wheat and sunflower can be grown successfully even in high saline soils (12-15 dS/m) by providing pre-sowing irrigation (of 6 cm depth). It is observed that salts in surface soil (0-30 cm) are leached out approximately at 60% leaching efficiency during pre-sowing irrigation.
- On saline soils (ECe 8-10 dS/m), irrigating cotton through drip at 2 to 3 days interval with saline water (<2.2 dS/m) resulted in higher kapas yield.
- In saline soils (ECe 6-7 dS/m) moving water table deeper than 1.2 m, drip irrigation at 2-3 days interval with saline water (<2.2 dS/m) or furrow irrigation once in 15-18 days resulted in higher brinjal yields.
- Threshold soil salinity levels (ECt) were worked out for Ashwagandha (4.87, 4.41 dS/m for seed and root respectively), Vetiver (6.0 dS/m), Palmarosa (5.02 dS/m), Khus grass (6.0 dS/m), Kamakasturi (4.8 dS/m), Tulsi (5.1 dS/m), Citronella (7.2 dS/m), Shatavari (3.96 dS/m) etc.
- Citronella could be grown in saline Vertisols of ECe up to 7.2 dS/m (Gangavathi).
- Rhodes, para and grazing guinea forage grasses could be grown in saline Vertisols of ECe up to 4-8 dS/m.

Hisar

- Irrigation with saline water of EC upto (6-8 dS/m) can be used in conjunction with canal water in cotton –wheat and pearl millet –mustard rotation alternately with 2C:1S. The technology paves way to arrest secondary salinization in canal command (Hisar).
- Saline water of EC 7.5 dS/m can be used in vegetable crops through drip irrigation method (Hisar)

Indore

- Studies were conducted in artificially created saline and sodic soils for evaluation of salinity and sodicity tolerance of important economic crops of the region viz, cotton, sorghum, paddy, maize, safflower, mustard, wheat and barley. Critical limits of crop tolerance (on the basis of 50% reduction in yield) have been found out in respect of the above crops. The list of cultivars tolerant to sole maximum salinity/ sodicity (observed under pot studies) is presented in following table.

Crop	Critical Limits	Varieties
	ESP	
Cotton	40-50	Vikram, 70 – IH - 452, Khandwa - 2, KH 33 / 1146, Jawahar Tapti, Jaydhar, RASI-2
Sorghum	35-45	SPV – 477, 462, 1041, CSH 5 & 9
Paddy	40-50	CSR-11,12, 13, 30, Kranti, IR 36
Maize	15-24	Ganga – 5
Safflower	40-50	JSF-1, IC-11839, IC- 11750, JSF- 144
Mustard	40-50	TH-17,UP-70, RLM-632, RIC-1012, 1013, Varuna, Pusa bold, CS 52, CSTR 332-1
Wheat	45-55	K - 227, WH –157, Raj 307 & 977, KRL 1-4, HI 1077, GW 173
Barley	48-56	DL4- 106, 120, 157, 165, BHS – 12

- A field experiment was conducted on sodic Vertisols at Salinity Research Station, Barwaha with three replications at 20, 30, 40 and 50 ESP which have already been created in the field. The data indicated that the survival per cent of different medicinal and aromatic plant species decreased with increasing levels of soil ESP. Most of the plant species were failed to survive beyond ESP 50. The survival of Babchi, Sadabahar and lemon grass was more than 50 % up to ESP 30 whereas, other plant species like Muskdana, Palmarosa and Kalmegh survived less than 50% at this ESP level. Palmarosa and Kalmegh have survival per cent less than 50 at 20 ESP as well. Babchi and Sadabahar had 72 & 52.3 % survival at ESP 30 which decreased to 31 & 11.3 % at ESP 40 respectively. Ashwagandh was found to very sensitive to sodic condition as it could not survive even at ESP 20.
- The experiment on screening of vegetable crops for sodicity tolerance under sodic black clay soils was conducted at different ESP levels. The survival percentage and yield of vegetable crops decreased with the increasing levels of ESP. Highest yield was recorded in case of cabbage (15.70 t/ha) followed by brinjal (10.50 t/ha) and cauliflower (9.80 t/ha) at ESP 25. The survival percentage of cabbage and cauliflower was less than 50 % at ESP 45 however the survival percentage of brinjal was more than 50 % even at ESP 55.
- Sapota and Ber were found to be sodicity tolerant fruit plants. Babchi, sadabahar and lemon grass are found suitable for cultivation sodic Vertisols up to ESP 30. Ashwagandh was found to very sensitive to sodic condition as it could not survive even at ESP 20.
- Azadirachta indica and Accacia nilotica, the tree species along with native check plant Prosopis juliflora are helpful in reclamation of sodic Vertisols. A successful crop production can be taken up after removal of tree species (10-12 years) under rainfed situations.

Tiruchirappalli

Evaluation of plants for sodicity tolerance

a. Crops and varieties

- The coarse grained rice variety TRY 1 and fine grained variety ADT 45 tolerates up to an ESP of 26
- Green gram variety Pusa Bold tolerates an ESP of 16.
- At higher ESP level of 36, pearlmillet cultivar UCC 17 performed better.
- Up to an ESP of 16, the crops *viz*., Maize (COH M4), Sunflower (CO 4), Sesame (CO 1), Bhendi (Parbhani Kranti), Cluster bean (Pusa Naubuhar) performed better.
- The threshold ESP for the sunflower variety CO4 and hybrid TCSH1 were 16.5 and 13.0, respectively.
- The ESP at 50% yield reduction for sunflower variety CO4 and hybrid TCSH1 were 37 and 34, respectively
- The threshold ESP for okra varieties were 13.5, 15.5 and 16 for hybrid No10, Arkha anamika and Parbhani kranti, respectively.
- The ESP at 50% yield reduction for okra varieties were 31, 34 and 30 for hybrid No10, Arkha anamika and Parbhani kranti, respectively.
- Threshhold ESP for cotton was fixed at 33 for varieties and 28 for hybrids

b. Trees Species

- T*amarindus indica, Bambusa bamboo*, *Lueceana leucocephala, Acacia leaucophloea, and Azardiracta indica* are suitable for agroforestry in rainfed sodic soils.

PC Unit Karnal

- Psyllium (*Plantago ovata* Forsk) known as Isabgol, a medicinal crop of global demand for its laxative value is a very promising crop for cultivation under dry land salinity without any significant yield reduction with saline water of EC 12 dS/m. Isabgol can be successfully grown with 2 number of saline water irrigations; first irrigation after dry seeding and second irrigation after 21 days of sowing (PC Unit, Karnal).
- Evaluated tree species for planting in highly calcareous saline soils with saline irrigation. The preferred choice of tree species for these conditions should be *Tamarix articulate, Acacia nilotica, Prosopis juliflora, Eucalyptus tereticornis, Acacia tortilis* and *Casia siamea* (PC Unit, Karnal)
- In calcareous saline soils, established the agri-horticultural system suited to bio-saline agriculture and the concluded that karonda, bael and aonla could be grown under saline irrigation of up to 12-14 dS/m(PC Unit, Karnal).

6. OPERATIONAL RESAERCH PROJECT (ORP)

6.1 Operational Research Programme at Agra

Use of Underground Saline Water at Farmers' Fields

In Operational Research Project (ORP) the field demonstrations for the use of poor quality groundwater were initiated from kharif 1993 in Karanpur village of Mathura district. The village is located at Fareh-Achhnera road only 6 km away from Fareh town. In 1999 the program was extended to two other villages i.e. Nagla Hridaya and Bhojpur. At these sites, medium and high SAR saline water are available. In the year 2000 the program was further extended to Savai village of Agra district to demonstrate the technologies on the use of alkali water. In kharif 2004, ORP was also started at Odara village of Bharatpur district in medium and high SAR saline water (EC_{iw} 6.0 to 23.5 dS/m and SAR 11-30 $(mmol/l)^{1/2}$. In 2006, one more site was also selected for dry land salinity demonstrations at Nagla Parasuram in Bharatpur District. In 2015-16, eleven farmers are selected using saline water (ECiw: 7.1 to 13.0 dS/m) of different villages i.e. Deen Dayal Dham (Nagla Chandra Bhan), Dhana Khema, Nagla Jalal, Garhi Pachauri and Dalatpur in district Mathura (U.P.) and Odara in Bhratpur district (Rajasthan).

From the year 2017 this program was shifted to three other villages i.e. Signa in Bichpuri block, district Agra and Jalal and Kurkunda in block Fareh, district Mathura. At these sites medium and high SAR saline water are available. The Table 6.1 clearly indicated that the water quality parameters pertaining to tube well water of the selected farmers. The year 2018-19 to 2019-20 fifteen farmers were selected in ORP saline water project**.** The pH of groundwater was almost normal in case of tube wells. The sodium range was recorded (28.9 to 110.7). The Ca+Mg were present in all the water samples but this value was ranged from (9.1 to 22.3). The all collected water samples, CO_3 was not found but HCO_3 was present. The chloride and sulphate were present in all the samples. The SAR ranged from 13.6 to 36.9 but RSC was absent.

Table 6.1: Water quality of farmer's tube well water

Farmers name	EC_{iw}	pH	Na	Ca+Mg	CO_3	HCO_3	Cl	SO_4	SAR	RSC
1.Mr.Kishan Gopal	6.0	7.5	47.2	12.8	-	10.5	21.7	27.8	18.7	-
2. Mr. Vijay Pal Singh	11.5	7.3	96.7	18.3	-	15.8	45.2	54.0	32.0	-
3. Mr. Mahesh Singh	5.8	7.2	47.5	10.2	-	9.7	19.6	28.7	21.1	-
4. Mr. Deepak Singh	10.2	7.4	90.2	11.9	-	10.2	31.5	60.3	36.9	-
5. Mr. Nand Kishor	6.3	7.3	49.6	13.2	-	12.7	20.8	29.5	19.3	-
6. Mr. Pratap Singh	7.2	7.4	59.1	12.8	-	11.9	27.5	32.6	23.4	-
7. Mr. Babu lal	5.3	7.6	40.3	12.7	-	11.5	20.7	20.8	15.9	-
8. Mr. Ram Veer Bhagat	13.3	7.3	110.7	22.3	-	18.7	56.5	57.8	33.2	-
9. Mr. Bhanwar Singh	6.5	7.6	54.4	10.7	-	9.5	26.6	28.9	23.5	-
10. Mr.Tufan Singh	6.4	7.5	52.1	11.9	-	11.9	27.1	25.0	21.4	-
11.Mr.Satish Sharma	3.8	7.5	28.9	9.1	-	7.8	10.2	20.0	13.6	-
12.Mr. Rajesh Singh	6.3	7.5	48.6	14.4	-	11.5	26.8	24.7	18.1	-
13.Mr.Chandra Pal	5.8	7.6	42.3	15.7	-	10.8	27.5	19.7	15.1	-
14.Mr.Nathi Lal	5.3	7.7	38.9	14.1	-	10.4	26.7	15.9	14.4	-
15.Ter Singh	8.3	7.7	61.3	21.7	-	16.8	32.3	35.9	18.5	-

The Table 6.2 clearly indicated that the all mustard growing farmers applied saline water for irrigation. Among wheat growing farmers, 2 farmers applied irrigation in 2 SW: 2CW mode and four farmers gave 1 SW: 1GW. For beet root crop one farmer applied 1SW:2GW and one farmer 2GW:1SW irrigation mode.

Table 6.2. Irrigation mode of ORP farmers and other farmers (2019-20)

Farmers name	Crop	ORP farmers	Other farmers
Mustard			
1. Mr. Vijay Pal Singh	Mustard	All saline water	All saline water
2. Mr. Nand Kishor	Mustard	All saline water	All saline water
3. Mr. Kishan Gopal	Mustard	All saline water	All saline water
4. Mr. Mahesh Singh	Mustard	All saline water	All saline water
5. Mr. Kalicharan	Mustard	All saline water	All saline water
6. Mr. Chandra Pal	Mustard	All saline water	All saline water
7. Mr. Babu Lal	Mustard	All saline water	All saline water
Wheat			
1. Mr. Deepak Singh	Wheat	1SW:2CW	All saline water
2. Mr. Prem Singh	Wheat	1SW:2CW	All saline water
3.Mr. Bhanwar Singh	Wheat	1SW:2GW	All saline water
4. Mr.Rajesh Singh	Wheat	2SW:2CW	All saline water
5. Mr.Nathi Lal	Wheat	1SW:1GW	All saline water
6.Mr. Ter Singh	Wheat	2SW:1GW	All saline water
Beet Root			
Mr. Ram veer Bhagat	Beet root	1SW:2GW	Nil
Mr Kishan Gopal	Beet root	2GW:1SW	Nil
Cauliflower			
Mr.Tufan Singh	Cauliflower(Early)	1SW:1GW	Nil
Mr. Tufan Singh	Cauliflower(late)	2SW:1GW	Nil
Tomato			
Mr.Tufan Singh	Tomato	1SW:2GW	Nil
Bottle gourd			
1.Mr.Tufan Singh	Bottle gourd	2SW:1GW	Nil
Coriander			
Mr. Tufan Singh	Coriander	1SW:1GW	Nil
Cluster bean			
Mr. Tufan Singh	Cluster bean	2SW:2GW	Nil

SW-Saline water, GW-good quality water, CW-Canal water

The ORP farmers and other farmers' pearl millet yields are presented in Table 6.3. It clearly indicated that mustard grain yield of ORP farmers ranged from (24.1 to 27.9 q/ha). It was higher compared to other farmers' mustard yield (22.3 to 26.0 q/ha). At harvest of mustard crop ECe ranged from (4.1- 5.0 dS/m) and pH (7.5 to 7.6).

Table 6.3: Grain yield of pearl millet (q/ha) ORP farmers' fields (2018-19 and 2019-20)

Name of farmers	ORP farmers yield	Other farmer yield	% in increase	At harvest ECe(dS/m)	pH
1.Mr.Tufan Singh	26.8	24.2	10.7	5.0	7.5
2. Mr. Vijay Pal Singh	27.9	25.9	8.2	4.1	7.6
3. Mr. Mahesh Singh	24.1	22.3	8.8	4.4	7.6
4. Mr.Nand Kishor	27.1	23.6	11.1	4.2	7.6
5. Mr. Bhawar Singh	27.7	26.0	10.0	4.3	7.6
6. Kalua	25.3	23.8	6.1	4.3	7.6
7.Nathi Lal	26.8	23.9	12.1	4.7	7.6

Wheat crop in ORP farmer's field

In the rabi season 2018-19 to 2019-20 the eight farmers sown wheat crop in their fields. The wheat variety KRL-210 was sown all the ORP farmers' fields other farmers sown difference wheat variety available market/own. The ORP farmers and other farmers' wheat yields are presented in Table 6.4 Data indicated that the ORP farmers' wheat grain yield ranged from 45.8 to 49.2 q/ha. Other farmers' wheat yield ranged from 39.7 to 44.9 q/ha. At the harvest of mustard crop, ECe ranged from (5.9- 8.2 dS/m) and pH (7.5 to 7.7).

Table 6.4 Grain yield of wheat (q/ha) ORP farmers' field (2018-19 and 2019-20)

Name of farmers	ORP farmers yield	Other farmer yield	% in increase	At harvest ECe(dS/m)	pH
1.Mr. Deepak Singh	49.2	44.9	9.4	8.2	7.6
2. Mr. Prem Singh	47.8	44.1	8.3	6.7	7.6
3. Mr. Bhawar Singh	47.3	43.4	11.7	6.7	7.6
4. Mr.Satish Sharma	45.8	40.8	12.3	5.9	7.6
5. Mr. Babu Lal	46.1	41.2	11.9	6.8	7.5
6. Nathi Lal	48.1	44.9	7.1	5.6	7.6
7.Rajesh	44.0	39.7	10.9	5.9	7.6
8. Ter Singh	46.2	43.2	9.2	8.2	7.7

Mustard crop in ORP farmer's field

In the rabi season 2018-19 to 2019-20 the nine farmers sown mustard crop in their fields. The mustard variety CS-58 was sown all the ORP farmers' fields other farmers sown difference wheat variety available market/own. The ORP farmers and other farmers mustard yield is presented in Table 6.5. It clearly indicated that the ORP farmers' mustard grain yield ranged from 25.2 to 27.6 q/ha. It ranged from 22.7 to 26.2 q/ha for other farmers. At the harvest of mustard crop, ECe ranged from 5.9 to 8.2 dS/m and pH from 7.5 to 7.7.

Table 6.5. Grain yield of mustard (q/ha) ORP farmers field (2018-19 and 2019-20)

Name of farmers	ORP farmers yield	Other farmer yield	% in increase	At harvest ECe(dS/m)	pH
1.Mr. Vijay Pal Singh	27.2	25.3	7.8	8.2	7.5
2. Mr. Pratap Singh	27.5	26.2	5.0	7.7	7.5
3. Mr. Nand Kishor	25.6	23.2	10.6	7.7	7.5
4. Mr.Kishan Gopal	25.2	22.7	11.0	6.2	7.5
5. Mr. Mahesh Singh	27.6	26.0	7.7	5.9	7.5
6. Kalua	26.3	24.8	6.0	6.2	7.5
7.Kalicharan	26.2	23.8	10.1	6.0	7.6
8. Candra Pal	27.2	24.5	11.0	7.2	7.7
9. Babu Lal	26.9	23.9	12.6	6.7	7.6

6.2 Operational Research Programme at Bapatla

Demonstration on gypsum tank to reclaim sodic water for irrigation to different crops

A demonstration under ORP was undertaken to show the farmers reclamation of sodic groundwater through gypsum tank and its positive effect of crop yield. The bore well water having RSC of 9.3 passed through gypsum beds to the existing crops of paddy, fodder jowar, pillipesara and paragrass to evaluate their performance at Elurivaripalem village of Chimakurthy mandal. The grain yield of paddy increased by 8.4% when irrigation water passing through gypsum. Similarly, the biomass of fodder jowar, pillipesara and paragrass increased to 5.7, 7.8 and 3.8 percent, respectively (Table 6.6).

Table 6.6 Effect of RSC water on grain yield of paddy and biomass of fodder crops

Treatments	Irrigation with RSC water(yield t/ha.)	Irrigation with gypsum treated water(yield t/ha.)	Percent yield increase
Paddy	3.75	4.07	8.4
Fodder Jowar	32.70	34.57	5.7
Pillipesara	21.9	23.6	7.8
Paragrass	65.7	68.2	3.8

Fodder crops in salt affected soils-under alternate use of land

The cultivation of food crops has a limited scope in areas where the ground water salinity is high. Under such conditions, growing of fodder crops is attempted as an alternate use of land for improving the livelihood of the farmers. Six fodder crops [T_1- Stylo-Stylosanthus, T_2-Hedge lucerne, T_3- Lucerne, T_4- Fodder sorghum (panthchari-6), T_5- COFS-29 (fodder jowar) and T_6- Sweet sudan grass-Sorghum Sudanese] were tested on large plots in farmers fields at Nidubrolu, Guntur district under saline conditions. The bore well water having salinity of 7.1 was used for irrigation. The initial soil salinity was recorded as 1.1 dS/m and the soil salinity increased to 5.6 dS m^{-1} after irrigation by saline water. Out of six fodder crops screened for saline condition, sweet sudan grass recorded the maximum biomass yield of 42.8 t ha^{-1} followed by CoFS-29 (39.7 t ha^{-1}) and Panthchari-6 (36.5 t ha^{-1}.). Hedge lucerne yielded the biomass of 31.4 t ha^{-1}. Stylo and Lucerne recorded the biomass yield of 7.2 and 8.7 t ha^{-1}, respectively.

Thus, sweet sudan grass and CoFS-29 can be used for fodder production under coastal Andhra Pradesh under saline conditions.

	
Sweet sudan grass with saline irrigation	**Fodder jowar with saline irrigation**

Demonstration on Gypsum Bed on farmers' field in Andhra Pradesh

In Prakasam district of Andhra Pradesh, the ground water quality in many of the places is of alkali in nature and the farmers use to grow paddy, fodders and plantation crops like subabul. The RSC of the ground water on farmer's field at Elurivaripalem village of Chimakurthi mandal in Prakasam district is found to be 9.3. An effort was made to demonstrate the reclamation of alkali water by passing through gypsum bed. The treated water coming through gypsum bed is given for irrigation of existing crops of paddy, fodder jowar, pillipesara and paragrass. The RSC of irrigation water after passing through gypsum bed is 4.5. Irrigation with treated water helped in increasing paddy yields by 8.4% (4.0 t ha^{-1}). Similarly, the biomass of fodder jowar, pillipesara and pragrass increased by 5.7% (34.57 t ha^{-1}), 7.8% (23.6 t ha^{-1}) and 3.8% (68.2 t ha^{-1}) respectively. The farmers felt happy in knowing the technology of passing RSC water through gypsum.

Paddy with reclaimed alkali water

6.3 Operational Research Programme at Indore

Use of lagoon sludge/spent wash and lagoon sludge application on crop production on farmer's field

The demonstrations on the field of Mr. Hariram Malviya (Village Bapalgaon) were conducted during kharif 2016-17 with paddy (CSR-30) as a test crop. One time application of lagoon sludge (LS) and raw spent wash (RSW) was done 30 days prior to transplanting of rice seedlings. Wheat crop was not raised in the same area during rabi season due to ponding of water from canal over flow in the area at the time of field preparation and sowing. The initial ESP, CEC and ECe of the soil were 42.3, 38.0 cmol (p+) /kg & 1.38 dSm^{-1}. Necessary plant protection and inter-culture operations were adopted as per package of practices. The data in Table 6.7 revealed that application of Lagoon Sludge @ 2.5 t ha^{-1} along with Raw Spent Wash @ 2.5 lakh L ha^{-1} increased grain and straw yield of paddy by 96 & 127 % over control respectively. Application of Lagoon Sludge @ 5.0 t ha^{-1} + RSW @ 2.5 lakh L ha^{-1} decreased the ESP to 29.3 after harvest of wheat as compared to its initial level of 42.3.

Table 6.7 Effect of lagoon sludge and spent wash applications on grain yield (t ha-1) of paddy and wheat on farmer's field

Treatments	Yield (t ha-1)		% increase in yield over control		ESP after harvest of crop
	Grain	Straw	Grain	Straw	
Paddy					
Control	0.94	1.95	-	-	40.6
Lagoon Sludge @ 5 t ha-1 Raw Spent Wash @ 2.5 lakh L ha-1	1.85	4.43	97	127	29.3

6.4 Operational Research Programme at Kanpur

Effect of CSR-Bio on tomato and cabbage in sodic soil at farmer's field

The purpose of experiment was to find out the suitable application method of CSR-Bio for vegetable production and to determine the physico-chemical changes in soil. Treatments were T_1- Control, T_2- CSR-Bio (soil application) and T_3- CSR-Bio (soil application + foliar spray).

Sr. No.	Item	Details
1	Crop	Tomato and cabbage
2	Varieties	Azad T-5 and Golden acre
3	No. of treatments	3
4	No. of replication	3
5	Design	RBD
6	Plot size	20 sqm
7	Spacing	40 x40 cm (cabbage) 60 x60 cm (Tomato)
8	Year of start	2015
9	Location	Farmer's field at Vinovanagar, Kanpur Dehat
10	Initial soil status	pH (9.10); EC (0.96 dSm-1); ESP 43.6; O.C. (%) 0.29

The maximum survival percentage, fruit/plant, diameter of fruit and yield of tomato was recorded 56.7%, 22.12, 3.24 cm and 117.98 q/ha and minimum in control plot (Table 6.8).The increment of yield was recorded 24.78% more treated with CSR-Bio (soil application + foliar spray) and 19.85% with CSR-Bio (soil application) over control.

Table 6.8 Effect of CSR-Bio on yield and yield attributes of tomato (mean of two year)

Treatments	Survival (%)	Fruit/plant	Diameter of fruit (cm)	Yield (q/ha)	Inc. (%)
Control	45.4	18.75	2.78	94.55	--
CSR-Bio (soil application)	55.2	21.43	3.21	113.32	19.85
CSR-Bio (soil application + foliar spray)	56.7	22.12	3.24	117.98	24.78

The maximum survival percentage, no of leaves, head weight and yield was recorded 67.5%, 10.45, 0.89 kg and 141.50 q/ha and minimum in control plot (Table 6.9). The increment of yield was recorded 26.06% more treated with CSR-Bio (soil application + foliar spray) and 21.90% with CSR-Bio (soil application) over control.

Table 6.9 Effect of CSR-Bio on yield and yield attributes of cabbage (mean of two year)

Treatments	Survival (%)	No. of leaves	Head wt (kg)	Yield (q/ha)	Inc. (%)
Control	55.0	8.92	0.75	112.25	--
CSR-Bio (soil application)	65.6	9.71	0.86	136.83	21.90
CSR-Bio (soil application + foliar spray)	67.5	10.45	0.89	141.50	26.06

View of tomato at farmer's field, Vinovanagar

View of cabbage at farmer’s field, Vinovanagar

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Indian Standard

IS 11624 : 2019

सिंचाई के पानी की गुणता हेतु — मार्गनिर्देश

(पहला पुनरीक्षण)

Quality of Irrigation Water — Guidelines

(First Revision)

ICS 13.060.01

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BUREAU OF INDIAN STANDARDS
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June 2019 **Price Group 3**

Farm Irrigation and Drainage Systems Sectional Committee, FAD 17

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Farm Irrigation and Drainage Systems Sectional Committee had been approved by the Food and Agriculture Division Council.

The quality of irrigation water is to be evaluated in terms of degree of harmful effects on soil properties with respect to the soluble salts it contains in different concentrations and crop yield. To evaluate the quality of irrigation water, this standard has been formulated as a guideline for advisory purposes.

The standard was first published in 1986. This revision has been undertaken to incorporate the following:

a) Grouping of poor quality ground water for irrigation in India.
b) Consideration of additional toxic elements such as sodium, fluoride, chloride and heavy metals such as selenium, cadmium, lead and arsenic, etc.
c) Water quality in relation to improved irrigation techniques.
d) Suitability of poor quality high saline and alkali ground waters for irrigation in India.
e) Upper permissible concentrations of trace elements in irrigation water.
f) Relative tolerance of crops to alkali stress.

In the formulation of this standard, considerable assistance has been derived from the Central Soil Salinity Research Institute, Karnal, Indian Institute of Water Management, Bhubaneshwar and Water Technology Centre, Indian Agricultural Research Institute, New Delhi.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

QUALITY OF IRRIGATION WATER — GUIDELINES

(First Revision)

1 SCOPE

This standard prescribes the guidelines for assessing the quality of irrigation water.

2 REFERENCES

The following standards contain provisions, which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

IS No.	*Title*
7022 (Part 1) : 1973	Glossary of terms relating to water, sewage, industrial effluents: Part 1
7022 (Part 2) : 1979	Glossary of terms relating ot water, sewage, industrial effluents: Part 2
7022 (Part 3) : 2018	Glossary of terms relating to water: Part 3 Marine water and related methods
11077 : 1984	Glossary of terms on soil and water

3 DEFINITION

For the purpose of this standard the definitions given in IS 7022 (Part 1), IS 7022 (Part 2), IS 7022 (Part 3), and IS 11077 shall apply.

4 SUITABILITY CRITERIA

4.1 The suitability of irrigation water depends upon several factors, such as, water quality, soil type, plant characteristics, irrigation method, drainage, climate and the local conditions. The integrated effect of these factors on the suitability of irrigation water (SI) can be qualitatively expressed by the relationship:

$$SI \propto QSPCD$$

where

Q = quality of irrigation water, that is, total salt concentration, relative proportion of cations/anions, etc;

S = soil type, texture, structure, permeability, fertility, calcium carbonate content, type of clay minerals and initial level of salinity and alkalinity before irrigation;

P = salt tolerance characteristics of the crop and its varieties to be grown, and growth stage usually categorized as tolerant, semi-tolerant and sensitive;

C = climate, that is the total rainfall, its distribution and evaporation characteristics; and

D = drainage conditions, depth of water table, nature of soil profile, presence of hard pan or lime concentration and management practices.

4.1.1 These factors act interactively. For example; in a particular climate, all factors enumerated in **4.1**, are likely to vary and interact either positively or negatively in relation to salt accumulation and degree of harmful effect on soil properties and crop growth. As such, a single suitable criterion is hard to be adopted for widely varying conditions. However, general broad guidelines have been developed for use by the field practitioners.

4.2 Besides these factors, presence of some ions in water such as calcium, sulphate, potassium and nitrate is favourable for crop growth, as water of more salinity can be used in the presence of these ions.

5 WATER QUALITY CRITERIA FOR IRRIGATION

5.1 The following chemical properties shall be considered for developing water quality criteria for irrigation:

a) Total salt concentration;
b) *p*H;
c) Sodium adsorption ratio;
d) Residual sodium carbonate or bicarbonate ion concentration; and
e) Toxic elements such as sodium, boron, fluoride, chloride and heavy metals, etc.

Though all the chemical characteristics are determined separately, these are present in varying amounts in each type of irrigation water. The chemical characteristics interact with each other and cause hazardous effects on soil properties and crop growth. As such the Electrical Conductivity (EC), Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are considered together in classifying the water. The dominating character would determine the characteristics as well as management option although management options for the other character would also be required simultaneously. For example, a water of high EC may have high SAR or RSC or boron or silica. In that event, gypsum may be required even for saline water having SAR > 20 or rich in silica.

5.1.1 *Total Salt Concentration*

It is expressed as the electrical conductivity (EC), in relation to hazardous effects of the total salt concentration. The irrigation water can be classified into two major groups that is marginally alkali and tonic (*see* Table 1).

5.1.2 *p*H

*p*H is an indicator of the acidity or alkalinity of a water, but is seldom a problem by itself for surface irrigation. The main use of *p*H in a water analysis is to detect abnormal water. An abnormal value not falling within 6.5 to 8.4 *p*H range is a warning that the water needs further evaluation as it may cause a nutritional imbalance or may contain a toxic ion. However, *p*H correction plays a very important role in minimizing the clogging of drippers for which a *p*H less than 7 is recommended.

5.1.3 *Sodium Adsorption Ratio (SAR)*

It shall be calculated from the following formula:

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

where

SAR = sodium adsorption ratio (millimole/litre)$^{1/2}$
Na^{+} = sodium ion concentration, me/litre;
Ca^{2+} = calcium ion concentration, me/litre; and
Mg^{2+} = magnesium ion concentration, me/litre.

NOTE — me/l = milliequivalent/litre.

In case the concentration of Na, Ca and Mg ions is expressed in terms of millimole/litre, then the equation for SAR could be written as:

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

In relation to the hazardous effects of sodium adsorption ratio, the irrigation water quality rating is given in Table 1. When SAR is more than 10, it could be high SAR saline or high SAR alkali depending upon the EC or RSC of the irrigation water (*see* Table 1).

5.1.4 *Residual Sodium Carbonate (RSC*)

It shall be determined by the equation:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

where

RSC = residual sodium carbonate (me/l),
CO_3^{2-} = carbonate ion concentration (me/l),
HCO_3^{-} = bicarbonate ion concentration (me/l),
Ca^{2+} = calcium ion concentration (me/l), and
Mg^{2+} = magnesium ion concentration (me/l).

In relation to the hazardous effects of high carbonate/bicarbonate ions concentration expressed as RSC, the irrigation water quality rating is given in Table 1. The high RSC is an indicator that SAR of the water in the soil solution might increase due to precipitation of calcium.

5.1.5 *Mg/Ca Ratio*

Besides the three parameters EC, SAR and RSC, water quality is affected by individual ions as well. Since Mg is considered to be an intermediate ion that is not as harmful as Na and not as good as Ca, excess of Mg as revealed by the Mg/Ca ratio is considered while using guidelines given in Table 3. If Mg/Ca ratio is more than 3.0 addition of gypsum is required to minimize the Mg on the exchange complex of the soils. However, calcium: magnesium ratio above 2.0 in water is beneficial.

5.1.6 *Cl/SO$_4$ Ratio*

Cl salinity is more harmful than the salinity due to SO_4 ions. If Cl/SO_4 ratio is more than 2, additional steps are required to minimize the harmful effect of chloride ions. On the other hand, sulphate: chloride ratio of more than 2.0 is beneficial. Chloride concentration in itself could be toxic beyond 75 mg/l causing severe problems when it exceeds 350 mg/l.

Table 1 Grouping of Poor Quality Ground Water for Irrigation in India
(*Clauses* 5.1.1 *and* 5.1.3)

Sl No.	Water Quality	ECiw (dS/m)	SARiw (millimole/litre)$^{1/2}$	RSC (me/l)
(1)	(2)	(3)	(4)	(5)
i)	Good	< 0.7	< 10	< 2.5
ii)	Saline:			
	a) Marginally saline	0.7 to 3.0	< 10	< 2.5
	b) Saline	> 3	< 10	< 2.5
	c) High-SAR saline	> 3	> 10	< 2.5
iii)	Alkali water:			
	a) Marginally alkali	< 4	< 10	2.5 – 4.0
	b) Alkali	< 4	< 10	> 4.0
	c) High-SAR alkali	Variable	> 10	> 4.0
iv)	Toxic water	The toxic water has variable salinity, SAR and RSC but has excess of specific ions such as chloride, sodium, nitrate, boron, fluoride, or heavy metals such as selenium, cadmium, lead and arsenic, etc		

5.1.7 *Toxic Water*

These waters have variable EC, SAR and RSC but excess of an individual ion that causes toxicity to plants resulting in reduced crop growth/yield. The ions could be chloride, sodium, nitrate, boron, fluoride, or heavy metals such as selenium, cadmium, lead and arsenic etc. Although N is quite useful nutrient for the growth of plants, waters with high N can cause quality problems in crops such as barley and sugar beets and excessive vegetative growth in others affecting their productivity.

Compensation in N is therefore, recommended when the N concentration exceeds 10 ppm NO_3-N (45 ppm NO_3).

Toxic waters need to be tested for specific ions as per location specific requirements.

5.1.7.1 *Boron content*

Boron, though a nutrient, becomes toxic if present in water beyond a particular level. In relation to boron toxicity, the irrigation water quality rating is given in Table 2.

Table 2 Water Quality Rating Based on Boron Content

(*Clause* 5.1.7.1)

Sl No.	Class	Boron (mg/l)
(1)	(2)	(3)
i)	Low	Below 1.0
ii)	Medium	1.0 – 2.0
iii)	High	2.0 – 4.0
iv)	Very high	Above 4.0

5.1.8 *Water Quality in Relation to Improved Irrigation Techniques*

Sprinkler and drip irrigation systems are fast expanding and the water quality requirement for these systems could be vastly different than for surface irrigation techniques. Iron concentrations of less than 0.3 ppm are required for micro-irrigation systems, since iron in water become oxidized to insoluble forms that could cause black or brown stains on foliage of plants if used with sprinkler irrigation. Similar case is with manganese. High chloride concentrations can cause leaf burn when applied with sprinkler irrigation. For sprinkler irrigation bicarbonate less than 1.5 me/l does not pose much problems but the problems increase and become severe when the bicarbonate content is 8.5 me/l.

Concentrations of ferrous iron as low as 0.15 - 0.20 mg/l are considered as a potential hazard for clogging of drip systems. Emitter clogging hazard is moderate for concentrations between 0.2-1.5 mg/l. Concentrations above 1.5 mg/l are considered to cause severe clogging problems. Concentrations of manganese should be < 0.10 mg/l for no problem and the severe problems would be experienced when concentration exceed 1.5 mg/l.

The phosphoric acid used as phosphorous fertilizer could react with available calcium in water and form insoluble phosphate, which precipitate leading to clogging of drippers. Under these conditions *p*H of the water should be decreased below 7 (*see* **4.1.2**) by using high dose of phosphoric acid in the water tank to avoid precipitation of phosphates.

6 WATER QUALITY RATING IN RELATION TO SOIL TYPE, RAINFALL AND CROP TOLERANCE TO SALTS

6.1 Guidelines for the upper permissible limit of electrical conductivity (EC) are given in Table 3 keeping in view the soil types, rainfall and three types of crops, that is Sensitive (S), Semi-tolerant (ST) and Tolerant (T).

Table 3 Suitability of Poor Quality Saline Ground Waters (RSC < 2.5 me/l, SAR <10 (mmol/l)$^{1/2}$ for Irrigation in India

(*Clauses* 5.1.5 *and* 6.1)

Sl No	Soil Texture Group	Crop Tolerance	ECiw(dS/m) Limit for Rainfall (mm) Region		
			< 350	350 – 550	> 550
(1)	(2)	(3)	(4)	(5)	(6)
i)	Fine	S	1.0	1.0	1.5
ii)	(>30 percent clay)	ST	1.5	2.0	3.0
iii)	Sandy clay, clay loam, silty clay loam, silty clay, clay	T	2.0	3.0	4.5
iv)	Moderately fine	S	1.5	2.0	2.5
v)	(20 to 30 percent clay)	ST	2.0	3.0	4.5
vi)	Sandy clay loam, loam, silty loam	T	4.0	6.0	8.0
vii)	Moderately coarse	S	2.0	2.5	3.0
viii)	(10 to 20 percent clay)	ST	4.0	6.0	8.0
ix)	Sandy loam, loam, silty loam	T	6.0	8.0	10.0
x)	Coarse	S	--	3.0	3.0
xi)	(<10 percent clay)	ST	6.0	7.5	9.0
xii)	Sand, loamy sand, sandy loam, silty loam, silt	T	8.0	10.0	12.5

NOTE — (a) The use of waters of 4.0 dS/m EC and above be confined to winter season crops only. They should not be used during the summer season. During emergencies not more than one or two protective irrigations should be given to the *kharif* season crops. (b) For soils having (i) shallow water table (within 1.5 m in *kharif*) and (ii) presence of hard subsoil layers, the next lower EC_{iw} is applicable.

6.2 Upper permissible limits of sodium adsorption ratio (SAR) and residual sodium carbonate(RSC) for various soil textures is given in Table 4. Lower limits of RSC are used for semi-tolerant while upper limits for sodicity tolerant crops.

6.3 The upper permissible limits of boron for ST and T crops are given in Table 5.

6.4 Upper permissible limits of various toxic ions and elements are reported in Table 6.

7 SALT TOLERANCE OF CROPS

There are intra-generic and inter-generic differences in salt tolerance of crops and thischaracter of crops and crop varieties could be exploited to use poor quality water. The data presented in Tables 7, Table 8 and Table 9 presents the relative tolerance of salts to soil salinity, soil alkali and boron. These tables could be used to select crops depending upon the kind and degree of the problem with water.

Table 4 Suitability of Poor Quality High SAR Saline And Alkali Ground Waters (RSC > 2.5 me/l, EC_{iw}< 4.0 dS/m) for Irrigation in India

(*Clause* 6.2)

Sl No.		SAR (mmol/l)1/2		Upper limits of RSC (me/l)		Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
		ST	T	ST	T	
i)	**Fine** (>30 % clay) Sandy clay, clay loam, silty clay loam, clay silty clay,	10	15	2.5	3.5	Limits pertain to *kharif*fallow/*Rabi* crop rotation when annual rainfall is 350-550 mm.
ii)	**Moderately fine** (20 to 30 % clay) Sandy clay loam, loam, silty loam	10	3.5 – 5.0			When the waters have Na < 75%, (Ca+Mg>25%) or rainfall is >550 mm, even the RSC values for tolerant crops becomes safe for ST crops.
iii)	**Moderately coarse** (10 to 20 % clay) Sandy loam, loam, silty loam	15	5.0 – 7.5			Grow low water requiring crops During*kharif*. Avoid rice/sugarcane. Presence of gypsum in soil is favourable
iv)	**Coarse** (> 10) Sand, loamy sand, sandy, loam, silty, loam, silt	20	7.5 –10.0			

Table 5 Suitability of Irrigation Water for Semi-Tolerant and Tolerant Crops in Different Soil Types

(*Clause* 6.3)

Sl No.	Soil Textural Group	Upper Permissible Limit of Boron (mg/l)	
		ST	T
(1)	(2)	(3)	(4)
i)	Fine (Above 30 % clay) sandy clay, clay loam, silty clay loam, silty clay, clay	2	3
ii)	Medium (20-30 % clay) sandy clay loam, loam, silty loam	2	3
iii)	Moderately coarse (10-20 % clay) sand, loamy sand, silty loam	2	3
iv)	Coarse (< 10 % clay) sand, loamy sand, sandy loam, silty loam, silt	1	2

Table 6 Upper Permissible Concentrations of Trace Elements in Irrigation Water

(*Clause* 6.4)

Sl No.	Element	Recommended Maximum Concentration (mg/l)	Remarks
(1)	(2)	(3)	(4)
i)	Al (Aluminium)	5.0	Can cause non-productivity in acid soils (*p*H < 5.5), but more alkaline soils at *p*H > 7.0 will precipitate the ion and eliminate any toxicity.
ii)	As (Arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
iii)	Be (Beryllium)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans

Table 6 — (*Concluded*)

(1)	(2)	(3)	(4)
iv)	Cd (Cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
v)	Co (Cobalt)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
vi)	Cr (Chromium)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
vii)	Cu (Copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
viii)	F (Fluoride)	1.0	Inactivated by neutral and alkaline soils.
ix)	Fe (Iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings
x)	Li (Lithium)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
xi)	Mn (Manganese)	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
xii)	Mo (Molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum
xiii)	Ni (Nickel)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline *p*H.
xiv)	Pb (Lead)	5.0	Can inhibit plant cell growth at very high concentrations
xv)	Se (Selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations
xvi)	Sn (Tin)		
xvii)	Ti (Titanium)	—	Effectively excluded by plants; specific tolerance unknown
xviii)	W (Tungsten)		
xix)	V (Vanadium)	0.10	Toxic to many plants at relatively low concentrations
xx)	Zn (Zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at *p*H > 6.0 and in fine textured or organic soils.

Table 7 Crop Groups Based on Response to Soil Salinity

(*Clause* 7)

Sl No.	Sensitive Group		Resistant Group	
	Highly Sensitive	Medium Sensitive	Medium Tolerant	Highly Tolerant
(1)	(2)	(3)	(4)	(5)
i)	Lentil	Radish	Spinach	Barley
ii)	Mash	Cow pea	Sugarcane	Cotton
iii)	Chickpea	Broad bean	Indian mustard	Sugar beet
iv)	Beans	Vetch	Rice (transplanted)	Turnip
v)	Peas	Cabbage	Wheat	Tobacco
vi)	Carrot	Cauliflower	Pearl millet	Safflower
vii)	Onion	Cucumber	Oats	Rapeseed
viii)	Lemon	Gourds	Alfalfa	Karnal grass
ix)	Orange	Tomato	Blue panic grass	Date palm
x)	Grape	Sweet potato	Para grass	Ber
xi)	Peach	Sorghum	Rhodes grass	*Mesquite*
xii)	Plum	Minor millets	Sudan grass	*Casuarina*
xiii)	Pear	Maize	Guava	*Tamarix*
xiv)	Apple	Clover, *berseem*	Pomegranate	*Salvadora*
xv)			*Acacia*	

Table 8 Relative Tolerance of Crops to Alkali Stress
(*Clause* 7)

Sl No.	Characteristics	ESP Range[1)]	Crops
(1)	(2)	(3)	(4)
i)	Sensitive	10-15	Safflower, mash, peas, lentil, pigeon pea, urdbean
		16-20	Chickpea, soybean
		20-25	Groundnut, cowpea, onion, pearl millet
ii)	Semi-tolerant	25-30	Linseed, garlic, *guar*
		30-50	Indian mustard, wheat, sunflower
iii)	Tolerant	50-60	Barley, *Sesbania*
		60-70	Rice (Transplanted)

[1)] Relative yields are only 50 percent of the potential in respective alkali range.

Table 9 Relative Tolerance of Crops to Boron
(*Clause* 7)

Sensitive (<1 mg/l)	Semi-Tolerant (1.0-2.0 mg/l)	Tolerant (2.0-4.0 mg/l)
Apple	Sunflower	Date palm
Grape	Potato	Sugar beet
Cherry	Cotton	Garden beet
Peach	Tomato	Alfalfa
Orange	Radish	Gladiolus
Grapefruit	Field pea	Broad bean
Lemon	Barley	Onion
	Wheat	Turnip
	Corn	Cabbage
	Rice	Lettuce
	Oat	Carrot
	Bell pepper	Cauliflower
	Sweet potato	

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