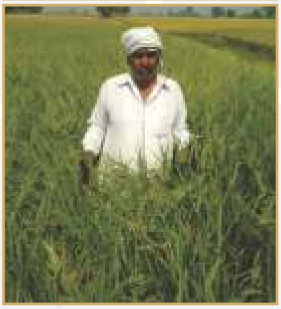
Successful Adaptations in Salt Affected Agroecosystems of India



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A RESOURCE BOOK

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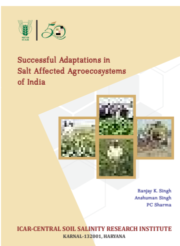

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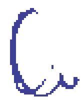
FOREWORD

The agricultural regions of India, like the water and agro-chemical intensive rice-wheat cropping system of Indo-Gangetic Plains, suffer from various kinds of physical and chemical land degradation. Nearly 6.73 Million hectares (M ha) of arable land have become less productive due to salinity/sodicity or combined impacts of waterlogging and salt accumulation. Estimates suggest that about 11.0 Million tones of cereal, pulses and oilseeds valued at INR 150.17 billion are lost annually due to salinity problem: such economic losses are likely to attain epic proportions by the middle of this century as salt-affected area is predicted to increase from 6.73 M ha to 16.2 M ha by 2050. Evidently, salt-induced land degradation has emerged as one of the major environmental issues at global [United Nations Convention on Combating Desertification (UNCCD)] and national (*e.g*., soil reclamation and watershed development programmes) levels. National priorities and objectives enshrined in the recently unveiled policies [*e.g*., Sustainable Development Goals (SDGs) and Land Degradation Neutrality (LDN)] call for concerted efforts for restoring the economic and ecological functions of such degraded lands. Consistent with the UNCCD estimates that investments in land reclamation and management provide about five times more returns, Government of India is making every possible effort for the revitalization of degraded lands including vast stretches of salt-affected soils in both irrigated and dryland areas of the country. Researches spearheaded by ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal since 1969 have led to the development of chemical, engineering, biological and agronomic solutions for giving a new lease of life to saline and sodic soils, often also underlain by poor quality water. Slow penetration of such doable technologies, however, remains a significant concern.

In order to ensure sustainable benefits, planned salinity management technologies especially those compatible with the local socio-economic and biophysical conditions need to be replicated on a large scale. This publication illustrates that planned technologies developed by ICAR-CSSRI, can turn the fortune of farmers grappling with salinity and associated social-ecological risks. I appreciate the painstaking effort of editors for the lucid narration of successes achieved and lessons learnt with such technologies on the farmers' fields. This compilation also demonstrates the synergy between planned knowledge and farmers' strategies. I wish this publication could provide valuable insights to the researchers and extension workers in planning future strategies based on knowledge generation and sharing approach. The information presented will also be of considerable practical utility to the agricultural professionals and policy makers in prioritizing programs and policies for the targeted reclamation and management of salt-affected lands for achieving the Sustainable Development Goods



Dated: 21st January 2019 **(A.K. Singh)**

PREFACE

Various kinds of physical and chemical degradation continue to take a heavy toll on soil health and productivity on about 147 Million hectare (M ha) area throughout India. Estimates suggest that salinity, sodicity and associated problems diminish the productivity of nearly 6.73 M ha area to varying degrees, resulting in the annual loss of about 17.0 Million tonnes of food grains, oilseeds and cash crops valued at Rs. 23,000 Crores. Although such quantitative estimates provide a reasonable approximation of the harmful impacts, basically in relation to farmers' sustenance and drain on national exchequer, spillover effects of salinization impairing the ecosystem functions and services soil's provide are also worth noting. While salinity remains a major driver of land degradation across the world, an impending ecological crisis (*e.g.*, pervasive land use, climate change impacts, fresh water scarcity, and seawater intrusion) is likely to magnify the problem several folds in the foreseeable future.

Precise assessment and monitoring of the land degradation as well as the productive management of degraded lands remain challenging tasks for the researchers, land owners and policy makers alike. In India, the Ministry of Environment, Forest and Climate Change (MoEF&CC) serves as the nodal agency for recording and reporting the extent of land degradation to the United Nations Convention to Combat Desertification (UNCCD). It is also tasked with bringing out and implementing the National Action Plans (NAPs) for combating desertification. Since its establishment in 1969, ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana has spearheaded the agricultural salinity research in country for developing and disseminating affordable management solutions to the salt affected areas. Testing and replication of proven salinity management technologies in different agro-ecological regions of the country in collaboration of various public and private agencies and the non-governmental organizations is another important area of work. Concerted efforts in the last few decades have led to the development of different chemical (gypsum-based package), engineering (sub-surface drainage, land shaping models and groundwater recharge) and biological (salt tolerant crops varieties and agroforestry systems) interventions for giving a new lease of life to the salt impaired lands. Nearly 2.07 M ha sodic area has been reclaimed so far through the gypsum-based package. Similarly, about 70,000 ha waterlogged saline area covered under sub-surface drainage is contributing considerably to food, income and employment generation.

Salt tolerant varieties in rice, wheat and mustard crops are currently being grown on about 1.19 M ha area annually, generating about Rs. 1833 Crores. In addition to these major technologies, many location-specific interventions (e.g., land shaping models) developed in the last few years are also increasingly being adopted by the farmers in different parts of the country.

In this publication, the successes achieved and the lessons learnt with on-farm demonstrations of the aforementioned technologies have been compiled with focus on the interventions compatible with the social-ecological milieus of a given area. A perusal of various case studies presented in this volume clearly reflects the synergy between the planned technologies and farmers' traditional ecological knowledge. It implies that integrated use of formal and informal practices is likely to be more sustainable and needs to be promoted through the policy push. Results of on-farm trials given in this compendium also evince that appropriate technological interventions could inculcate entrepreneurial habit among the farmers. This publication becomes more important for providing the real field experiences and insights that could be helpful to achieving some targets of the Sustainable Development Goals (Target 15.3: life on land) and UNCCD policy. The approaches and adaptive strategies discussed here can help in developing the transformative projects required for achieving some of the targets of the Land Degradation Neutrality (LDN) policy. We are confident that success stories provided in this volume would be of immense practical use to the different stakeholders having an interest in revitalizing the degraded lands.

Ranjay K. Singh
Anshuman Singh
Parbodh Chander Sharma

Editors

ACKNOWLEDGEMENTS

The editors thank with gratitude all the farmers who collaborated with various scientific teams of ICAR-Central Soil Salinity Research Institute, Karnal for adopting and implementing the planned technological solutions to alleviate the salinity and sodicity risks in their crop fields. Editors also thank the Director ICAR-Central Arid Zone Research Institute, Jodhpur and all the Heads of Divisions and Regional Research Stations of ICAR-CSSRI for active support in providing the information compiled in this volume. We thank Indian Council of Agricultural Research, New Delhi (Lal Bahadur Shastri challenge research project and Farmer FIRST project) and different external agencies (NAIP, Krishi Vigyan Kendras, State Line Departments and private stakeholders) for direct and indirect support during the course of these collaborative works.

Editors

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THEME 1

TECHNOLOGICAL INTERVENSIONS FOR MANAGING SODIC SOILS

Blooming Salt Affected Lands

केन्द्रीय मृदा लवणता अनुसंधान संस्थान

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1969-2019

Management of Sodic Soils of Indo - Gangetic Plains : Gypsum, Crop Varieties and Other Technologies

About 6.7 million hectares (Mha) of land in India is salt-affected causing loss of about 11.18 million tones of cereal, pulses and oilseeds valued at ≈ INR 150.17 billion. Such huge yield losses not only adversely affect the livelihoods of individual farmers but also drain the national exchequer. A sizeable area of land in Haryana is affected by sodicity. Farmers face serious constraints in bringing such lands under cultivation. Despite land reclamation efforts made by the State Line Departments for reviving the productivity of degraded sodic lands using gypsum based technology, inadequate availability of seeds of salt tolerant crop varieties has long been a major concern because salt tolerant varieties could be a key biological solution for meneging such soils.

In Haryana state of India, sodicity affected lands are found in patches, interspersed with normal soils. Even in normal soil areas, some fields often exhibit very high soil pH (up to 10), resulting in problems like surface water stagnation and stunted crop growth. Vast areas of sodicity affected lands were reclaimed in different districts of Haryana and Punjab using the gypsum technology developed by ICAR-CSSRI, Karnal in 1970s and 1980s. However, some areas still suffer from sodicity problem, particularly in sub-surface (>15-30 cm) depths. In such lands, high soil pH (9-10) and presence of sub-surface hard pan often cause surface water logging and poor root growth, adversely affecting the rice and wheat crops.

Continuous irrigation with alkali waters leads to gradual build-up of salt, increasing the soil sodicity (soil pH_2 >8.2). Soil sodification adversely affects soil physico-chemical properties and crop growth. Mined gypsum ($CaSO_4.2H_2O$) is the most preferred ameliorant for reclaiming the sodic soils. This is because of its comparatively lower price due to government subsidies and the ease in application as compared to other chemical amendments. However, the gypsum production/availability is limited to only 6-7 million tons per year in India (by-product gypsum and natural gypsum) from all the availabl sources. For reclaiming the increasingly expanding sodic soils, excessive reliance on limited gypsum resources is thus unsustainable. Pressmud is produced as a waste product during sugar manufacturing. Pressmud enhances organic matter content of the soil, improves soil physical conditions, acts as a soil conditioner and or a source of macro and micronutrients (Zn, Cu, Fe and Mn), generally deficient in calcareous alkali soils.

Farmers growing salt sensitive rice and wheat varieties in such soils report yield losses to varying extents. Genetic improvement of rice for salt tolerance received impetus with the identification of land races namely Damodar, Dasal and Getu endemic to the Sunderbans area of West Bengal. These landraces carrying the genes imparting salt tolerance were used for selecting high yielding, salt tolerant, semi-dwarf and early maturing rice varieties (CSR 1, CSR 2 and CSR 3) with better grain quality. These and subsequent successes ultimately paved the way for release of salt tolerant rice 'Basmti CSR 30' (Yamini). In the last few decades, this variety has become highly popular among the Basmati farmers of North-Western India, apparently due to its better performance in saline and sodic soils. Similar successes were achieved with another salt tolerant rice variety 'CSR 36' in many salt affected parts of India. In early phases, salt tolerant wheat ('KRL 1-4' and 'KRL 19') and mustard ('CS 54', 'CS 56' and 'CS 58') varieties were release by ICAR-CSSRI, Karnal. Later on, two more salt tolerant wheat varieties namely 'KRL 210' and 'KRL 213', were also released.

In this section, we discuss about the successes achieved with the interventions of salt tolerant crops varieties, gypsum, pressmud and groundwater recharge technology in the reclamation and management sodic soils in various parts of Haryana, Uttar Pradesh and Punjab States of India.

Case study one: Livelihood empowerment through salt tolerant rice 'Basmati CSR 30'

Salt tolerant 'Basmati CSR 30' is one of the most popular and premium rice varieties in the salt affected areas of North-West India. In this study, we are presenting the huge success of this variety in sodic soils of Karnal, Haryana.

Approaches, interventions and outcomes :

After becoming familiar about the high yield potential, of 'CSR 30' under

Fig 1.1 'Basmati CSR 30' on Mr. Singh's field.

marginal situations, a farmer Mr. Isham Singh of Kachhwa village of Karnal procured its seeds for cultivation in sodic soils (pH 8.4 to 8.9) (**Fig 1.1**). In comparison to other farmers who transplant rice just after the planking, Mr Singh transplants the crop after two days of planking, as he believes that this practice helps reduce salinity and weed infestation in the standing rice crop to a great extent. He hires migrant laborers from Bihar state for rice transplanting, who, he believes, are far efficient in rice transplanting than the local laborers. This practice illustrates how traditional ecological knowledge (TEK) from two diverse locations can be blended for ecological sustainability. It is worth mentioning that during initial two years, Mr. Singh could harvest about 3.0 t grain yield ha^{1} which increased to about 3.4 t ha^{-1} after he followed the recommendations given by ICAR-CSSRI, Karnal. This again shows that TEK and scientific knowledge can be blended to achieve better outcomes. Mr. Singh believes that 'Basmati CSR 30' is more resilient to both abiotic and biotic stressors, lessening the use of external resources for crop protection. Mr Singh reported that he earned a net income of about Rs. 130,000 ha^{-1} from 'CSR 30' cultivation which is nearly thrice the profit realizations from other locally popular rice varieties.

The success of Mr. Singh in achieving more profits in a ecologically sustainable way shortly captured the imagination of other fellow farmers, leading to the increased adoption of this variety by 10 more farmers in the Kachwa village. One such farmer Mr. Vikram Singh reported that CSR 30 cultivation increased his farm income considerably such that he purchased 12 ha of agricultural land near Itarasi, Madhya Pradesh where he started growing 'CSR 30' organically for generating more returns.

Another farmer Mr. Gursevak Singh of neighboring Baras village of Karnal district followed the suit and started growing 'CSR 30' commercially on about 1.5 ha land. Although he previously grew this variety along with other Basamti types like 'Pusa 1121' and 'Pusa 1509', the yields were rather low. However, after coming into contact of ICAR-CSSRI, Karnal he made some changes in the traditional practice including use of improved seeds of 'CSR 30' and application of small amounts of gypsum. Prior to that, he used the

Fig 1.2. 'Basmati CSR 30' crop in a partially reclaimed sodic land

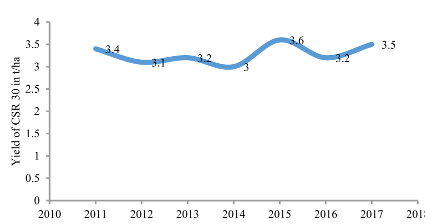

Fig 1.3. Yield performance of 'Basmati CSR 30' in a partially sodic land over years

seeds obtained from other farmers and did not pay any attention to overcoming the soil sodicity. Even very low application of gypsum (~ 3.0 ha^{-1}) than recommended (15-20 t ha^{-1}) resulted in better crop performance (Fig 1.2) and significant increase in the rice yield (Fig. 3), attributed to the integrated use of gypsum, FYM (~ 12.0 t ha^{-1}) and salt tolerant variety. He also grew chick pea in few sodic plots to enrich soil fertility. He was also advised to retain rice and wheat residues for improving the soil organic matter content and water holding capacity. He observed that adoption of these practices also minmized surface water stagnation in the succeeding wheat crop. Like other farmers growing 'CSR 30', Mr Singh also clipped the extra vegetative growth in about 2 month old plants to prevent the lodging. After adopting these agronomic practices, Mr. Singh earned a net profit of about Rs. 140,500 ha^{1} from 'CSR 30' cultivation.

Contributors: Ranjay K Singh, Anshuman Singh, PC Sharma and SK Sharma*. ICAR-Central Soil Salinity Research Institute, Karnal, Haryana. * Deceased.

Case study two: Co-production of adaptive knowledge for enhancing the productivity of wheat variety 'KRL 210'

ICAR-CSSRI, Karnal has been working with farmers for managing the problem of sub-surface sodicity in the reclaimed lands. In this context, the Institute has established rapport with a number of farmers suffering from this problem to suggest them chemical, biological and agronomic remediel measures.

Approaches, interventions and outcomes:

Mr. Surjeet Singh, a large scale farmer of Baras village of Karnal, known for his grassroots innovations, visited ICAR-CSSRI for getting advisory for the management of soil sodicity, seed production of salt tolerant wheat variety 'KRL-210', and for developing his own seed network (farmer-farmer-market). After soil sampling, he was provided agroadvisories for sodicity management. Mr. Singh sowed 'KRL 210' seeds during the first fortnight of November with zero or reduced tillage using a seed-cum-fertilizer drill. For harvesting the bold grains of ' KRL 210' (for seed purpose), he calibrated the seed-drill for sowing 'KRL-210' variety with lower seed rate of 52 kg ha^{-1} (Fig 1.4) at row spacing of 18 cm against the recommended seed rate (100 kg ha^{1}) and row spacing (22 cm) (Table 1.1). Sometimes, he used only 20 kg seed ha^{-1}. Mr. Singh also reduced the nitrogen fertilizer application by 10% (135-140 kg N ha^{-1}), but applied 15% higher P (58-60 kg P_2O_5 ha^{-1}) (Table 1.1).

Regardless of the variety, Mr. Singh usually irrigates wheat crop only once or twice. For example, during 2016-17, he irrigated 'KRL-210' crop only once after 30 days of sowing. No subsequent irrigation was done as crop

Fig 1.4. Seed crop of 'KRL210' (farmer: Surjit Singh)

Table 1.1. Adaptation practices of Mr. Surjit Singh compared with other farmers (2013-17)

Adaptation components	Mr. Singh's practices	Other farmers' practices
Variety	KRL 210	HD 2967
Seed rate (kg ha^{-1})	52	100
Method of sowing	Zero till	Rotavator/zero till
Spacing (cm)	18	20-22
Fertilizer application	--	--
Nitrogen (kg N ha^{-1})	135-140	165-195
Phosphorus (kg P2O5 ha^{-1})	58-60 kg	50
Number of irrigations	1-2	3-4

water requirement was met by the rainfall received on 6 rainy days (96.3 mm) during January and March 2017. After harvesting the crop on 4th April 2017; wheat yield was recorded from 4 random crop cutting plots (4 m^2). Compared to the average yield of around 6.7 ha^{-1} during 2013-14 to 2015-16 (Table 2), wheat yield increased to a maximum of 7.7 t ha^{-1} during 2016-17 (Fig 1.4). Consistent increase in 'KRL 210' yield was attributed to the blended use of the farmer's traditional ecological knowledge (TEK) and the formal Practices. Increase in average wheat yields were apparently due to increased number of effective tillers (452-476m^{-2}) and higher grain weight [(46.2-48.1 g1000 $grains^{-1}$). In addition to obtaining higher yield, Mr. Singh was also able to save 25-30% crop inputs and thus higher monitory returns (Table 1.2).

Table 1.2. Income generated from the seed productin of 'KRL 210'

Adaptation components	Area covered under 'KRL 210' (in acre)	Cost (ha^{-1})	Yield range (t ha^{-1})	Mean yield (t ha^{-1})	Seed sell (t $year^{-1}$)	Rate (Rs q^{-1})	Yearly total income (Rs.)	Yearly net income
2018	34	22500	--	--	--	--	--	--
2017	24	21250	6.3-7.73	6.9	8.0	3000	2,40000	125000*
2016	20	21250	6.4-7.10	6.8	10.0	3000	300000	125000
2015	8	20000	6.3-6.8	6.5	12.5	3000	3,75000	215000
2014	0.8	18750	6.2 -6.9	6.6	4.0	3500	140,000	125000
Mean				2637	6.7	3125	263750	147500
	17.36	20750	--	50				

* About 40 q wheat was sold as deshi wheat for chapatti purpose @ Rs. 3500q^{-1} = Rs 140, 000.

Contributors: Ranjay K Singh, Parvender Sheoran, Kailash Prajapat, Anshuman Singh and PC Sharma. ICAR-Central Soil Salinity Research Institute, Karnal, Haryana.

Case study three: Adoption of salt tolerant variety 'KRL 210' for higher wheat yields

Despite reclamation of large sodicity affected areas in Haryana, sodic soils still exists in the patches in different districts including Karnal where the problem of sub-surface sodicity is also observed. This study provides an account of the success for achieving higher wheat yields through salt tolerant variety 'KRL 210'.

Approaches, interventions and outcomes

Munak village of Karnal district of Haryana has been served by ICAR-CSSRI, Karnal since the early years of its establishment. Throughout 1970s and early 1980s, experiments conducted here played a major role in establishing gypsum as an ideal ameliorant for the degraded sodic lands. After years of experimentation, gypsum treated agricultural lands of Munak village became cultivable, as soil pH steadily declined in the 0-30 cm surface (from 9.9 to 10.04 to 8.9 to 9.1). In the ensuing decades (1980-1990s), farmers started growing coarse grain varieties of rice and wheat, though yields were rather low (i.e. 3.5 to 4.5 t ha^{-1} in coarse grain rice and 3.2 to 4.1 t ha^{-1} in wheat). This situation persisted until ICAR-CSSRI, Karnal again made efforts for popularizing the salt tolerant varieties of rice and wheat. During a farmers fair at Karnal, some farmers of Munak village informed us that water permeability was still poor even in the gypsum treated lands. This problem was particularly visible in winter months when even little rainfall caused water stagnation and crop yellowing. Subsequently, a team of ICAR-CSSRI scientists visited Munak village and collected soil samples from several sodic fields. It was observed that soil pH varied between 8.2 to 8.7 at 0-15 cm and between 8.9 to 9.3 at 15-30 cm depth. Based on soil analysis results, farmers were advised for applying gypsum and cultivating salt tolerant rice ('Basmati CSR 30') and wheat ('KRL 19' and 'KRL 210') varieties.

Based on the previous experience of relatively lower yields (3.2 to 4.5 t ha^{1}) in 'KRL 19', however, farmers were more interested in adopting 'KRL 210'. One of the selected farmers Mr. Pargat Singh also applied gypsum (8.0 t ha^{-1}) for lowering the sodicity. Further, using own creativity; he also applied crop residues and FYM for improving the soil fertility. He was provided the seeds of 'KRL 210' for cultivation on 1.2 ha of sodic land. 'KRL 210' seeds were sown during the first week of November after two ploughings (farmers' practice). Seed germination was much better than other varieties. First irrigation was given after 25 days of sowing. Nutrient application was as usual, but he also applied zinc sulphate to boost the crop growth. Crop was irrigated only twice. Timely monitoring and evaluation were done. The mean numbers of tillers in 'KRL 210' was 458 m^{2} with mean plant height of 101 cm

Fig 1.5. Performance of 'KRL 210' crop in sodic lands of Mr. Pargat Singh

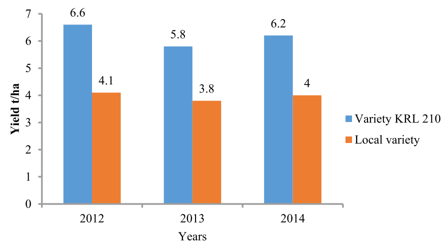

Fig 1.6. Yield performance of 'KRL 210' in sodic lands over years

(Fig 1.5). Random crop cutting experiment results indicated that 1000 grain weight of 'KRL 210' was 34.2 to 41.2 g with mean value of 38.6 g.

In the first year (2012), Mr. Singh obtained a yield of 6.6 t ha^{-1} (Fig 1.6). Average yields of KRL 210 were, however, slightly lower in years 2013 and 2014 (5.8 and 6.2 t ha^{-1}) (Fig 1.6). In spite of this, the grain yield of 'KRL 210' was much higher over the locally popular variety (3.2 to 4.1 t ha^{-1}). According to Mr. Singh, he spend Rs. 22500 ha^{1} on gypsum application and crop cultivation and obtained gross income of Rs. 84810 ha^{-1}which remained more or less constant in 2013 and 2014 because yield reductions in were compensated by the higher MSP (Fig 1.6).

Mr. Singh, quite impressed with the performance of 'KRL 210', planned to expand this variety on 4 ha sodicity affected land. Mr. Singh perceived that more number of tillers, high yield potential, tolerance to waterlogging and lodging were the major attributes of 'KRL 210', distinguishing it from other wheat varieties grown on sodic lands of his village. Initial success of 'KRL 210' paved the way for its popularity among other farmers of Munak village who contacted Mr. Singh for the purchase of 'KRL 210' seeds. About 30 farmers purchased 15 q seeds of 'KRL 210' from him @ Rs. 2500 to 3000 q^{-1}. Thus, Mr. Singh not only earned Rs. 4,1250 but also played a lead role in the diffusion of 'KRL 210' wheat variety.

Contributors: Ranjay K Singh, Parvender Sheoran, Thimmappa K, R Raju, Parveen Kumar, Tekram Sharma and DK Sharma. ICAR-Central Soil Salinity Research Institute, Karnal, Haryana.

Case study four: Community based management of sodic soils for enhancing ecological resilience

A considerable acreage of sodicity affected community lands in Haryana and Punjab states are leased to the farmers on yearly basis. These lessee farmers investing on such community lands (Rs. 20,000 to 35,000 $acre^{-1}$ for salt affected and Rs. 30,000 to 45,000 acre^{-1} for normal lands) obtain very low rice and wheat yields. For example, soils with high pH (9.0 to 9.8) and low soil organic carbon (0.22 to 0.68) produce only 3.3 to 4.0 t ha^{-1} grain yield of coarse rice, 2.2 to 3.0 t ha^{-1} of Basmati rice and 3.5 to 4.5 t ha^{-1} of wheat.

Approaches, interventions and outcomes

In this backdrop, ICAR-CSSRI, Karnal recently extended a technology package for reviving the productivity of sodicity impaired community land in Begampur village of Karnal district. About 40 ha sodic area was sampled and soil samples analyzed for understanding the constraints.

Soil pH was found to be 8.0 to 10.1 in the upper 0-15 cm layer and up to 10.5 at 15-30 cm depth. The soils were low in soil organic carbon (73.33%), nitrogen (100.0%), zinc (66.7%), boron (86.7%), iron (33.3%) and manganese (93.3%) (Table 1.3). These parameters were also found to be low in the farmers' fields. To enhance the adaptive capacity of these farmers, two (October and November 2017) Goshthis were organized with the active participation of male and female farmers, Village Sarpanch, and other stakeholders including officials of State Agriculture and Revenue Departments, and Private Input Suppliers. During these goshthis, farmers were informed about the rising deficiency of soil organic carbon and crop nutrients due to the indiscriminate use of chemical fertilizers and the burning of crop residues. In order to sensitize them about the importance of

Table 1.3. Nutrient status of community land soils in Begampur village of Karnal

	Number of samples (%)					
Soil pH_2	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
	Soil organic carbon			**Nitrogen**		
Normal (<8.2)	00.00	00.0	00.0	00.0	00.0	00.00
Sodic (>8.2)	73.33	26.66	00.0	100.0	00.0	00.00
	Phosphorus			**Potassium**		
Normal (<8.2)	00.00	00.0	00.0	00.0	00.0	00.00
Sodic (>8.2)	00.00	6.66	93.33	00.0	80.0	20.00
	Sulphur			**Zinc**		
Normal (<8.2)	00.00	00.0	00.0	00.0	00.0	00.00
Sodic (>8.2)	20.00	26.66	60.0	66.66	6.66	00.00
	Boron			**Iron**		
Normal (<8.2)	00.00	00.0	00.0	00.0	00.0	00.00
Sodic (>8.2)	86.66	13.33	00.0	33.33	13.33	6.66
	Manganese			**Copper**		
Normal (<8.2)	00.00	00.0	00.0	00.0	00.0	00.00
Sodic (>8.2)	93.33	00.0	00.0	6.66	00.0	53.33

Fig 1.7. A view of farmers' goshthi

Fig. 1.8. 'KRL 210' crop on women farmers' field

Fig 1.9. 'KRL 210' crop in a sodic land

balanced nutrient use, a total of 25 farmers were also provided Soil Health Cards and agroadvisories during these interface meetings.

In order to manage these stressors, the Village Panchayat sought consultancy services from ICAR-CSSRI, Karnal for the detailed diagnosis of problems and the possible management options. Ultimately, ICAR-CSSRI succeeded in convincing the concerned farmers for stopping the crop residue burning such that Village Pachayat formally passed a resolution for no burning of the crop residue (Fig 1.7). The Panchayat also exhorted the famers for soil reclamation and management using the recommended practices.

During these Goshthis, a review of various aspects (Soil Health Cards, gypsum requirements and performance of salt tolerant wheat variety 'KRL 210') was also done (Figs 1.8 & 1.9). For managing rice and wheat residues on sodic community lands, relevant knowledge and information for the purchase of machinery (improved mulcher and moderated seed drill for wheat) were also provided to the Village Panchayat. The farmers were also informed about custom hiring of farm machinery, agro-practices (gypsum application, laser leveling, green manuring and direct seeding of salt tolerant Basmati rice 'CSR 30') recommended for reducing the impacts of abrupt weather on soils and crops. Notably, intense rains during January and February in the last couple of years led to about 30% decrease in wheat yields. As a follow-up action, 10 farm women who were provided 'KRL 210' seeds (free of cost), were also given 'Basmati CSR 30' seeds. Complete technical know-how is being extended to the Village Panchayat and farmers for sustainable rice and wheat production on these salt affected lands. Farmers are also being encouraged to form the Self-Help Groups for commercial seed production and marketing.

This could be perhaps the first example where the expenses incurred on developing Soil Health Cards were borne by the Village Panchayat itself. Gypsum application for lowering the soil pH along with the above mentioned agro-practices could increase rice and wheat yields significantly. During

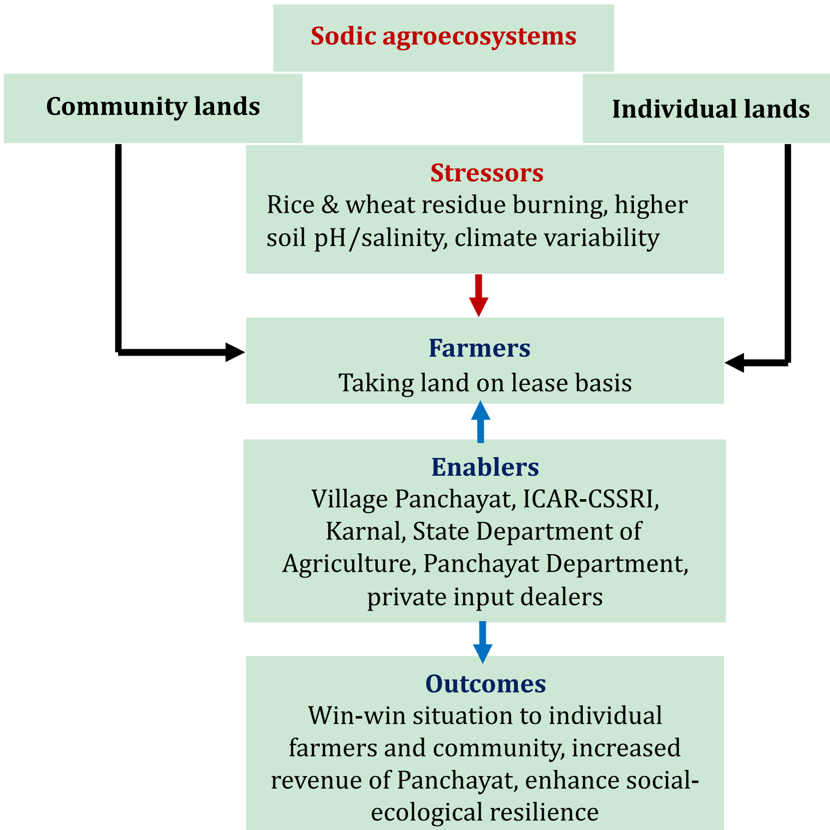

Fig 1.10. Conceptual framework being tested to enhance social-ecological resilience of sodic agroecosystems

2018, the grain yield of 'KRL 210' was found to be between 4.8 to 5.5 t ha^{-1} and that of 'Basmati CSR 30' between 2.7 to 3.2 t ha^{-1}. Some farmers in the Begampur village also grow muskmelon as relay crop in wheat (an example of autonomous adaptation) in furrows during the first week of February when wheat shoots are clipped for the use as fodder. This practice helps them increase the income while reducing the risks. Muskmelon plant residues remaining after the fruit harvest are mixed into the soil during July for enhancing the fertility. It is expected that the auction prices of such community lands where planned (e.g. gypsum, salt tolerant varieties) or autonomous adaptation strategies (e.g. relay cropping of muskmelon) are being adopted would increase considerably compared to the present rate of Rs. 90,000 ha^{-1}. Lessee farmers, who follow resilient practices on community lands, need to be incentivized for promoting such farmer-led innovations. A multi-stakeholders approach, as in this study, can really be a win-win situation for the productive management of degraded common property resources, resulting in increased resilience of agroecosystems (Fig 1.10).

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Case study five: Managing heavy textured sodic soils through gypsum application and 'CSR 36' rise cultivation

In many arid and semi-arid regions of India, poor quality gorundwater is a major factor limiting the crop productivity. Nearly a quarter of arbale lands in Punjab and Haryana states are underlain with alkali gorundwater. The problem is particularly severe in Ghaggar plains covering parts of Ambala, Kurukshetra and Kaithal districts (Haryana) and Patiala (Punjab). Prolonged use of alkali groundwater in irrigation leads to soil sodification, drastically imparing the soil health and crop production.

Approaches, interventions and outcomes

In Pattijunia village of Patiala district of Punjab, sodicity is a major enviromenal stress. This village has been adopted by ICAR-CSSRI, Karnal for providing agroadvisories to the farmers for managing sodic soils and waters which often result in heavy yield losses. The main source of irrigation in this village is alkali groundwater (RSC 2.5 to 3.0 meq L^{-1}). The problem of irrigation induced sodification is further exacerbated due to heavy texture of soils. When alkali waters are utilized for irrigation, calcium gets immobilized because of its precipitation as calcium carbonate, leading to the excessive saturation of soil with sodium. Similar problems plagued the farm land of Mr. Jagjit Singh resulting in repeated crop failures. In some years, he was even not able to recover the costs incurred on sowing (wheat) and transplanting (rice). Effects of alkalnity were more obvious in years with intense winter rains and/or deficient monsoon.

Our intercactions with Mr. Singh and other farmers revealed that these agroecosystems were quite productive during the 1980s. Since the early years of 1990s, however rainfall variability has increased and run-off flows from Kale-Amb area decreased. These climatic and hydrological constrints togather with land use changes have lowered natural groundwater recharge substantially.

Rice is the main *kharif* crop in Pattijunia village. Like other farmers, Mr. Singh was barely able to harvest ~2.5 t ha^{-1} with locally popular varieties suffering from heavy plant mortality, reproductive sterility and poor grain filling (Fig 1.11). In case of wheat, seed gemination was invariably poor.

Fig 1.11. Burned crop of locally popular rice variety in highly sodic land

Fig 1.12. Farmer Mr. Singh with bumper crop of 'CSR 36'

Whole of the wheat crop used to become yellowish and later on succumbing of alkali stress shortly after the first irrigation. After Mr. Singh agreed to adopt the technologies and methods developed by ICAR-CSSRI, Karnal; a team of scientist visited his field for understanding the extent of the problem so that appropriate advisories could be provided. After soil sampling and analysis, he was provided Soil Health Card along with complete agroadvisories. Ultimately, he adopted the reclamation package consisting of gypsum and salt tolerant rice variety ('CSR 36').

In order to enhance the soil fertility and reduce the sodicity stress, Mr. Singh also applied FYM (5.0 t ha^{-1}) at lump sum cost of Rs. 15000. After some informal experimentation, he found that incorporation of 30 to 40% of rice residues in October had an adverse effect on wheat crop. However, incorporation of the chopped rice resudes during May followed by mixing into the soil gave good results. Mr. Singh obtained average grain yield of 5.0 t ha^{1} in 'CSR 36' (Fig 1.12) when the crop was transplanted in the gypsum treated fields (5-6 t ha^{-1}). However, grain yield was only about 3.6 t ha^{-1} in the unamended fields (Table 1.4). Yield increase in rice due to adoption of 'CSR 36' was 100% and 44% with and without gypsum application, respectively, as compared to locally popular rice variety. B: C ratio was the highest (1.81) with 'CSR 36' grown in the gypsum treated fields (Table 1.4), but only 1.46 in

Table 1.4. Economics of salt tolerant rice variety 'CSR 36' in sodic soils

Particular	Locally popular variety	Salt tolerant rice 'CSR 36' ha^{-1}	CSR 36+Gypsum application @ 5-6 t ha^{-1}
Rice yield (t ha^{-1})	2.5	3.6	5.0
Gross return(Rs.)	45000	64800	90000
Cost of cultivation (Rs.)[1]	34807	34807	39007
Net return (Rs.)[2]	443	29993	50993
B:C Ratio	1.29	1.46	1.81

Source: [1]Directorate of Economics and Statistics, MOA (year 2015-16). [2]MSP @ 1410 q^{-1} (2015-16) the unamended soils. Of late, several other farmers of this village are contacting Mr. Singh to learn the science and art of rice 'CSR 36' cultivation, and are willing to work in collaboration of ICAR-CSSRI, Karnal and other stakeholders for augmenting the rice yields. It is expected that such collaborative efforts can help extent the cultivation of salt tolerant rice varieties not only in this village but also in the other areas of Patiala district suffering from the sodicity problem. In so far as Mr. Singh is concerned, he seems to be now fully convinced about the huge potential of this integrated package and is willing to experiment with other techniques and varieties (e.g., 'Basmati CSR 30') for further improving his farm incomes.

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Case study six: Co-adaptive strategies to manage sodicity and climate risks in farming

Several parts of Punjab and Haryana, the 'food bowl' states of India, suffer from salinity and sodicity stresses to varying extents. Nearly 0.38 m ha salt-affected area in these two states urgently requires technological interventions for sustaining the crop productivity and arresting the land degradation. However, development of robust adaptive strategies to cope up with soil and water related constraints continues to be a daunting task for the policy makers and researchers alike. Many parts of Patiala district of Punjab, lying in the Ghaghar basin, suffer from the problem of high sodicity in soil and irrigation water. The affected lands display degraded soil structure, causing heavy reductions in rice and wheat yields. Although these problems are not new to the region, they have progressively attained critical levels; especially in the areas experiencing erratic rainfall since the last two decades. Before mid-1980s, normal rainfall over most of the region was a boon to the local farmers in that run-off carrying fertile alluvium replenished the soil fertility while rainwater percolation kept groundwater alkalinity in check. Unfortunately, erratic rainfall during 1986 to 2016 (normal annual rainfall in 17 years, excess in 7 and deficient in 6 years) had adversely affected the salt balance in the soils and groundwater as evidenced by the steady increase in residual sodium carbonate (RSC) content of groundwater, higher soil pH and poor soil permeability. Fresh watertable has consistently declined further enhancing the risks in agricultural production. In general, farmers in sodicity affected parts of Patiala district have poor access to improved salinity management technologies for sustaining the farm production.

Fig 1.13. Adverse impact of high RSC irrigation water (4.5 meq L^{-1}) and soil sodicity (pH_2 9.5) on rice crop

Approaches, interventions and outcomes

It was in the year 2009 when a group of farmers from Budhmour and Jodhpur villages of Patiala confronting sodicity-induced crop losses approached the scientists of ICAR-CSSRI, Karnal. They narrated in detail as how steady rise in groundwater alkalinity and the accompanying land degradation had brought their lives to a standstill. Repeated crop failures in rice and wheat, ascribed to heavy plant mortality, yellowing, reproductive sterility and poor grain setting (Fig 1.13) had become quite common resulting in moderate (30-40%) yield losses. Years of deficient rainfall, farmers told, spelled doom by causing virtually complete loss of production. Farmers received a warm response from the Institute. A multidisciplinary team of scientists was constituted to visit the affected villages to understand the nature and extent of the problem. Subsequently, repeated visits were made to collect the socio-economic profiles of the affected farmers as well as soil and irrigation water samples so that appropriate remedial measures could be implemented.

Participatory research and technological interventions

Diagnosis of soil and irrigation water samples from Yodhpur and Budhmour villages revealed heavy soil texture (silt + clay ~80.0%), high pH_2 (8.5-9.5), moderate salinity (EC_2 0.7-0.9) and high RSC in groundwater (3.5-4.1 meq L^{-1}). Soils were also found to be deficient in organic carbon, available N and available P (Table 1.5).

Table 1.5. Physico-chemical properties of sodicity affected lands in the study area

Soil (0-15cm)	Soil			Water				
Soil pH_2	Soil EC_2 (dS m^{-1})	Organic carbon (%)	Available N (kg/ha)	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})	RSC meq L^{-1}	pH	EC (dSm^{-1})
8.5-9.5	0.7-0.9	0.4-0.5 (low)	143.9 (low)	21.2 (low)	228.8 (medium)	3.5-4.1 (high)	7.8-8.2	0.7-0.8

Note : No. of Soil samples 28; No. of water samples 9

The initial results of soil and water analysis were communicated to the selected farmers. This was for the first time when affected farmers came to know about '*RSC*' problem in irrigation water which was in fact the main underlying cause for land degradation and poor crop yields. Because it was a preliminary analysis, detailed investigations were necessary to provide suitable agro-advisories to the farmers based on long-term trends. Consequently, a participatory research plan was conducted for the four consecutive years (2009-2012) to draw the valid conclusions.

Success in rice crop

Based on the results of participatory diagnosis, uneven land surface, high RSC in irrigation water and susceptibility to waterlogging were identified as the major stresses. Accordingly, appropriate scientific interventions including chiseling (10.2 ha), laser leveling (1.2 ha) and gypsum application to neutralize RSC water (16.8 ha) were implemented. Besides, farmers were also provided improved seeds of salt tolerant Basmati rice 'CSR 30' for a comparative evaluation with locally popular coarse grain variety Pusa-44 (Table 1.6).

Table 1.6. Participatory technological interventions in the affected lands

Interventions	Yield	
	'CSR 30' (t ha^{-1})	'Pusa 44' (t ha^{-1})
Chiseling (10.2 ha)	1.99	4.61
Without chiseling	1.85	4.21
% increase	8.0	10.0
Laser leveling (1.2 ha)	2.04	4.83
Without leveling	1.89	4.17
% increase	12.0	15.0
Gypsum application through gypsum bed (16.8 ha)	2.71	5.37
Without gypsum	1.98	4.07
% increase	37.0	29.0

(Source: CSSRI Annual Report, 2009; with modifications)

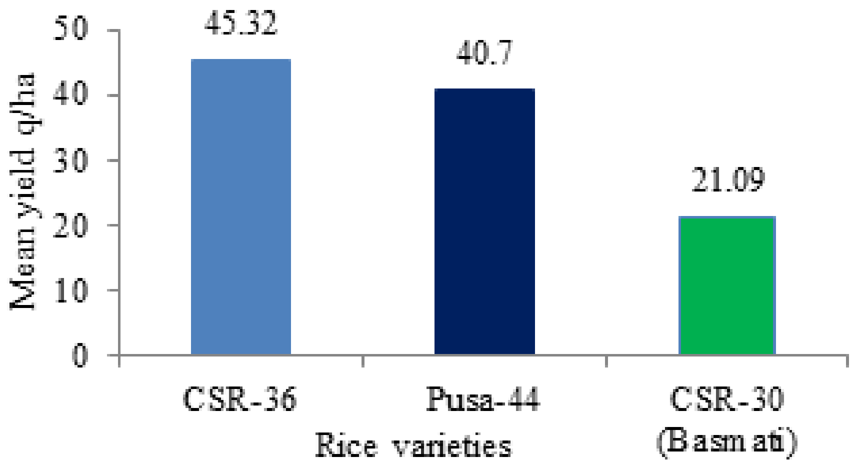

Fig 1.14. Performance of salt tolerant and sensitive rice varieties (2008-2017) irrigated with high RSC water in selected villages of Patiala district

A multidisciplinary team of scientists involved in different projects and activities through which interventions were made, assessed the success. Results indicated that chiseling improved the grain yield of 'Basmati CSR 30' and 'Pusa 44' by 8.0% and 10.0%, respectively. Similarly, lesser leveling enhanced the yields by 12.0% in CSR-30 and by 15% in Pusa-44. In contrast, when high RSC irrigation water was passed through the gypsum beds (kept in tube-well chamber) increase in the grain yield was relatively higher (37.0%) in 'Basmati CSR 30' than in 'Pusa 44' (29.0%) (Table 1.6).

Encouraging results obtained in this participatory project (Table 1.6) were further shared with the farmers of nearby Yodhpur, Pattijunia and Kharabgarh villages who faced similar problems. Specifically, these farmers were motivated to adopt improved management practices and salt tolerant cultivars of rice ('CSR 36' and 'CSR 30') and wheat ('KRL 210') to stabilize the farm incomes. Due to these efforts, out of 35 sampled farmers, ≈60.0% of the farmers applied gypsum in the affected lands, 40.0% adopted lesser leveling, 15.0% tested chiseling and 5.0% adopted gypsum-bed technology for neutralizing RSC in irrigation water. Average rice yields were ≈4.4 and 4.0 t ha^{-1} in 'CSR 36' and 'Pusa 44', respectively (Fig 1.14) reflecting an increase of ≈10.0% in ' CSR 36' over 'Pusa 44'. It is pertinent to mention that although some farmers in the study area had adopted 'Basmati CSR 30' in 2007-2008, shortly before these interventions commenced, they failed to obtain satisfactory yields due to non-adoption of gypsum-based technology. Subsequently, gypsum application- either in soil or through irrigation water- considerably improved 'Basmati CSR 30' yields enabling the farmers to

Fig 1.15. Impact of chiseling and gypsum application on the 'Basmati CSR 30' rice crop grown with high RSC water (4.0 meq L^{-1}) irrigated field

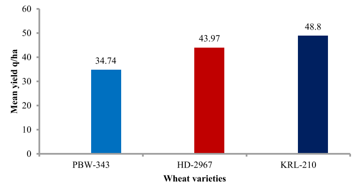

Fig 1.16. Performance of wheat varieties during 2008-2017 in sodicity affected lands of Patiala district

Fig 1.17. 'KRL 210' crop in a sodic field (Farmer : Mr. Lakhbir Singh)

harvest ≈2.1 t ha^{-1} grain yield since 2010 (Fig 1.15). Majority of the local farmers are now fully convinced that integrated adoption of gypsum technology and 'Basmati CSR 30' rice is an attractive proposition.

Success in wheat crop

Taking a cue from the astonishing success in rice crop, efforts were also started to enhance wheat yields under similar conditions. In this area, farmers grew wheat variety 'PBW-343' during 2008-2012 and obtained average yields of 3.8 t ha^{-1}. During 2013-2017, several farmers started cultivating 'HD-2967' which gave relatively higher average yields of 4.4 t ha^{-1} (Fig 1.16). In the mean time, in 2015, salt tolerant wheat cultivar 'KRL 210' was demonstrated on selected farmers' fields (Fig 1.17) where it outperformed both 'PBW-343' and 'HD 2967'. The mean grain yield of 'KRL 210' (4.9 t ha^{-1}) was ≈29.0% and 10.0% higher compared to 'PBW 343' and 'HD 2967', respectively, under identical levels of sodicity in soils and irrigation water.

A strong majority of the studied farmers (85.0%) informed that lack of government subsidy was the major hindrance to the adoption of gypsum-bed technology involving one-time lump sum investment of ≈ Rs. 35,000 unit^{-1} for constructing the special chambers. As a consequence, though aware of potential benefits, most of the small and medium farmers were unable to adopt this technology. In comparison, relatively higher adoption of laser land leveling as attributed to the nominal costs (≈Rs. 3000 ha^{-1}) of custom hiring every 3rd year. Declining availability of good quality agricultural grade gypsum is another constraint hampering gypsum use. Average calcium sulphate in gypsum collected from the study area has been found to be very low (≈42.0%) compared to the prescribed 72.0%. Farmers facing reduced gypsum supplies often procure it from the reliable sources in neighbouring Haryana state, further enhancing the application costs.

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Case study seven: Waste to wealth- Pressmud as potential ameliorant for sodic soils

Considering the rapidly declining gypsum availability, there is an urgent need for developing efficient alternative amendments for reclaiming the remaining sodic area of North-Western India. Nearly 11.0% of the total area of Kaithal district (2,6301 ha) of Haryana is salt affected comprising of 15,986 ha sodic and 10,315 ha saline soils. In Kaithal block, sodic soils (6122 ha) predominate where groundwater used for irrigation is also sodic. These soils are slightly (4313 ha) to moderately (1809 ha) sodic in nature. There is a Co-operative Sugar Mill in Kaithal district which can provide the pressmud required for reclaiming the sodic soils of district (Fig 1.18). There are several process in safe disposal of byproduct pressmud. Some previous studies have shown the beneficial effects of the organic amendments like pressmud in neutralization of RSC (residual sodium carbonate) in irrigation water with a concomitant reduction in sodicity and increase in crop productivity. In this background, we carried out an experiment on farmers' field for showing the potential use of pressmud as a reclaimant.

In this study, five villages (Mundri, Kathwar, Geong, Sampli Kheri and Bhaini Majra), were selected under Farmer FIRST project. A systematic and extensive survey of soil and water quality indicated that 40.1% of the total cultivable area in these 5 villages was sodicity affected (soil pH_2>8.5) with 90% of the surveyed area having high residual alkalinity in irrigation water (RSC_{iw}>2.5 meq L^{-1}, threshold value defining the critical limit for safe use of groundwater for irrigation purpose). We noted a positive correlation between soil sodicity buildup with increase in RSC of irrigation water (R^2=0.64) (Fig 1.19). An intensive transect walk, group discussions (Fig 1.20) and personal interactions were conducted with the selected farmers of these villages to record their knowledge on conventional practices of sodic soil reclamation and crop management.

Fig 1.18. Dumping of pressmud near Sugar-Mill

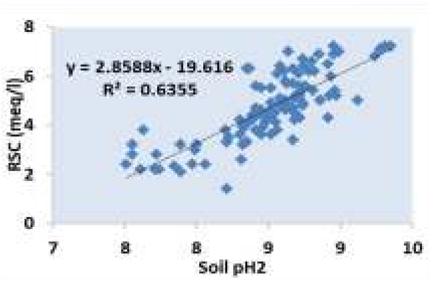

Fig 1.19. Correlation between soil sodicity and irrigation water alkalinity

Fig 1.20. Group discussion with farmers of Mundadi village

Fig 1.21. Pressmud treated sodic field with 'KRL 210' wheat (Farmer : Mr Tarsem Singh)

We came to know that farmers in the study area were using gypsum as a soil ameliorant without giving any consideration to gypsum application for neutralizing the high RSC in irrigation water. None of the interviewed farmers had ever applied pressmud for reclaiming the sodic soils. Taking this knowledge gap into account, multi-stakeholders meet including farmers, scientists, representatives of Haryana Land Reclamation and Development Corporation and State Department of Agriculture was carried out with the objective of developing conjunctive use (gypsum and pressmud) package for enhancing the crop yields in sodicity affected soils.

There was a large heterogeneity under field conditions owing to variable soil sodicity and irrigation water alkalinity. To manage this, technology validation trials were categorized into six groups accordingly to stress intensity: soil pH_2<8.0, 8.0-8.5, 8.50- 8.75, 8.75- 9.0 and >9.0 and RSC: <3, 3-4, 4-5, 5-6, 6-7 and >7 meq L^{-1}. To demonstrate the complementary effects of pressmud, participatory research was carried out with a large number of farmers on sodic lands (2000 m^2 area at each location). Pressmud was applied @ 10 t ha^{-1} as improved practice (IP) and compared with farmer's practice (unamended control) (FP) at 37 locations in the rice-wheat production system (Fig 1.21).

Pressmud was applied in the month of June and incorporated into top 10 cm soil 15 days before rice transplanting. Grain yields of rice and wheat harvested from 37 locations of farmers' field in terms of system productivity (wheat equivalent yield) strongly ($p<0.05$) reflected the influence of soil sodicity (soil pH) and residual alkalinity in irrigation water (RSC_{iw}). The cumulative yield gain with the application of pressmud was relatively better with the increase in soil pH and deterioration of irrigation water quality (Fig 1.22). Complementary effects of applying pressmud as reclamative/ neutralization ameliorant proved its effectiveness in sustainable use of poor quality waters for the rice-wheat system of the North-Western India. The mean yield advantage was ~15% and ranged

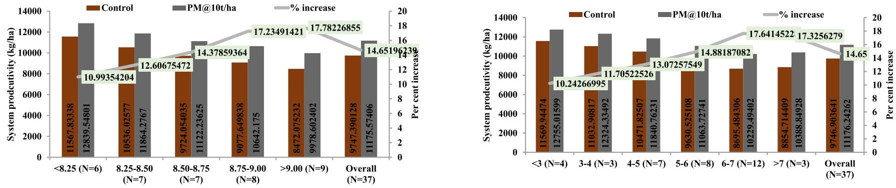

Fig 1.22. Effect of pressmud application on system productivity (wheat equivalent yield)

between 11.0 to 17.8% and 10.2 to 17.3% under high soil pH and RSC water conditions, respectively, over the farmers' practice (un-amended).

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Lessons learnt

These long-term studies (3-5 years) reflected the high potential of 'Basmati CSR 30' in improving farm incomes in the partially reclaimed sodic areas of Haryana. It also emerged that genetically pure seeds could play a major role in improving 'Basmati CSR 30' grain yields, suggesting the need for strengthening the seed network. It is worth mentioning that despite price fluctuations in some years, 'Basmati CSR 30' growers were able to fetch much higher incomes than those cultivating other rice varieties, as it gave relatively higher grain yields in sodic soils compensating the monetary losses to a great extent. There is a need for some policy changes to ensure stability in the market price of 'Basmati' rices in general and that of 'CSR 30' particular. Similarly, salt tolerant wheat 'KRL 210' showed a much higher yield potential than other improved varieties in sodic areas of North-West India. Location specific adoption of appropriate technology can make a real change: transforming the business-as-usual farming into an ecologically sustainable and profitable venture. It is also desirable that farmers should create their own Farmer Producer Organizations (FPO) for minimize the market risks.

For the community based management of sodic lands, gypsum should be provided at subsidized rate. In Haryana state, only a few Village Panchayats apply gypsum for reducing the sodicity in community lands. This could enhance the capacity of Village Panchayat and the individual farmers in informal decision making so that degraded sodic lands are converted into productive economic assets. It is also suggested that a multi-stakeholder framework could be of considerable help to the policy makers for bringing out the farmers/community centric policies for the restoration of salt affected lands.

Experience gained during participatory trials with the farmers of Patiala district also suggests that a single technology may not provide desired benefits in areas grappling with multiple stressors including soil sodicity, poor fertility, high RSC in irrigation water and climate variability. The need of hour is to ensure integrated adoption of two or more proven technologies for harnessing the productivity of salt-affected lands. There is conclusive evidence that technological interventions can lead to manifold increases in the productivity of saline and sodic soils provided farmers' proactively work with the scientists and extension functionaries. A need is being felt for MOU between the Government of Punjab and ICAR-CSSRI, Karnal to fast track the adoption of an integrated package of improved technologies *viz*., chiseling, laser land leveling, salt tolerant cultivars, gypsum-bed technology and groundwater recharge, among a large number of farmers reeling under the adverse impacts of sodicity, fresh water scarcity and climate variability.

Precise irrigation water management and appropriate soil reclamation techniques are the key management issues in sodic agroecosystems of Northwestern India. The pressmud application not only helped in better utilization of this byproduct, but also helped achieve sustainable crop yields while reducing the dependence on gypsum. Scientific diagnosis of sodicity in soil and water, developing strong farmer-scientist interface, and participatory research could work as suitable location specific adaptive strategies for managing the sodicity problem. Notwithstanding the success achieved in managing the sodic lands with the aid of gypsum and salt tolerant cultivars, there is still scope for systematic planning and implimentation of planned knowledge with farmers and other stakeholders in the sodicity affected parts of Patiala district. Long-term trials can generate useful insights for convincing the policy makers so that such agro-technques receive policy support for managing the widespread problems of sodicity and waterlogging in different parts of Punjab and neighbouring states.

Management of Sodic Lands in Uttar Pradesh: Reducing Risks and Strengthening Farmers' Livelihoods

Land degradation caused by salinity and sodicity has emerged one of the major environmental issues for which both international (UNCCD) and national policies (e.g. watershed programme) have been developed and implemented from time to time. Salinity and sodicity caused either by geogenic or anthropogenic processes directly (and indirectly) affect food and livelihood needs of people dependent on them. They often also cause damage to the ecosystem services in the long-run. Such problems can be managed in three ways: preventing the land degradation, reclaiming the degraded lands and making sure that lands being reclaimed do not bounce back into the same loop. About 1.37 M ha agricultural land in Uttar Pradesh (UP) is affected by sodicity and salinity stresses. Phase wise programmes were implemented in UP to reclaim sodic lands to provide livelihood options to the farmers. Various options including chemical (gypsum), engineering (landshaping) and biological (salt tolerant varieties) technologies have been developed and demonstrated to the farmers with varying degrees of success.

Per capita availability of cultivated land in country is declining due to natural and developmental factors. Under such a scenario, conversion of wastelands (including sodic and saline) into cultivable land has become a challenging task for the governments and developmental agencies. In such lands, an investment of $ 1 can provide about five times ($ 5.0) returns as per the estimates of UNCCD (United Nations Convention on Combating Desertification). Most of the sodic lands in UP are leased to the poor landless laborers and farmers having dismal capacity for reclamation. State Government has set the yearly targets for reclaiming sodic soils in different areas of UP. However, dissemination of doable solutions to the target areas (particularly resource-poor farmers) remains an important concern. Despite the availability of proven technologies, majority of marginal farmers living in degraded ecosystems find it difficult to adopt them. In many areas, farmers having sodicity affected lands are compelled to quit farming and migrate to the cities/town in search of employment. This process of migration not only results in the overexploitation of resources in urban and peri-urban areas, but also causes further degradation. Objectives enlisted in the SDGs (Sustainable Development Goals) and LDN (Land Degradation Neutrality) call for the measures for restoring the economic and ecological functions of such degraded lands.

In order to manage sodic lands, there is a need for participatory planning, learning and implementation of planned technologies compatible with the socio-economic and biophyiscial conditions of farmers. In this backdrop, successes achieved in sodic soil reclamation through action oriented research in different parts of UP is discussed in the following sections.

Case study one: Bumper production of salt tolerant mustard variety in sodic soils of Pratapgarh district

Pratapgarh district of UP has about 47000 ha sodicity affected area; a source of livelihood to the thousands of small and marginal farmers. Rice-wheat cropping system is predominant, covering about 88% of the total cultivated area of the district. Out of this, nearly 32% area severely suffers from sodicity and salinity problems such that only one crop (rice) is grown in a year. In this study, we are presenting how partnerships between different institutions can bring smiles to the farmers' faces (through intervention of salt tolerant mustard variety developed by ICAR-CSSRI, Karnal).

Approaches, interventions and outcomes

In Pratapgarh district, Kunda and Lalganj Tehsils are particularly highly affected by the twin problems of sodicity and high watertable. Because of high watertable conditions, wheat cultivation is seldom possible in most of the area. Although, 15-20% farmers have tried to cultivate wheat in the past, but the performance of wheat crop was rather poor due to waterlogging problem. Majority of the farmers follow rice mono-cropping (rice in *kharif* and fallow in *rabi* (Fig 1.23).

Initially, Krishi Vigyan Kendra (KVK), Pratapgarh team responsible for transferring the agricultural technologies in this area, contacted the farmers suffering from sodicity probelms. After the transect walk for assessing the field conditions, soil samples were collected for analysis. In addition, KVK team also approached ICAR-CSSRI, Regional Research Station, Lucknow for discussing this issue in greater detail. Soil analysis indicated that soil pH in selected farmers' field ranged from 8.2 to 10.3, and EC from 0.56 to 1.66 dS m^{-1}. As a follow-up action, the ICAR-RRS, Lucknow and KVK

Fig 1.23. Fallow fields after rice harvesting

Fig 1.24. Intervention of salt tolerant mustard variety 'CS 56'

Fig 1.25. Bumper crop of mustard 'CS 56' on a sodic land

Pratapgarh teams visited these sodicity affected villages (2014-15) and interacted with the farmers. It was ultimately decided to introduce salt tolerant mustard variety 'CS 56' in the affected area. Ten kg breeder seeds of 'CS 56' variety were provided to KVK, Pratapgarh for multiplication and production of certified seed. During *rabi* 2015-2016, KVK produced 5.0 q of certified seed and sold about 3.20 q of this to a total of 160 farmers from affected villages (Kama patti, Kashbaalatifpur, Dhingwas, Chhachhamau, Beersinghpur, Dhorehut, Kushuwapur, Meerapur of Babuganj, Rampur Sangramgarh and Kalakankar).

Finally, 'CS 56' crop was sown after rice in sodicity affected lands (Fig 1.24). In addition, KVK, Pratapgarh also conducted a cluster demonstration on 60 ha sodic area belonging to 158 farmers. Total area covered under the 'CS 56' was, thus 124 ha covering to 318 farmers. Based on crop cutting data, the average yield of 'CS 56' was found to be about 1.65 t ha^{-1}, considerably higher than average mustard yield (1.0 t ha^{-1}) in the district.

During 2016-17, KVK Pratapgarh produced about 11.0 q certified seeds of 'CS 56' of which about 4.0 q seed was sold to 192 farmers of various villages (Kodar khurd, Asthwa, Khanwari, Kushmer, Manar, Shuklan Ka Purva, Sahabad, Rampur, Lallupatti villages, etc). These farmers earlier grew wheat in the *rabi* season and obtained very poor yields (<2.0 t ha^{1}). KVK Pratapgarh conducted front line demonstrations on 375 farmers fields covering 150 ha sodic land in the study villages and compared the

Table 1.5. Economic impact of mustard 'CSR 56' cultivated in sodic areas of Pratapgarh district

Cluster no.	Number of Farmers	Soil pH	Area in ha	Grain yield (q ha^{-1}) of STVs	Grain yield (q ha^{-1}) of traditional varieties	Yield enhancement over traditional variety	Cost economics with salt tolerant variety			Cost economics with salt tolerant variety		
							Gross Return (Rs ha^{-1})	Net Return (Rs ha^{-1})	B:C Ratio	Gross Return (Rs ha^{-1})	Net Return (Rs ha^{-1})	B:C Ratio
I	42	8.2	15	17.0	10.1	68	40400	28020	2.96	68000	51910	4.4
II	38	8.6	14	16.2	10.8	50	43200	30150	2.96	64800	49350	4.1
III	25	9.0	14	15.8	10.1	56	40400	28300	2.96	63200	51260	4.4
IV	41	8.5	15	16.6	11.2	48	44800	31250	2.96	66400	51540	4.4
V	32	8.5	12	16.15	10.1	60	40400	25740	2.96	64600	50100	4.4
VI	52	9.1	20	15.5	9.6	61	38600	25450	2.96	62000	46370	3.9
VII	44	8.2	16	17.0	10.3	65	41000	27425	2.96	68000	54200	4.9
VIII	35	9.0	14	16.1	10.0	61	40400	25860	2.96	64400	50100	4.5
IX	50	8.5	20	17.15	8.7	97	34000	20390	2.96	68600	51270	4.8
X	35	9.1	14	16.5	10.2	62	40800	25510	2.96	66000	51900	4.6

performance of 'CS 56' with locally popular varieties 'Varuna' and 'Urvashi'. Crop cutting data revealed that 'CS 56' yielded 65 to 90% more grain yield than 'Varuna' and 'Urvashi' (Table 1.7). The farmers growing 'CS 56' obtained average seed yields of 1.6 to 1.8 t ha^{-1} with a net return of about Rs. 46000 to 54000 ha^{1} (B:C ratio of 3.9 to 4.4). Some of the farmers sold the seeds of 'CS 56' to the neighboring farmers @ Rs 80 kg^{-1}. With the introduction of CS 56 in these villages, farmer's income has increased about two fold (Fig 1.25, a happy farmer with CS 56).

Based on the performance of 'CS 56' variety and the farmers' demand, KVK Pratapgarh produced about 12.0 q certified seed during 2017-18 and sold 2.38 q seed to 379 farmers belonging to 25 villages. Some of the farmers having normal soils also preferred 'CS 56' because of its high yield potential over the traditional varieties. KVK also conducted cluster demonstration on 154 ha^{-1} sodic soils under National Initiative on Climate


दैनिक जागरण

परती भूमि पर 'पीले सोने' की फसल

Fig 1.26. Coverage by the print media

Resilient Agriculture (NICRA) project on 125 farmers' fields suffering from sodicity. Based on soil pH, demonstrations were divided into ten clusters. Variety 'CS 56' was compared with traditional varieties 'Varuna' and 'Urvashi'. Soil pH of the selected fields varied from 8.2 to 9.1 and EC from 0.58 to 2.14 dS m^{-1} (Table 1.7). The yield of salt tolerant variety 'CS 56' ranged from 1.58 to 1.72 t ha^{-1} with an average of 1.64 t ha^{-1} as compared to traditional varieties (0.9 to 1.12 t ha^{-1}).

After crop harvesting, surveys were conducted and it was found that about 17.38 t mustard was sold in the market by the farmers who were cultivating 'CS 56'. With these efforts, mono-cropped sodic lands have been converted into double cropping system. The success in adoption of 'CS 56' is encouraging more and more farmers to adopt this variety. With the introduction of 'CS 56' mustard variety, lands otherwise kept fallow during the *rabi* season, could make a significant contribution to the edible oil pool of country. This success story was also appreciated and covered by the local media (Fig 1.26).

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Case study two: Integration of planned knowledge and autonomous strategies for managing the sodic soils

Efforts have been made by several agencies including the State Government, research institutions and World Bank to develop reclamation and management technologies for improving the farmers' livelihoods in sodic areas. ICAR-CSSRI, Karnal has been at the forefront in developing such solutions (chemical, engineering and biological) and providing them to the developmental agencies. Some such projects were also implemented on farmers' field, and one such initiative is presented in the succeeding section.

Approaches, interventions and outcomes

ICAR-CSSRI, Regonal Research Station, Lucknow has been working directly on farmers' field in the sodicity affected areas of Uttar Pradesh. In this endeavor, Mr. Rajesh Pratap Singh, a farmer in Nunari Bahadurpur village of Kanpur Dehat district of UP was selected after interactions and discussions. Mr. Singh had inherited 4 ha of land which remained barren since the time of his forefathers. Like his forefathers, Mr. Singh was unable to grow crops on this land, apparently due to lack of access to the reclamation technologies. Mr. Singh came into contact of the scientists of ICAR-CSSRI, Regional Research Station, Lucknow during a Kisan Mela organized at ICAR-Indian

Fig 1.27. Soil sampling from barren sodic land

Fig 1.28. Pressmud to be applied

Fig 1.29. Harvested crop of rice 'CSR 30'

Institute of Sugarcane Research, Lucknow in 2015. After a brief discussion, he was assured that all possible efforts will be made to restore the productivity of his sodic land lying barren for decades. Shortly thereafter, a team of ICAR-CSSRI, RRS, Lucknow visited his field to assess the situation (Fig 1.27). Soil samples were collected and analyzed. The Hindi Bulletin "*Usar Sudhar Nirdeshika* (Sodic Soil Reclamation Directory) developed by ICAR-CSSRI, RRS, Lucknow containing month-wise activities for reclamation of sodic soils was also provided to Mr. Singh. In the follow-up action, Mr. Singh first installed a diesel operated tube-well to meet the water requirement necessary for leaching of salts after gypsum application, and later on for use in irrigation. He also prepared farm bunds, divided the land in to one acre plots and leveled them with a tractor mounted leveler. He procured gypsum from Uttar Pradesh Bhumi Sudhar Nigam and applied 200 bags (50 kg each) after proper leveling. Gypsum was mixed into 0-15 cm soil by tractor operated cultivator followed by ponding of 10 cm water continuously for 10 days to hasten the leaching of salts. After leaching, 72 bags (50 kg each) of pressmud, collected from Balrampur Sugar Mill, and about 20 tons of FYM were also applied and mixed in the surface layer (Fig 1.28).

During *kharif* 2015, Mr. Singh planted salt tolerant rice variety 'CSR 36' on 3 ha of reclaimed land and harvested an average grain yield of 5.75 t ha^{-1} (Fig 1.29). He sold the grains on local market, fetching Rs. 10500 t ha^{-1}. After harvesting of 'CSR 36', Mr. Singh sowed salt tolerant wheat variety 'KRL 210' and harvested an average grain yield of 2.5 t ha^{1}. Like rice, he earned Rs. 12,000 t ha^{-1} from 'KRL 210'. He also grew *dhaincha* (Sesbania) after wheat harvest in *kharif* 2016 and mixed it into the soil after 40 days of sowing. During 2016, Mr. Singh again added about 20 tons of FYM in the field and followed the same cropping pattern using the above mentioned cultivars. He harvested 5.0 t ha^{-1} rice and 2.4 t ha^{-1} wheat. During 2017, however, he replaced rice 'CSR 36' with another salt tolerant short duration variety of rice ('CSR 43') in *kharif* but continued with wheat variety 'KRL 210' in *rabi* season.

Table 1.8. Autonomous strategies (local knowledge) followed by Mr. Singh

Strategy number	Components of autonomous strategies acre^{-1}	Rice variety	Cost (Rs. ha^{-1})	Yield (t ha^{-1})
1	40 q Jalkumbhi (water hyacinth*) +75 q FYM	CSR 36	11200	5.5 to 6.0
2	Recommended dose of gypsum + 70 q FYM+ 50 q pressmud	CSR 36	21700	6.0 to 6.5
3	Khoi (sugarcane residue after extraction of juice) + Sagrica 10 kg (IFFCO seaweed product) + 75 q un-decomposed FYM	CSR 36	19500	6.5 to 7.0

Note : Cost of cultivation with each autonomous component was Rs. 9480 acre^{-1}. The activities were carried out in the last week of may

Autonomous strategies for reclaiming sodic lands

Mr. Singh also tried to integrate other interventions such as microbial culture developed by ICAR-CSSRI RRS to enhance the decomposition of organic matter. In addition, he also developed some autonomous strategies based on his own knowledge, and tried to integrate them with the formal knowledge (Table 1.8). For example, he uses three different strategies where *jalkumbhi* (water hyacinth) from village ponds, pressmud and *khoi* (sugarcane bagasse) are added to the soil for improving organic matter content. Salt tolerant rice variety 'CSR 36' or 'CSR 43' is a common component of these strategies. Using these strategies, Mr Singh got very high yields of 'CSR 36' ranging from 5.5 to 7.0 t ha^{-1} (Table 1.8). The cost of autonomous reclamative strategies was the lowest (Rs. 11200) in strategy one and the highest (Rs 21700) in strategy two. Other costs of rice cultivation were found to be normal (Rs. 23700 ha^{-1}). For his efforts in reclaiming sodic soils and cultivating bumper crop through a blend of formal and informal knowledge, Mr. Singh has received recognition and rewards(Fig. 1.30).

The success of Mr. Singh in using integrated strategy including salt tolerant rice ('CSR 36' and 'CSR 43') and wheat ('KRL 210') varieties has made other farmers aware about these interventions. They are now approaching Mr. Singh for getting the seeds of these salt tolerant varieties. Mr. Singh informed us that he had supplied the seeds of both 'CSR 36' and 'KRL 210' varieties to about 50 farmers from the surrounding villages where high soil sodicity is an important limitation to crop production. Our observations suggest that Mr. Singh and other such farmers are playing a critical role in creating a local seed network of the salt tolerant varieties. Notably, four other farmers (Mr. Arjun Singh, Mr. Brijesh Tiwari, Mr. Kallu Tiwari and Mr. Shailendra Tiwari) have followed the suit and are using the strategies tested by Mr. Singh to harness the productivity of their sodic lands.

Fig 1.30. Mr. RP Singh receiving award from Hon'ble Agriculture Minister, Govt. of UP

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Case study three: Barren to bountiful: Livelihood security with integrated adaptive strategy

It is believed that collaborative efforts between research institutions and farming communities can effectively bridge the gap, bringing degraded salty lands under crop production. With this idea in mind, ICAR-CSSRI RRS, Lucknow worked with a number of farmers in Uttar Pradesh, and one such success is presented in the following section.

Approaches, interventions and outcomes

ICAR-CSSRI RRS, Lucknow worked with Mr. Shrishant, from Narsinghauli village of Sitapur district of UP to see whether recommended package of practices were effective in reviving the productivity of severely sodic lands. Mr. Trivedi had 16 ha of sodic land lying uncultivated since the last few decades, as neither him nor his forefathers were aware about the technological solutions. The dream of Mr. Trivedi for reclaiming his sodic lands remained unfulfilled until he listened a radio talk on "reclamation methodology of salt affected soils" delivered by one of the scientists of ICAR-CSSRI, RRS, Lucknow, UP and broadcast by All India Radio. He then approached the ICAR-CSSRI, RRS, Lucknow and discussed about the protocol for the reclamation of sodic soils. Mr. Trivedi was specifically motivated for adopting gypsum-based package comprising of gypsum application and the salt tolerant rice and wheat varieties for greening his sodic lands. Although Mr. Trivedi was quite convinced, and agreed to adopt the suggested package, the cost of reclamation was beyond his reach. Also, gypsum was not easily available on the local market. Therefore, he approached the Project Manager, Uttar Pradesh Land Reclamation Development Corporation (UPLDC), Sitapur in April, 2012 and requested him for providing the gypsum at subsidized rate. Project Manager UPLDC, Sitapur agreed to supply 500 bags of gypsum (25 tonnes) at subsidized rates. Mr. Trivedi was also advised to install a tube-well at his farm to meet the water requirement necessary for self leaching after gypsum application and for subsequent use in irrigation. He installed the tube-well by taking a loan of Rs. 50,000 from a nationalized bank, and initiated the soil reclamation process (Fig 1.31). Initially, he made bunds on 8 ha land as per suggestions. As the field was not properly leveled, he was advised to get the leveled before gypsum application for effective reclamation. After soil testing, he applied the recommended dose of gypsum in the leveled field. Gypsum was applied only on 8 ha of land followed by ponding with water for 10 days to leach out the salts. On remaining 8 ha land, Mr. Trivedi applied pressmud obtained from a local Sugar Mill and applied on ~ 4.2 ha area. He informed us that the total expenditure incurred on the reclamationof ~ 4.2 ha land was about Rs. 1.6 lakhs.

During *kharif* 2012, Mr. Trivedi planted 'NDR 359' on 12.8 ha of the reclaimed land. He harvested good crop with an average yield of 3.22 t ha^{1} and sold it on the local market @ Rs. 9000 t^{-1}. During *rabi* 2012, Mr. Trivedi sowed traditional wheat variety 'Lok 1' and harvested an average grain yield of 1.6 t ha^{-1} which fetched him Rs.12000 t^{-1}. After wheat harvesting, Mr. Trivedi cultivated Sesbania as green manure crop on 8 ha of land and turned it in to the field 40 days after the sowing.

During 2013, Mr. Trivedi again purchased the gypsum and reclaimed his remaining 4.2 ha of land. He was then suggested to adopt salt tolerant rice variety 'Basmati CSR 30' on 4 ha land, while cultivating rice variety 'NDR 359' on 12 ha. He was able to harvest 2.625 t ha^{-1} grain yield of 'Basmati CSR 30' (Fig. 1.31) and sold it @ Rs. 56000 t^{-1}, earning Rs. 4, 48000. Thus, the average

Fig 1.31. Sal tolerant rice 'Basmati CSR 30' crop

Fig 1.32 Salt tolerant wheat 'KRL 19' crop

income per hectare was around Rs. 1,12,000 in comparison to rice variety 'Narendra 39' yielding only 3.62 t ha^{-1} and was sold @ Rs. 1300/q with an income of Rs. 3,24000 form 12 ha of land. The average income earned was Rs.27,000 ha^{-1}. After harvesting of rice, he paid his bank loan and purchased his own tractor.

In *rabi* season of 2013-14, Mr. Trivedi adopted salt tolerant wheat variety 'KRL 19' on his whole 16 ha farm (Fig 1.32). He was able to harvest average yield of 3.04 t ha^{-1} which was sold @ Rs. 12000 t^{-1}. During a short span of two years, he earned a net income of Rs. 6.0 to 8.0 lakh from the reclaimed lands. With the adoption of scientific approaches and technical support from ICAR-CSSRI, RRS, Lucknow, and concerted efforts of Mr. Trivedi his barren lands have become bountiful.

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Case study four: Integrated adaptations for managing the sodic soils

In the series of efforts being made for enhancing the resilience and productivity of sodic lands in the central Indo-Gangetic Plain of UP, we are presenting another success story achieved in Hardoi district of UP.

Approaches, interventions and outcomes

In this project Santaraha village of Hardoi district of UP was selected for reviving the productivity of sodic alnds by disseminating appropriate technologies to the farmers' field. The average size of land holdings in this village was ~0.62 ha, and majority of the farmers belonged to the marginal category. Crop production was an important activity contributing about 68% of the total household income. After rapport building, few farmers were selected based on their interest and willingness to shoulder the responsibility for joint learning and application of formal knowledge developed by ICAR-CSSRI for reclaiming the sodic lands. After collecting the socio-economic and other basic information, the reclamation process started in April 2011. Works like bunding and construction of field drains, irrigation channels, leveling and link drain were initiated. Land owners were asked to collect the soil samples from each plot after training them (Fig 1.33). To ensure water availability for leaching of salts as well as for irrigating crops, one tube well was established for each 4.0 ha land area. Analysis of the soil samples revealed that pH ranged between 8.5 to 10.1, and the gypsum requirement (GR) between 8.2 to 14.8 t ha^{-1}. Gypsum was provided to the farmers @ 25% of estimated GR value. Agricultural grade mineral gypsum

Fig 1.33. Scientists interacting with the beneficiary farmers

Fig 1.34. Performance of 'CSR 36' in sodic soils of Santaraha village

containing S (16.1%), Ca (18.3%), Mg (0.04%) and Na (0.18%) was applied in the month of June 2012 and was mixed uniformly in the top soil (0-15 cm). After application and mixing of gypsum, fields were ponded with 10 cm water for 10 days to displace the reaction product of Ca-Na exchange down to the root zone. After proper leaching, pressmud containing S (0.23%), Ca (11%), Mg (1.65%), total C (26%), total N (1.33%), total P (1.08%) and total K (0.53%) was broadcast uniformly @ 10 t ha^{-1} and mixed into the top soil. During reclamation process, farmers shared a substantial amount of costs on labour and other inputs. All the initial pre-reclamation activities (*e.g.*, leveling of land and amendments and inputs) were also managed by the farmers. After three years, all the gypsum treated lands were brought under cultivation.

Table 1.9. Average yield (t ha^{-1}) of salt tolerant rice variety 'CSR 36' during pre and post reclamation phases

Year	Soil Sodicity class				
	Normal	Slightly sodic	Moderately sodic	Sodic	Severely sodic
	Salt tolerant rice variety 'CSR 36'				
Pre-reclamation pose					
2009-2010	4.81	2.92	1.21	0	0
2010-2011	4.94	2.98	1.25	0	0
2011-2012	4.86	2.95	1.20	0	0
Average 4.87	2.95	1.22	0	0	
% yield loss	-	39.43	74.95	100	100
Post reclamation pose					
2011-2012	5.10	4.83	4.38	3.87	2.79
2012-2013	5.23	5.12	4.73	4.54	3.10
2013-2014	5.32	5.04	4.86	4.86	3.23
Average 5.21	4.99	4.65	4.42	3.04	
Yield loss (%)		4.35	10.74	15.16	41.65

Table 1.10. Average yield (t ha^{-1}) of salt tolerant wheat variety 'KRL 19' during pre and post reclamation phases

Year	Soil Sodicity class				
	Normal	Slightly sodic	Moderately sodic	Sodic	Severely sodic
	Wheat variety 'KRL 19'				
Pre-reclamation phase					
2009-2010	3.57	2.76	1.23	0	0
2010-2011	3.70	2.85	1.41	0	0
2011-2012	3.67	2.84	1.62	0	0
Average 3.65	2.82	1.42	0	0	
% yield loss	-	22.74	61.09	100	100
Post reclamation phase					
2011-2012	3.67	3.13	2.76	2.10	1.63
2012-2013	3.81	3.43	3.02	2.63	1.82
2013-2014	3.84	3.53	3.12	2.72	2.10
Average 3.77	3.36	2.96	2.48	1.85	
Yield loss (%)	-	10.87	21.48	34.21	50.92

After the reclamation activities were complete, seeds of salt tolerant rice 'CSR 36' (*kharif* season) and wheat 'KRL 19' (*rabi* season) were provided to the concerned farmers by ICAR-CSSRI RRS, Lucknow for field demonstration. For 'CSR 36', thirty-day-old seedlings were transplanted in the first week of July month, and improved management practices were followed.

Adopted farmers were provided suitable agroadvisories from time to time. Variety 'CSR 36' performed well in sodic soils (Fig 1.34). The yield of 'CSR 36' declined in slightly sodic and moderately sodic soils during pre-reclamation period (39.43 and 74.95%, respectively) (Table 1.9); whereas, the yield reduction of this variety in severely sodic soil was 100% before reclamation period (Table 1.9). Results indicated that yield losses in wheat 'KRL 19' during pre-reclamation period in slightly sodic and moderately sodic soils were 22.74 and 61.09%, respectively (Table 1.10). In post-reclamation period, the yield loss in 'KRL 19' in slightly sodic, moderately sodic, sodic and severely sodic soils reduced to be 10.87, 21.84, 34.21 and 50.92% compared to the normal soils (Table 1.10).

During the first year of reclamation, a net return of Rs.15,533 was obtained from slightly sodic soils (Fig 1.35). With the increasing soil sodicity, the net returns in the first year were relatively less (Rs.12,502, 41293 and 56,677, Fig 1.35). In 2012-13, net returns increased remarkably, because expenditure on reclamation occurred only in 2011-12. A further increase in net returns occurred in 2013-14.

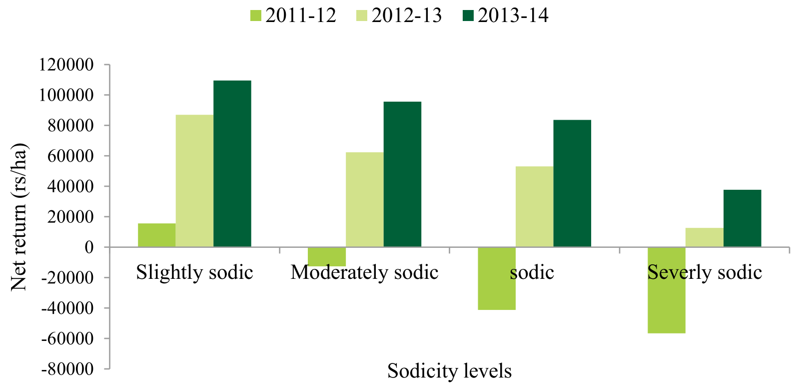

Fig 1.35. Cumulative net returns from rice farming over a three year period of reclamation

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Lessons learnt

The foregoing account makes it clear that material resource-poor farmers may often be not able to harness the productivity of sodic soils. Instead, multi-stakeholder approach involving the scientists, farmers and agricultural input dealers can be of immense help in resolving the problem precisely in areas where salinity and/or sodicity are the major stresses to the crop cultivation. The State agencies can join the hands with research and technology transfer institutes for developing networks and partnerships in defining, diagnosing and managing such lands. This, while saving the resources, can also provide sustainable solutions to the farmers who despite having large land holdings have become ecologically marginalized.

Technological interventions, if implemented timely with the aid of experts, can transform unproductive barren sodic lands into income and employment generating assets. Together with this, integrated application of autonomous and planned adaptations can be a sustainable game changer approach in revitalizing such salt impaired lands for various social-ecological benefits. However, before recommending such a strategy for large-scale adoption, systematic investigations are necessary to reach to definitive conclusions and testing the research hypothesis that could result in the development of solutions appealing to various stakeholders including policy makers. A synergistic coordination among research, development and market institutions could be a key enabler to make policy-centric (planned) knowledge functional for durable outcomes. The successful reclamation and management of sodic soils can pave the way for other farmers to make their salt affected soil productive, and thus contributing to the LDN and SDGs policies.

THEME 2

DRAINAGE AND SALT TOLERANT CROP VARIETIES FOR MANAGING WATERLOGGED SALINE SOILS

Blooming Salt Affected Lands

केन्द्रीय मृदा लवणता अनुसंधान संस्थान

C S S R I

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Management of Irrigation-induced Salinity and Associated Stressors for Sustaining Livelihoods

Canal irrigation has played an important role in the success of Green Revolution in India. Government of India paid due attention for creating irrigation infrastructure in order to bring more and more area under irrigation to feed the burgeoning population of the country. India has a vast network of canals with majority of them being unlined, resulting in excessive seepage losses. Introduction of water intensive crops, poor water management practices and over-irrigation all together result in very poor irrigation use efficiency. Water and land productivity are declining in different canal command areas of country. Excessive seepage coupled with poor field irrigation losses have resulted in extensive waterlogging and salinization in canal irrigated commands, adversely affecting the agricultural productivity.

Nearly 2.95 M ha area in the country has turned saline in the intensively irrigated arid, semi-arid and sub-humid regions. Saline soils are adversely affecting crop productivity and sustainability of agriculture in the irrigated commands. Saline soils are spread across 16 states (Punjab, Haryana, Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Telangana, Tamil Nadu, Kerala, Madhya Pradesh, West Bengal, Bihar, Odisha and Uttar Pradesh). ICAR-CSSRI, Karnal has estimated the annual crop production and monetary losses due to the soil salinity problem at the national level to be 5.66 million tonnes and Rs. 8,000 crores, respectively. Saline soils having shallow watertables (2 m below the surface) are termed as waterlogged saline soils.

In Haryana, about 2.32 lakh ha land is affected by excess salts. In areas having poor quality ground water and experiencing climate variability, salinity stress enhances the risks of resource-poor farmers manifold. About 10% of the states's land has watertable at 3 m depth from surface. Nine districts are hit by the twin problems of waterlogging and soil salinity. Out of 44.21 lakh ha area in Haryana, more than 50,000 ha has shallow watertable (<1.5 m). Salinity in waterlogged soils is often 35 to 40 dS m^{-1} against the upper limit of 4 dS m^{-1}. Most of the existing and potential waterlogged saline soils occur in arid and semi-arid regions in central inland depression basin of the state, encompassing Rohtak, Jhajjar, Bhiwani, Hisar, Sonepat districts and some parts of Jind, Fatehabad, Sirsa and Palwal districts.

South-Western part of Punjab (India) is also adversely affected by irrigation-induced salinity, taking a heavy toll on natural resources and suppressing the crop yields to varying extents. The depressional location, over irrigation, lack of drainage and constant seepage from Rajasthan and Sirhind feeder canals are the major factors that have caused gradual rise of saline watertable, leading to waterlogging and salinization of about 2.0 lakh hectares of fertile land. In recent past, shifts in cropping patterns and on-farm irrigation mismanagement have dealt a severe blow to the traditional cotton-wheat sequence and Kinnow orchards. Continual degradation of natural drains, some policy flaws (poor implementation of sub-surface drainage projects and erratic supply of canal water), climate variability and irrigation with poor quality groundwater are further aggravating salinity and associated risks, threatening the livelihoods of thousands of farmers. Despite efforts and investments, the farmers have not been able to manage these soils.

This study presents an account of successes delivered through sub-surface drainage (SSD) technology and salt tolerant crop varieties in waterlogged saline soils of Haryana, Punjab, Maharashtra and Karnataka.

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

Waterlogged saline soils are difficult to reclaim through conventional means. In order to productively manage waterlogged saline soils, SSD technology developed by ICAR-CSSRI, Karnal which has been successfully adopted in various parts of India.

Approaches, interventions and outcomes

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

Cost of SSD installation is quite high and varies greatly from state to state depending on climate, drain depth and spacing, layout and design, machinery to be used, crop factors, outlet condition, etc. The cost of SSD system on 2017 price level is about Rs. 74,000-79,000 ha^{-1} for alluvial soils with pumped outlet (drain spacing, 60-67 m and depth 1.5 m), and Rs. 110,000 ha^{1} for heavy soils/Vertisols with gravity outlet (drain spacing 30 m and depth 1.2 m). Expenses on drainage materials and mechanized installation constitute 50-55 and 31-33% of the total system cost, respectively. SSD technology has been implemented in public-private partnership (PPP) mode for large scale reclamation in Maharashtra and Karnataka states. Twenty-five drainage contractors from Maharashtra and Karnataka, and about 150 officers from state line departments of Haryana, Punjab, Maharashtra, and Karnataka have been trained for designing and implementing the SSD technology, and for post-project operation and maintenance. About 5,000 farmers of different states (Haryana, Punjab, Maharashtra, Karnataka and Gujarat) have also been trained for efficient operation and maintenance of SSD systems. Considering the huge potential, SSD technology has been implemented at community scale in some states involving a multi-stakeholders approach. Successes achieved in different states of India are discussed in the succeeding sections :

Case study one: Successful SSD projects in Haryana

In Haryana, waterlogging and salinity problems result in the annual loss of about 1.2 lakh tonnes of food grains valued of Rs 124 crores. These waterlogged saline soils are mainly distributed in 12 districts (Rohtak, Jhajjar, Charkhi Dadri, Sonipat, Bhiwani, Hisar, Jind, Kaithal, Fatehabad, Sirsa, Palwal and Faridabad) located in the Western Yamuna, Bhakra and Agra canal commands of the state. About 10,884 ha waterlogged saline lands in Haryana have been reclaimed through SSD technology till June 2018, benefitting 7,665 farmers. In Haryana, 47 villages representing 200 blocks of 10 districts have been covered under SSD.

The Jagsi cluster of Sonepat district in the Western Yamuna canal command receives average annual rainfall of about 650 mm. Rice-wheat, cotton-wheat and cotton-mustard cropping systems predominate in sandy loam texture alluvial soils. Total area affected by waterlogging and salinity in Jagsi village and Sonepat district was 950 ha and 2,892 ha, respectively. Haryana Operational Pilot Project (HOPP), ICAR-CSSRI, Village Panchayat and farmers were all involved in the planning, installation, operation and monitoring of SSD system in the Jagsi cluster. While HOPP was responsible for selecting the sites for SSD project, site survey and project design and preparation of DPR; the technical guidance in site identification, approval of

Table 2.1. Periodic changes in water level and salinity at Jagsi SSD site

Parameter	Pre-project		Post- project		
	Mar 2008	May 2009	June 2012	June 2015	June 2017
Water table Depth	1.12-1.60	1.05-1.50	1.61-2.10	2.00-2.35	2.05-2.45
Water salinity	3.96-4.28	3.90-4.30	3.03-3.50	2.6-3.20	2.5-3.00
Soil EC_e	3.60-26.3	4.30-27.6	4.30 -7.02	3.5-6.40	2.62-5.23
Soil pH_s	7.5-8.10	7.53-8.16	7.58-8.10	7.6-8.12	7.81-8.20

SSD design and layout and monitoring and evaluation was provided by ICAR-CSSRI, Karnal. Sensitization of farmers and providing them training were also the responsibilities of ICAR-CSSRI team. Formation of farmers' drainage society, obtaining farmers' agreement for project implementation, implementation of SSD system, supply of pump set and diesel fuel, operation and maintenance for the first year and transfer of completed drainage blocks to the farmers was done by HOPP and the Soil Conservation Department.

SSD system was installed during 2009 in Jagsi village in 6 drainage blocks (S-25 to S-30), while 4 drainage blocks (S-31 to S34) were covered in May 2011. Total area reclaimed by SSD in village was about 430 ha (10 drainage blocks). Analysis of periodic data at SSD the sites of Jagsi indicated significant changes in watertable and salinity after the implementation of SSD system (Table 2.1; Fig 2.1).

From the pre-project Landsat imagery taken at different intervals, it was found that 63-80% area in 10 drainage blocks at Jagsi site was affected by moderate soil salinity (EC >8 dS m^{-1}) on 12th February 2007 (Table 2.2). After SSD intervention in 2009 and 2011 (post-project period), soil salinity was reduced to 26% of the area on 4th April, 2011 and disappeared completely from imageries of 28th May 2014 and 22nd February 2016. This was attributed

Fig 2.1.Waterlogged saline soil (left), installation of SSD system (third), post-project bumper wheat crop (right)

Table 2.2. Periodic spatial changes in salinity at Jagsi site

Site	Distribution of surface soil salinity using satellite data (%)		
	Pre-project	Post- project	Post- project
		(4th April 2011)	(28th May 2014)
Moderate salinity	63-80	26	0

Table 2.3. Periodic changes in cropping intensity

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

to the proper pumping of saline water by the beneficiary farmers. After about 2 years, the drainage water was also reused for irrigation in both rice and wheat crops.

Cropping intensity in rice-wheat, cotton-wheat and cotton-mustard systems improved significantly from 80 to 168, 100 to 170 and 125 to 170%, respectively (Table 2.3). The recorded yields of rice and wheat were observed to increase in the range of 3.50 to 4.2 and 4.90 to 5.64 t ha^{1}, respectively during *kharif* 2017 and *rabi* 2016-17. This technology has benefitted 290 farmers owning 430 ha of salt affected lands. To make pumping of saline water effective and manage the entire process at farmers' level, 10 farmers' drainage societies were formed. Out of these, a total of 4 societies were effective in delivering the intended services. The major constraints experienced at Jagsi site included poor collection of farmers' share for diesel fuel required for effectively operating the pumping unit, and irregularity in the meetings of the drainage societies.

Fig 2.2. Pre-project field condition, installation of SSD system and saline water flow in collectors to open drain (top row); and good crops after SSD installation (bottom row)

Case study two: Successful SSD Projects in Maharashtra

A SSD project was designed and implemented on 362 ha land at Urun Islampur village of Sangli district of Maharashtra in 2013-14 with financial support from RKVY (Rashtriya Krishi Viksh Yojna). The waterlogged saline Vertisols of Urun Islampur are located in the lift irrigation project operated by farmers in the Krishna river catchment. This was implemented by Rex Polyextrusion Pvt. Ltd in coordination with Water Conservation Department, Government of Maharashtra. Out of total 362 ha area, 190 ha area benefitting 224 farmers was monitored for the impact evaluation. Analysis of watertable data indicated that watertable was near the ground surface (0.3-0.5 m) and soil salinity was moderate (EC< 15 dS m^{-1}).

After design was approved by ICAR-CSSRI, SSD was installed in the identified saline black soils (Fig 2.2). Lateral pipes were placed at spacing of 30 m and depth of 1.0-1.5 m (average 1.2 m) with depth of collectors ranging from 1.5 to 2.0 m (average 1.75 m). The outlet type was gravity for disposing off the drained water into a surface drain. Lateral pipes were made the perforated PVC material of 80 mm diameter and non-perforated collector pipes were of 80-315 mm dia. Lateral pipes were installed by small drainage trencher and collector pipes by hydraulic excavator suitable for black soils.

After about 5 years of SSD intervention, an impact assessment was carried out. Results indicated that sugarcane, turmeric, cotton and others major crops could be grown successfully from the first year of SSD installation itself (Fig 2.2). Earlier, these crops were not performing well in the same fields. Watertable, soil salinity and soil ESP reduced significantly from 0.55 to 1.90 m, 3.4-16.3 to 1.20-3.13 dS m^{-1} and 12 to 5%, respectively (Table 2.4). Overall, there was a significant increase in yield by 80 to 150% in sugarcane, turmeric, and cotton crops and beneficiary farmers expressed satisfaction with SSD technology. After SSD intervention, sugarcane yield increased from 40-55 to 80-85 t ha^{-1}, and 95-110 t ha^{1}, respectively in the first and second years of installation. Here, SSD technology was implemented with the financial support of Central Government, State Government and the

Table 2.4. Pre and post-project changes in watertable, soil salinity and sodicity at UrunIslampur (Sangli) SSD site

Parameter	Phase	
	Pre-project	Post- project
Water table depth (m)	0.5-0.6	1.8-2.0
Soil salinity (d S m^{-1})	3.4-16.3	1.2-3.1
Soil ESP	7.0-17.0	5.0-6.0
Sugarcane yield (t ha^{-1})	40-55	95-110

farmers in the ratio of 60:20:20 giving B:C ratio of 1.5 to 3.1, internal rate of return (IRR) of 20-56% and payback period of 2-3 years.

During the process of land reclamation, clogging of lateral pipes by the sugarcane roots was frequently reported by the farmers. It was found that water leakage at lateral and collector junction was responsible, and was fixed accordingly. Realizing the quick returns from SSD technology, in terms of reducing watertables and soil salinity and increasing crop yields, so far about 250 farmers have installed SSD systems on their farms ranging in area from 0.5 ha to 20 ha using their own resources. Farmers' drainage societies were formed for spreading awareness about benefits of SSD technology, capacity building and maintenance of SSD system as no pumping operation was involved. Although farmers have refined the drainage system by introducing close lateral spacing at 15 m for faster reclamation; it often leads to over drainage in the longer run. Thus, there is scope for the further refinements in the technology. During the last year, SSD installation picked up in the black cotton soils regions of Maharashtra in a big way.

Case study three: Successful SSD Projects in Karnataka

SSD technology was implemented in Ugar Budruk site of Belgaum district of Karnataka in 2010-11. The total area of waterlogged saline Vertisols was 925 ha owned by over 605 farmers in the lift irrigation command of Krishna river. The project was monitored for a period of 3 years for impact assessment. It was found that the yield of sugarcane in newly planted and ratoon crops increased to 119.0 and 82.0 t ha^{1}, respectively as compared to 42.0 and 26.0 t ha^{1} in the pre-SSD phase. Overall, sugarcane yield increased by up to 300%. The B:C ratio of SSD technology ranged from 1.5 to 3.2 and internal rate of return (IRR) was 20 to 58% in payback period of 2 to 3 years. A total of 605 farmers have benefitted from SSD technology. Refinement was made in the drainage system by introducing close lateral spacing at 15 m for faster reclamation of waterlogged and saline-sodic soils. Although, this refinement led to over drainage in the longer run which was further managed by closing some of the lateral lines.

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Case study four: Salt tolerant wheat 'KRL 210' is a promising option for managing multiple stresses

Approaches, interventions and outcomes

The waterlogged salinity affected villages of Haryana and Punjab states were selected after rapport building with Village Panchayat members, extension workers and progressive farmers. Before taking any decision, waterlogged salinity affected lands were extensively surveyed and transect walks were carried out with the farmers. From each site, soil and water samples were collected before making any intervention.

In Siwanamal village of Jind district ~300 ha land suffers from shallow watertable (0.4-1.0 m), moderate to high soil (EC_2: 2.48-10.20 dS m^{-1}) and groundwater (EC: 2.23-4.63 dS m^{-1}) salinity. The risks caused by salinity and associated problems have further been compounded by the strong climate variability and socio-political stressors, making agriculture a non-remunerative activity. Taking these stressors into consideration, a team of scientists from ICAR-CSSRI, Karnal visited Siwanamal village in May, 2012 and interacted with some progressive farmers having installed SSD on their lands with the technical help provided by the Institute. After soil and water analyses, detailed plan was developed in consultation with the selected farmers. Among these famers, Mr. Sunda Singh took the lead and adopted salt tolerant wheat variety 'KRL 210' on 1.2 ha area. Earlier, he cultivated locally popular salt sensitive wheat varieties giving poor grain yields. Many a times, wheat crop failed due to waterlogging.

Seeds of salt tolerant wheat variety 'KRL 210' were provided to Mr. Singh for frontline demonstration. Further, he also purchased 'KRL 210' seeds for sowing in marginally saline lands (EC 1.5 to 2.5 dS m^{-1}) having good quality water for irrigation. Mr. Singh sowed 'KRL 210' using the zero-till technique. Other management practices, including fertilizer application, were based on the soil analysis report. Seed drilled wheat had good germination as compared to the crop sown by broadcasting. Number of tillers per plant and better response to applied nutrients were other two attributes of KRL 210, impressing Mr. Singh and his fellow farmers. Mr Singh narrated this experience in his own words:

> *Sora mitti main 'KRL 210' ka jamaw, futaw awam khad ke prati isaki paridam bahut achha hai. Ye sare gun hi ham kisano ko kisi bhi fasal prajati ke liye akarsit karte hain*.

Thus, Mr. Singh was able to harvest up to 4.8 t ha^{1} wheat grain yield compared to only 1.0 to 1.5 t ha^{1} in the locally popular wheat varieties. Of course, the role of SSD, implemented since 2012 cannot be overlooked in reducing the soil and water salinity risks. As average grain yield of 'KRL 210' was nearly 3.0 t higher than locally popular varieties (1.2 t ha^{-1}), his income from wheat cultivation increased considerably (Fig 2.3). At the then prevailing MSP for wheat (@ 1350 q^{-1}), Mr. Singh earned a gross return of Rs. 31,050. After deducting the average cost of cultivation (Rs. 6500 ha^{-1}), he saved a net income of Rs. 24550 ha^{-1}. The success of 'KRL 210' variety prompted other farmers who contacted Mr. Singh for getting the seeds. Mr. Singh thus sold about 1.2 t seeds of 'KRL 210' @ Rs 3000 q^{-1} and earned Rs. 36000. After fetching good returns from seed sale, Mr. Singh contacted the local seed retailers for developing a seed network. From second year onwards, he started selling 'KRL 210' seeds directly to the local dealers.

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Case study five: Adoption of salt tolerant 'Basmati CSR 30' Rice reduces crop failure risk in salines soils

ICAR-CSSRI, Karnal and Haryana Operational Pilot Project (HOPP) have made collaborative efforts for reclaiming the waterlogged saline soils by installing the sub-surface drainage (SSD) following a community based approach in various parts of Haryana. Salt tolerant rice varieties are recommended for cultivation during the initial two years after SSD installation for better results.

Approaches, interventions and outcomes

In this context, Siwanamal village of Jind district, where SSD was installed in the year 2012, was adopted to demonstrate the potential of salt tolerant rice variety 'Basmati CSR 30' in 2012 (continued till 2014). A progressive farmer Mr. Tarsem Singh was selected and provided the seeds of 'Basmati CSR 30'. Soil and water sampling were done every year during 2012-2014 (**Table 2.5**) and he was provided Soil Health Card with detailed agroadvisories.

Fig 2.3. Bumper crop of wheat 'KRL 210' (Farmer : Mr. Sunda Singh)

Fig 2.4. Bumper crop of rice 'Basmati CSR 30' (Farmer : Mr. Tarsem Singh)

Table 2.5. Yield performance of rice 'Basmati CSR 30' in saline soils

Years	Soil pH_2	Soil EC_2	Grain yield (t ha^{-1})
2012	8.10-8.50	2.5 to 8.41	*
2013	8.10-8.30	1.5-6.58	2.82
2014	8.30-8.49	0.43-2.09	3.20

**Crop was lost due to an extended dry-spell resulting crop burning and further damaged was caused by flash flood*

Following his traditional ecological knowledge, Mr. Singh raised the nursery of 'Basmati CSR 30' in upland soils where salinity was not a problem, and good quality water was available for irrigation. His idea behind this practice was to reduce the impacts of soil salinity and climatic risks during the months of May to June when temperature is up, and evaporation high leading to salt deposition in the crop root zone.

Mr. Singh used to transplant 'Basmati CSR 30' when factors like low temperature, higher humidity and onset of rainfall lower the salinity by hastening salt leaching below the root zone. Although costly, he always prefers to hire migrant Bihari laborers for rice transplanting as they have better skills in maintaining higher plant population per hill and per unit area. Mr. Singh experienced that in relatively more saline soils, 'CSR 30' crop growth was partially suppressed. However, it still needed clipping after about two months of transplanting. He applied the NPK fertilizer following the recommended management practices for resulting a healthy crop (Fig 2.4).

By applying a combination of formal and location specific strategies, Mr. Singh obtained 2.8 to 3.2 t ha^{-1} grain yield during 2013-14. His produce fetched Rs. 2800 q^{-1} in 2013 and Rs. 3000 q^{-1} in 2014 and thus he earned Rs. 78960.0 ha^{-1}. After deducting the cost of cultivation (Rs ~27500 ha^{-1}) (2014), he had a net income of Rs. 51460 ha^{1} from 'Basmati CSR 30'.

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Case study six: Adoption of salt tolerant wheat 'KRL 210' reduces crop failure risk in saline soils

This case study presents a success of how intervention of salt tolerant wheat variety 'KRL 210' in saline area of Jind district could help farmers (community scale) to harvest better grain yields in stressful conditions.

Approaches, interventions and outcomes

The successes of Mr. Sunda Singh attracted other farmers of Siwnamal village towards salt tolerant wheat variety 'KRL 210'. Majority of the farmers in Siwnamal village have small and marginal land holdings. The adaptive

Fig 2.5a. A multi-disciplinary team of CSSRI visiting salinity affected fields of Siwanamal village and interacting with farmers

Fig 2.5b. A multi-disciplinary team of CSSRI visiting salinity affected fields of Siwanamal village and interacting with farmers

Table 2.6. Soil salinity in crop fields of Siwanamal village (Jind)

Parameters	Soil pH_2	Soil EC ($dS\ m^{-1}$)
Mean	8.36	4.45
CV*	4.61	10.5

**CV=Coefficient of variations*
Note: These data are based on three years of observations with 6 farmers

capacity of these farmers is poor and they do not have access to the formal knowledge and technologies (SSD and salt tolerant rice and wheat varieties'). Analysis of soil and water samples indicated that watertable in Siwanamal village was shallow (0.4-1.0 m), had moderate to high soil (EC_2: 2.48-10.20 dS m^{-1}) and groundwater (EC: 2.23-4.63 dS m^{-1}) salinity. The mean soil pH was about 8.36 (Table 2.6).

Taking these stressors into consideration, a team of scientists from ICAR-CSSRI, Karnal started working with the farmers of Siwanamal village from May 2012 onwards. The affected farmers were mobilized with different extension activities including transect walks and Goshthis (Fig 2.5a & 2.5b). In addition to field visits and timely agroadvisories, selected farmers also visited ICAR-CSSRI Experimental Farm at Karnal for acquainting themselves with the improved techniques for salinity management. Concerted efforts from 2012 to 2014 succeeded in convincing the farmers about usefulness of an integrated package (SSD and salt tolerant crops varieties) for increasing the productivity of waterlogged saline lands. To test this idea, a total of 10 frontline demonstrations (FLDs) were conducted on the farmers' field during 2013-14. Encouraging results convinced the farmers and FLDs were continued till 2015. Before 2013 (at this time SSD was least functional), cultivation of salt sensitive locally popular wheat varieties gave very poor yields. Again repeated crop failures were also caused by the water stagnation.

Table 2.7. Performance of of salt tolerant wheat variety 'KRL 210' in saline soils (community scale)

Components	Years	
	2013-2014	2014-2015
Yield range (t ha^{-1})	3.91-4.8	4.41-5.41
Total income (Rs. ha^{-1})	54627	78686
Cost of cultivation (Rs ha^{-1})	36534	40423
Net benefit (Rs ha^{-1})	18093	38263
B: C	1.50	1.95

Although selected farmers were initially reluctant in adopting 'KRL 210' variety; good results in the first year (2013-14) increased its acceptability. While most of the farmers earlier used more seeds (@ 115-125 kg ha^{-1}) for sowing through broadcasting, adoption of zero tillage sowing method reduced the seed rate by about 29% (100 kg ha^{-1}). Zero tillage method of sowing also ensured better seed germination. Zero-till sowing slowly became a fruitful intervention; mainly because of less soil disturbance and thus minimum salt induced injury to the germinating seeds. Farmers could harvest 3.91 to 4.8 t ha^{-1} grain yield (Table 2.7) (average 4.45 t ha^{-1}) in 'KRL 210' compared to very low yield (0.8 to 1.4 t ha^{-1}) in other varieties. The grain yield further increased during 2014-15 (4.41 to 5.41 t ha^{-1}). Extremely impressive performance of 'KRL 210' shortly made it highly popular among the local farmers (Fig 2.6). Beginning with 100 ha area in 2013-14, farmer led extension increased 'KRL 210' coverage to 180 ha in 2014-15.

About 78.5% of the farmers opined that 'KRL 210' performed better than other varieties during the periods of high intensity rains (e.g. January to first week of March, 2013 and 2014). The farmers also informed that 'KRL 210' matured uniformly 4-5 days earlier than other wheat varieties in this area. Tolerance to salinity, high rainfall and waterlogging tolerance coupled

Fig 2.6. Scientist interacting with farmers for assessing performance of 'KRL 210' in saline soils of Siwanamal village

with superior grain quality for *chapatti* making were other major factors contributing to its popularity**.** More than 2000 farm families in and around Siwanamal village have directly and indirectly benefitted by adopting 'KRL 210' in the lands with SSD, covering ~300 ha area.

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Case study seven: Adaptation to waterlogged salinity through salt tolerant crop varieties in South-Western Punjab

This farmer-participatory study was conducted in Fazilka district of Punjab where salinity onslaught continues to swallow productive farmlands at an alarming rate. Severity of the problem is evidenced by the development of waterlogged saline lands over a sizeable part of the district. Repeated crop failures frequently occur in many parts putting the livelihoods of thousands of farmers at risk.

Approaches, interventions and outcomes

This study was carried out with a group of 35 farmers from 7 villages of Abohar block of Fazilka district following rice-wheat, cotton-wheat and Kinnow based cropping systems. Study was conducted from 2015 to 2018 using participatory and diagnostic approaches. Results indicated that majority of the sampled farmers perceived salinity to be the major ecological stressor (mean score 38.6) (Fig 2.7), adverse effects of which were being further compounded by climate variability (34.48), policy and institutional (27.19) and socio-cultural (25.85,) stressors. Farmers in the study villages use salty groundwater (mean EC_{iw} ~2.6 dS m^{-1}) conjunctively with canal

Fig 2.7. Impact of secondary salinity on wheat seed germination (Farmer : Mr. Sahil)

Fig 2.8. A declining kinnow orchard

Fig 2.9 'KRL 210' wheat crop in saline soils

water (irregular water supply) for irrigation. Sometimes, they are also compelled to use saline drainage waters (mean EC_{iw} ~3.5 dS m^{-1}) in irrigation, further increasing salt load in the soil. Periodic availability of fresh canal water lessens the salinity impact to some extent. Gradually rising saline watertable has particularly seriously affected Kinnow cultivation in this area. Majority of Kinnow orchards have either declined or facing heavy risks in areas where watertable is within 4 m depth from surface (Fig 2.8).

Salt tolerant rice varieties [‘CSR 43’ (14) and ‘CSR 30’ (7)] were demonstrated on 21 farmers’ fields. The farmers were motivated to adopt these cultivars for reducing the yield losses. The mean values of soil pH and EC_e in the demonstration fields were ~9.2 and 1.7 dS m^{-1}, respectively. Results indicated that compared to locally popular rice variety yielding around 3.5-4.0 t ha^{-1}, yield of ‘CSR 43’ (4.7-7.2 t ha^{-1}, mean 4.7 t ha^{-1}) was much higher. In ‘Basmati CSR 30’, and yield ranged between 2.4-3.2 t ha^{-1} (mean 3.0 t ha^{-1}). Farmers earned 12-18% more profit in terms of resource saving and income from ‘Basmati CSR 30’, while it was 8-12.0% higher in ‘CSR 43’ variety.

Demonstrations of salt tolerant wheat variety ‘KRL 210’ were also conducted on 35 farmers (saline) lands (Fig 2.9). Based on soil and water

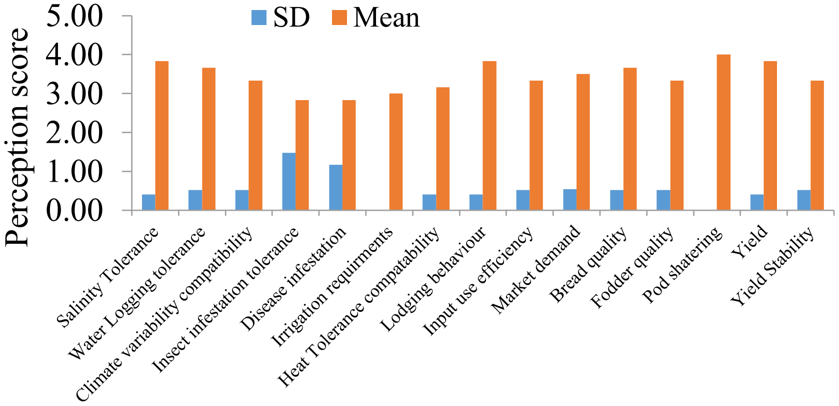

Fig 2.10. Perception of farmers (n=35) about attributes of salt tolerant wheat variety 'KRL 210'

analyses, the selected farmers were provided Soil Health Cards along with suitable agro advisories. The experience of farmers who have adopted 'KRL 210' was assessed using 15 parameters. Results showed that 'KRL 210' got a score of 3.0 against majority of the stressors including soil salinity, climate variability, waterlogging and tolerance to lodging (Fig 2.10). Wheat 'KRL 210' yielded 4.8-5.7 t ha^{-1} at soil salinity level of ~4.0 dS m^{-1} compared to 4.2-4.8 t ha^{-1} yield in the locally popular variety. In fields where, soil pH and salinity were relatively low (pH ≤8.9 and EC ≤2.5 dS m^{-1}), 'KRL 210' produced up to 6.2 t ha^{-1} grain yield. Based on the cost of cultivation and MSP obtained, it was found that farmers fetched 8-12% more profit with 'KRL 210' than with local wheat.

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Lessons learnt

Soil and water salinity are the serious hazards to farming, marginalizing even the resource-rich farmers. We learnt that even farmers with large land holdings were in the same position as were small and marginal farmers due to waterlogging and salinity problems. Situation improved continuously after SSD installation and crop cultivation became possible with the proper integration of salt tolerant rice and wheat varieties. Formal knowledge was modified in some cases so that farmers can make their own adaptations according to their biophysical and socio-economic conditions. In 'Basmati CSR 30', crop there was less probability of salt induced yield loss and less water demand during the peak hours of summer season. However, there is a need of some bonus support from the government and stability in the market price for promoting Basmati rice in North-Western India. Started with few selected farmers, success of salt tolerant wheat variety 'KRL 210' became more apparent and could convince other farmers for its adoption. It was learned that salt tolerant rice ('CSR 30') and wheat ('KRL 210') varieties can be integrated with SSD even in those areas where salinity was marginal but climate variability higher.

SSD has more potential than other technologies for reclaiming the waterlogged saline soils across the country. It provides immense benefits in terms of enhanced provisioning of different ecosystem services and in improving soil and water quality and crop yields. It emerged that SSD system (community scale) could have been more effective if social scientists and state agencies had been involved since the beginning. Inadequate capacity building of farmers for effective pumping operation and maintenance, and delay in the transfer of drainage blocks to the farmers after completion of

SSD installation, were the major impediments to spread of SSD technology. At the community level, the involvement of farmers in monitoring and evaluation and refinement stages was not up to the mark. In areas where gravity outlets are easily available, even individual farmers could realize the benefits of SSD technology, involving their own members for its proper functioning. A large part of the income generated from the lands with SSD system goes for the repayment o bank loans; an issue that needs to be looked by the policy makers for encouraging the farming communities for the widespread adoption of this technology. The COP (Conference of Parties) 14 on UNCCD/LDN policy is scheduled to take place in India during 2019. Insights of such successful models which have arrested land degradation, can be shared and presented before the policy makers who are in process of developing transformative projects to meet out the target of land degradation nuetality in India before 2030.

THEME 3

SALT TOLERANT CULTIVARS FOR MANAGING DRYLAND SALINITY

Blooming Salt Affected Lands

केन्द्रीय मृदा लवणता अनुसंधान संस्थान

1969

C S S R I

1969-2019

Managing Dryland Salinity: Planned Technologies Complement Farmers' Creativity in Enhancing Income and Environmental Sustainability

Land degradation and desertification have become serious environmental concerns across the world. Soil degradation caused by salinization and sodification is a major issue in North-Western region of India because it reduces the potential productivity of agricultural lands. Factors responsible for the development of salt affected soils in this region include high evapotranspiration losses, low and erratic rainfall and presence of salty groundwater at shallow depths. As farmers have limited access to fresh water, use of poor quality groundwater becomes inevitable in irrigation further increasing the salinity and sodicity risks. The projections indicate that irrigation induced secondary salinization is likely to increase manifold in arid and semi-arid regions in the next few decades. Rajasthan state of India has 1.18 M ha salt affected area. At least 28% of the country's total poor quality waters are also found in Rajasthan, where nearly 84% of groundwater used for irrigation is of poor quality.

Vulnerability caused by ecological (e.g., soil and water salinity, and land use changes), climatic (climate variability) and socioeconomic stressors has compelled the local communities of Rajasthan to evolve the means and ways of sustaining their livelihoods. For example, in Pali district suffering from constraints like salinity and limited fresh water availability, local farmers and their family members often migrate to the cities and towns in search of employment. Pali district receives annual rainfall about 500 mm over a short span of about three weeks. Open-wells are the main source of irrigation water (75.0%) followed by the village ponds (20.0%) and tube-wells (5.0%). Unfortunately, salinity of open-well water in the last two decades or so has increased considerably. Local communities are of view that pervasive land use coupled with climatic aberrations are the main causes behind increased salinity of open-well waters which currently ranges from 4.0 to as high as 16.0 dS m^{-1}. It is due to this reason that low water requiring crops like coarse grains (bajra), oil seeds, pulses and seed spices are widely grown here. Of late, however, changing lifestyles and certain government policies seem to have caused a shift from low to high water demanding crops like wheat (irrigated) and vegetables.

Twin constraints of salinity and water scarcity widespread in dryland areas (like Pali) are conventionally managed through various engineering, agronomic and biological practices. In this study, we are presenting the successes and experiences gained from biological

Table 3.1. Soil and groundwater salinity of agricultural lands in selected villages of Pali district of Rajasthan

Farmer	Village	Development block	Soil pH_2 Min	Soil pH_2 Max	Soil EC_2 Min	Soil EC_2 Max	Water EC_{iw} Min	Water EC_{iw} Max
Mr Pemaram	Hemawas	Pali	7.79	8.4	0.69	2.5	1.2	2.5
Mr Malaram	Rampura	Rohat	8.77	8.88	1.09	2.42	2.5	8.85
Mr Ram Bharti	Kharda	Rohat	7.40	8.10	0.50	7.0	3.5	9.5
Mr Ishak Khan	Nimbara	Pali	8.20	8.8	0.79	1.78	1.5	2.68
Mr. Champa Lal	Banta	Marwad junction	8.10	8.90	0.78	2.0	4.2	6.8
Mr. Ghisu Ram	Sonai Manji	Pali	7.8	8.7	0.85	1.68	6.7	9.2
Mr Amar Singh	Dholeria	Rohat	8.4	8.9	0.11	0.68	6.5	9.5
		Mean	8.066	8.67	0.69	2.58	3.73	7.00

Min= Minimum; Max= Maximum

interventions (i.e. salt tolerant wheat and mustard varieties) for increasing crop yields under such situations. Since 2012, ICAR-CSSRI, Karnal and ICAR-CAZRI Krishi Vigyan Kendra (KVK) Pali have made concerted collaborative efforts for providing the local farmers viable solutions to lessen the salinity and associated hazards in different villages of Pali district. Resource mapping and agroecosystem analysis were carried out before recommending the appropriate salinity management practices to the farmers. Estimation of soil and water samples collected from the farmers' fields indicated that soils of the study area were saline-sodic in nature and underlain with saline groundwater (Table 3.1). In addition, a few scientist-farmer interface meetings were also organized to sensitize the farmers about timely adoption and implementation of improved salinity management practices. During these meetings, we tried to strike a balance between the planned technologies and farmers' practices to ensure that introduced technologies were compatible with the social-ecological milieu and were continued by the local farmers.

Case study one: Successful adoption and diffusion of wheat variety 'KRL 210'

The preceding account reflects the high vulnerability of the farmers of Pali district to salinity and associated problems. The risks caused by these stresses are further compounded by their weak economic status and restricted access to the institutional knowledge and technologies. Our interactions with the farmers revealed that most of them were unaware of salt tolerant crop cultivars capable of providing stable yields in stressful situations. The foregoing study illustrates how an appropriate intervention (i.e. salt tolerant wheat variety) could help the farmers in successfully overcoming the salinity and associated problems.

Approaches, interventions and outcomes

Hemawas Village of Pali district of Rajasthan was purposively selected. This village has a total population of 4012 with literacy rate of 56.7%. As this is a water scares area, several efforts were made in past to create permanent sources of drinking and irrigation water; Hemawas dam being one of them (Fig 3.1). Some farmers of the village have their agricultural lands in the dam catchment having heavy textured soils prone to cracking. Such farmers grow wheat, mustard and muskmelon (as cash crop) on the residual moisture. In contrast to other open-wells in the dam catchment yielding highly saline water, salinity is quite low in a few open-wells near the study field. Arable lands in the dam area (a common property resource) are leased to the farmers by the district administration for a period of one year. The lessee farmers carryout various agricultural activities either alone or in a *sajha* system (informal institution). The purpose of *sajha* system is to pool the resources and spread the crop risks caused by climatic, edaphic and socioeconomic factors. In order to support the farmers in copping-up with salinity induced risks, ICAR-CSSRI, Karnal made an effort to introduce salt tolerant wheat variety 'KRL 210' in 2017.

Initially, a group of farmers from Hemawas village having lands in the dam area and interested in cultivating 'KRL 210' wheat on residual soil moisture, were sampled. Based on various considerations, a farmer Mr. Pemaram was finally selected. He was provided the seeds of salt tolerant wheat variety 'KRL 210'. After soil and irrigation water analyses, he was provided the Soil Health Card and agroadvisories. Mr. Pemaram informed us that soil salinity in lands at some distance from the dam not only affected the crop establishment, but also caused human health problems such as skin burning and feet decay. Higher salinity, especially in the years of deficient or no rainfall, necessitated the use of about 10 % more seeds to maintain the desired plant population of wheat. Similarly, additional expenses on labour were also necessary for lifting the irrigation water for protective irrigation in wheat crop on such lands.

Fig 3.1. A partially saline field in Hemawas dam catchment

Fig 3.2. Wheat 'KRL 210' crop (Farmer : Mr. Pemaram)

Mr. Pemaram sowed the seeds of 'KRL 210' in the muddy soils in the dam catchment by broadcasting in the last week of December when water level recede to the lower depths (Fig 3.1), making soil cultivable. Besides better germination percentage and tolerance to salinity and diseases, 'KRL 210' plants had 4 to 5 effective tillers per plant compared to only 2 to in locally popular wheat varieties. Better growth and tillering in 'KRL 210' seemed to be due its better response to the fertilizer applications. Mr. Pemaram was able to harvest 3.65 to 4.1 t ha^{1} grain yield from 'KRL 210' (Fig 3.2) in partially saline heavy texured soils as compared to other varieties (2.8 to 3.1 t ha^{-1}), reflecting a yield gain of about 12%. Mr. Pemaram earned Rs. 62525 ha^{-1} after selling his wheat at MSP of Rs. 1525 q^{-1} (2016-17). After deducting the cost of cultivation (~ Rs. 24500 ha^{-1}), he could thus save a net income of Rs. 38025 ha^{-1} from 'KRL 210 compared to about Rs. 27270 ha^{-1} from other varieties in the previous years.

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Case study two: Successful intercropping of 'KRL 210' wheat in *Khejri* groves

This study is based on three years of collaborative work with a farmer in the Rampura village. Majority of the farmers in this village have small and marginal land holdings and they follow diverse strategies for sustaining the livelihoods. About 85.0% of the farmers have 1 to 4 open-wells as the source of irrigation water for wheat and seed spices. Other major crops grown are sorghum, moong, mustard, taramera, chick pea and chilli. Livestock rearing is also a major source of income to the local farmers.

Open-wells are considered to be the backbone of socio-ecological resilience. Unfortunately, 75% of such open-wells have gradually become saline (EC 5.0-13.0 dS m^{-1}), compelling the farmers to abandon them such wells. The groundwater used from remaining open-wells for irrigation is also marginally to moderately saline (1.29-8.85 dS m^{-1}) (Fig 3.3).

In addition to salinity, other social-ecological factors (e.g. inappropriate sand mining, land use changes, etc.) are also threatening the livelihoods of the farmers. These stressors are being managed by both planned and local strategies. In this backdrop, an effort was made to introduce salt tolerant wheat variety 'KRL 210' in this area. A medium farmer

Fig 3.3 A saline open-well

Fig 3.4. Performance of 'KRL 210 in saline field of Mr. Mala Ram

Mr. Malaram of Rampura village was selected. He cultivates cumin, pearl millet, moong, wheat and barley crops. After a few transect walks, soil and water (open-well) samples were collected and analyzed for providing him the Soil Health Card and agroadvisories. He sowed 'KRL 210' wheat using 80 kg seed ha^{1} in the second week of November in the inter-row spaces of *khejri* (*Prosopis cineraria*), a popular agroforestry tree in this area. Mr. Malaram believes that *khejri* provides a favorable micro-climate for the growth of inter-crops including wheat. Litter fall from the trees also adds good amount of organic matter to the soil. Different crop management practices including NPK application were carried out as per farmers' practice. In addition, Mr. Malaram also added cow-dung for improving the water holding capacity of the soil. Wheat 'KRL 210' was irrigated four times with marginally saline water from the open-well. Mr. Malaram has recently purchased open-wells near a tributary of Luni river passing through his agricultural field for having water of acceptable quality. Last year, he blended the water from this open-well with marginally saline water from another one for irrigating the wheat

Fig 3.5. A 'KRL 210' demonstration cum seed production plot at KVK, Pali

crop including 'KRL 210'. By adopting 'KRL 210', he obtained grain yield of 2.8 to 3.5 t ha^{-1} (Fig 3.4) as compared to 1.8 to 2.5 t ha^{1} in *Kharchia* variety, an increase of about 40%. Mr. Malaram earned Rs. 53375 ha^{-1} by selling the wheat at MSP of Rs 1525 q^{-1} (2016-17). After deducting the cost of cultivation (Rs. 27000 ha^{-1}), he thus saved Rs. 25875 ha^{-1}. He narrated his experience with 'KRL 210' wheat as: "This variety appears to be a better option than other varieties for obtaining good yields in the salt affected soils. It performs well in soils where other varieties even fail to germinate. This variety has good tolerance to salinity and diseases, and produces grains of superior quality for *chapatti* making".

Better performance of 'KRL 210' has attracted other farmers with about 10 of them having started its cultivation by procuring the seeds from Mr. Malaram. Considering the potential of 'KRL 210' wheat, KVK, Pali has also started its farm demonstration (Fig 3.5). Efforts are also being made for seed multiplication so that local farmers can be supplied required amounts of seed in the coming years.

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Case study three: Success of 'KRL 210' wheat in dam water irrigated saline soils

Although gypsum application is a feasible solution for reclaiming the sodic soils and waters, real challenge lies in using saline waters in irrigation. Use of salt tolerant crops and cultivars having low leaching requirement is increasingly being seen as a viable option for managing the salinity problem.

Approaches, interventions and outcomes

In this study, Kharda village of Pali district was selected for understanding the problems caused by soil and water salinities. We initially selected a few farmers in 2016 for implementing the planned technologies. Ultimately, Mr. Ram Bharti, a progressive farmer having 1.6 ha land in the Luni river basin, where irrigation water is saline (EC_{iw} 3.5 to 9.5 dS m^{-1}) was selected. Mr. Bharti is a well known grower of *Kharchia* variety of wheat in this area. During the years of good rainfall, soils and water in Kharda dam (saline watershed) display marked reductions in salinity (Fig 3.6) which is then distributed through canals for irrigating wheat and mustard crops. In Kharda village, wheat is grown on residual moisture to avoid salinity shock in the beginning.

Fig 3.6. Rainwater harvested in Kharda dam for irrigating wheat and mustard crops

Some farmers also apply a pre-sowing irrigation for better crop establishment.

Mr. Bharti was provided the seeds of salt tolerant wheat variety 'KRL 210' for sowing in 0.8 ha area. After sowing during the second week of November, he applied 5 irrigations using partially saline (EC 0.91 to 2.54 dS m^{-1}) water from the Kharda dam. Subject Matter Specialists of KVK, Pali monitored the crop performance and provided him agroadvisories periodically. 'KRL 210'showqed about 90% germination with each plant having an average of 5 effective tillers (Fig 3.7). Mr. Bharti obtained grain yield of 3.5 to 4.0 t ha^{-1} (Table 3.2). Owing to better salinity tolerance, higher grain yield, disease tolerance and superior grain quality, 8 other farmers of Kharda village also procured 'KRL 210' seed from Mr. Bharti (@ Rs. 3200 q^{-1}) for sowing in the next season. Higher wheat yields increased the incomes of Mr. Bharti. Earning from 'KRL 210' crop was used for purchasing agricultural implements and land leveling. He also purchased plastic pipes for carrying irrigation water to his field, resulting in virtually no seepage which in

Table 3.2. Performance of KRL 210 in saline soils

Yield (t ha^{-1})		Gross Return (Rs. ha^{-1})		Net Return (Rs. ha^{-1})		B:C Ratio	
KRL 210	Local	KRL 210	Local	KRL 210	Local	KRL 210	Local
3.5 to 3.97	2.4	43,400	33,500	27,600	19,500	2.7	1.9

Fig 3.7.Mr Ram Bharti with 'KRL 210' crop

previous years was a major cause behind increasing salt load in soils.

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Case study four: Integrated adaptation ensures bumper harvest of 'KRL 213'

Uncertainty in crop production is a key feature of the dryland ecosystems, adversely affecting the farmers' livelihoods. As mentioned previously, salt induced risks to farming are often further compounded by strong climate variability and repeated droughts. Results of this study suggest that a judicious blend of planned and autonomous strategies can turn the fortunes of farmers having salt affected lands.

Approaches, interventions and outcomes

A farmer Mr. Ishak Khan of Nimbara village of Pali district having limited resources and saline land was selected. Mr. Khan came into contact of KVK, Pali during 2012 to know about high yielding crops compatible with the

Table 3.3 Adaptation practices of Mr. Ishak Khan and other farmers

Adaptation components	Mr. Ishak Khan	Other farmers
Variety	KRL 213	Raj 3077
Seed rate (kg ha^{-1})	110	120
Number of tillage	Tillage (4)	Tillage (6)
Spacing (cm)	22	25
Fertilizer application		
Nitrogen (kg N ha^{-1})	60-80	120-140
Phosphorus (kg P2O5 ha^{-1})	-	40
Irrigation (no.)	5	6-7
Yield (t ha^{-1})	4.48	3.53
Cost of cultivation (Rs. ha^{-1})*	24500	23400
Gross returns @ Rs 1625 q^{-1}	90750	51770
Benefit : Cost ratio	4.1	2.2

*Other input costs being considered common while calculating cost of cultivation under both the practices.

conditions of his farm. Based on soil and water testing report, Mr. Khan was advised to adopt wheat variety 'KRL 213' for commercial cultivation. He sowed the seeds of 'KRL 213' in the first week of November using a seed-cum-fertilizer drill. He also applied FYM (5 t ha^{-1}) and other required inputs (Table 3.3). Although wheat crop was normally irrigated five times, only 2-3 irrigations were sufficient to meet the crop water requirement in years of winter rainfall (*Mawat)* (December and January).

Mr. Khan also used his own creativity *viz* application of pond clay (rich in organic matter) and reduced irrigating as he believed that over irrigation was major cause of low wheat yields. For seed production, Mr. Khan calibrated the seed-drill for sowing 'KRL 213' variety with a seed rate of 110 kg ha^{-1} at 22 cm row spacing (Table 3.3). During 2012-2017, several local farmers interacted with Mr. Khan regarding the performance of 'KRL 213' (Fig 3.8). Every year, the crop was harvested and grain yield was recorded from five random crop crop-cutting plots (5x5 m^2 area). The average yield of 'KRL 213' in the past five years (2012-2017) was estimated to be 4.75 t ha^{-1} Fig 3.9).

Fig 3.8. Wheat 'KRL 213' crop in saline soils

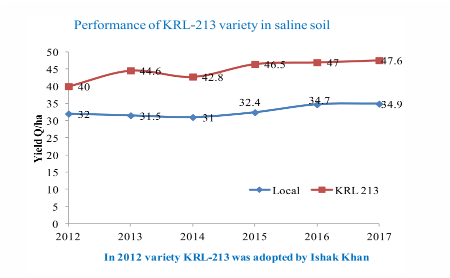

Fig 3.9. Yield performance of wheat 'KRL 213' over the years

Agronomic practices like summer ploughing, *in-situ* rain water harvesting, incorporation of crop residues and preparation of false seed beds to minimize the weed infestation were the major reasons behind the success of Mr. Khan. He also sprayed zinc sulphate @ 5 kg per hectare at the tillering stage for further enhancing the wheat yield. These creativities resulted in relatively more number of effective tillers (448-460 m^{-2}) and higher grain weight [(44.5-47.6 g/1000 grains).

Adoption of 'KRL 213' resulted in the saving of 25 to 30.0% of the resources, leading to higher returners and environmental sustainability (Table 3.3). Mr. Khan could earn Rs. 87,500 ha^{-1} by selling seeds of 'KRL 213'. This was much higher as compared to returns from previous crops using old varieties (Rs. 62,600 ha^{-1}). Another interesting point was that Mr. Khan has been experimenting with different moisture levels and sowing times since 2012 to counteract the adverse effects of climatic aberrations. Aforementioned management practices made his venture with 'KRL 213' a success story for others. Not only Mr. Khan's farm has become more productive, his family members no longer migrate to the cities in search of employment.

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Case study five: Reaping benefits from salt tolerant mustard variety 'CS 54'

In dryland areas afflicted by multiple stresses like excessive evapotranspiration, lack of fresh water for irrigation and the uncertainty of climate, coarse grains, pulses and oilseed crops play a significant role in diversifying the cropping systems. In many parts of Pali district of Rajasthan suffering from soil salinity, mustard is a major crop. In the succeeding section, we provide evidence as how adoption of a salt tolerant mustard variety could be a viable income generating option in salt affected soils.

Approaches, interventions and outcomes

Keeping various considerations into account, we first surveyed the Banta village of Pali district. After through discussions, Mr. Champa Lal, a small land holder, was chosen. Mr. Lal has been cultivating mustard as a major *rabi* oilseed crop since the last few decades. However, he never obtained satisfactory yields due to salinity problem. After several transect walks, soil and water samples were collected and analyzed. Based on the laboratory

Table 3.4. Adaptation practices of Mr. Lal compared with other farmers

Adaptation components	Mr. Champa Lal practice	Other farmers
Variety	CS 54	Traditional
Seed rate (kg ha^{-1})	4	5
Number of tillage	Tillage (5)	Tillage (6)
Spacing (cm)	30	20
Fertilizer application		
Nitrogen (kg N ha^{-1})	60	30
Phosphorus (kg P2O5 ha^{-1})	40 kg	50
Irrigation (no.)	4	2
Yield (t ha^{-1})	1.36	0.917
Cost of cultivation (Rs. ha^{-1})*	17400	16100
Gross returns @ Rs 4500 q^{-1}	61200	34387
Benefit : Cost ratio	3.5	2.1

*Other input costs being considered common while calculating cost of cultivation under both the practices.

Fig 3.10. Mr. Champa Lal with 'CS 54' crop in his field

report, Mr. Lal was provided Soil Health Card and suitable agroadvisories in 2013. In order to enhance his adaptive strategies, Mr Lal and fellow farmers were also sensitized about salinity management options available during the *Kisan Goshthis* and interaction meets organized in the village. In addition, he was also trained for the commercial seed production of mustard (e.g. rouging, optimum isolation distance, seed treatment, sowing method, identification of off type plants and other agronomic practices). Ultimately, he decided to adopt salt tolerant mustard variety 'CS 54' for cultivation (Fig 3.10).

Mr. Lal sowed 'CS 54' crop around mid October using a seed-cum-fertilizer drill. For harvesting the bold grains (for seed purpose), he used about 20.0% less seeds (4 kg ha^{-1}) than other farmers with a row spacing of 30 cm (Table 3.4). Mr. Lal normally applied 4 irrigations and followed other crop management practices. In years with good winter rainfall, however, he reduced the number of irrigations (2 or 3). After crop harvesting, grain yield was recorded from 3 random crop-cutting plots each of 4 m^2 area. In the last five years (2013 to 2017), grain yield of 'ÇS 54' ranged from 1.27 to 1.45 t ha^{-1} compared to 1.04 to 1.27 t ha^{-1} in the locally popular varieties. Better performance of 'CS 54' variety resulted in almost 25.0% saving of crop inputs and thus more profits (Table 3.5).

Table 3.5 Yield performance of mustard 'CS 54' in saline soils

Farmer	Yield (t ha^{-1})/ $Year^{-1}$				
	2013	2014	2015	2016	2017
Champa Lal	12.72	12.96	13.41	14.20	14.50
Other farmers	8.34	8.54	9.20	9.7	10.10

After acquiring new skills in seed production, Mr. Lal successfully multiplied 'ÇS 54'seeds for supplying to other farmers of nearby villages. Besides routine sale, he also sold on an average 1.5 t seed of 'CS 54' every year at a price of Rs. 3950 q^{-1}. This way, he earned Rs. 61225 ha^{-1} only from seed sell. Association of Mr. Lal with KVK, Pali and the technical knowledge provided by the ICAR-CSSRI, Karnal together made 'CS 54' mustard variety an economically and ecologically viable option for improving the productivity of salt affected soils.

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Case study six: Commercial adoption of 'CS 56' mustard reduces the farmers' risks

Recognizing the huge socio-economic importance of mustard crop in the study area, KVK, Pali took an initiative to boost mustard production in salt affected soils of Pali district of Rajasthan. The scientists of ICAR-CSSRI, Karnal were also consulted so that farmers did not face any problem in managing the saline soils where mustard crop was to be grown.

Approaches, interventions and outcomes

In this study, Sonai Manjee village of Pali district well known for the production of moong in *kharif* and mustard in *rabi* seasons, was selected. Arable lands in this village are affected by salinity to varying degrees. The present average yield of mustard in this village is ~ 1.0 t ha^{1}. As farmers lack access to the quality seeds of improved varieties, there exists a wide gap between the actual and potential yields. After a thorough analysis of the existing situation, a farmer Mr. Ghisu Ram having salt affected lands was selected. We motivated him for adopting salt tolerant mustard variety 'CS 56'

Fig 3.11. Farmers learning about 'CS 56' cultivation

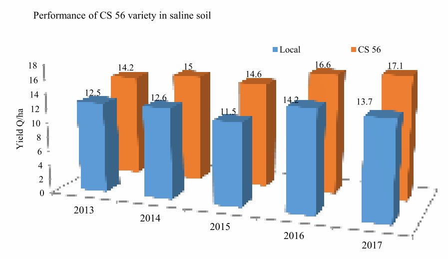

Fig 3.12. Yield performance of mustard variety 'CS 56' over the years

Table 3.6. Adaptive practices of Mr. Ghisu Ram as compared with other farmers

Adaptation components	Mr. Ghisu Lal's practices	Other farmers
Variety	CS 56	T 59
Seed rate (kg ha^{-1})	3.5	5
Number of tillage	Tillage (3-4)	Tillage (5)
Spacing (cm)	30	25
Fertilizer application		
Nitrogen (kg ha^{-1})	60	80
Phosphorus (kg P_2O_5 ha^{-1})	-	30
Sulphur (kg ha^{-1})	25	15
Irrigation (no.)	3-4	2
Yield (t ha^{-1})	1.55	1.29
Cost of cultivation (Rs ha^{-1})*	18900	19900
Gross returns @ Rs 4500 q^{-1}	74700	45150
Benefit : Cost ratio	3.7	1.9

*Other input costs being considered common while calculating cost of cultivation under both the practices.

in the place of traditionally grown variety since 2013. Scientific inputs from ICAR-CSSRI, Karnal further improved his adaptive capacity for managing the salinity risk. Subsequent to these efforts, Mr. Ram started growing mustard variety 'CS 56' successfully (Fig 3.11). On an average, this variety yielded around 1.6 t ha^{-1} (Fig 3.12). Mr. Ram sowed seeds of 'CS 56' in the first week of October using a seed-cum-fertilizer drill. Contrary to this, other farmers sow the mustard crop in the second week of October. By pre-poning the sowing by one week, Mr. Ram could virtually overcome the problems caused by heavy aphid and powdery mildew attacks. For harvesting the bold grains, Mr. Lal used only 3.5 kg seed ha^{1} at row spacing of 30 cm (Table 3.6). The reason for relatively higher spacing, as narrated by Mr. Ram was:

This variety ('CS 56') adapts well to the local soil and climatic conditions resulting in profuse vegetative growth even with the use of poor quality groundwater. It thus needs relatively more space for biomass production.

Although he usually applied 3 to 4 irrigations since the past few years, no irrigation was done after the last week of January to prevent the outbreak of orobanchae, which is increasingly becoming a notorious weed of mustard crop in the Pali district. Crop yield is not adversely affected even when no irrigation is done in the last week of January, because crop water requirement is mostly fulfilled by the rainfall received during the preceding months and adequate moisture is maintained till the crop harvest.

Mr. Ram obtained an average grain yield of ~ 1.7 t ha^{-1} from 'CS 56' in the past five years (2013-2017). Relatively higher yields during the last two years in particular seem to be due to better crop management and appreciable reductions in soil and water salinity after winter rainfall. Autonomous agronomic manipulations by Mr. Ram (e.g., lower seed rate and early sowing to cope-up with climate variability) were the key to better performance of 'CS 56', resulting in the saving of resources by almost 20.0% (Table 3.6). Besides routine sell on MSP, he also sold about 1.56 t 'CS 56' seeds annually at a price of Rs. 4500 q^{-1}, earning Rs. 74,700 ha^{-1} from seed sale.

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Case study seven: 'KRL 210' wheat is an ideal option for highly saline soils

Pali district lying in the Transitional Plains between the Aravalli ranges and Western arid region is drained by the ephemeral Luni river. Local farmers grow bajra, maize, guar, sesame and pulses under rainfed condition in *kharif* season and wheat, barley and mustard in *rabi* season under irrigated condition. Although groundwater in many parts of Luni river basin is partially to moderately saline, groundwater is exceedingly saline in Dholeria and nearby villages. Despite some location specific practices, lack of access to the external resources and technologies seems have put the local farmers in a vulnerable situation.

Approaches, interventions and outcomes

In this study, Dholeria village of Pali district was selected to assess the scope for managing salt affected soils through formal knowledge. After group discussions and personal interactions with the farmers, Mr. Amar Singh having 10 ha of salt affected land was selected for the planned interventions. He irrigates the crops using the saline water from an open-well. After soil and water analyses, Mr. Singh was provided Soil Health Card and suitable agroadvisories. Prior to this intervention, Mr. Singh has regularly tried to access and use planned technologies for managing his saline lands. In year 2012, Mr. Singh came into contact of KVK, Pali to learn appropriate techniques for obtaining higher crop yields. Meanwhile, Mr. Singh and other farmers of this village also came into contact of a team of ICAR-CSSRI, Karnal involved in the implementation of a project on strengthening climate change adaptations in the salt affected areas of Pali district. Subsequent

Table 3.7 Adaptation practices of Mr. Amar Singh compared with other farmers

Adaptation components	Mr. Singh's practices	Other farmers
Variety	KRL 210	Raj 3065
Seed rate (kg ha^{-1})	120	100
Number of tillage	Tillage (4)	Tillage (5)
Spacing (cm)	22	20
Fertilizer application		
Nitrogen (kg ha^{-1})	80-100	160-175
Phosphorus (kg P_2O_5 ha^{-1})	-	50
Irrigation (no.)	5-6	6-7
Yield (t ha^{-1})	3.75	3.35
Cost of cultivation (Rs ha^{-1})*	22800	21900
Gross returns @ Rs 1625 q^{-1}	84375	51615
Benefit : Cost ratio	3.7	2.3

*Other input costs being considered common while calculating cost of cultivation under both the practices.

collaboration between KVK, Pali and ICAR-CSSRI, Karnal ultimately paved the way for demonstrations of high yielding salt tolerant wheat variety 'KRL 210'. Before this, like other farmers, Mr. Singh cultivated low yielding and more input demanding local variety *Kharchia,* which gave very low profits.

Before sowing, the field was brought to fine tilth using disc plough and cultivator, and FYM was applied @ 6 t ha^{1}. 'KRL-210' seeds were sown in a cross sowing pattern in the second week of November using a seed-cum-fertilizer drill. Seed rate was kept to 120 kg ha^{1} and sowing was done at row spacing of 22 cm against the recommended seed rate (100 kg ha^{-1}) and row spacing (20 cm) (Table 3.7). Wheat 'KRL 210' crop was periodically monitored by a team of KVK, Pali. In contrast to 6-7 irrigations in *Kharchia*

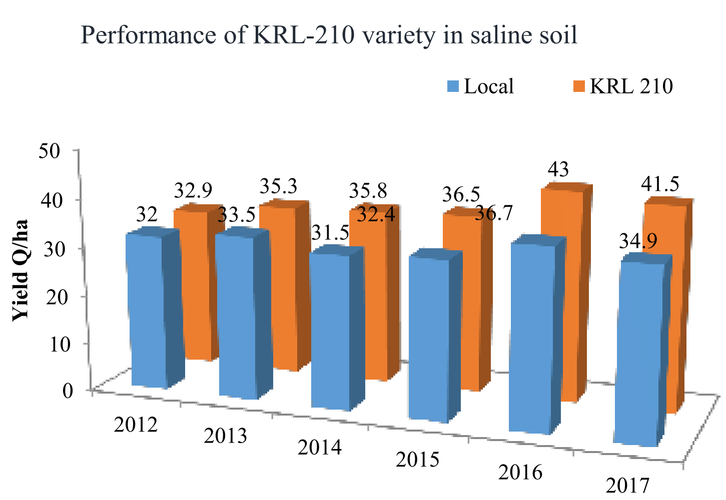

Fig 3.15. Performance of 'KRL 210' in saline soils over the years

variety in the previous years, Mr. Singh applied only 5-6 irrigations in 'KRL 210' crop. Based on the better performance of 'KRL 210' in saline soils (Figs 3.13 & 3.14), it was subsequently also adopted by other farmers. Mr. Singh obtained an average grain yield of 3.75 t ha^{-1} in the past five years (2014-2018). In 2016-17, he even got a grain yield of 4.3 t ha^{-1} (Fig 3.15). Presently, Mr. Singh is selling his entire harvest of 'KRL 210' as seed due to high demand from the fellow farmers earning Rs. 90,750 ha^{1}.

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Lessons learnt

Successful outcomes of these interventions implied that biological solutions (i.e. salt tolerant crop cultivars) could be a viable option for enhancing the economic returns from salt affected soils. Before these studies were conducted, farmers of the study area were barely able to produce wheat and mustard crops for their household needs. However, adoption of salt tolerant wheat and mustard cultivars led to manifold increases in the yields such that they were able to sell a considerable portion of the harvest as seed, fetching remunerative returns. Seeds of different salt tolerant cultivars of wheat and mustard are currently being traded on the local markets, creating a seed network and inculcating an entrepreneurial habit among the local farmers.

The huge success of these farmer participatory studies suggests that farmers can become entrepreneurs provided efforts are made to increase the crop yields such that surplus produce is sold as seed at much higher prices. Despite the fact that some success has been achieved in developing the local seed networks (at village or cluster of few villages) there is a considerable scope for replicating this model at the district and regional scales. We propose that district development departments, research institutions, KVKs, NGOs and progressive farmers need to be aligned to the ongoing efforts for the anticipated benefits. Results of these studies also suggested that farmers' perception of salinity is somewhat narrow as it is seen solely in relation to economic yields. Re-vegetation of saline lands through salt tolerant crops and cultivars may also provide some intangible benefits including carbon sequestration for minimizing the impacts of climatic warming. It is also clear that a synergy between planned technologies and traditional ecological knowledge is achievable with little efforts. Preceding observations reflect the need for blending and applying the inclusive knowledge derived by integrating the scientific inputs and formers' wisdom on a large scale.

Harnessing the Potential of Salt Tolerant Crop Cultivars: Transforming Degraded Saline Vertisols into Bountiful Assets

In India, about 6.73 M ha arable land is salt affected of which 2.22 M ha is found in Gujarat state alone. Gujarat has the longest coastline (1600 km distance) in the country of which about 1125 km is adversely affected by the seawater ingress. About 5 to 7.5 km wide strip of the inland area has been rendered saline. Out of 33 districts in the state, about 25 are affected by salinity stress. Salt induced land degradation remains a major challenge to sustainable farming in the state. Vast areas are also facing imminent threats of becoming barren; crop production and productivity have declined due to secondary salinisation in excessively irrigated lands in canal command areas or those irrigated with saline groundwater in coastal areas. Economically viable agro-management practices while helping in the management of salt affected black soils and saline groundwater in this region can also increase agricultural production and thus better incomes to the farmers.

Case study one: Indigenous cotton: An ideal option for coastal saline soils of Gujarat

Approaches, interventions and outcomes

ICAR-CSSRI, Regional Research Station, Bharuch (Gujarat) is continually striving to develop appropriate measures for enhancing the soil quality and crop yields in the saline Vertisols of Gujarat state. Besides, surveying, identifying and characterizing the salt affected soils in the coastal and inland areas of Gujarat, this Station is also involved in searching and developing biological, engineering and chemical based technologies to reclaim and manage the salt affected lands.

In this endeavor, a number of villages have been adopted from where soil samples were collected and Soil Health Cards issued to the farmers. Among various options, indigenous cotton (*desi cotton*)- known for its short staple characteristics, deep root system, resistance to diseases, and pests and drought appears to be a promising solution for enhancing the economic value of these soils. After field trials for two years, RRS Bharuch has found *desi* cotton variety (G. Cot. 23) to be salt tolerant and high yielding (Fig 3.16). On-farm trials of this variety were conducted on farmers' fields in Bhal area (Rajpara village of Dholera taluka of Ahmedabad district), Bara tract (Bojadra and Kalak villages of Jambusar taluka, Bharuch district) and Saurashtra (Kodinar, Mangrol and Sutrapada) during 2011-2013 (two years). Results indicated that yield of G Cot 23 was between 1.8 to 1.9 t ha^{-1}. Apart from this, cultivation of other *desi* cotton lines were also taken in Kalak (Fig 3.17) and Bojadra villages giving seed cotton yield of 1.6 to 1.9 t ha^{-1}.

Fig 3.16 'G. Cot. 23' cotton in trial on Samni Farm, Bharuch

Fig 3.17. 'G. Cot. 23' crop on a farmers' field

Cultivation of *Herbaceum* cotton lines is currently also being taken-up in the Bhal area, Bara tract area and Saurashtra regions having saline black soils. G. Cot. 23 variety was also demonstrated on farmers' fields in saline Vertisols in four villages (Rajpur, Mingalpur, Shela and Kamatalav in Dhandhuka taluka) of Ahmedabad district. The soil salinity in these villages varied from 9.4 to 10.2 dS m^{-1}, and the yield of cotton between 1.7 to 1.8 t ha^{-1}.

Based on these encouraging results, collaborations were established with various NGOs. This helped in expanding the cultivation of salt tolerant *Herbaceum* cotton (G.Cot 23) in saline coastal areas of Bharuch, Anand, Ahmedabad and Junagadh districts. Remunerative returns from its cultivation shortly led many other farmers to adopt this cultivar for commercial cultivation in about 10,000 ha area. It is worth mentioning that cost of cultivation of *desi* cotton (Rs. 18,000 to 21,000 ha^{-1} in rainfed condition) being much lower than *Bt* lines and hybrids (Rs 40,000 to 45,000 ha^{-1}) in addition to better performance in saline soils also gave momentum to its cultivation. By adopting this variety, farmers are earning net income of Rs. 45,000 to 50,000 ha^{-1}, particularly in South Gujarat (Bojadra and

Fig 3.18. Farmers' training programme for 'G Cot 23' cultivation

Kalak villages) with B:C ratio of 1.8 to 2.0. These encouraging results were also disseminated among the farmers through Village Goshthis and training programmes (Fig 3.18). The NGOs, viz., VIKAS (Jambusar), ATAAPI (Jambusar) and MAHITI (Dholera) provided the voice based messages on 'G. Cot. 23' cultivation and its cultural aspects to the farmers in selected villages.

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Case study two: Adoption of salt tolerant 'KRL 210' on salt affected Vertisols

Approaches, interventions and outcomes

Local wheat varieties give very poor grain yields in saline Vertisols of Bharuch district of Gujarat. In this study, a farmer Mr. Amarsinh Gulabsinh Parmar of Bojadara village of Bharuch district was selected for demonstrating salt tolerant wheat variety 'KRL 210'. Mr. Parmar has 12 ha of saline land (EC 1.6 to 4.2 dS m^{-1} and pH ~ 8.15). Due to salinity and high clay content, Mr. Parmar faced problems of waterlogging, soil erosion, poor germination and low wheat productivity. He was provided Soil Health Card along with agroadvisories for maximizing the returns from his saline land. He was also provided seeds of "KRL 210' wheat for cultivation on 1.6 ha area in 2013. For improving the soil fertility, Mr. Parmar also applied FYM. To increase the resource use efficiency and reduce the adverse effects of soil salinity, he also leveled his field (for uniform application of irrigation water). He reported that 'KRL 210' performed better compared to other locally

Fig 3.19. Wheat 'KRL 210' crop in a saline field

popular wheat varieties in terms of higher number of effective tillers per plant, input response, grains per earhead, better grain quality and overall yield. To diversify the cropping system and spread the risks of crop failure, he also planted some fruit trees. The cost of cultivation of 'KRL 210' was calculated to be Rs 20,000 to 21,000 ha^{-1}. Average grain yield was 4.0 t ha^{-1} (Fig 3.19) as compared to 3.25 t ha^{-1} in wheat variety 'GW 496'; an increase of 23.07%. Based on the better performance of 'KRL 210', about 10 fellow farmers contacted him for purchasing the seeds.

Case study three: Adoption of wheat 'KRL 210' on a (community scale) on saline Vertisols

Approaches, interventions and outcomes

Subsequent to the good performance of 'KRL 210' on Mr. Amar Singh Parmar's farm, a plan was developed to expand the area coverage under this variety on other (8) farmers'fields suffering from salinity (EC: 4.4 to 5.7 dS m^{-1}; pH 7.7 to 8.4). The average field size of farmers selected for providing the seeds of 'KRL 210' was 0.30 ha (Table 3.8). After soil and water analysis, these farmers were provided detailed agroadvisories for higher wheat yields. 'KRL 210' demonstration plots were also periodically monitored. A few farmers'

Table 3.8. Yield performance of KRL 210 on farmers' field in saline Vertisols of Bharuch district, Gujarat

Farmer	Year of adoption	Area (ha)	Salinity (dS m^{-1})		pH		Cost of cultivation ha^{-1}	Yield of local variety (t ha^{-1})	Yield of KRL 210 (t ha^{-1})	Yield increase (%)	Gross income**	Net income
			Min.	Max	Min.	Max						
Mr. Bhagwansingh Phoolsingh Solanki	2017	0.2	5.8	6.9	7.6	8.6	15000	1.95	2.25	13.33	36562.5	30562.5
Mr. Talsibhai Sivabhai Patel	2017	0.2	6.0	8.0	7.8	8.2	17500	1.50	2.25	33.33	36562.5	29562.5
Mr. Shrvanbhai Jasonbhai Rathod	2016	0.4	5.6	7.8	7.7	8.8	20000	1.95	3.25	40.00	49562.5	41.562.5
Mr. Devendra Singh Pratapsinh Parmar	2013	0.8	3.5	4.5	7.8	8.5	17500	3.00	4.00	25.00	54000.0	47000.0
Mr. Ashwin Singh Madhavsingh Raj	2016	0.2	1.8	4	7.9	8.4	13750	3.50	4.75	26.31	72437.5	66937.5
Mr. Ghanshyam Singh Jaswantsingh Raj	2014	0.2	2.5	4.5	7.6	8.7	12500	3.00	4.50	33.33	63000.0	58000.0
Mr. Bhadreshbhai Patel	2017	0.2	3.6	6.0	7.8	8.3	15000	1.90	2.80	32.14	45500.0	39500.0
Mr. Bharat Bhai Narsangbhai	2016	0.2	3.5	4.2	7.6	8.2	20000	2.00	3.00	33.33	45750.0	37750.0
Mean		0.3ha	-	-	7.7	8.4	16406.3	2.35	3.35	29.60	50422.0	44187.5

*Area under KRL 210.
** MSP of corresponding year was used to calculate gross and net income

Fig 3.20. Performance of 'KRL 210' on saline field in Samni village

goshthis were also organized in the adopted villages. Farmers were advised to continue with their local practices of FYM application, land leveling and conjunctive use of saline and canal waters for irrigation (Table 3.9). Sowing was done in the third week of November. Crop was irrigated 4 to 5 times and was fertilized as per recommendation. Variety 'KRL 210' performed well giving very good germination, effective tillers per plant, higher yield and better grain quality (Fig 3.20).

The crop was harvested in the second week of April. The mean grain yield of 'KRL 210' was 3.35 t ha^{1} as compared to 2.35 t ha^{-1} in local wheat variety, an overall gain of 30.0%. The mean cost of cultivation

Table 3.9. Farmers' practices for enhancing the resilience of wheat 'KRL 210'

Farmer	Diffusion of 'KRL 210'	Practices	Other crops taken
Mr. Bhagwansingh P Solanki	6	Field leveling and FYM	Cotton ('G. Cot. 23')
Mr. Talsibhai Sivabhai Patel	5	Field and conjunctive use of water	Arhar and cotton
Mr. Shrvanbhai Jasonbhai Rathod	2	Field leveling, FYM and conjunctive use of water	Cotton ('G. Cot. 23'), Mungbean, wheat
Mr. Devendra Singh P Parmar	5	Field leveling, FYM and conjunctive use of water	Cotton ('G. Cot. 23'), arhar and wheat
Mr. Ashwin Singh M Raj	5	Field leveling, FYM and conjunctive use of water	Cotton ('G. Cot. 23'), castor and arhar
Mr. Ghanshyam Singh J Raj	4	Field leveling, FYM and conjunctive use of water	Cotton ('G. Cot. 23'), sorghum and mungbean
Mr. Bhadresh Bhai Patel	3	Field leveling, FYM and conjunctive use of water	Cotton ('G. Cot. 23'), wheat and arhar
Mr. Bharat Bhai Narsang Bhai	10	Conjunctive water use and FYM	Cotton ('G. Cot. 23'), mungbean, castor and wheat

FYM= Farm yard manure. Note : 'KRL 210' Seeds were replaced every third year.

was calculated to be Rs. 16,406 ha^{-1} and the net profit to be of Rs. 44187 ha^{1} (Table 3.8). We found that every individual farmer participant in this study diffused the seeds of 'KRL 210' to at least 2 farmers and sometimes up to 10 farmers.

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Lessons learnt

Salt tolerant crop varieties seem to be a viable option for enhancing the productivity of saline Vertisols. Although a single technology (e.g. salt tolerant wheat variety 'KRl 210') can increase the adaptive capacity of the farmers to cope-up with the salinity induced risks, it would always be better to include other components in the adaptation plan for better results. As seeds of wheat 'KRL 210' are available in limited quantity, there is vast scope for State Agricultural Department for multiplying the seeds to bridge the supply gap. Partnerships with private firms and NGOs can also be of considerable help in this regard. Progressive farmers should also be promoted to form the Farmer Producer Companies (FPOs) for commercial seed production and distribution. Such local arrangements can ensure the supply of required amounts of seed at affordable prices to the farmers willing to take up ' KRL 210' cultivation in saline Vertisols.

THEME 4

LAND SHAPING MODELS FOR MANAGING WATERLOGGED SODIC AND COSTAL SALINE LANDS

Blooming Salt Affected Lands

केन्द्रीय मृदा लवणता अनुसंधान संस्थान

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Land Modification with Grassroots Learning on Integrated Farming System Models

Waterlogging is a common problem caused by excessive irrigation in the command areas. Heavy textured soils with poor drainage are particularly highly susceptible to the irrigation induced secondary salinity. Uttar Pradesh (UP) state has large sodic area concentrated mainly in the central and eastern parts. Waterlogged sodic soils are difficult to reclaim by traditional gypsum based package. It is seen that in seepage prone areas salt accumulation is prominent on the soil surface whereas continuous seepage in the deeper soil profile keeps salts moving along the seepage water. Remote sensing based mapping indicated that about 10% land was waterlogged sodic in Raebareli district.

Approaches, interventions and outcomes

Efforts have been made by ICAR-CSSRI, RRS Lucknow to develop certain models for managing the twin problems of waterlogging and sodicity. Biodrainage (trees planted at 2 m x 2 m) over an area of 1.2 ha and single lateral interceptor drain installed at an average depth of 1.60 m below the ground surface over a length of 400 m were found to be ineffective in controlling canal seepage at Kashrawan reach of Sharda Sahayak canal. Hence, there was a need for a technology suited to the needs of individual farmers for combating the problems of waterlogging and sodicity.

Land modification based integrated farming system (LMBIFS) models

Gypsum based sodic land reclamation technology is in effective under shallow water table conditions (< 2.0 m below the surface). In waterlogged sodic lands, repeated gypsum application is cost prohibitive. Lowering of water table below 2.0 m depth prior to the gypsum application for effective salt leaching and sustainable reclamation and management of waterlogged sodic soils is an essential requirement to avoid secondary sodification. Subsurface horizontal drainage is a proven technology to lower down the watertable, but non-availability of natural gravity outlets is a major constraint to the base of this technology in certain parts of Indo-Gangetic Plains. The rate of seepage increases with soil depth resulting in high salt accumulation on soil surface. The idea of inverting low pH deeper soil profiles upside down in a pre-specified soil column outlined a hypothesis of land modification based integrated farming system model for the reclamation of waterlogged sodic soils. Based on hypothesis, two types of LMBIFS models: (i) fish pond based integrated farming system (FPBIFS) and (ii) raised and sunken bed based integrated farming system (RBBIFS) were demonstrated in Kashrawan village of Raebareli district in Sharada Sahayak

Table 4.1. Description of IFS Models in Sharda Sahayak canal command

Farmer name	Village	Block	Construc- -tion year	District	Model	Distance from canal (m)	Model (area, ha)
Mr. Jaidrath	Kashrawan	Bachhrawan	2006	Raebareli	FPBIFS	175	1.00
Mr. Ram Kumar Patel	Kashrawan	Bachhrawan	2008	Raebareli	RBBIFS	42	0.36
Mr. Ghastia Ram & Dinesh	Patwakheda	Mohanlalganj	2012	Lucknow	FPBIFS	185	0.75
Mr. Kalwati Devi	Patwakheda	Mohanlalganj	2015	Lucknow	FPBIFS	100	0.21
Mr. Jitendra Singh	Lalaikheda	Mohanlalganj	2015	Lucknow	FPBIFS	73	0.46
Mr. Sherbahadur*	Salempur Achaka	Mohanlalganj	2015	Lucknow	FPBIFS	83	0.33

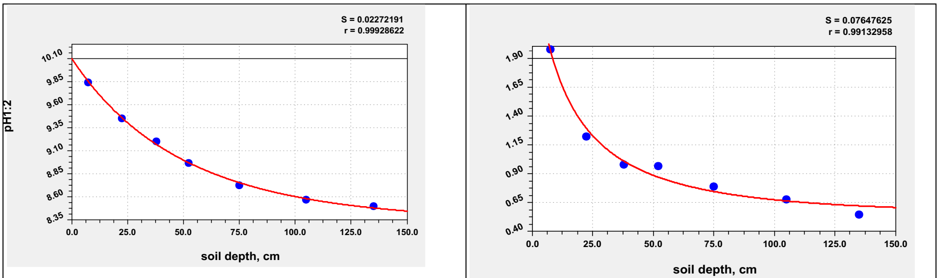
* Waterlogged conditions

canal command. One FPBIFS model was also constructed during 2012 at Patwakheda village of Mohanlalganj block of Lucknow district. Two more such FPBIFS models were also constructed in 2015 at Lalaikheda and Patwakheda villages of Mohanlalganj Block (Table 4.1). One FPBIFS Model was constructed under waterlogged condition only in Salempur Achaka village of Mohanlalganj block.

Case study one: FPBIFS Model at Kashrawan

First FPBIFS model, designed for retaining an average standing water depth of 1m for nearly 10 months was constructed at the field of Mr. Jaidrath of Kashrawan village in Bachhrawan block of Raebareli district. He had joint land holding of 1.33 ha, despite the reclamation efforts, the land remained uncultivated since long. The initial variations of soil pH_2 and EC_2 with soil depth are shown in Fig 4.1.

Due to continuous seepage from the canal, pH_2 and EC_2 decreased with increasing soil depth indicating it to be a suitable site for FPBIFS model. Areas under fish pond, field crops, fruits, forages and vegetables were 0.40, 0.25, 0.15, 0.10 and 0.10 ha, respectively. The depth of fish pond was kept as



$$1{:}2 = \frac{8.339}{1-0.17421^{\;-0.0173038}}$$

$$1{:}2 = \frac{0.55335}{1-0.80275^{\;-0.015797}}$$

Fig4.1. Variation in soil pH_2 and EC_2 with soil depth

Fig 4.2. Crop performance in first FPBIFS Model in Kashrawan village

1.75 m for maintaining 1.0 m average water depth for a period of 10 months. Fluctuations in water depth during rainy to summer seasons were kept in mind while deciding the depth of fish pond. Width of elevated field bed was kept 50 m, matching the boundary conditions and convenience to the farmers. The height of the elevated field bed was decided to keep the watertable below 2 m from the surface of elevated field bed for keeping secondary sodification in check. The average height of elevated field bed was kept 1.5 m above the ground surface.

The crops were successfully grown over the raised bed for three to four years (Fig4.2). B:C ratios of wheat, mustard, onion and garlic were 1.13, 2.43, 4.42 and 15.60, respectively in *rabi* 2010, and of rice and sorghum 1.88 and 2.71, respectively, in *kharif* 2011. B:C ratio of fish stocking was calculated to be 2.63 during the first year. Overall, B:C ratio for 2010-11 was 4.45 including the fish stocking.

Soil pH_2 of elevated field beds ranged from 8.17 to 8.67 and EC_2 from 1.63 to 4.66 dS m^{-1}, after five years of pond construction. The size of elevated field bed was large enough having tendency to accumulate salts in the mid of the bed due to slow rate of watertable drawdown. Farmers were advised to grow summer crops during *zayad* season for enhancing the salt leaching. Green manuring was also advocated for improving the soil fertility and water transmission characteristics of the soil

Fig 4.3. Crop performance in RASBBIFS Model in Kashrawan village

Case study two: RASBBIFSM Model at Kashrawan

For catering to the needs of small to marginal farmers, RASBBIFS was constructed at a distance of 200 m from FPBIFS model at the field of Sri Ram Kumar in Kashrawan village of Bachhrawan block of Raebareli district. He had joint land holding of 2.40 ha. The area was lying uncultivated due to waterlogging and sodicty. The depth of sunken bed was limited to 0.60 m and width of raised bed at top was 2.0 m. The width of the sunken bed at the bottom was 7.0 m. Rice and water chestnut were grown in sunken beds and vegetables over the raised beds. Overall, B:C ratio for *kharif* 2013 and *rabi* 2013-14 were calculated to be 2.76 and 1.72, respectively. Five years average B:C ratio was worked out to be 3.08 without eucalyptus and 6.44 with eucalyptus. Crop performance was observed to be good (Fig 4.3) and model was successful in waterlogged sodic conditions. Mango, guava, lemon, neem, acacia and eucalyptus were also planted on the outer raised bed. Too small width of raised bed was the major limitation of this model.

Initial soil pH_2 at the site ranged from 9.31 to 10.47 and EC_2 from 0.43 to 1.78 dS m^{-1}. The pH of surface soil reduced to 8.28 and EC was always < 2.0 dS m^{-1} after five years. This method could be considered suitable for establishing orchards in waterlogged sodic soil for any size of land holding since it does not require much investment. Vegetable production is also possible by adopting this model. Top width of raised bed was too narrow for crop cultivation and moving tractor mounted machineries. Narrow raised bed helped in quick draining of bed internally, reducing the rate of secondary sodification.

Case study three: FPBIFS Model at Patwakheda

Second improvised FBIFS model was constructed at Patwakheda village of Mohanlalganj block of Lucknow district over an area of 5913 m^2. A farmer, Mr. Ghasita who had 2.13 ha of land, was selected for demonstrating this model. Mr. Ghasita and family members used to migrate to Lucknow city for daily earnings. The area under pond was 3138 m^2 and under elevated field bed 2775 m^2. The width of raised bed was kept 24 m initially which was reduced by 1m after settlement of the soil and edge of the elevated field bed (Fig. 4.4, crop performance over the system). Five cropping systems namely rice-wheat-moong, mustard-vegetables, vegetables-vegetables, fodder and pisciculture were tried over FPBIFS model as per the needs of Mr. Ghasita. The productivity of rice, wheat and moong were recorded to be 4.88, 4.96 and 1.08 t ha^{-1} with corresponding B:C ratio of 2.1, 2.4 and 2.0, respectively. The water productivity of rice was 16.2 Rs m^{-3}, and of wheat and moong 31.6 Rs m^{-3}. B:C ratios of vegetables were higher compared to other crops. The maximum B:C ratio of 5.5 was found in brinjal with water productivity of 33.4 Rs m^{-3}. B:C ratio of Napier-Hybrid-CO-4 planted on slope of the pond was 4.7 and water productivity was 207.1 Rs m^{-3}. The net income of Rs. 157500 was recorded from fish stocking with B:C ratio of 4.1. Overall, B:C ratio and water

Fig 4.4. Crop performance in first modified FPBIFS model in Patwakheda Village

productivity of the crops were observed to be 3.2 and 85.9, respectively. Average initial soil pH at the site was >9.5 which reduced to 8.5 after two to three years. No salt accumulation has occurred on the top soil so far.

Case study four: FPBIFS Model at Lalaikheda

Third FPBIFS model was designed and demonstrated during 2014 over an area of 4692 m^2 consisting of pond area (2356 m^2) and elevated bed area (2336 m2) at Lalaikheda village of Mohanlalganj block of Lucknow district. Mr. Jitendra Singh having 2.53 ha of land, was the farmer who adopted FPBIFS model. Salt tolerant 'CSR 43' rice was grown initially over elevated field bed and its productivity was 5.40 t ha^{1}. The input cost of rice production was Rs. 5419.0 ha^{1}. The gross return from the first rice crop was Rs.14270.0 giving a B:C ratio of 2.63. During *rabi* season, salt tolerant wheat variety 'KRL 210' was sown producing 2.54 t grain yield ha^{-1} with a B:C ratio of 2.05. The B:C ratio of pigeon pea and *rabi* vegetables were 5.20 and 4.42, respectively. Tomato grown over elevated field beds recorded productivity of 40.33 t ha^{-1} resulting in B:C ratio of 7.95 during 2017-18. The land and water productivity of the tomato crop were 4.033 kg/m^2 and 201.64 Rs/m^3, respectively. Intensive fish stocking gave the highest return of Rs. 587700.00 from 2336 m^2 pond leading to gross return of Rs.

Fig 4.5. Crop performance in FPBIFS model in Lalaikheda village

Table 4.2. Comparative study of the LMBIFS Models

Model	Major components	Farmer	Model cost (in Rs. lakh)	B: C	Risk reduction (%)
FPBIFS-1	Fish and cereal crops	Mr. Jaidrath	3.42	1.13-15.60	80%
RASBBIFS	Vegetable Fruits	Mr. Ram Kumar	0.31	3.08-6.44	100%
FPBIFS-2	Fish Cereals Vegetables	Mr. Ghasita & Mr. Dinesh	1.56	2.10-5.50	100%
FPBIFS-3	Fish Cereals Vegetables	Mr. Jitendra Singh	2.01	2.05-7.95	100%

2515839.0 ha^{-1}. Average initial soil pH of the raised bed was 9.54 during 2014 which reduced to 8.45 during 2017. No signs of salt accumulation have been observed so far. The model was found to be highly lucrative with very low pay back period due to intensive fish stocking. The crop performance over the elevated field bed is shown in Fig. 4.5.

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Lessons learnt

Foregoing discussion shows that land shaping models have considerable scope for reducing the soil pH and watertable in canal command areas where gypsum based reclamation may not be possible. These models could provide an opportunity to move from conventional farming to diversified and environmental sustainability. Crop diversification options could help the farmers to increase their incomes. Reductions in the soil pH and EC were satisfactory and durable in all models except for first one. Crop failure risks due to excessive rain or drought were negligible (Table 4.2). These models have tremendous potential for restoring and rejuvenating sodium impaired agroecosystems.

The policy makers of State Department of Agriculture and the agencies dealing with land degradation have visited these models to assess the scope for their large scale application. These models could also provide opportunity for the capacity building of various stakeholders who are in the process of managing degraded lands caused by waterlogged sodicity. Besides some technical complexities and time consuming process, one major limitation was that the successful functioning of such models is dependent on multi-stakeholders approach. Each stakeholder has to play a synergistic role to enhance the performance of such models. There is strong need of institutional and policy supports to such kinds of grassroots models to meet the target of UNCCD/LDN of India.

Landshaping Technologies and Location-specific Adaptive Strategies for Infusing Resilience into Saline Coastal Agro-ecosystems

The coastal zone interfaces the transition between the terrestrial and marine landscapes and their associated ecosystems services. It comprises not only shoreline ecosystems, but also the upland watersheds draining into coastal waters, and the near shore sub-littoral ecosystems influenced by land-based activities. India has a 7517 km long coastline along the main land and two major island ecosystems: Andaman and Nicobar Group of Islands in the Bay of Bengal and the Lakshadweep Islands in the Arabian Sea. Seawater intrusion is a growing problem in the coastal areas across the globe. The problem often magnifies during the dry season when rainfall is inadequate to leach the salts below the crop root zone. The vast deltaic region on the East Coast forms the rice-bowl of the country. Agriculture, agroforestry and pisciculture are widely practiced in the coastal areas of West Bengal and Andaman and Nicobar Island. However, the productivity of agriculture here is very low due to tidal inundation and salinity, and a number of socioeconomic, institutional and technological constraints. The problem of salinity induced stressors is expected to aggravate in the foreseeable future due to climate change impacts and poor adaptive capacity of the farmers.

The crop (mainly rice) productivity of coastal West Bengal is very low as compared to other parts of India. The rice is grown almost rainfed; after rice harvest the lands remain fallow during rest of the year. Farmers of this region also practice rice-fish cropping system for their sustenance. They usually transplant rice in uplands while local species of fish are reared in the lower lands. However, these subsistence resources are not sufficient for meeting diverse needs of farm families round the year. Abundant brackish water, though a boon to rice crop, could be a boon for aquaculture development in this area. Large areas suffering from brackish water can be harnessed for producing high value fish and other aquatic resources provided adequate technological and policy support is in place to deal with the location specific problems.

Approaches, interventions and outcomes

Considering this scenario, a number of participatory research trials were conducted at the farmers' field over a period of time. With the support of progressive farmers, team of scientists did several rounds of transect walks in selected villages from West Bengal and Andaman Nicobar Island to understand the diversity of landscapes and the management of salinity stress. This helped in choosing the fields for soil and water sampling. Representative farmers were selected based on the salinity stress, size of land holdings and their willingness to participate in research trials. Soil and water samples of the selected farmers were collected and analyzed before implementing the desired technologies. It was found that soil EC varied from 1.8 to 18.9 (dS m^{-1}) while water EC ranged between 0.5 to 24.8 dS m^{-1}. The status of salinity in soil and water of the studied farmers of coastal areas of West Bengal and Andaman Nicobar Island is presented in Table 4.3. The interventions made of modified land shaping models on different farmers' fields are presented in the succeeding sections.

Land Shaping: A Game Changer Technology

Case study one: Mr. Kisan Mridha

Considering the potential of land shaping techniques in improving the soil quality and crop yields, a participatory research trial was started at the farmers' field in the South 24 Pargnas district of West Bengal. After baseline survey, ICAR-CSSRI RRS, Canning Town (West Bengal) scientists chose Mr. Kisan Mridha of Chandkhali village, Canning block purposively as the farmer participant for technology demonstration. Mr. Mridha, a middle aged (55 years) farmer owns a small piece of low-lying land (~0.25 ha) where he grows rice and fish.

Mr. Mridha had only about 0.02 ha land area for storing irrigation water and fish cultivation. Using these resources, he was barely able to arrange two square meals a day. Furthermore, he earned a meagre Rs. 3200 per annum from monocropping of traditional rice varieties (Sabita and Geetanjali), compelling him to migrate to Kolkata city and work as a daily-paid labourer for earning the bread and butter. Year 2010 was a turning point in his life: after coming into contact of ICAR-CSSRI RRS, West Bengal; he decided to adopt the farm pond technology for crop intensification which was extended to him under the then operational National Agricultural Innovation Project

Table 4.3. Soil pH and salinity (EC_2) before interventions

Farmer	Soil pH_2		Soil EC_2 (dS m^{-1})		Water pH		Water EC (dS m^{-1})	
	Min	Max	Min	Max	Min	Max	Min	Max
Mr. Kisan Mridha	5.5	7.9	2.8	15.7	6.5	8.1	0.5	23.6
Mr. Amal Mondal	3.8	7.9	3.1	18.7	0.4	21.4	4.9	8.4
Mr Bimal Mridha	3.9	7.8	3.5	18.9	0.6	20.5	4.7	8.6
Mr. Panchanan Shao	6.1	7.9	2.1	14.9	0.3	19.1	6.0	7.8
Mrs. Anjali Sardar	5.4	6.3	5.4	12.6	5.8	7.4	0.4	8.5
Mr. Ajit Mridha	5.4	6.3	5.7	13.5	5.8	7.4	0.4	8.5
Mrs. Malati Das	6.5	7.8	1.8	8.3	6.5	8.0	0.5	18.6
Mr. Radhagabinda Jana	6.3	7.9	2.0	10.1	6.2	7.8	0.7	24.8

Min= Minimum; Max: Maximum

Table 4.4. Economic impact of farm pond technology adopted by Mr. Kisan Mridha

Components	Before intervention					After intervention				
	Area (ha)	Produ--ction (Kg.)	Cost (Rs.)	Return (Rs.)	Net return (Rs.)	Area (ha)	Prod--uction (Kg.)	Cost (Rs.)	Return (Rs.)	Net return (Rs.)
Kharif rice	0.233	720	4000	7200	3200	0.106	480	2200	4800	2600
Kharif vegetable						0.08	1310	4000	11880	7880
Rabi rice	0	0	0	0		0.106	420	2600	5040	2440
Rabi vegetable						0.08	860	4000	7780	3780
Fish	0.020	80	300	5600	5300	0.066	250	1500	30000	28500
Total	0.253	800	4300	12800	8500	-	5490	14300	59500	45200

Kharif vegetables: Okra, bottle gourd, pumpkin, basilla, colocasia, yam, cow pea); *Rabi* Vegetables: Cauliflower, knol khol, spinach.

(NAIP). Under this technology package, his 0.25 ha farm area was reshaped for creating a farm pond (0.066 ha) (Fig 4.6) while rest of the area was divided into three parts: 0.08 ha plot for vegetable and guava cultivation (Fig 4.7) and another 0.106 ha plot for rice cultivation. Since then, he started growing diverse vegetable crops (okra, bottle gourd, pumpkin, basilla, colocasia, yam and cow pea in *Kharif*, and cauliflower, knolkhol and spinach in *Rabi*) and high yielding varieties of rice (Amal-mana in *Kharif*, and Canning 7 and Lal Minikit in *Rabi*). Land modification not only decreased the soil salinity to a great extent but also enabled him to store rain water in the newly created pond for fish rearing and for providing assured irrigation to the vegetables and rice crop throughout the year. These interventions turned his fortunes as evidenced by several folds increase in the income from the same piece of land. The economic impact of these interventions is presented in Table 4.4. In sharp contrast to the pre-intervention phase, Mr. Mridha was now able to manage the monetary and nutritional needs of his family in a far better way.

Fig 4.6. A view of farm pond

Fig 4.7. Cultivation of vegetables

Case study two: Mr. Amal Mondal

Another milestone was achieved when collaborative efforts of ICAR-CSSRI RRS, Canning Town and BCKV, Mohanpur (WB) succeeded in extending the farm pond technology to Mr. Amal Mondal, a small landholder (1 Bigha of land) of Korakati village in the North 24 Parganas district. During 2012, land shaping technique was implemented on Mr. Mondal's farm with financial support from NAIP. Analysis of soil and water samples established that high salinity in soil and irrigation water was the main cause behind poor rice yields such that Mr. Mondal could hardly earn Rs. 5100 by growing the *kharif* rice.

Using simple earth maneuverings, nearly one fifths of his farm area was converted into an 8 feet deep pond for fish rearing while the excavated soil was used to create the raised dikes for vegetable cultivation. Along with vegetables (colocasia, cabbage, cauliflower, knolkhol, amaranthus etc), he also planted some multipurpose trees (neem, subabul etc) and fruit plants on the boundary of pond dikes (Table 4.5; Fig 4.8). Inputs like improved vegetable seeds and tree saplings etc. were supplied to him. After land modification, soil salinity reduced considerably, virtually eliminating the risk of salt-induced crop failure. After these interventions, he started practicing integrated farming system using fish, vegetables and agroforestry trees as components. He now grows *colocasia,* okra, pumpkin, ridge gourd etc. during *kharif* and beetroot, knol khol, beans, tomato, carrot, radish etc. during *rabi* season (Fig 4.8). He cultivates high value fish [*Anabas testudineus* (koi), *Clarias batrachus* (magur) and *Channa striatus* (sol)] in the pond (Fig 4.9). He is now earning almost every day by selling the produce on the local market after fulfillment of his family demand. His net income has incresed from Rs. 4,050 to to Rs. 18,220 (Table 4.5).

Table 4.5. Economic impact of technological interventions at Mr. Mondal's farm

Crop	Before project					After project				
	Area (ha)	Total input (Rs.)	Total output (q)	Gross return (Rs.)	Net return (Rs.)	Area (ha)	Total input (Rs.)	Total output (q)	Gross return (Rs.)	Net return (Rs.)
Kharif rice	0.133	1050	3.4	5100	4050	-	-	-	-	-
Kharif vegetables	-	-	-	-	-	0.093	1675	3.3	5940	4265
Rabi vegetables	-	-	-	-	-	0.093	1220	4.25	6375	5155
Fish	-	-	-	-	-	0.027	1200	0.4	10000	8800
Trees	-	-	-	-	-	0.013	-	-	-	-
Total	0.133	1050	3.4	5100	4050	-	4095	7.95	22315	18220

Kharif vegetables: Okra, bottle gourd, pumpkin, basilla, colocasia, yam, cow pea); Rabi Vegetables: Cauliflower, knol khol, spinach.

Fig 4.8. Winter vegetables in the field

Fig 4.9 Fish produced in the pond

Case study three: Mr. Bimal Mridha

In order to replicate the farm pond technology at other locations where salinity was an important limitation to farming, ICAR-CSSRI RRS, Canning Town in collaboration of BCKV, Mohanpur then selected another farmer Mr. Bimal Mridha of Tushkhali village in Sandeshkhali-II block of North 24 Parganas district. Mr. Bimal Mridha is a small farmer with only 1 bigha (7.5 bigha equals to 1 ha) of land and earned only Rs. 4620 y^{-1} by cultivating low yielding *kharif* rice. The soil and water samples were analyzed for estimating the salinity.

During 2011-12, farm pond land shaping technique was implemented on his farm. About 20% of the total farm land was dug to make an 8 feet deep pond and the excavated earth was used for creating the upland and boundary land forms. Rest of the land was used for the cultivation of *Kharif* rice. Some fruit plants (lemon, guava etc.) were also planted at pond dikes. A vermi-compost unit was established for reducing the chemical fertilizer use in vegetable crops. In addition to timely agro-advisories, key inputs like improved vegetable seeds and tree saplings were also supplied to the beneficiary farmer. In a short span of time, highly saline farm land of Mr. Mirdha displayed nearly 50% reduction in salt content making it suitable for intensive cultivation even with crops (e.g., fruits, vegetables) considered to be highly sensitive to salinity.

After these interventions, his land became suitable for a range of crops including rice, vegetables, fruits and fish. He now grows vegetables like okra, pumpkin, ridge gourd, cucumber, water melon etc. in the *kharif* season and cabbage, cauliflower, knoll-khol, amaranthus etc in the *rabi* season (Fig 4.10). In addition to fish culture [rohu (*Labeo rohita*) and katla (*Catla catla*)] in the pond (Fig 4.11), fruit trees like citrus and guava have been planted at the pond dike (Table 4.6). These efforts paid devidends, making Mr. Mirdha self reliant and increasing his income [Rs. 7800 in fish to Rs. 5300 in vegetables (both the seasons)]. Now he does not migrate to the Kolkata city

Fig 4.10. Winter vegetables on modified land plots

Fig 4.11. Fish rearing in farm pond

Table 4.6. Economic impact of integrated crop-vegetables-fish production at Mr. Bimal Mridha's farm

Crop	Before project					After project				
	Area (ha)	Total input (Rs.)	Total output (q)	Gross return (Rs.)	Net return (Rs.)	Area (ha)	Total input (Rs.)	Total output (q)	Gross return (Rs.)	Net return (Rs.)
Kharif rice	0.133	1300	3.7	5920	4620	0.080	1480	2.9	4640	3160
Kharif vegetables	-	-	-	-	-	0.027	735	1.25	2875	2140
Rabi vegetables	-	-	-	-	-	0.027	843	1.06	2120	1277
Fish	-	-	-	-	-	0.027	1300	0.7	9100	7800
Total	0.133	1300	3.7	5920	4620	-	4358	5.91	18735	14,377

in search of employment. About 10 farmers are now in his network to learn about these interventions.

Ridge and furrow, and farm pond technique

Case study four: Mr. Panchanan Shao

In another intervention, 'ridge and furrow' and 'farm pond' technologies were demonstrated on the land of Mr. Panchanan Shao, a young farmer in Motgoran village of Basanti block of South 24 Parganas district. This poverty ridden family was struggling to meet the livelihood needs. Waterlogging and high soil salinity were severe impediments to his efforts to raise the farm income and strengthen the food security. Prior to these interventions, he grew *kharif* season rice (traditional variety) and some seasonal vegetables in his kitchen garden.

In 2012-13, landshaping techniques (ridge and furrow, and farm pond) were demonstrated on his farm under NAIP (Fig 4.12). Additionally, his family members were trained for new farming skills. After adopting these land shaping models, the gross income of Mr. Shao increased by five times compare to the pre-intervention phase in a short span of one year (Table 4.7).

Table 4.7. Economic impact of diversification through vegetables and fish on Mr. Shao's income

Particular	Baseline				After project			
	Area (ha)	Cost (Rs.)	Produ- -ction (q)	Gross return (Rs.)	Area (ha)	Cost (Rs.)	Produ- -ction (q)	Gross return (Rs.)
Kharif								
Rice	0.27	5000	6	5700	0.27	3500	7.20	6840
Bitter gourd	0.07	3500	8	9600	0.20	15000	33.00	39600
Cucumber	0.07	3850	13.5	10800	0.13	12000	45.00	36000
Ridge gourd	0.00				Mixed crop with Cucumber	1150	2.00	1600
Rabi								
Rice	0.00				0.27	7000	15.00	15750
Tomato	0.10		29.5	17700	0.27	15000	100.00	60000
Khnolkhol	0.00				Mixed with tomato	1000	5.00	2500
Brinjal	0.00				0.10	8500	25.00	25000
Pumpkin	0.01				Mixed crop with Brinjal	1100	7.00	5600
Fish								
Prawn	0.02	1000	0.18	3150	0.20	19500	0.75	18750
Carp							2.50	20000
Cat fish							0.15	2250
Other							0.08	1400
	0.53	13350.00	57.18	46950.00		83750	235290	

Further, cultivation of vegetables also improved the nutritional security of his family. Mr Shao no longer migrates to Kolkata city for wage earning.

Broad bed and furrow land shaping technique

Case study five: Mrs. Anjali Sardar

A single intervention may not invariably be well suited to different locations suffering from a common problem; as was the case with Dashrathpur village of Rangat town of Andaman and Nicobar Islands. After completing certain formalities, a woman farmer namely Mrs. Anjali Sardar from Dashrathpur village was cosen to impliment the 'broad bed and furrow land shaping technique' in collaboration with ICAR-CARI, Port Blair, Andaman and Nicobar Islands in turn with the existing situation.

Mrs. Sardar lost her means of subsistence after the *Tsunami* of 2004 as her entire agricultural holding was turned into a saline wetland. Goat

Fig 4.13. Broad bed and furrow model

rearing and work as a labourer were the only sources of subistence. In 2011, under NAIP, broad bed and furrow (BBF) landshaping technique was intervened on her waterlogged saline land (Fig 4.13). The BBF technique involved shaping of land for creating broad beds (4-5 m width and 1 m height) and furrows (5–6 m width and 1 m deep) with a provision of fish shelter (2 m x 4 m x 1 m) alternatively at the end of the furrow in low-lying lands. While raised beds were used for cultivation of vegetables, fish were grown in the furrows. This system also provided the scope for *in-situ* rainwater harvesting (3800 $m^3 ha^{-1}$) for irrigating the crops during the dry season. Mrs. Sardar was also imparted the skills for managing the new system. Subsequentely, she strated cultivating vegetables like okra, bottle guard, bitter guard and chilli etc. in *kharif* and amaranthus as short duration intercrop for sale on the local market. The total cost incurred in developing BBF model was Rs 1.92 lakhs ha1, 90% of which was borne under NAIP.

Shortly after implimention, BBF technique led to apprecable reductions in soil pH (from 6.63 to 5.88) and EC (from 2.90 to 1.18 dS m^{-1}); thus improved soil quality and better crop yields. Reduced salt load also minimized the risk of crop failure. By selling the vegetables on the local market, she earned a good amount of money. An effort was also made to add value to her traditional knowledge of fish culture. After undergoing training, she started rearing carp fish in the furrows. Mrs. Sardar was also persuaded for adding the duckery and piggery components for diversifying the income portfolio. High impact of these interventions helped in increasing the income substantially: Rs. 20,000 y^{-1} from vegetables and Rs. 16,000 y^{-1} from fish.

Case study six: Mr. Ajit Mridha

Astonishing success of BBF system on Mrs Sardar's land attracted many other local farmers, providing us enough reasons to replicate the BBF model on their farms. One such farmer Mr. Ajit Mridha of village Dashrathpur Village, Rangat town of Andaman and Nicobar Islands after coming into our contact agreed to implement this system on his farm. Mr. Mridha is dependent on rice-fish culture and to some extent on seasonal vegetables for sustenance. Like Mrs. Sardar, his cultivable land was inundated by saline water after *Tsunami* in 2004, compelling him to quit the farming and exploit other feasible means of livelihood. After several rounds of discussions with him, our team chalked out the plan for implimenting the BBF model. Initially, the land was was leveled for improving the drainage (Fig 4.14), followed by shaping of land for creating the broad beds (4–5 m width and 1 m height) and furrows (5 – 6 m width and 1 m deep) with a provision of fish shelter (2 m x 4 m x 1 m) at the end of the furrow in low-lying areas. Raised beds were used for cultivation of vegetables round the year and fish were cultivated in the furrows. This system also provided the scope for *in situ* rainwater harvesting (~3800 $m^3 ha^{-1}$) for irrigating the second crop during the dry season.

The total cost incurred in developing BBF model was Rs 1.92 lakhs ha^{-1}, 90% of which was supported under NAIP project. With change in the lanshape, the soil pH reduced from 6.63 to 5.88 and EC from 2.90 to 1.18 dS m^{-1} due to salt leaching . Land modification enabled him to grow vegetables (okra, bottle guard, bitter guard, green chillies and amaranthus) successfully in *kharif* season. He was also provided the seeds of salt tolerant rice variety 'CSR 36' (Fig 4.15) for obtaining better yields. Cultivation of salt tolerant rice variety enabled him to meet the family requirement round the year. He earned Rs. 30,000 from vegetables and increased the food security of his family by including vegetables, poultry and fish in the diet.

Fig 4.14. Broad bed and furrow model implemented at Mr Ajit's farm

Fig 4.15. Bumper crop of rice 'CSR-36' in a salt affected field

Diversification through high value sunflower crop

Case study one: Mrs. Malati Das

In the coastal areas, sub-surface water is generally saline and unsuitable for human consumption and crop irrigation. Fresh water is found generally at 300 to 400 m depth, rendering its lifting cost and energy prohibitive. During winter and summer seasons, most of the lands in the area remain fallow due to scarcity of irrigation water and increase in soil salinity. However, few farmers cultivate *rabi* rice by the intensive exploitation of groundwater. Under such circumstances, Ramkrishna Ashram Krishi Vigyan Kendra (RAKVK), South 24 Parganas district in collaboration of ICAR-CSSRI-RRS, Canning Town introduced the oilseed crop sunflower for cultivation in this area. The crop was compatible with local agro-climatic conditions owing to its low water requirement and moderate tolerance to salinity. Ultimately, a woman farmer Mrs. Malati Das having 0.39 ha land in Madhabpur village was selected for introducing the sunflower. Earlier, she grew traditional varieties (Sabita, Swarna, Pankaj etc.) of *rabi* rice earning only about Rs.7200.0 y^{-1}. After taking up sunflower (Sun-bright, PAC-36) crop, Mrs. Das was able to harvest 0.64 t seed yield from 0.39 ha area within a period of 3 months (Fig 4.16). Economic analysis indicated that sunflower crop gave a net benefit of

Fig 4.16. Sunflower crop in a saline field

Rs. 8475.00 in the *rabi* season. Better crop of sunflower also helped her to meet the daily requirement of edible oil. Additionally, sunflower thalamus was used as the cattle feed and as organic manure in the crop fields.

Case study two: Mr. Radhagabinda Jana

About 25% of medium and some low lands of Sundarbans are moderately saline in nature with soil EC varying from 2.0 to 3.0 dS m^{-1} and pH from 8.0 to 8.5. Under such conditions, crop growth and yield suppressed. Cotton cultivation could be an ideal option for maximizing the returns to the farmers in such soils.

In this backdrop, Kuemuri village from Patharpratima block of South 24 Parganas district was selected purposively for exploring the prospects of cotton cultivation. After rapport building, a farmer Mr. Radhagabinda Jana was selected. He is a small farmer having 0.27 ha of salt affected land (Fig 4.17). Like other farmers of this area, he cultivates rice (Ranjit, Pankaj, Swarna etc) during *kharif* season. However, in winter, there was no scope of crop cultivation due to delayed harvest of *kharif* rice. These problems were further compounded by the scarcity of good quality irrigation water. As a result, the monocropped rice land produced a meager income of Rs. 3,750.00 y^{-1}. This challenge was taken into account and cotton varieties namely LRA5166 (2010-11) and Surabhi (2011-12 and 2012-13) were introduced in his field during *rabi* season. As hypothesized, cotton being a deep rooted crop required less irrigation water and withstood salinity (Fig 4.18). As expected, cotton yield was good providing handsome return (Table 4.8) against no return in *rabi* season. He thus fetched a B:C ratio of around 2.1 compared to only 1.31 in *kharif* rice. Marketing of cotton was also linked with the Cotton

Fig 4.17. Fallow saline land during rabi season

Fig. 4.18. Cotton cultivation enhances the economic value of fallow saline lands

Table 4.8. Economic impact of integrated crop-vegetables-fish production at Mr. Bimal Mridha's farm

Parameters	Before Intervention			After Intervention	
	Kharif	*Rabi*	*Rabi* (2010-11)	2011-12	2012-13
Productivity (q/0.266 ha)	Paddy: 2.86	Fallow	Cotton: 2.28 q	Cotton:2.63 q	Cotton:3.14 q
			(Var.-LRA5166)	(Var-Surabhi)	(Var-Surabhi)
Gross Income (Rs./ 0.266 ha)	2574.00	-	6840.00	8679.00	12246.00
Labour employed	36	44	44	44	
(man-days/ 0.266 ha)					
Benefit : cost	1.39	1.91	1.96	1.98	

Corporation of India (CCI), Kolkata so that he could sell the cotton at the price fixed by the government without involving the middlemen.

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Lessons learnt

The successes achieved with the land shaping models lead to the conclusion that adequate technical support to the farmers can play a critical role in augmenting the productivity of coastal saline lands. The beauty of the aforementioned land modification techniques is that they are doable and do not involve very heavy investments. Choice of a particular land shaping technique would vary with the magnitude of waterlogging and salinity problems and the prevailing social-economic conditions. We believe that a multi-stakeholder framework involving research institutions, government agencies, NGOs, private companies and farmers can lead to the quick dissemination of these models in the targeted areas, albeit with certain modifications. In contrast to other salinity management technologies, land shaping makes the soils suitable for cultivating even salt sensitive crops like fruits and vegetables. Once implemented, these models could be self sustaining minimizing the dependence on external resources and technologies. Needless to say, similar local practices in the study areas and other parts of the country could provide useful insights for further refinements.

THEME 5

BIO-ENHANCERS FOR IMPROVING CROP PRODUCTIVITY IN SALT AFFECTED SOILS

Blooming Salt Affected Lands

केन्द्रीय मृदा लवणता अनुसंधान संस्थान

C S S R I

1969

1969-2019

Plant Growth Enhancers for Reducing Salt Induced Risks

Uttar Pradesh state of India has about 1.37 M ha sodicity affected area. Similar to other parts of Indo-Gangetic Plains, crop productivity in Uttar Pradesh has shown a declining trend in the last few years which can be attributed to the losses caused by different biotic and abiotic stresses as well as inappropriate crop management practices. High sodicity and associated problems like surface water stagnation are often a major cause of poor crop yields in many parts of Uttar Pradesh state. The problem of sodicity has conventionally been managed by applying gypsum and growing salt tolerant crop cultivars. Unfortunately, availability and quality of good quality gypsum are decreasing with each passing day, enhancing the interest in alternative means for increasing the productivity of sodic soils. Several studies suggest that biofertilizers containing plant growth promoting microbial isolates could be a viable means of augmenting agricultural productivity while sustaining the soil health. Although several such bio-formulations are available in India, none of them are known to be efficient in improving the productivity of salt-affected soils. In this regard, the research carried out at ICAR-CSSRI RRS, Lucknow have led to the development and commercialization of a few promising bio-formulations. The successes achieved with these products on framers' fields are briefly discussed in the succeeding paragraphs:

Case study one: Halophilic microbial formulations for sustainable crop production under saline conditions

Approaches, interventions and outcomes

With the objective of cost efficient and environment-friendly management of sodic soils, salt tolerant (halophilic) bacterial strains of N-fixers and Phosphate solubilizing bacteria (PSB) were isolated from the native salt affected soils. These strains were characterized for plant growth promotion and tested for their tolerance to different levels of salinity. These bacterial

Fig 5.1. Liquid Bioformulations-'Halo-Azo' and 'Halo-PSB'

strains exhibit mechanisms like the biosynthesis of plant growth regulators, (e.g., IAA, ACC deaminase), exo-polysaccarides, siderophores, phosphate solubilization and are able to fix the nitrogen. This way, they play an important role in sustaining the growth of salt stressed plants. The efficient strains of N-fixers and P-solubilizers were mass cultured and prepared in suitable standardized media as liquid bioformulations *viz*. 'Halo-Azo'and'Halo-PSB'. These bioformulations can either be used for seed/seedling treatment or soil application (Fig. 5.1). Application of these bioformulations helps increase the availability of nutrients like nitrogen and phosphorous to the plants in saline and sodic soils. Enhanced nutrient availability ensures better root development, nutrient uptake and thereby vigorous crop growth. These formulations also help in the maintenance of soil health by minimizing the environmental pollution caused by the fertilizers and other agrochemicals. Being affordable to the resource poor farmers, their commercial use can not only reduce the cost of cultivation but may also help promote organic farming. Multi-location testing and validation of the bioremediation potential of these liquid bioformulations were conducted during 2014-17 in the eight districts of U.P. to reach to valid conclusions regarding their efficacy in promoting crop growth and yield on sodic soils.

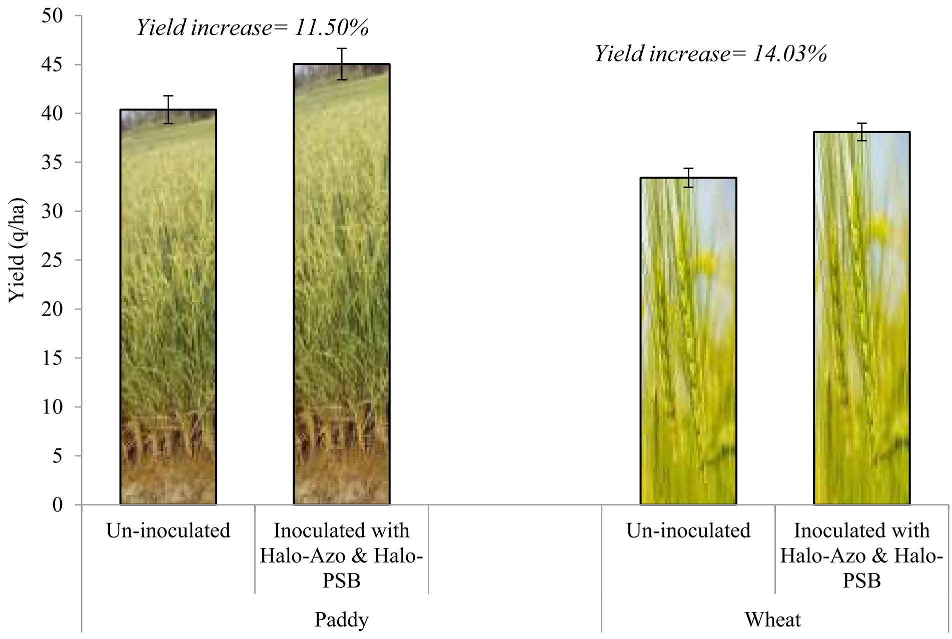

Fig 5.2. Impact of liquid bioformulations on rice and wheat yields at multilocations (bars show standard error)

Results indicated that rice and wheat grain yields increased by about 11.5% and 14.0%, respectively when the seedlings were inoculated with 'Halo-Azo' and 'Halo-PSB'compared to the un-inoculated control (Fig. 5.2). Thus the B:C ratio increased from 2.10 to 2.31 in rice and from 2.26 to 2.59 in wheat with the use of these bioformulations which were found to be efficient in soils having pH between 7.5 to 9.8. Application of these bio-enhancers keeps the soils biologically active and helps in boosting the soil fertility. These bioformulations were adopted by farmers covering nearly 300 ha in 2017 and about 338 haduring 2018 (in *rabi* and *kharif* seasons) in sodicity affected parts of Lucknow, Raebarelli, Unnao, Sitapur, Hardoi, Sultanpur, Kausambi, Pratapgarh, Agra and Eatwah districts of UP. The crops grown with the aid of these bio-formulations included rice, wheat, mustard, brinjal, cauliflower, field pea, tomato and sugarcane. Looking to the potential of this technology, ICAR-AgriInnovate India Ltd has commercialized 'Halo-Azo' and 'Halo-PSB' for widespread use by the farmers.

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Case study two: 'CSR-BIO'- a promising bio-formulation for enhancing crop productivity in salt affected and normal soils

Approaches, interventions and outcomes

For alleviating the location-specific problems plaguing horticultural production in sodic soils, ICAR-CSSRI RRS,Lucknow has developed a bio-growth enhancer called 'CSR-BIO'. This bio-enhancer consists of a consortia of growth promoting bacteria and fungi (*Bacillus pumilus, B. licheniformis,* and *Trichoderma harzianum*) isolated from salt affected soils and cultured on a single dynamic patented medium (Fig 5.3). Application of 'CSR-BIO'

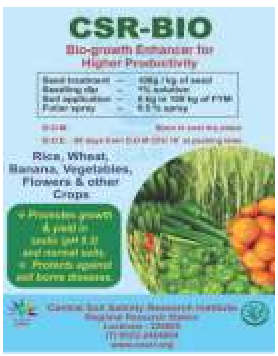

Fig 5.3. Bio-growth enhancer 'CSR-BIO'

Fig 5.4. Bumper crop of banana with 'CSR-BIO' use

sustains the production of commercial vegetable crops in sodic soils (pH ≤9.2). When used in combination of 'CSR-biohardening' technology, it makes commercial banana cultivation possible in sodic soils.

It is recommeded to treat theseeds/tubers with 1% liquid formulation of 'CSR-BIO' for 30 min. Alternatively, in case of soil application, 5 kg of the carrier material or 3 l of liquid formulation and 100 kg of FYM/Vermicompost are mixed and shade dried for 6 days. After this process, they may be applied to the crops 7-10 days after planting. Soil drenching and foliar application with 1% liquid formulation can also be done during 1st flowering period of horticultural crops including tomato, chillies, capsicum and okra.

'CSR-BIO' application promotes the crop growth by enhancing the production of plant growth regulators, by mobilizing the nutrients like phosphorous (PSB) and potassium, and by protecting the crop against major diseases like blight and wilt. Long-term trials have indicated that application of 'CSR-BIO' increases the yield of vegetables like tomato and potato upto 22%. It also reduces the use of fertilizers by about 25% in crops like rice, wheat, maize, tomato, potato and chilli. In case of banana, drenching of secondary hardened plants can be done before planting with 1% of 'CSR-BIO' liquid formulation. This product can also be used in banana crop after mixing with the compost (5 kg of carrier material or 3 l of liquid formulation mixed with 100 kg of FYM/vermicompost and shade dried for 6 days) to enhance the fruit yield (Fig. 5.4). The procedure for applying CSR-BIO in banana crop is given in Table 5.1. Results indicated that there was upto 18% increase in the fruit yield of banana (Fig.5.4), and fertilizer use decreased by about 25%. Looking to the potential impacts of CSR-BIO, it was patented and commercialized by ICAR, New Delhi and licensed to the four firms (Table 5.2).

'CSR-BIO' use has been instrumental in bringing about 250 ha of degraded and reclaimed sodic soils under horticultural crops, and thus helped in earning of Rs.153.6 crores (till 2017). 'CSR-BIO' has become

Table 5.1.Procedure and schedule for applying CSR-BIO in banana crop

Plant stage	Procedure of applying CSR-BIO
At the planting	100 g/plant or 20 ml of 1 % liquid diluted with 1% jiggery water
2nd month after planting	100 g/plant or 20 ml of 1% liquid diluted with 1% jaggery water
4th month after planting	100 g/plant or 20 ml of 1% liquid diluted with 1% jaggery water
8th month after planting	100 g/plant or 20 ml of 1% liquid diluted with 1% jaggery water
10 months after planting	100 g/plant or 20 ml of 1% liquid diluted with 1% jaggery water

Table 5.2. Impact of CSR-BIO on the production of commercial horticultural crops

Firm	Quantity produced (2012-15)	Area covered	Yield increase (%)	Crops	Diseases controlled
CSSRI, RRS, ICAR Lucknow	22 tonnes (solid) 3000 L (liquid)	1200 ha	12-15	Paddy, wheat, potato, banana, tomato, capsicum, okra, gladiolus, mango and guava (both salt affected and normal soils)	Wilt of tomato, banana, Fe+ availability, Blight of potato and Paddy smut
M/S Krishicare Bioinputs, Tamil Nadu	140 tonnes (solid) 1200 L (liquid)	2200 ha	18-24	Ixora, banana, jasmine and Green house tomato	Wilt of Ixora, Fe+ availability and Blight of potato
M/S Alwin Industries, Madhya Pradesh	164 tonnes (solid) 6000 L (liquid)	7000 ha	18-22	Chilies and garlic etc.,	Wilt and blight
M/S Jai Visions Agri-Tech, Ghaziabad, U.P	3 tonnes (solid)	400 ha	15-18	Gladiolus and Potato	Blight of potato
M/s Khandelwal Biofertilizers, Karnataka	6500 L	2000 ha	16-20	Chick pea, pigeon pea, cumin and pomegranate	Blight and wilt control

***Source:** *ICAR-CSSRI, Newletter 2014, Vol 20 (2)*

popular in the nine states of the country, covering about 12800 ha area. Trials conducted on the farmers' field indicated that 'CSR-BIO' use has increased the crop yield by 18-20% and income by 15-20% ha^{-1} of the small and marginal farmers growing horticultural crops (potato, tomato, chilli and banana).

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Lessons learnt

Development of aforementioned bio-formulations has opened a new era in agricultural salinity management. Their large-scale commercial use can reduce the dependence on chemical amendments (e.g., gypsum) considerably. Some major advantages of these bio-products include a low cost, ease in application and their environmentaly benign nature. In addition to augmenting the crop yields, they also have the potential for bio-remediation, bringing steady improvements in the quality of degraded sodic lands. The positive impact of 'CSR-BIO' in sustaining the horticultural production on degraded sodic lands is particularly noteworthy and calls for testing the efficacy of 'Halo-Azo' and 'Halo-PSB' in horticultural crops. Efforts are also underway for developing the similar bio-formulations for sustaining the crop productivity in saline soils.

THEME 6

GROUNDWATER RECHARGE FOR MANAGING WATER STAGNATION

Blooming Salt Affected Lands

केन्द्रीय मृदा लवणता अनुसंधान संस्थान

CSSRI

1969

1969-2019

Drainage-cum-Recharge Structures: An Ideal Option for Managing Water Stagnation and Enhancing Groundwater Quality

Agricultural systems of North-West India face heavy risks caused by the over-exploitation of groundwater and soil degradation. Of late, air pollution caused by rampant burning has further magnified the environmental degradation. Looking to these problems, government is advocating crop diversification through *kharif* maize in the place of water guzzling rice crop (production of 1 kg of rice requires ~ 3000 l water). However, being highly susceptible to waterlogging, maize should ideally be grown in properly drained land. The natural drainage system has almost diminished with the developmental activities and crop submergence is a major problem during the extreme rainfall events. These processes have caused adverse impacts on soil quality and ecosystem functions. A number of crop landraces are now extinct in the state of Haryana due to the factors like changes in the land use pattern and increasing soil and water salinity. During monsoon season and sometimes during winters, intense rains cause serious threats to crops. Therefore, locally compatible solutions for managing the water related risks are urgently needed for the diversification through low water requiring crops like maize.

The issues of irrigation water scarcity and its deteriorating quality in Haryana and Punjab States are well known to the policy makers. Farmers face problems in irrigating their crops with such saline/sodic waters. There could be several approaches to restore the water resources and enhance and agro-ecological resilience with appropriate design and location specific learning with farmers. The individual farmers' based groundwater recharge structures can be one such option for the safe disposal of flood and flash water into groundwater that otherwise go waste or cause damage to the standing crops. In many parts of India including Haryana and Punjab, groundwater has also become brackish.

Case study one: Renovation of abandoned tube-well into drainage-cum-recharge structure for crop diversification

Approaches, interventions and outcomes

Intensive exploitation of groundwater during Green Revolution days caused widespread drying of the tube-wells in Haryana. However, such dry tube-wells can be converted into vertical drainage facility, if tube-well pipe remains intact. To validate this hypothesis, an innovative farmer namely Mr. Vikas Chaudhari was selected for implementing groundwater recharge structure (GWRS) on his field. Mr. Chaudhari was interested in

Table 6.1. Economic analysis of recharge well during high intensity rain

Crop	Area (ha)	Saving (%)	Additional production (q)	Additional income (Rs)	Payback period
Maize	1 ha	50-75	35-50	Rs 40000	In one season
Wheat	2 ha	30	30	Rs 48000	-
Total				Rs 98000	-

diversification through maize crop in his relatively low lying field prone to waterlogging during heavy rainfall. In the recent past, maize and wheat crops in such low lying fields were severely affected by the intense rainfall. Out of the total land holding (8 ha), 2 ha area suffered from waterlogging problem. Mr. Chaudhuri visited ICAR-CSSRI, Karnal for expert consultation. Subsequently a team of ICAR-CSSRI, Karnal scientists visited his farm and advised to him to renovate the abandoned tube-well for the safe disposal of the runoff water.

With technology support from ICAR-CSSRI, Karnal, Mr. Chaudhari renovated his abandoned tube well into a drainage well in 2011. The filtration option was also provided to retain physical impurities carried with the runoff water. It contains brick masonry of 4.4 x 4.5 x 4.5 ft. The tube well pipe was extended up to the field surface with perforated pipe of larger diameter. The perforation was in upper 3 ft and 1.5 ft pipe length at the bottom was kept blind to facilitate sedimentation. The perforated portion was wrapped with nylon net of 42x 62 mesh size (Fig 6.1). Since, it was renovation of an existing (abandoned) tube-well, expenditure of only Rs 20000 was required for the filtering unit. After creation of drainage option, Mr Chaudhari was able to drain out the excess water and recharge the groundwater (Fig 6.2). Consequently, he could grow maize and wheat crops successfully (Fig 6.3). The economics of this intervention was worked out on the basis of observations recorded and feedback received from the beneficiary farmer (Table 6.1). Thanks to this intervention, Mr. Chaudhari was able to get 50% of maize and 30% of wheat yields even in years of very heavy rainfall compared to the previous years when intense rains resulted in

Fig 6.1. A renovated groundwater drainage cum recharge structure

Fig 6.2. Working of renovated groundwater drainage cum recharge structure

Fig 6.3. Maize and rice crops on Mr. Chaudhari's farm

almost complete crop damage. In monitory terms, he earned additional incomes of Rs 40000 and Rs 48,000 by protecting maize and wheat crops from submergence.

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Case study two: Augmenting groundwater resources to enhance agro-ecological resilience

Sustainability of agriculture in North-Western India is threatened due to an alarming decline (@ 0.6- 1.0 m/ annum) of watertable, increase in pumping cost and deterioration in groundwater quality. This is particularly true for highly productive, water intensive and widely prevalent rice-wheat growing areas of Haryana and Punjab. Moreover, climate change is predicted to intensify highly variable and intense rainfall events, requiring greater efforts for managing the problems of water scarcity and flash floods. Groundwater decline can be prevented to some extent by groundwater recharge using rain and excess canal water.

Approaches, interventions and outcomes

ICAR-CSSRI, Karnal has developed a small groundwater recharge structure for the individual farmers. The hypothesis behind development of small structure was a farmer having such a structure in his field will look after the cleaning, repair and maintenance needs which are otherwise major limitations with community-based recharge structures. The recharge structure consists of a conventional cavity tube-well and a recharge filter. It is constructed by drilling a bore hole until a sandy layer is found below a clay layer. A blind PVC casing pipe is drilled into the clay layer and sand is pumped out until a stable cavity is developed below the clay layer. To prevent clogging, surface runoff from rainfall or excess canal water is first passed through a graded recharge filter consisting of layers of coarse sand, small gravel and boulders in a small brick masonry chamber. The developed techniques are fast and do not requires land for surface ponding. They also serve as small vertical drainage systems and save the crops from submergence caused by heavy rains.

A tube-well type recharge structure was installed at Mr. Ramesh Kumar's field in Sawant village of Karnal district of Haryana during 2011 (Fig 6.4). The objective was to safeguard his rice and wheat crops by disposing

Fig 6.4. Groundwater recharge structure

Fig 6.5. Recharge of groundwater in kharif season

Table 6.2. Economic analysis of recharge well during high intensity rain

Crop	Area (ha)	Saving (%)	Additional production (q)	Additional income (Rs.)
Wheat	0.5 ha	100	20	28000.0
	1 ha	50	20	28000.0
Rice	0.5 ha	70	21	21000.0
	1 ha	25	12	12000.0
Total				81000.0*

accumulated runoff water in a low lying area, and augmenting groundwater resources as well. Mr Kumar grows rice and wheat crops on his 1.5 ha land. In the recent past, crops were affected frequently during intense rainfall because of accumulation of runoff water from >40 ha surrounding area. After installation, it was estimated that disposal rate of installed structure into groundwater was 5 to 7 l/sec (Fig 6.5). The cost of installation of recharge structure was Rs 50,000. After installation of groundwater recharge structure, Mr. Kumar was able to cultivate rice and wheat crops successfully. The maximum economic benefit was realized in wheat crop as it is very sensitive to waterlogging (Table 6.2).

About 70% and 25% crop saving in 0.5 and 1 ha cropped areas, respectively, was observed after quick disposal of accumulated run-off into groundwater. Similarly, in wheat, crop saving was 50 % on 1.0 ha land, while 100% on 0.5 ha. In monetary terms, considering additional incomes, it was found that this structure saved about Rs 81,000 by saving his crop from submergence. In this analysis, benefits reaped by the neighboring farmers were not included who also noticed partial reduction in waterlogging induced damage to the crops.

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Case study three: Rainwater harvesting through drainage-cum-recharge structure for managing water stagnation

Farmers having low lying lands often face crop failures cased by the flash floods and/or intense rainfall. Sometimes, this problem is compounded by the high RSC in groundwater in many areas of Kaithal district. In this study, we are discussing how best such stresses (water stagnation and poor groundwater quality) can be managed by installing drainage-cum recharge structures.

Approaches, interventions and outcomes

In this backdrop, a participatory work was started in selected villages (Mundri, Geong, Kathwar, Sampli Kheri and Bhaini Majra of Kaithal district of Haryana under the Farmer FIRST project. Situation analysis indicated the problems of poor quality groundwater (high RSC>2.5 meq L^{-1}) (Fig 6.6), soil sodicity (soil pH>8.2), low water infiltration rate and crop submergence during the periods of intense rains in the selected villages. To provide location specific solution for addressing these problems, a drainage-cum-recharge structure (cavity type) was installed at the field of Mr. Chandi Ram of Kathwar village. Mr Ram, having about 40 years of experience in farming, has 3.5 ha of sodicity affected land. He has been facing the problem of poor germination in wheat crop due residual alkalinity in irrigation water. Further, heavy damage to the standing wheat crop also frequently occurred in the poorly permeable lands in the years of sudden heavy downpour.

The recharge cavity, consisting of a conventional cavity tube-well coupled with sand-cum-radial filtration unit, was constructed by drilling a bore hole until a sandy layer found below a clayey layer. A high pressure (10 kg/m^2) blind PVC pipe of 9'' (22.5 cm) was drilled upto 210 feet depth into the clay layer and sand was pumped out until a stable semi-spherical cavity was developed (Fig 6.7). Periodic point observations through observation wells were recorded over the seasons. Results indicated that rise in watertable (up to 1 m) during the monsoon period (July-September 2017) beneath the

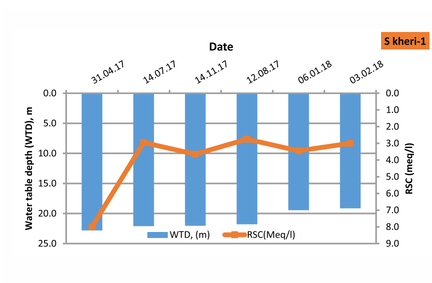

Fig 6.6. Watertable depth and alkalinity

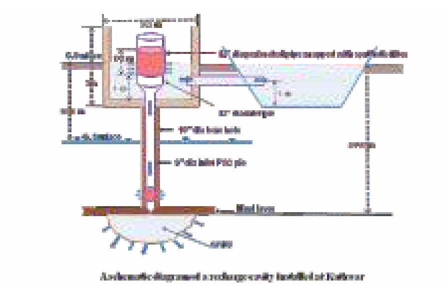

Fig 6.7. Design of groundwater recharge structure

Fig 6.8. A flooded field after heavy downpour

Fig 6.9. Recharge of flooded water

recharge structure led to concomitant reduction in residual alkalinity of irrigation water (RSC: 1.5-2.5 meq L^{-1}). Piezometers were also installed at 10, 30 and 50 m distances from the main unit to monitor the spatio-temporal improvements in water quality.

Heavy downpour during the last week of June 2017 (150 mm on a single day) immediately after rice transplanting resulted in complete crop submergence (Fig 6.8). The installed drainage-cum-recharge structure reduced flood volumes and thus saved the rice crop (Fig 6.9) in the lowest 5 ha area; though low to modest impact was clearly visible in the surrounding fields. The total cost of the structure was about Rs. 2.5 lakh. Considering the re-transplanting cost for rice in 5 ha area and 15 to 25% potential yield reduction under delayed transplanting, the direct benefit to the farmer (Mr. Ram) was estimated to be Rs. 30000 to 35000. The payback period for the selected intervention was estimated to be 2 to 3 years with net present value (NPV) of approximately Rs. 1.34 lakhs, B:C ratio of 1.25 and internal rate of return (IRR) of 19%. These results indicated the economic feasibility of investments on drainage-cum-recharge structure.

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Lessons learnt

The experiences gained with farmers during these studies indicated that conversion of abandoned tube-wells into drainage-cum-recharge structures could be a potential solution for draining the excess water from the low-lying lands, making crop diversification possible. Highly waterlogging sensitive crops like maize in place of rice could also reduce crop water requirement, lower the groundwater pumping and its adverse consequences including groundwater decline. Location specific recharge structures were effective in the safe disposal of excess runoff water and saving the crops in low lying portions of the field. Contrarily, intense rainfall caused complete failure of rice crop or sometimes necessitated re-transplanting, inflecting the production cost and putting farmers' livelihoods at risk. In sodic or even reclaimed sodic soils, moderate winter rainfall causes severe damage to the wheat crop due to waterlogging as soils are poorly permeable to the water. Groundwater recharge technology is of immense help in such situations, enabling the farmers to save their crops by disposing the flash flood at fast rate into ground water than natural condition. This technology can play a critical role in areas where soil and water related problems limit the agricultural productivity.

Groundwater recharge is helpful in reducing the adverse effects of alkali water application on soils and crops, and is a potential solution for preventing run-off induced soil loss, and for improving the quality of salty groundwater. While immediate benefits include the minimum damage to the crops from water inundation and thus stable crop yields, this technology could bring tangible improvements in soil and groundwater quality in the long run. In a nutshell, policy push is needed for promoting this technology on large scale so that excess run-off which otherwise goes waste or causes damage is harnessed for various social-ecological benefits. This technology has potential for integration with the other climate change adaptation policies in the states of Haryana, Punjab and UP, and in other areas where water intensive rice-wheat cropping system predominates.

'KRL 210' with *Khejri* (*prosopis cineraria*)

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