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Cropping systems intensification in the salt affected coastal zones of Bangladesh and West Bengal, India

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1 Acknowledgments

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2 Executive summary

The contiguous coastal zone of the Ganges delta in Bangladesh and West Bengal, India is of great significance for food security, biodiversity conservation, fisheries production and climate change adaptation and mitigation. Due to its low elevation, the delta is highly vulnerable to inundation from rising sea levels. Within this low lying deltaic region, large areas known as ‘polders’ have been enclosed and protected from seawater flooding by man-made earth embankments which protect inhabited and cropped land. The population of the region is about 40 million in Bangladesh and 23 million in West Bengal. These areas are disadvantaged by poverty, food insecurity, environmental vulnerability and limited livelihood opportunities. The governments of Bangladesh and West Bengal have targeted the coastal zone as the region most in need of poverty alleviation and improvement in food security.

Following a scoping study in 2011 (LWR/2011/066), ACIAR launched an initiative for the coastal region of the Ganges Delta which aims to lift agricultural productivity and hence rural welfare by increasing cropping intensification. There are 3 projects under this initiative including this project (LWR/2014/073, CSI4CZ) which deals with water and biophysical aspects. There are two other projects, one on salinity tolerance screening of crop varieties (CIM/2014/076) and the other on community-level risk management for socially inclusive and sustainable agricultural intensification (SIAGI, LWR/2014/072). Krishi Gobeshona Foundation of Bangladesh (KGF) co-funded this project following an MoU signed between ACIAR and KGF.

The project aimed to sustainably increase cropping intensity and productivity in the coastal zones of Bangladesh and West Bengal particularly in the dry (Rabi) season through integrated soil, water and crop management. The project was for the period of 4 years (Nov 2015 to October 2019). Due to a delayed start, the project was further extended up to October 2020. CSIRO led the project with one university from Australia (Murdoch University), 3 government organizations and 1 university from Bangladesh (Bangladesh Agricultural Research Institute, Bangladesh Rice Research Institute, Institute of Water Modelling, and Khulna University) and one government research institution (Central Soil Salinity Research Institute), one university (Bidhan Chandra Krishi Viswavidyalaya) and one NGO (Tagore Society for Rural Development) from West Bengal, India.

The activities of the project were carried out in 3 selected polders: Amtali, Barguna and Dacope, Khulna in Bangladesh and Gosaba Island in West Bengal, India. The activities included understanding of the surface water and groundwater resources, groundwater recharge/discharge mechanisms, salt and water dynamics and their trends in three selected polders, and crop production responses to various improved crop water management strategies. These were done through detailed salt and water balance calculations, surface water, groundwater and salinity interaction modelling at the polder level, field experiments, demonstration and crop production modelling at the field level, and by integrating the modelling results, socio-economic evaluation of cropping options and co-learning with farmers.

Apart from the polder level modelling, extensive field experiments and demonstration were conducted in the fields within the polders in every cropping season (Kharif-I, Kharif-II, and Rabi) over the last 5 years. Total number of experiments conducted was 275 involving about 3,000 (total of all seasons) farmers, of which 15% were women. These experiments were on improvement of the productivity of main Kharif-II rainfed rice, introduction and finding suitable varieties of Kharif-I (Aus) and Rabi (Boro) rice, introduction of new crops/varieties, screening, early establishment using different techniques such as zero tillage, relay cropping, dibbling, mulching, etc., management of different Rabi season

crops, use of different types of irrigation and drainage, limiting the harmful effects of waterlogging on crops in saline soils, selection of suitable cropping patterns, and use of storage ponds for water harvesting and irrigation in the Rabi season. The results of these experiments and underpinning model assessments have demonstrated strategies that are likely to increase productivity, cropping intensity and profitability. Significant achievements of the projects are summarized below.

1. A novel time-series model of water and salt stores and flows in an idealised polder has been developed and used to analyse the impact of climate change and management strategies and the impact of flood inundation and water management of the polders, and their consequences on cropping intensification. The main impacts of climate change are through the indirect impacts on salt concentrations due to projected increase or decrease rainfall. Management practices to remove salt from polders are therefore likely to be effective in combatting the impacts of projected climate change. In the event of cyclone-induced inundation, the model simulations suggest that with sound maintenance of infrastructure and sound management, particularly of soil drainage, the polders and islands of the Ganges delta could recover fairly quickly from inundation events.
2. Surface water, groundwater and salinity interaction models for the polders have been developed and used to simulate scenarios such as saline groundwater pumping for drainage, and impact of climate change. The results show that pumping of saline groundwater for drainage will reduce the groundwater level in the polders. However, saline water from the rivers will then flow inwards to the aquifer. Due to climate change, the existing water logging problem will further deteriorate in future due to the increase in groundwater level. The distribution of groundwater salinity due to climate change shows that there is risk of salinity propagating into the deep fresh water aquifer.
3. Electromagnetic soil survey was introduced and used to understand spatial variability of salinity up to a depth of 1.6 m and a procedure was developed using GIS to incorporate the apparent soil conductivity in covariance analysis to improve the efficiency of experiment testing treatments. A linear regression model was also developed to predict tuber yield from the ECa data which can be used to out-scale yield from a trial site to a surrounding area with ECa measurements.
4. We developed a novel technique for simulating surface-soil salt build-up and the associated Rabi crop response in applying the APSIM model under saline soil conditions. This has been a major step forward for cropping systems modelling in saline zones in general – not just for the CSI4CZ project. We also developed new APSIM modules – APSIM-Grasspea and APSIM-Lentil.
5. We conducted a range of scenario simulations using the validated APSIM model to help understand crop responses to management change and environmental drivers in the CZ. The model has been particularly useful in understanding the risk, or variability in crop performance as driven by environmental constraints.
6. Significant advancement made in APSIM modelling. Improvements were made by modifying the model to accept daily inputs of groundwater depth and salinity, validation of the inclusion of osmotic potential approach to simulate the effects of soil salinity on crop growth, validation of SWIM3 within the APSIM environment, and introduction, calibration and validation of new pulse (grass pea and lentil) models in APSIM.
7. Several new high yielding and short duration varieties of Aman or Kharif-II rice such as BRRI dhan87, BRRI dhan77, BRRI dhan76 for Bangladesh and Pratikshya for West Bengal have been found suitable, profitable and preferred by the farmers. The

yield of these varieties is 0.5 to 1.0 t ha^{-1} higher over existing varieties, 15-20 days shorter in duration which facilitates early sowing of Rabi crops, and provide more than 50% higher net benefit.

8. We first introduced growing vegetables with Aman/kharif in bags over the highly water-logged rice fields in Bangladesh. While some farmers gained additional benefit some farmers also lost due to loss in rice yield and higher initial investment. However, in Gosaba it was observed that farmers/farm women can increase their income substantially (least 3 fold) by this technology from the existing level of rice only cultivation.
9. Cultivation of Aus rice (BRRI dhan48) in the Kharif-I season was feasible and profitable in Bangladesh. Production of Aus rice in the coastal area is an option for cropping intensification and is getting popular with the farmers. The number of farmers increased from 12 to 59 over 3 years.
10. Boro rice was introduced in the project sites in Bangladesh and was found highly suitable, profitable and adopted by the farmers. The number of farmers increased from 35 in 2017-18 to 86 in 2019-20. Net benefit of Boro rice at average yield (5.4 - 5.7 t ha^{-1}) were between Tk. 55,030 ha^{-1} and 59,385 ha^{-1}. Farmers were satisfied and are willing to continue Boro rice cultivation as this is more resilient to extreme weather events compared to other non-rice crops.
11. We tested many new crops to find out their suitability for growing in the coastal saline soil in the Rabi season. In Bangladesh, we found several new crops such as foxtail millet, English spinach, barley, garlic along with sunflower, maize, mustard, pumpkin, etc. are suitable for cultivation and they are profitable. At Gosaba, among the 20 crops tested, farmer's preference analysis reveals that broccoli, Indian spinach, mung bean, mustard, and other vegetables are favoured by the farmers.
12. Zero tillage (ZT) potato cultivation is the breakthrough technology of the project which has been taken up by the farmers in Gosaba rapidly. The number of farmers increased from 23 in 2016-17 to 208 in 2019-20. The main reason for its adoption is the ease of cultivation and economic profitability ($2,498 ha^{-1} against around US$500 ha^{-1} from conventional practice) and it is expected that increasing numbers of farmers will continue to grow over the coming years. ZT potato was also found successful at Dacope. If we can achieve ZT potato on only 5% of the land (150 ha) in Gosaba, then the total benefit will be about AU$ 400,000 $year^{-1}$.
13. We determined the optimum time of sowing, establishment methods (zero tillage, dibbling, transplanting, use of machinery, etc.), management practices (use of mulch, fertilizer rate and application, spacing, intercropping, etc.) and conjunctive use of fresh water and saline water for irrigation for some of the suitable crops.
14. Waterlogging and poor surface drainage due to unexpected heavy rainfall are becoming a major constraint to the production of Rabi crops in the coastal region. Testing of the effect of surface drainage on crop growth of maize and sunflower indicates that drainage saves the crop and provides significantly higher yield.
15. Use of mini pond in 3-6% of the total service area for storing water in the wet season and use them in the Rabi season for growing crops as part of integrated farming was suitable and highly profitable in Dacope.
16. Low-cost drip irrigation system is very promising and financially feasible with favorable economic return and payback period of 1.91 years in Gosaba. Small-scale drip irrigation using a plastic bottle beside plants such as okra, tomato, onion, knolkhol, beet and chilli in Gosaba were also profitable.

17. Several suitable and profitable cropping patterns have emerged based on our research over the last four years for the study areas. Some of the highly profitable cropping patterns for Bangladesh sites are sunflower-rice-rice, maize-rice-rice, pumpkin-rice-rice, etc. The current dominant cropping pattern is fallow-fallow-rice. For Gosaba, profitable cropping patterns are Kharif rice-ZT potato-green gram, Kharif rice-ZT potato, Kharif rice-maize, etc.
18. The project made considerable scientific advances in understanding and modelling the crop systems and hydrology of the Ganges Delta. So far, 26 journal papers are published and 4 others are with journal for review. Several (at least 10) are under preparation. There were 30 conference presentations.
19. There are evidences that farmers are adopting the technologies developed by the project and are getting economic benefit. The project was initiated during 2016-17 with 384 farmers (46 women), which increased to 1,204 farmers (226 women) in 2019-20. In all sites, it is evident that the project team’s intervention is having significant social impacts as many farmers have already adopted the demonstrated technologies.
20. There is evidence that the Ministry of Agriculture in Bangladesh is using the information generated from the project. They allocated AU$425K to our partner BARI for a project on "Production, dissemination and postharvest technology development of sunflower for saline lands of coastal region" during July 2018 to June 2021) for promoting cropping intensification in the region.
21. Project activities were reported extensively with interview of local scientists in the national electronic and print media over the last 4 years. There were 5 TV programs (about 25 min each) fully based on the project activities in the national TV channel ATN Bangla and BTV.
22. In every season, several Farmers Field Day, community gatherings, and visits to the field sites were organized in collaboration with local leaders, extension officials and other stakeholders at each site to communicate and disseminate the project output to the farmers.
23. We organized two high level communication workshops with the policy makers in Dhaka and Kolkata. In Kolkata, the Agriculture Advisor to the Chief Minister attended the workshop.
24. Honourable Minister of Agriculture of the Government of Bangladesh visited the project activities in Dacope, Khulna on 12 March 2020 and commented that “*through these activities there will be agricultural revolution in the southwestern coastal area*”.

However, there is still much to be done to increase the resilience of this system by mitigating risks and increasing the productivity of crops by best management agronomic practices that specify optimal plant population, row spacing, seed depth and rate, time of sowing, fertilizer rate and placement. Over the last 4 years, we encountered untimely heavy rainfall during the Rabi season. So further research is needed to design and evaluate the most effective forms of drainage, including the possibility of sub-soil drainage to decrease the risk of crop failures or delayed sowing due to heavy rainfall events in the early Rabi season. Further research is also needed on the relative tolerance of Rabi season crops to waterlogging and flooding during the crop establishment phase.

Within the coastal zone, the landscape is diverse, particularly in land type or elevation. The cropping intensification options will vary according to land type. So the next steps are to identify packages of resilient technologies suitable for different parts of the region with different characteristics. A key element of this process is to address the issue of risk inherent in wider adoption of our technologies, particularly the risks associated with variable climate in combination with variable environments (water tables, soils type, and local salinity dynamics). Assessment of risks from climate variability and climate change, which may not be evident in a four-year project, requires a research effort using methods of long term risk evaluation.

3 Background

The contiguous coastal zones of Southern Bangladesh and West Bengal in India have similar geomorphology, soils and agro-climatic conditions and can jointly benefit from collaborative research on major limitations to livelihood enhancement. Within this low lying deltaic region, large areas known as 'polders' (http://en.wikipedia.org/wiki/Polder) have been enclosed and protected from seawater flooding by man-made earth embankments. Polders protect inhabited and cropped land, whereas the mangrove forest reserves of the Sundarbans in both Bangladesh and West Bengal are unprotected and are mostly in a natural state.

The ground level in polders is almost the same as the water level in the rivers. These being tidal rivers the level of water rises and falls with the tides, and are also affected by monsoon rain flows and sea water surges. This make the drainage of rain water accumulated in the polders difficult. Drainage can usually occur at low tide, creating the possibility of gravity drainage of excess water during the rainy season. Thus the management of the sluices controlling the flow of water between the polder and the rivers is complex.

Due to this difficult drainage situation and the ~ 2000 mm of annual rain concentrated mostly in the monsoon season, polders are prone to flooding, and salinity in the dry season. About 65% of the coastal zone of Bangladesh and West Bengal is affected by various levels (low to high) of salinity in the dry season (Brahmachari, undated; SRDI, 2010).

There are 139 polders in Bangladesh and a less well developed polder system in the Sundarban region of West Bengal. This report relates to the inhabited and cropped areas of the polders, and not to the forest reserves.

The population of the region is about 40 million in Bangladesh and 23 million in West Bengal. These areas are disadvantaged by poverty, food insecurity, environmental vulnerability and limited livelihood opportunities (MoA, 2013; Sánchez-Triana *et al.*, 2014). The living standards of residents of the West Bengal coastal region are described as dismal; Sánchez-Triana *et al.* (2014) showed that, of a typical group of residents, 19% get only one meal a day and for 6% of them it would be a substandard meal; 65% live below the poverty line. Similarly in Bangladesh, 65% of the population in the coastal zone live below the poverty line compared with 40% for the whole country.

Traditionally, farmers cultivate low-yielding local rice varieties under rainfed conditions in the wet season (Karim, 2006; Rashid *et al.*, 2014; Sarangi *et al.*, 2014; Sarangi *et al.*, 2015b). The average yield of Aman rice in the coastal districts is the lowest in Bangladesh (1.5 to 2.0 t ha^{-1}) compared to yields of 3.0 to 3.5 t ha^{-1} achieved in the other districts (BBS, 2011; Mainuddin *et al.*, 2014). Due to standing floodwaters, the average yield of wet season rice in the coastal zone of West Bengal (< 2.0 t ha^{-1}) is below both the national average (2.4 t ha^{-1}, 2011-12) and the average of West Bengal (2.6 t ha^{-1}) (Sarangi *et al.*, 2015a).

In the dry season, most land remains fallow due to: (i) late rice harvest and prolonged waterlogging (which delays the planting of Rabi crops and exposes the late planted crops to high soil salinity and untimely rains during the latter part of the season), and (ii) the lack (or perceived lack) of good quality irrigation water for Rabi season irrigation (Brahmachari, undated; Mainuddin *et al.*, 2013; Mondal *et al.*, 2008). A scoping study funded by ACIAR (LWR/2011/066) showed that there are over 700,000 ha of under-utilized land that can be brought under cultivation during the Rabi season (Mainuddin *et al.*, 2013). Schulthess *et al.* (2015) showed that there are about 800,000 ha left fallow or underutilized in the poldered coastal zone. Thus, the cropping intensity in the districts along the coast of

Bangladesh is below 150% (2009-10) compared to the country average of 183% (Mainuddin *et al.*, 2014). Similar conditions (fallow lands in the Rabi season and low cropping intensity) exists in the coastal zone of West Bengal (Sarangi *et al.*, 2015a).

The scoping study (LWR/2011/066) and workshops held in Bangladesh and West Bengal in September 2014 and February 2015 (during the development of the proposal) confirmed that there is widespread soil and water salinity and limited availability of irrigation water under current management regimes. Salinity of soil, surface water and groundwater varies significantly both spatially and temporarily.

The annual rainfall is adequate for two crops per year, but little of the excess in the monsoon can be stored as surface or groundwater. Indeed, waterlogging is a problem in the late wet season and early dry season due to infrastructure that impedes rapid drainage from polders, current inefficient polder water management practices, and low soil permeability. Later in the dry season, soil drying leads to salinity problems (in-situ soil salinity due to the shallow saline groundwater) which may be exacerbated by the use of brackish water for irrigation.

In West Bengal, there are reports of extreme acidity in pond water due to acid sulphate soil layers at the base of the ponds. Notwithstanding these constraints, it is considered (and subject to much discussion at project development workshops) that cropping can be intensified through several management strategies including surface drainage of excess water at the end of the wet season, better understanding and use of the limited fresh groundwater (bearing in mind the potential acid sulphate soil problems), better maintenance and use of limited surface water storage, separation of lands of higher and lower elevation taking advantage of existing infrastructure (e.g. roads) and strategic construction of small levees, planting of earlier maturity and shorter season rice varieties during to provide better timeliness of crops in relation to water availability, increased use of salt tolerant Rabi cultivars, and optimising areas of cropping in relation to areas devoted to surface storage.

The scoping study (LWR/2011/066) proposed that the main barriers to crop intensification in the coastal zone are poor or missing linkages between field-level cropping choices and the polder scale water and salinity management decisions. Despite substantial research by many agencies in the coastal zone to increase crop productivity, studies continue to overlook the linkages between field-level cropping choices and the polder scale water and salinity management decisions.

There is also limited knowledge of cropping and management options, and poor availability of salt-tolerant varieties of crops. Moreover, as noted by Tuong *et al.* (2014) "*water resources in the coastal zone have largely been misunderstood and under-utilized. In reality, valuable resources are available which can be used to support agricultural and aquacultural production and livelihood improvement of farming families and communities"*.

There may also be the opportunities for strategic pumping of saline groundwater during the dry season which will increase the amount of freshwater recharge and thereby fresh water for irrigation from groundwater during the dry season. Realising this potential (while avoiding the potential acid sulphate soil problems noted earlier) relies on developing the opportunities in a systematic and integrated way. Mandal *et al.* (2011) also identified high soil salinity and water scarcity, non-scientific nutrient management, scarcity of good quality irrigation water during the Rabi season, low crop diversification, and under-utilised brackish water resources as major critical gaps for crop intensification in the coastal region of West Bengal.

Most previous studies (e.g. LWR/2005/146, Humphreys *et al.*, 2015; Rawson, 2011; Sarangi *et al.*, 2014; Sarangi *et al.*, 2015b) focused either on field-scale crop management or on polder/regional-scale water management and modelling (e.g. Humphreys *et al.*, 2015; IWM and CEGIS, 2007; Yu *et al.*, 2010), but did not link the two which is essential for long-term sustainable intensification of the region. The key research questions for sustainable intensification of the cropping system in the coastal zone include:

1. Where, when and how much low salinity surface water is available for irrigation and where and how can groundwater be used sustainably for irrigation? What are the spatial and temporal trends in surface water, groundwater, and soil salinity and how do they interact?
2. Will strategic pumping of saline groundwater during the dry season increase the amount of freshwater recharge and thereby significantly increase the amount of fresh water available for irrigation from groundwater during the dry season?
3. What are the best options for using available fresh water resources to increase production of dry season crops such as wheat, maize, pulses and oilseeds; e.g. irrigation practices such as flood, furrow or drip, mulching, land shaping and crop nutrient management? How profitable and sustainable are these options?
4. Can polders be managed and redesigned to improve drainage to enable production of earlier maturity (modern) rice varieties during the wet season, earlier drainage of monsoon floodwaters, for earlier planting of dry season crops, and for storage of non-saline water for irrigation of pre- and post- monsoon crops?
5. What barriers to improved water management in polders are presented by farmers' crop and management preferences and other water users and how can they be overcome?

Following the recommendations of the scoping study in 2011 (LWR/2011/066), ACIAR launched an initiative for the coastal region which aims to lift agricultural productivity and hence rural welfare by increasing cropping intensification. There are 3 projects under this initiative including this project 'Cropping system intensification in the salt affected coastal zone of Bangladesh and West Bengal, India (CSI4CZ, LWR/2014/073) which deals with water and biophysical aspects. There are two other projects, one on salinity tolerance screening of crop varieties (e.g. legumes, wheat, etc. only in Bangladesh, CIM/2014/076) which commenced on July 2018 and the other on community-level risk management for socially inclusive and sustainable agricultural intensification (SIAGI, LWR/2014/072) which commenced on January 2016 for 4 years. Krishi Gobeshona Foundation (KGF) of Bangladesh has identified the coastal zone as a research priority area and co-funded the CSI4CZ project in Bangladesh and the salinity tolerance screening project (CIM/2014/072), following an MoU signed between ACIAR and KGF for research funding collaboration.

4 Objectives

The project aims to sustainably increase cropping intensity and productivity in the coastal zones of Bangladesh and West Bengal particularly in the dry/Rabi season through integrated soil, water and crop management.

This will be achieved through the following objectives and activities;

I. Develop a sub-regional scale understanding of the surface water and groundwater resources, recharge/discharge mechanisms and trends in the case study polders.

   1.1 Compile and review existing literature and data on soil, surface water, groundwater, salinity, climate change impacts, changes in river flow, and increase in population and their impacts on the coastal zone.

   1.2 Conduct water balance analyses of the selected polders based on the collected (secondary) data and the outputs of the regional water balance analyses done under the Bangladesh Integrated Water Resources Assessment project.

2. Develop a detailed understanding of the salt and water dynamics of the selected polders and explore the opportunities for pre-monsoon and post-monsoon groundwater abstraction regimes that improve groundwater quality and availability during the dry season.

   2.1 Prepare detailed maps of the selected polders which include roads and channels, embankments, location of water structures, soil types and current cropping practices, and the subdivision of the polder based on hydrology, irrigation and drainage channels, groundwater surfaces, DEM, etc.

   2.2 Review existing BWDB polder level flood, irrigation and drainage management regimes and operation procedures and consult with the community about the polder operation and management.

   2.3 Identify and set up field monitoring points at strategic locations to gather data on water levels, salinity and flows.

   2.4 Develop analytical and modelling procedures to quantify and simulate salt and water (both surface water and groundwater) dynamics and fluxes, and for linking this with the outputs of the sub-regional water balance analyses (objective 1) and the inputs and outputs of the APSIM simulations (objective 3 and 4).

   2.5 Apply the model(s)/procedure(s) in Bangladesh to evaluate the water and salinity dynamics for different polder water management (both irrigation and drainage) conditions and cropping systems and management.

3. Develop detailed understanding of crop production, water balance and salinity responses to various improved polder-level water management strategies and cropping system and management options.

   3.1 Extend the capability of APSIM to dynamically simulate soil and plant salt interactions in the root zone for Rabi crops such as wheat, maize, etc. and further validate the APSIM-ORYZA salinity routines developed under the LWR/2008/19 project for rice.

   3.2 Establish a data collection protocol for the field experiments (set up under objective 4) to understand salinity dynamics in the crop root zone and soil-water-salt-plant interactions. The data are used to parameterise the APSIM model, and subsequently for calibration and validation.

3.3 Define scenarios through farmer workshops for testing in model simulations and on farm and apply APSIM to evaluate crop and water management options for land and water productivity and to mitigate root zone salinity.

4. Test suitable cropping system x management options and water and salt management strategies (developed in 2 and 3) through field evaluation and co-learning with farmers.

4.1 Select sites for cropping trials in farmers' fields within the selected polders and characterise soil salinity and other soil parameters' variability and water resource availability.

4.2 Identify and select possible cropping options based on farmers' preferences, results of activities under objectives 1-3, regional researcher and extension personnel opinions, and activities of the sister projects, and set up on-farm experiments, farmer participatory trials and demonstrations in the 4th season.

4.3 Conduct socio-economic analyses (cost benefit analysis, market conditions, household demand and preferences, value addition of agro-products, women vis-a-vis farm family enterprise, risk and sustainability, etc.) of the possible cropping options for intensification. Explore the potential for private sector involvement in input and market chains with direct in the ground involvement of Shushilan with this project, the NGO partner of the sister SIAGI (LWR/2014/073) project.

4.4 Evaluate the different cropping options by linking the field experimental results with the results of objectives 1 and 2 and 3, and cross-correlating with the output of the sister projects such as farmers preferences, value chain, involvement of private sector input supply and agri-marketing companies, etc. Select feasible and sustainable cropping options for intensification under a range of polder water management options for the selected polders.

5 Methodology

5.1 Location and characteristics of the study area

Three study locations have been chosen for this work, two in Bangladesh and one in West Bengal, to provide contrasts in salinity status and water management. These locations are polder 43/1 at Amtali, Borguna (in the Patuakhali region) and polder 31 in Dacope, Khulna of Bangladesh and one island in the district of South 24 Parganas of West Bengal (Figure 5.1). The area of polder 43/1 at Amtali is 205 km^2 and the area of polder 31 at Dacope is about 103 km^2. The area of Gosaba Island in West Bengal, India is about 36 km^2. The main characteristics of these 3 locations are compared in Table 5.1. The observed annual average rainfall and potential evapotranspiration from 1994 to 2018 were, respectively about 2.5 and 1.2 m at Amtali; 1.8 and 1.3 m at Dacope; and, 1.9 and 1.4 m at Gosaba. The population density in these 3 polders/Islands are 548 person km^{-2}, 1024 person km^{-2}, and 831 person km^{-2}, respectively for Amtali, Dacope and Gosaba (CEGIS, 2016a; 2016b; Ghosh and Mistri, 2020). The people of the coastal zone depend mainly on agriculture for their livelihood (Mainuddin *et al.*, 2019a; 2020). Traditionally, farmers cultivate low-yielding local rice varieties under rainfed conditions in the wet season (Ghosh and Mistri, 2020; Maniruzzaman and Kabir, 2019; Sarangi *et al.*, 2015b). Cropping is limited in the dry season and most land remains fallow (Mainuddin *et al.*, 2019a; Mandal *et al.*, 2020; Saha *et al.*, 2019).

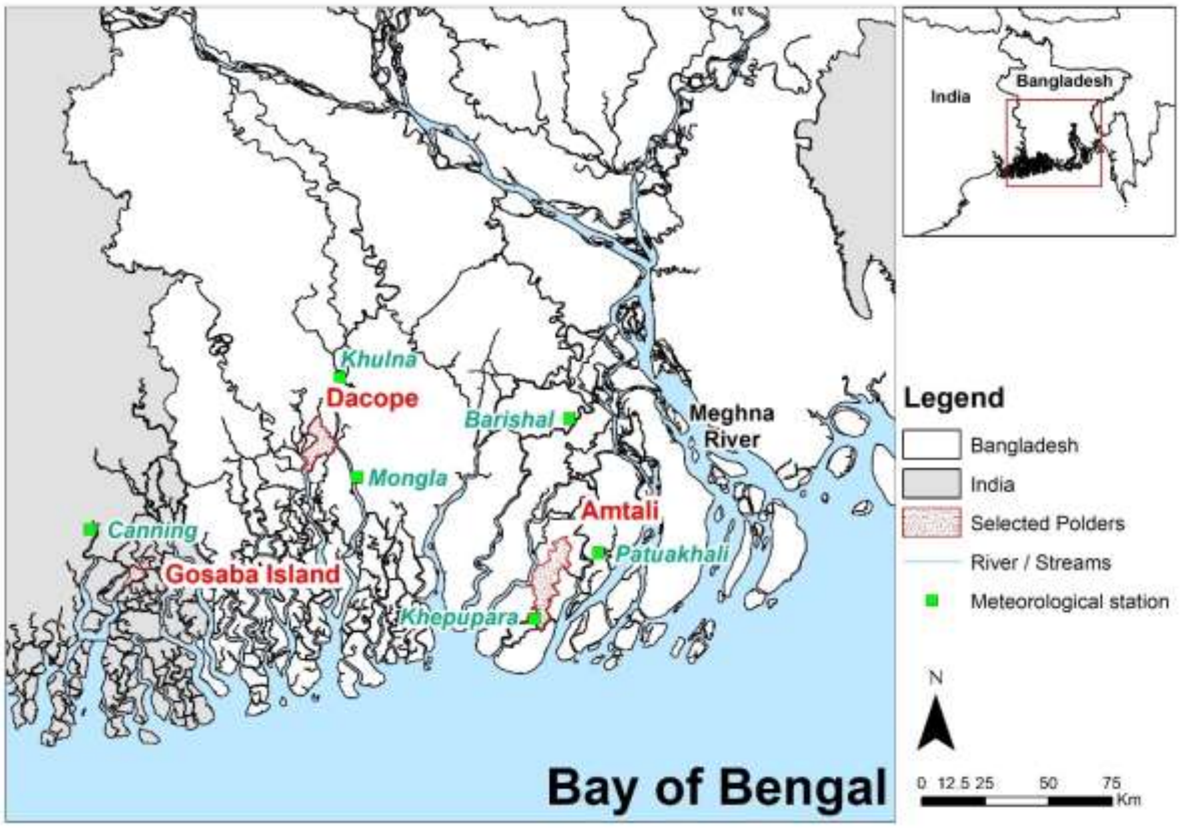

Figure 5.1 Location of the selected polders/islands

Taken together, the three sites present a range of different issues and opportunities and require tailored local research. Within each study area, site selection for field experiments are based on land types, (low, medium, high land), polder management (functioning sluice gates and local management), occurrence and maintenance of canals and ponds.

Table 5.1 Location and characteristics of study locations (see also Figures 5.2–5.6)

Location	Main characteristics	Research partners
Polder 43/1, Amtali, Borguna	Pronounced inundation but low salinity. Available fresh water from outside polder (river water) for supplementary irrigation in Rabi and Kharif I season. Boro and Aus rice are also options for this region.	BARI, BRRI, IWM
Polder 31, Dacope, Khulna	High salinity and prolonged inundation of low and medium land. Fresh river water available for irrigation for a limited period of time after the end of the rainy season e.g. to early February near Khulna city.	BARI, BRRI, IWM, Khulna University
Gosaba Island, South 24 Parganas, West Bengal	Salinity and inundation vary with elevation within polder. No freshwater available from outside polder in Rabi and Kharif I seasons. Supplementary irrigation depends on collection of rain water from the monsoon season in ponds and canals. Pond water prone to acid discharge and salinisation with the passage of the dry season.	BCKV- Gosaba CSSRI-Rangabelia, TSRD

Comprehensive details on the process of selection of these 3 polders and the initial assessment based on the field visit and reconnaissance survey are given in the inception report of the project.

The activities to achieve the objectives of the project can be broadly classified into following 3 categories.

1. Polder level analysis and modelling (objectives 1, 2 and 4)
2. Cropping experiments at the field level and crop modelling (objective 3 and 4)
3. Socio-economic analysis and integration (objective 4)

The research opportunity in Bangladesh differs from that in West Bengal because of differences in prior information and models, institutional set-up, and the current or intended activities of other projects. Therefore, as detailed below, our approach differs somewhat in Bangladesh and West Bengal. In particular, we undertake only preliminary water balances in West Bengal, and also undertake no groundwater modelling there. Farm and market socio-economic assessments, and institutional analysis are undertaken by the sister project LWR/2014/72 in Bangladesh, but not in the coastal zone of West Bengal. Hence, we undertake socio-economic survey assessment and institutional analysis in West Bengal, described in greater detail below.

Prior regional water balance analysis (Kirby *et al.*, 2014) undertaken under the CSIRO-DFAT funded project on Integrated Water Resources Assessment (CSIRO *et al.*, 2014) and the ACIAR funded scoping study (Mainuddin *et al.*, 2013) underpins Objective 1 and 2 activities in Bangladesh. By contrast, in West Bengal, there has been no equivalent study of water balance modelling. Hence, only a preliminary water balance analysis was undertaken in West Bengal with most focus on Objectives 3 and 4.

5.2 Polder level analysis and modelling

5.2.1 Land use

Existing land use, cropping practices, farm level data at Amtali and Dacope were collected through reconnaissance survey, village census and farm household survey. Group discussion was conducted in each village to develop a database on socio-demographic features, evaluation of cropping systems, farming systems, farmers' perception about climate and environment change, farming risks, constraints and their adaptation responses during November 2016–January 2017.

The cropping system and the spatio-temporal variability of crops and fallow land particularly during the post-monsoon season, at the Gosaba island of Indian Sundarbans, was assessed by using multi-dated Sentinel -2 data. The Sentinel – 2 data offers 10-20 m spatial resolution, 5 – day revisit frequency, global coverage and compatibility to the Landsat missions and provides new opportunities for regional to global agriculture monitoring. A field survey was conducted on 23rd March 2018 for ground observation of land situation during the time of satellite passage, in order to collect training classes as well as ground truth validation of classification output.

5.2.2 Climate

More than 40 years (1970–2017) of historical daily temperature and rainfall data in the study region were examined. The stations at Khulna and Mongla, are around the cropping experiment site in Polder 31, Patuakhali and Khepupara are in the vicinity of the sites in Polder 43, and Canning is close to the experiment site on Gosaba Island (Figure 5.1). Locations and data information of all observations are listed in Table 5.2. We also installed automatic weather station in each site to record daily weather parameters for crop modelling.

Table 5.2 Observatories in coastal zone in Bangladesh and West Bengal, India

Observatories	Canning	Khulna	Mongla	Barishal	Patuakhali	Khepupara
Latitude (N)	22°18'	22°47'	22°28'	22°43'	22°20'	21°50'
Longitude (E)	88°40'	89°34'	89°36'	90°22'	90°20'	90°41'
Elevation (m)	3.5	2.1	1.8	2.1	1.5	1.8
Data start	1966	1974	1991	1949	1973	1974
Data end	2017	2017	2017	2017	2017	2017

To further investigate the variations in extreme weathers in long term, 27 climate indices of different climate parameters, such as annual maximum temperature and rainfall and annual longest dry period, were computed using software RClimDex designed by Climate Research Division, Canada (http://etccdi.pacificclimate.org/index.shtml). Here we focussed on nine indices which are listed in Table 5.3. Based on the daily precipitation over the last 40 years, the variation in trends was detected and the significance was tested.

Table 5.3 Definition of extreme air temperature and precipitation indices applied in this study

Indices	Definition	Unit
TMAXmean	Annual average of monthly maximum value of daily maximum temperature	°C
TMINmean	Annual average of monthly minimum value of daily minimum temperature	°C
SU25	Annual count of days when daily maximum temperature > 25 °C	days
DTR	Monthly mean difference between daily maximum and minimum temperature	°C
RX1day	Monthly maximum 1-day precipitation	mm
RX5day	Monthly maximum consecutive 5-day precipitation	mm
PRCPtot	Annual total precipitation in wet days with precipitation >= 1mm	mm
CDD	Annual maximum number of consecutive days with precipitation <1 mm	days
CWD	Annual maximum number of consecutive days with precipitation >=1 mm	days

5.2.3 Characterisation of water resources

For monitoring river and trapped or stored canal water salinity, three spots were selected at a certain distance in both Amtali and Dacope in Bangladesh as shown in Figure 5.2. The measurement was taken once in a week at 9:00 am on every Sunday. Irrigated rice field water salinity was measured at the same date and time.

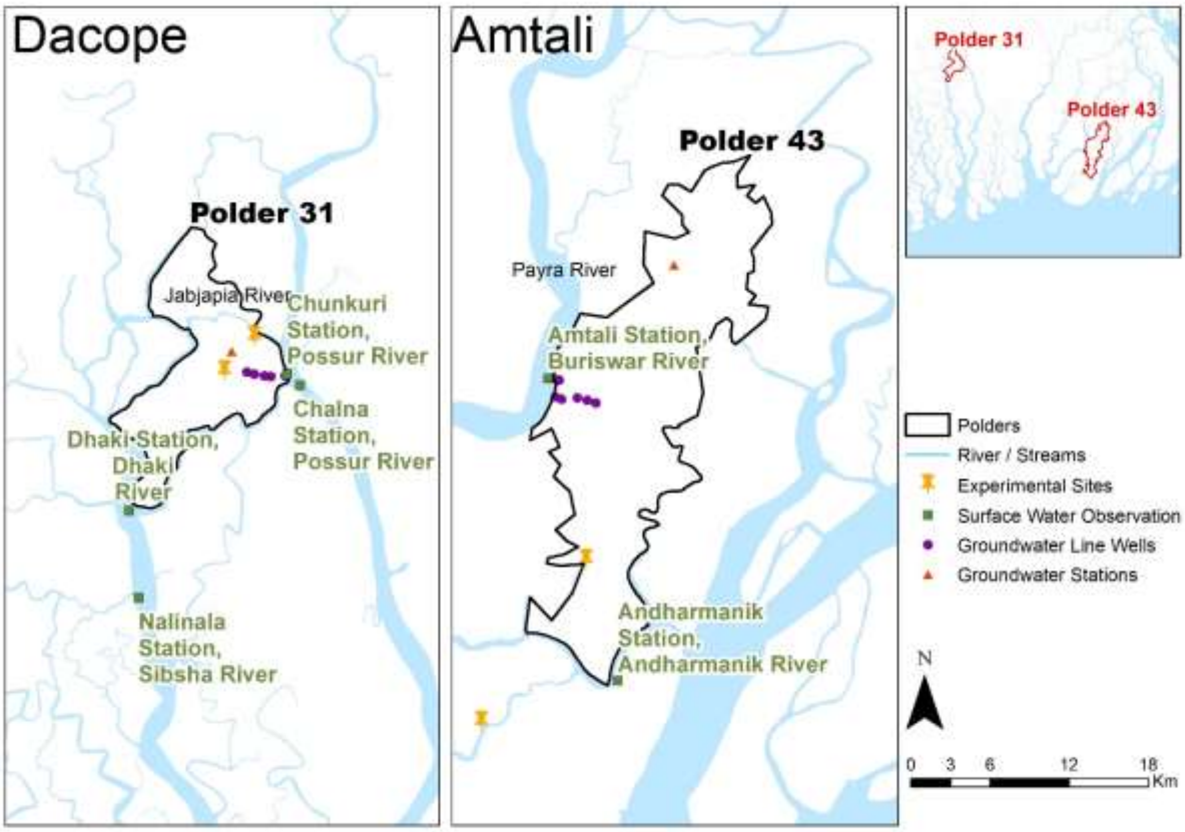

Figure 5.2 The experiment sites, surface water and groundwater observation points in the polder 31 and 43 in the coast of Bangladesh

We also installed observation well in one corner of the experimental field of Dacope, Khulna and very near to the experimental field at Sekandarkhali village of Amtali, Borguna to measure groundwater level and salinity. We installed 10 observation wells (5 at the site of

CSSRI and 5 at the site of BCKV) in Gosaba Island. We also monitored depth of water and salinity of rivers, canals, and ponds at 29 points around the experimental sites in Gosaba Island. The locations of these observation points and the groundwater observation wells are shown in Figure 5.3.

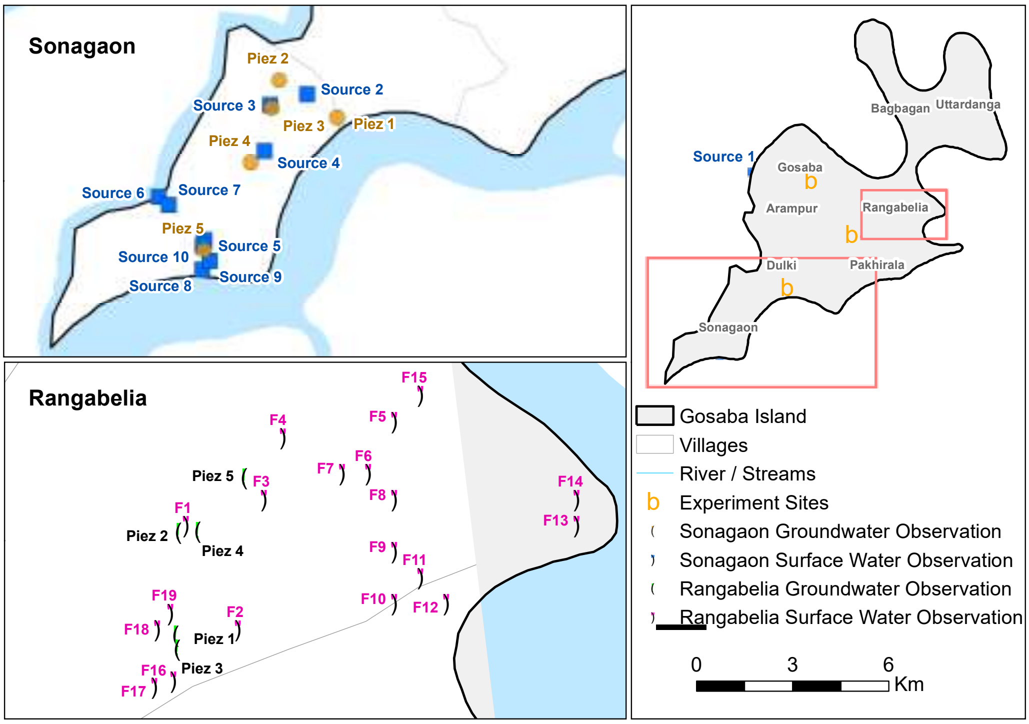

Figure 5.3 The experiment sites, surface water and groundwater observation points in the Gosaba Island, West Bengal, India.

5.2.4 Polder level salt and water balance modelling

We have developed a novel time-series model of water and salt stores and flows in an idealised polder to investigate water and salt management strategies for crop production, including strategies to cope with climate change, sea level rise and flood inundation. We know of no other model that simulates the overall water and salt balance of a polder, and that can assess a wide range of polder water and salt management strategies. The conceptual basis of the water and salt balance in a polder is shown in Figure 5.4. The polder is conceived as a unit with an area of crops, and an area of canals and ponds. Other areas, such as houses and roads, are small and are not considered in the model. The area of canals and ponds may be varied to model one potential water and salt management strategy, that of increasing the volume of water stored for use in irrigation. Increasing the area of canals and ponds leads to a corresponding decrease in the cropped area.

The model tracks the stores of salt and water in (i) the soil, (ii) the shallow groundwater, and (iii) the canals and ponds, and the movements of salt and water between these three stores. The model also tracks the movements of salt and water from these stores to the external environment of the deeper groundwater (which in our model means groundwater below the freshwater lens), the rivers that surround the polder, and the atmosphere. The shallow groundwater will rise in the wet season and fall in the dry season. It will generally have a salt concentration different to that of the deeper groundwater. It is conceived as a layer or lens which sits on top of the deeper groundwater, as found in the Ganges delta (Worland *et al.*, 2015), and other environments such as small Pacific islands (White and Falkland, 2010). Whereas there is some mixing between fresh groundwater lenses and the underlying groundwater (White and Falkland, 2010), for simplicity we model the shallow transient layer as not mixing with the deeper groundwater. However, deeper groundwater may be accessed by capillary rise if it is shallow enough and if the shallow groundwater lens is exhausted.

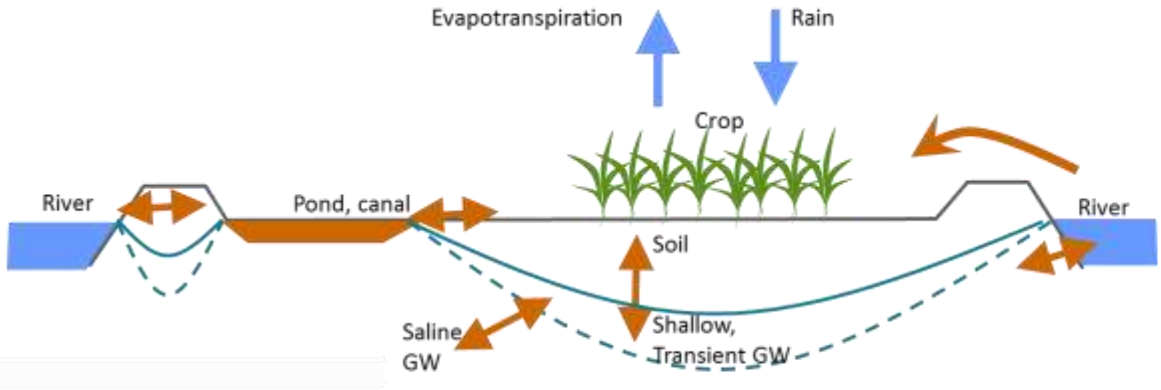

Figure 5.4 Schematic diagram of key processes governing water and salt balances in a polder. The blue arrows depict the movement of water without salt – rainfall and evapotranspiration. The brown arrows depict the movement of water and salt between four main water and salt stores; the rivers, groundwater, surface canals and ponds, and the soil. GW denotes groundwater.

Each of the three stores of water and salt is considered to be a single store; there is no differentiation of soil into several layers, for example. The movement of water between the stores and with the external environment is based on simple process models, as described below. The movement of salt is based on the movement of water and the concentration of salt in the water. The model uses a monthly timestep.

Three instances of the model were developed, one for each of the project field sites at Amtali and Dacope in Bangladesh, and at Gosaba Island in West Bengal, India. The model for each polder was calibrated with field data from the experimental plots, and with results of APSIM simulations of the experiments. The calibrations using the experimental data generally involved simulations over about a three-year period. The calibrations using the APSIM results involved simulations over a 24-year period for Amtali and Dacope (from 1994 to 2018), and over two years at Gosaba (from 2016 to 2017). To examine the influence of the variation in parameters, we performed a sensitivity analysis of the model using a Monte-Carlo approach. More detail about the model development, calibration, validation and sensitivity analysis can be found in the Annex report 3 and at Mainuddin *et al.* (2019b) and Mainuddin *et al.* (2020).

We used the model to examine the impact of management opportunities for increasing crop production (six different scenarios), impact of projected climate change (5 scenarios), impact of change in river salinity (1 scenario) and impacts of storm induced flood inundation (3 scenarios). The detail about these scenarios are given in the Annex Report 3 and in Mainuddin *et al.* (submitted) and Mainuddin and Kirby (submitted).

5.2.5 Surface water, groundwater and salinity interaction modelling

Groundwater models are developed to simulate water movement and salt transport in the river and through the porous medium of aquifer for a range of existing and possible future conditions. Seawater intrusion is a natural process, where the groundwater flow depends on hydraulic gradient and fluid density variation between freshwater and seawater and the transport mechanics includes convective and dispersive processes (Bear *et al.*, 1999). FEFLOW – a widely used modelling software for simulating GW solute transport process, is being applied in this study for investigating the salinity dynamics considering both spatial and temporal variability. The approach and methodology adopted for the groundwater model development is shown in Figure 5.5. Two separate models have been developed for the two selected polders in Bangladesh (Figure 5.6). The details about the model development, data collection, calibration and validation are given in the Annex Report 4.

The groundwater modelling is undertaken only in Bangladesh as planned in the proposal. However, we studied surface water and groundwater interactions in Gosaba Island through a master student's thesis research at the Indian Institute of Technology, Kharagpur, West Bengal (Arjun, 2019). CSSRI and BCKV facilitated the research by providing data and input. The student spent two weeks in November 2018 at CSIRO to work on the model. The study focussed on 2-D vertical cross-sectional modelling of surface water (SW)-Groundwater (GW) interactions in Gosaba Island of Sundarbans delta using the MODFLOW model with the help of PEST utilities (for manual calibration). The model was calibrated (Feb 2017–May 2018) and validated (Jun 2018–Jan 2019) using head data from five piezometers (installed by CSSRI for the project) along the Gosaba Island cross-section. The thesis has also explored a comprehensive parameter sensitivity analysis in terms of piezometric head simulations at these 5 locations considering eleven major SW-GW influencing parameters. The details are given at Arjun (2019).

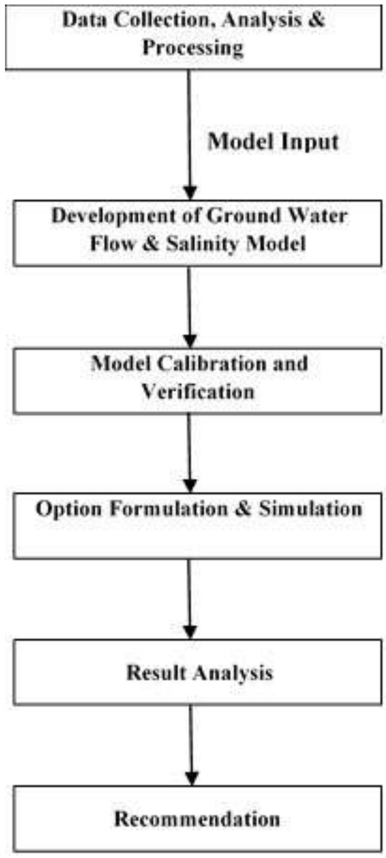

Figure 5.5 Methodology of the Groundwater Salinity Modelling

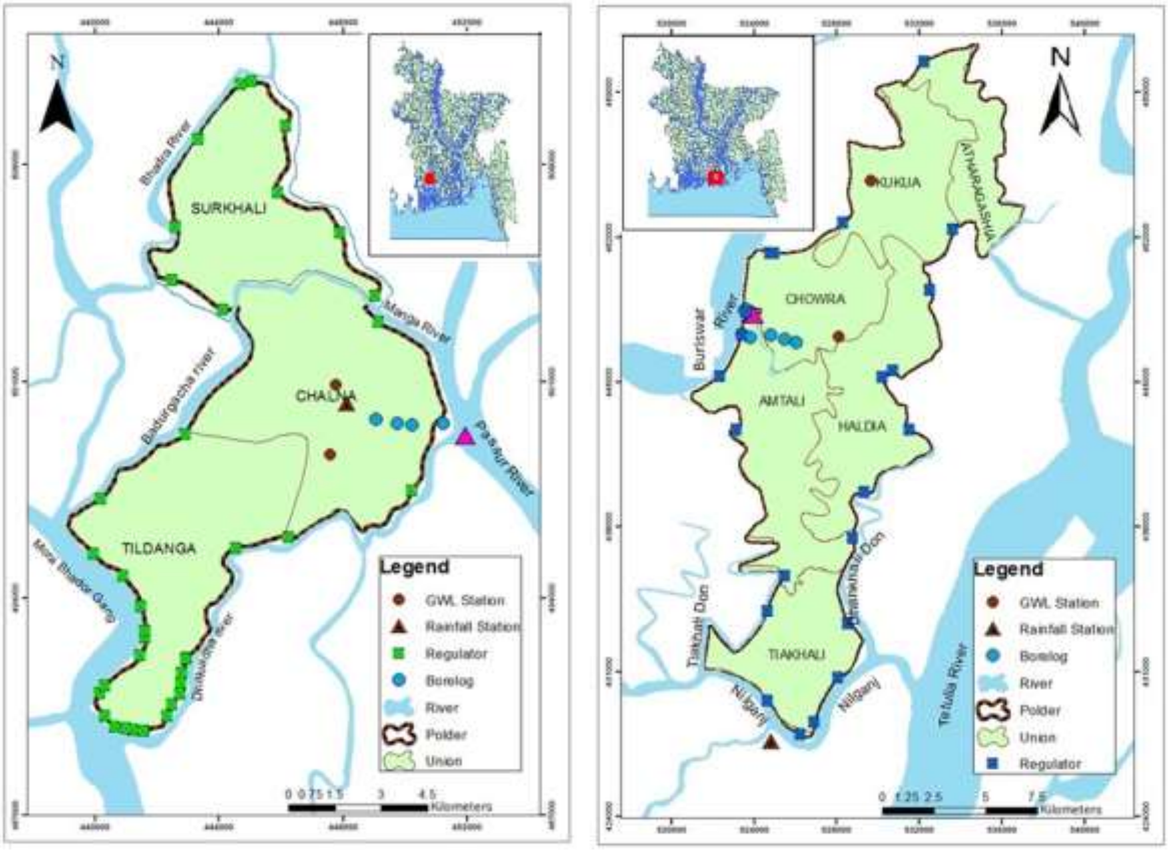

Figure 5.6 Map showing the modelled polders, Polder 31(left) & Polder 43/1(right)

5.3 Cropping experiments at the field level and crop modelling

5.3.1 Field Experiments

In each location, we set up series of field experiments throughout the years. There are 3 crop seasons. These are Kharif II (July-October), Rabi (November–February) and Kharif I (March to June). Kharif II is the wet season (WS), Rabi is the dry season (DS) and Kharif I is the pre-monsoon or early wet season (EWS). Based on climate, November to April is considered as dry season and May to October is considered as wet or monsoon season. In the crop intensive regions (such as northwest, central) of Bangladesh 2 to 4 crops are grown in a year including 3 rice crops in three seasons; Aus in Kharif I, Aman in Kharif II, and Boro rice in Rabi season. Other non-rice crops are grown mostly in the Rabi and Kharif I seasons. However, in the salt-affected coastal zones of Bangladesh and West Bengal, only Aman rice (mostly long duration and late maturing) is grown as described earlier. In West Bengal, Boro rice is grown widely in the other region along with other non-rice crops in the Rabi and Kharif I season.

Site selection for experiments within each study polder are based on suitable infrastructure (e.g. near a sluice gate to enable good drainage management) to test drainage and irrigation options (canals and ponds for dry season water storage, and canals for drainage of monsoon water). We consulted with the farmers and community to find areas where all farmers are willing to synchronise their cropping systems. The field experiments focus on the main land type of each polder (low, medium or high land) to maximise the opportunities for out-scaling of results.

We set up field experiments in all 3 seasons in all locations. We were supposed to start field experiments in the Rabi season of 2015 (starting in November 2015) but was not possible due to delay in processing of the contracts. So field experiments started from the Kharif II season in July 2016. So we have covered 4 Kharif II seasons (2016-2019), 3 Kharif I seasons (2017-2019) and 4 Rabi seasons (2016-2019). Table 5.4 shows the number of experiments conducted in each season, the area covered and the number of farmers (gender disaggregated) for each location. Non-rice crops grown in the Rabi and Kharif I season overlaps so it is difficult to separate them. However, in case of rice though the season sometimes overlaps but the varieties are different for each season. However, in Table 5.4 Kharif I and II are reported together (for rice only). Non-rice experiments conducted in the EWS or Kharif I season are reported with Rabi season. Experiments were not concentrated in one area inside the polder. They were distributed inside different locations within the polders and that grew every year. So within each polder, there were multiple locations (up to 5-6 km apart) for experiments and demonstrations.

The experiments conducted can be classified into the following broad categories for the Kharif and Rabi seasons.

Kharif season

1. Introduction and selection of suitable variety for Aus rice (Kharif-I) in the cropping pattern in the sites of Bangladesh
2. Selection of suitable Kharif-II (also called T. or transplanted Aman) rice verities for facilitating Rabi crops
3. Rice establishment method and soil amelioration
4. Growing vegetables crops with wet season rice under waterlogged lowland condition

Rabi season

1. Introduction and selection of suitable variety and sowing time for Boro (dry season) rice
2. Use of water savings technologies such as alternate wetting and drying (AWD) and use of mulch for Boro rice

The main focus of this project is to grow crops in the Rabi season thus increasing the cropping intensity. Over the last four years, we have experimented with a range of Rabi season non-rice crops in the study area. These experiments can be broadly classified into the following categories:

1. Screening of suitable crops for coastal region
2. Finding suitable time of sowing for different crops
3. Crop establishment methods
4. Crop management
5. Amendment of soils, utera systems, relay cropping, etc.
6. Irrigation, drainage, and water management
7. Out-scaling and demonstration of different crops
8. Selection of suitable and profitable cropping pattern

We introduced and tested latest available varieties of Aus, Aman/Kharif and Boro rice. We also introduced and conducted experiments with a range of non-rice crops such as maize, wheat, barley, sunflower, potato, tomato, water melon, pumpkin or sweat gourd, garlic, spinach, mustard, garden pea, broccoli, chilli, tomato, grass pea, lentil, different types of Kharif and Rabi season vegetables (e.g. different types of gourd and beans).

Table 5.4 No of experiments, area covered, and farmers involved in 2018-19

Location	No. of experiments		Area (ha)		Farmers involved			
	Kharif	Rabi	Kharif	Rabi	Kharif		Rabi	
					Male	Female	Male	Female
2016-17[1]								
Amtali	10	12	5.9	5.2	106	14	106	14
Dacope	4	7	4.7	4.7	27	6	27	6
Gosaba	2	6	2.1	3.7	36	3	36	3
Total	**16**	**25**	**12.7**	**13.6**	**169**	**23**	**169**	**23**
2017-18								
Amtali	9	24	21.0	14.2	131	4	102	7
Dacope	12	24	14.2	8.9	89	4	42	8
Gosaba	4	10	2.9	6.3	18	2	93	11
Total	**25**	**58**	**38.1**	**29.4**	**238**	**10**	**237**	**26**
2018-19								
Amtali	7	26	18.8	29.0	134	15	128	0
Dacope	9	24	49.9	13.0	281	15	83	0
Gosaba	7	11	5.9	12.9	27	4	163	84
Total	**23**	**61**	**74.6**	**55.1**	**442**	**34**	**374**	**84**
2019-20								
Amtali	6	17	50.8	28.7	281	21	131	3
Dacope	7	26	26.4	20.8	167	22	124	4
Gosaba[2]	4	7	2.2	6.1	58	23	217	153
Total	**17**	**50**	**79.3**	**55.6**	**506**	**66**	**472**	**160**

Note:
[1] In addition to the number of farmers given mentioned in the table, another 183 farmers were involved in water management activities and preference analysis conducted by BRRI at Amtali and Dacope.
[2] Area of CSSRI was not included

All experiments were set up considering statistical design such as split-plot design or randomized control block design (RCBD) with at least 3 replications. For crop establishment (e.g. spacing, seed rate, etc.), input used (fertilizer, pesticides, etc.) and intercultural management, standard guidelines (if they are not subject to study) were followed. All required soil, crop and weather data were collected following standard procedures. Each experiment was conducted at least for two seasons to validate the results. Some were conducted for 3 years as well. In Bangladesh, most of the experiments were conducted in both locations (Amtali and Dacope). Appropriate statistical procedures such as analysis of variation (ANOVA), analysis of co-variation (ANCOVA), least significant difference (LSD) were used to analyse the results of the experiments.

Apart from the well-designed experiments, we also set up crop cafeteria where we tested and demonstrated many crops in small plots to see their potential in the region. In the 3rd and 4th year, we also set up a large number of demonstration plots for some of our successful technologies (such as zero-tillage potato, sunflower, water melon, spinach, etc.) at different parts of the selected polders. For the demonstration trial, only the basic data (input used, yield and biomass) were collected. All experiments (except two on-station mirror experiments on Boro rice for APSIM modelling) were set up in the farmers' field in collaboration with the farmers. More details on the individual experiment such as hypothesis tested, design, data collection, statistical analysis, etc. can be found in the Annex Reports 7-13.

5.3.2 Electromagnetic soil survey

Short range variability of soil properties (e.g. salinity and waterlogging as shown in Figure 5.7) confound cropping trial analytics in the salinity affected Coastal Zone of Bangladesh and West Bengal. These soil properties effectively mask the treatment effects of cropping trials as their direct impact has a greater influence on yield than the treatment factors e.g. (sowing date, crop variety or drainage condition etc).

Figure 5.7 Soil properties like waterlogging and salinity reduce biomass or yield confounding treatment effects like date of sowing or variety in cropping trial experiments.

We planned to use EM techniques to reduce the effects of these soil factors and optimize cropping experiments in the projects study areas using five key objectives:

1. Select the appropriate equipment and software for EM technology
2. Use EM techniques to improve trial site selection processes
3. Investigate relationships between ECa, Soil EC1:5 and soil water content and develop models at field or plot scale
4. Understand when & how to use ECa in covariance analysis to improve trial results
5. Build capacity among our in-country researcher cohort to use the above techniques independently

The EM team assessed several techniques and instruments with the capabilities to assess Apparent Conductance (ECa) within the rootzone of typical crops under investigation. The DualEM1HS was selected as it has more robust calibration requirements, onboard memory and global positioning system. This device also had the capacity to measure four separate depth intervals in a single measurement pass. These features were superior to other alternatives along with a more user-friendly data acquisition and calibration protocols making it easier to build operational capacity among non-specialist users.

Open source software identified and adopted by the project team includes QGIS and SAGA are spatial analysis programs. Jamovi is a user interface for R statistical programming suit and these applications are available as freeware which is attractive for the large number of our project team members. EM4Soil was also purchased by the project for inversion modelling of ECA data.

5.3.3 Crop modelling using APSIM

The APSIM work in this project was broken into three phases – (i) *parameterisation, calibration and testing* (establishing model credibility in this environment); (ii) *model improvement*; followed by (iii) *scenario analysis* (asking the “what if?” questions of the validated model). Full detail is given in Annex Report 5.

We established field experiments in farmers’ fields within the selected sites to understand the salt-soil-water-plant relationships at the crop root zone and its interaction with the groundwater table and the polder level water management strategies. Data collected from the field experiments were used to parameterize, calibrate and validate the APSIM model, and the model outputs (particularly drainage of water vertically past the crop root zone) are used as inputs for other project components (polder salt and water balance model described in Section 5.2.4 and surface water, groundwater and salinity interaction modelling described in Section 5.2.5). We used soil moisture, salt and nutrient monitoring equipment developed under other ACIAR projects (FSC/2013/002) to obtain the required data.

Also, in order to maximise the flexibility in applying the APSIM model under saline soil conditions, we have developed a novel technique for simulating surface-soil salt build-up and the associated Rabi crop response. In this technique, we simply provide the model with daily water table depth and salinity data, daily climate, and daily salinity dynamics of the water sources being used for irrigation. This is in contrast with previous cropping systems salinity studies where the crop response is driven by soil salinity that has been input directly into the model. We have developed a technique to actually simulate soil salinity build-up, in response to the other previously mentioned environmental variables. This has positioned us well to explore the performance of farmer management adaptations under both historical and future climate scenarios, as future climate modelling exercises can supply us with changes in river water salinity, water tables height and salinity etc., but cannot give us soil salinity dynamics. For all future applications in saline region crop modelling – we don’t need to be given soil salinity dynamics – we can now simulate them. This has been a major step forward for cropping systems modelling in saline zones in general – not just for this project.

Apart from regular APSIM crops which we have calibrated and tested, this project has also developed and tested two brand new modules. These are APSIM-Grasspea and APSIM-Lentil. The development of new models in APSIM requires high-quality experimental data over different sowing dates, different fertiliser amounts, and ideally a couple of different locations to check geographical response. The broad geographical nature of this project has provided these, but also additional non-project datasets were sought and collated from drastically different environments in India.

5.4 Socio-economic analysis and integration

There are two elements to the socio-economic evaluation of the promising technologies and crops.

Firstly, in both Bangladesh and West Bengal, gross margin analysis identifies the farm level financial prospects. Such analyses are in any event usually considered in these organisations as a necessary feature of evaluating new technologies and crops. We also conducted preference analysis for selecting preferred varieties or technologies by the farmers, and evaluation of impact of new technologies on farmers economic conditions and livelihood. These analyses were conducted by economists in the project team.

The second element was planned for West Bengal only as the sister SIAGI project (LWR/2014/072) was not having any activities there unlike Bangladesh. In Bangladesh, SIAGI project carried out comprehensive socio-economic activities in both polders. We worked with them but did not undertake any socio-economic work ourselves (apart from the gross margin analysis and preference analysis mentioned above). LWR/2014/072 undertook following activities in Bangladesh:

1. Determine household typologies and characterise livelihoods based on access to resources, institutional arrangements, constraints and opportunities, and land tenure
2. Undertake value chain analyses (characterising input-output links and backward-forward relationships)
3. Determine current (real and perceived) issues of social inclusivity and equity in communities
4. Understand the visions, aspirations, livelihood potentials and choices of farmers (male, female and youth) and landless, both individually and communally
5. Undertake policy analysis and mapping of the institutional landscape
6. Conduct environmental and climatic characterisation of study areas
7. Document good practices in achieving social inclusion, resource mobilisation and technology adoption (NGO, GO, private sector)
8. Conduct integrated risk assessment based on results from activities above (1-7).
9. Identify opportunities to manage risk and promote social inclusivity and equity under different agricultural development scenarios using scenario and trade-off analysis
10. Design and implement stakeholder engagement and capacity building process
11. Develop and promote principles underpinning equitable value chains (including Public-Private-Partnerships to support socially excluded groups)
12. Refine and disseminate best practice guidelines for NGOs and CBO
13. Document key research approaches and develop accessible tools for other researchers (e.g. other ACIAR projects) to adopt and expand into this new and growing research area
14. Engage policy makers and decision makers to improve the effectiveness of existing and future policies targeting social inclusion and equity of agricultural intensification
15. Synthesise and communicate results.

SIAGI project already completed their activities and submitted the final report. The detail methodology used and results can be found elsewhere in the project final report.

In West Bengal, due to budget constraints, we were not able to carry out all the activities listed above. However, we carried our substantial socio-economic activities (including baseline and end-line survey) as listed below following the survey instruments and guidelines developed under the SIAGI project.

1. Socio-economic status of the farmers from baseline survey
2. Existing cropping systems and farmers practices
3. Achievement towards evolving new cropping systems - experimental vs farmers practice
4. Economics and financial feasibility of solar powered drip irrigation system (SPDIS) and Low-cost drip irrigation system (LCDIS)
5. Profitability, energetics and GHGs emission estimation from rice-based cropping systems
6. Impact of project interventions on cultivation practices
7. Impact of project interventions on expenditures and return on cultivation practices
8. Farmers' perception on different project interventions
9. New technical knowledge and likely change in cultivation practices
10. Critical constraints, issues and possible way forward towards adoption of new practices
11. Determinants of cropping system intensification
12. Women participation in agricultural operation
13. Return to investment on research project

The method used in doing these analyses are given in Annex Reports 12 (page 61-77) and 13 (p 47-83) and in Mandal *et al.* (2020) and Ray *et al.* (2019; 2020).

In Bangladesh, we also worked closely with SIAGI project to organize male and female farmers, share-cropper and landless labourers to manage water in the canal. We facilitated formation of the Water and Silt Management Committee (WSMC) in both Amtali and Dacope. Through the committee at Amtali we supported re-excavation of a 2-km canal for bringing water from the Payra river and to store water for irrigation in the dry season. The excavation done in consultation and participation of the local leadership and administration. In Dacope, the committee has been managing the regulator to keep fresh water in the canal which was used for irrigation. We have had consultation meeting with the farmers in every season. We also organized Farmers Field Day at the end of each cropping season to communicate and disseminate the achievements of the project. In Gosaba, TSRD played a pivotal role in community engagement and dissemination. They also facilitated organization of farmers training in the field, at CSSRI and BCKV.

6 Achievements against activities and outputs/milestones

A summary of the achievements is provided below for each objective and activity.

Objective 1: Develop a sub-regional scale understanding of the surface water and groundwater resources, recharge/discharge mechanisms and trends in the case study polders.

no.	activity	outputs/ milestones	completion date	comments
1.1	Compile and review existing literature and data on soil, surface water, groundwater, salinity, and climate change impacts, changes in river flow, and increase in population and their impacts on the coastal zone.	Report on existing water resources, salinity, conceptual understanding of water flow dynamics, SW-GW flow and salinity interactions, and hydrogeological settings in Bangladesh.	Jun 2017	Initiation of the work was delayed due to delay in signing the agreement. However, for objective 1 and 2 while some intermediate activities were delayed, the final product was not. We have mostly covered for the initial lost time. Please see Annex Report 1 and 3. There are also some detail in Annex Report 10-13. In addition to the Annex Reports, we published two papers (Hossain *et al.*, 2019; Yu *et al.*, 2019) in the Journal of the Indian Society of Coastal Agricultural Research (ISCAR). An overview on the climate, hydrology, land use, and vulnerability was also published in the ISCAR journal (Mainuddin *et al.*, 2019a).
1.2	Conduct water balance analyses of the selected polders based on the collected (secondary) data and the outputs of the regional water balance analyses done under the Bangladesh integrated water resources assessment project.	A dynamic water balance model showing different components. Report on surface water and groundwater resources, recharge/discharge mechanisms and trends in the case study polders.	Oct 2019	Initial model set up was done in October 2016. We kept updating the model until October 2019. The model has been published in Journal of Hydrology (Mainuddin *et al.*, 2020) and in the ISCAR journal (Mainuddin *et al.*, 2019b). Two papers on scenarios are under review in the journals Climatic Change (Mainuddin *et al.*, submitted) and Ocean and Coastal Management (Mainuddin and Kirby, submitted). Please see Annex Report 3. Field level water balance done in Gosaba is described in Annex Report 12.

Objective 2: Develop a detailed understanding of the salt and water dynamics of the selected polders and explore the opportunities for pre-monsoon and post-monsoon groundwater abstraction regimes that improve groundwater quality and availability during the dry season.

no.	activity	outputs/ milestones	completion date	comments

2.1	Prepare detailed maps of the selected polders which include roads and channels, embankments, location of water structures, soil types and current cropping practices, and the subdivision of the polder based on hydrology, irrigation and drainage channels, groundwater surfaces, DEM, etc.	Maps based on hydrology, irrigation and drainage channels, topography. Available to all project partners.	Jun 2017	We have prepared some maps which are given in the inception report submitted with the annual report of 2016. The rest are done after June 2016 which were presented in the annual report of 2017. The final report on this objective (Annex Report 4) includes the prepared maps.
2.2	Review existing BWDB polder level flood, irrigation and drainage management regimes and operation procedures and consult with the community about the polder operation and management.	Report on sustainable field and polder irrigation and drainage management plan.	Nov 2016	In both sites, we not only prepared a different irrigation and drainage management plan, we have implemented this with the help of the community leaders. For the last four years, farmers with the help of our local partners constructed bund to store water in the canal. In 2016-17, there was very few fields under any crops in the dry season in this area except our experiments. But since 2017-18, due to availability of water in the canal, many farmers cultivated many crops in this area including rice. The details on the number of farmers and area of cultivation are given in the main section of the report.
2.3	Identify and set up field monitoring points at strategic locations to gather data on water levels, salinity and flows.	Monitoring networks installed and database available of all equipment and data recorded.	Dec 2016	We have done this in all 3 sites. However, the instrument and piezometers could not be installed until the end of the monsoon season in December 2016. There was water in the fields until the end of November 2016.
2.4	Develop analytical and modelling procedures to quantify and simulate salt and water dynamics and fluxes, and for linking this with the outputs of the sub-regional water balance analyses and the inputs and outputs of the APSIM simulations.	The output of this sub-activity is the better calibrated model the results of which is part of the report showing the results of the activity 2.5.	Jun 2018	We already identified the modelling procedures, developed the model and identified and implemented (through exchange of data and output) linkages of this model with the polder water balance model and the APSIM model. Final APSIM outputs have been used in the model for calibration, validation and scenarios analysis.

2.5	Apply the model(s)/procedure(s) in Bangladesh to evaluate the water and salinity dynamics for different polder water management conditions and cropping systems and management.	A comprehensive report produced at the end of the project which includes all aspects of the objective 2.	Jun 2020	Final report on the activities of this objective is given as Annex Report 4. Summary results are included in the Results and Discussion section.

PC = partner country, A = Australia

Objective 3: Develop detailed understanding of crop production, water balance and salinity responses to various improved polder-level water management strategies and cropping system and management options.

no.	activity	outputs/ milestones	completion date	comments
3.1	Extend the capability of APSIM to dynamically simulate soil and plant salt interactions in the root zone for Rabi crops such as wheat, maize, etc. and further validate the APSIM-ORYZA salinity routines developed under the LWR/2008/19 project for rice.	Official APSIM model enhanced for salinity response of Rabi crops Report on capability of salinity algorithm.	Jun 2020	For the APSIM model, the initial plan was to use the 2015-16 season field experiments data for calibration and 2016-17 data for validation of the model. But as explained earlier, we were not able to set up experiments in the Rabi season of 2015-16. The Rabi season experiments were stated in 2016-17 season. This delay has affected the final validation of the APSIM model which was done using the data of the 2017-18 season.
3.2	Establish a data collection protocol for the field experiments (set up under objective 4) to understand salinity dynamics in the crop root zone and soil-water-salt-plant interactions. The data will be used to parameterise the APSIM model, and subsequent calibration and validation.	A report showing the detail of APSIM model setup, calibration and validation.	Dec 2017	We have established data collection protocol which are circulated to the partners. This was reported during the annual report of 2016 and 2017. General data collection protocol was followed by experimentalists; however some experiments are collecting more detailed and regular data than others.

3.3	Define scenarios for testing in model simulations and on-farm through farmer workshops and apply APSIM to evaluate crop and water management options for land and water productivity and ability to mitigate root zone salinity.	Report on the process of scenario development and scenarios chosen.	Jun 2020	Scenario analysis using the model was completed and described in Annex Report 5. The key results are given in the Results and Discussion section of the report.

Objective 4: Test suitable cropping system x management options and water and salt management strategies (developed in 2 and 3) through field evaluation and co-learning with farmers.

no.	activity	outputs/ milestones	completion date	comments
4.1	Select sites for cropping trials in farmers' fields within the selected polders and characterise soil salinity and other soil parameters' variability and water resource availability.	A report on EM methodology and benchmark data of soil salinity for the sites.	Jun 2020	Three different polders were selected. These are Amtali in Borguna, Dacope in Khulna and Gosaba Island in West Bengal. We prepared and submitted a report in July 2017 including the analysis and data collected from the field through survey in 2017. We revised the methodology based on survey in 2018 and 2019 and refined the methodology. The Annex report 6 shows the detail methodology developed and used.
4.2	Identify and select possible cropping options based on farmers' preferences, results of activities under objectives 1-3, regional researcher and extension personnel opinions, and activities of the sister projects, and set up on-farm experiments, farmer participatory trials and demonstrations.	Reports at the end of every season and the final report.	Jun 2020	This was our main activity in the field. We conducted series of experiments on introducing new varieties of Aman/Kharif rice, introduction of Aus and Boro rice (in Bangladesh only), introducing new technologies of growing crops such as growing vegetables with Aman rice, zero tillage cultivation of potato and garlic, use of mulch, different ways of establishing crops, different types of irrigation and drainage, testing of cropping patterns, soil amelioration and use of bio-fertilizer, relay cropping, etc. The summary results are given in the Results and Discussion section of this report. The detail are given in the Annex Reports 7-14. There are also 17 papers published in the special issue of the ISCAR journal. So we produced 29 journal papers (25 published, 4 are in journal review) and 30 conference papers. Many journal papers are in preparations.

4.3	Conduct socio-economic analysis of the possible cropping options for intensification. The potential for private sector involvement in input and market chains will also be considered under this sub-objective	Report on the economic benefit of cropping options suitable for sustainable intensification.	Jun 2020	We conducted socio-economic analysis every year. A summary is given in this report. The details are given in Annex Reports 7-13. In addition 3 papers (Mandal *et al.*, 2020; Ray *et al.*, 2019; 2020) are published exclusively on socio-economic issues.
4.4	Evaluate the different cropping options by linking the field experimental results with the results of objectives 1 and 2 and 3, and cross-correlating with the output of the sister projects. Select feasible and sustainable cropping options for intensification under a range of polder water management options for the selected polders.	Report	Jun 2020	We linked the polder salt and water balance model with the APSIM model which uses data from the field experiment results. Using the salt and water balance model we ran a series of cropping options for the polders which are described in Mainuddin *et al.* (submitted) and Mainuddin and Kirby (submitted). APSIM model was also used to run different cropping scenarios which are described in Annex Report 5. We also evaluated cropping options through field trails and socio-economic analysis. We found several suitable cropping options for intensifications which are described in the results and discussion section of the report. The details are given in the Annex Reports (7-14). There are also a few journal papers (Mandal *et al.*, 2020; Ray *et al.*, 2019; 2020; Saha *et al.*, 2019; Sarker *et al.*, 2019), specifically on the evaluation of the cropping options.
4.5	A FINAL SYNTHESIS REPORT INTEGRATING THE OUTPUT OF ALL OBJECTIVES WILL ALSO BE PRODUCED.	Report	Jun 2020	This report which includes 14 Annex Reports.

7 Key results and discussion

7.1 Land use, climate, water resource and salinity trend

7.1.1 Land Use

In Bangladesh, within the polders we selected several locations for setting up our experiments. The most dominant cropping pattern in the selected area and in general within the polders was Kharif-II rice-fallow-fallow. Kharif-II rice is the main crop grown in the area and this is mostly for subsistence. In Amtali, in the Kharif-I or early wet season, few farmers grow local varieties of Aus rice if there is available fresh water nearby. In the Rabi season, there are some vegetables cultivated only around the household. Rabi season cultivation including Kharif-I rice covered only about 10-15% of the cultivable area at Amtali. In Dacope, after harvesting Kharif-II rice, the land was used for grazing cattle in the Rabi and Kharif-I seasons. There was no crop. So, the cropping intensity in the area was around 100% in Dacope and around 110% in Amtali as most areas remained fallow in the Rabi and Kharif-I season. That provided the opportunity to increase cropping intensity in the area through improving cultural practice and cultivation of Rabi and Kharif-I crops. There was also opportunity to improve the productivity of the Kharif-II rice by introducing recent varieties suitable for cultivation in these areas. A detail description on the evaluation of the land use, cropping and farming systems, and farmers' perception on risks of farming, and climate and environmental change for the selected sites at the commencement of the project in 2016 is given in Annex Reports 1 (p 12-20) and 10 (p 5-23).

In Gosaba Island of West Bengal, the multi-dated Sentinel – 2 data were classified by supervised classification to generate thematic map for determination of the spatiotemporal variability of cropped and fallow land during the period of November 2017 to March 2018. The land use map of 11 November 2017 (Figure 7.1) showed a large proportion of land under crop vegetation. This coincides with growing period of Kharif-II rice. The fallow land during this period was very less. In the classified image of 15 January 2018 and 30 January 2018, we found small part of crop land representing the grass pea grown while the fallow land (fallow-1 and fallow-2 in Figure 7.1; fallow-1 is dry land and fallow-2 are wet land) covered major part of the study area. The classified image of 14 February 2018 showed some patches of wetland which were subsequently covered by Boro rice classified as crop-2 in the classified image of 1 March 2018 and 21 March 2018. This was also supported by ground truth observations. The crop-1 in these images might be predominantly green gram or other vegetable crops like chilli because grass pea was completely harvested. The periodical ground observations revealed five predominant cropping system viz. rice (Kharif-II) – fallow, rice – fallow – Boro rice, rice – grass pea – fallow, rice – fallow – chilli, rice – fallow – green gram in the area. The area under Boro rice cultivation in the villages was very low, varying from 1 to 6% of total area of the respective villages. The area coverage under water bodies that include ponds, canals, khals and bheries (used for brackish water fish cultivation) varied from 4 to 11% of the lands. More detail can be found at Ghosh *et al.* (2019) and in Annex Report 2.

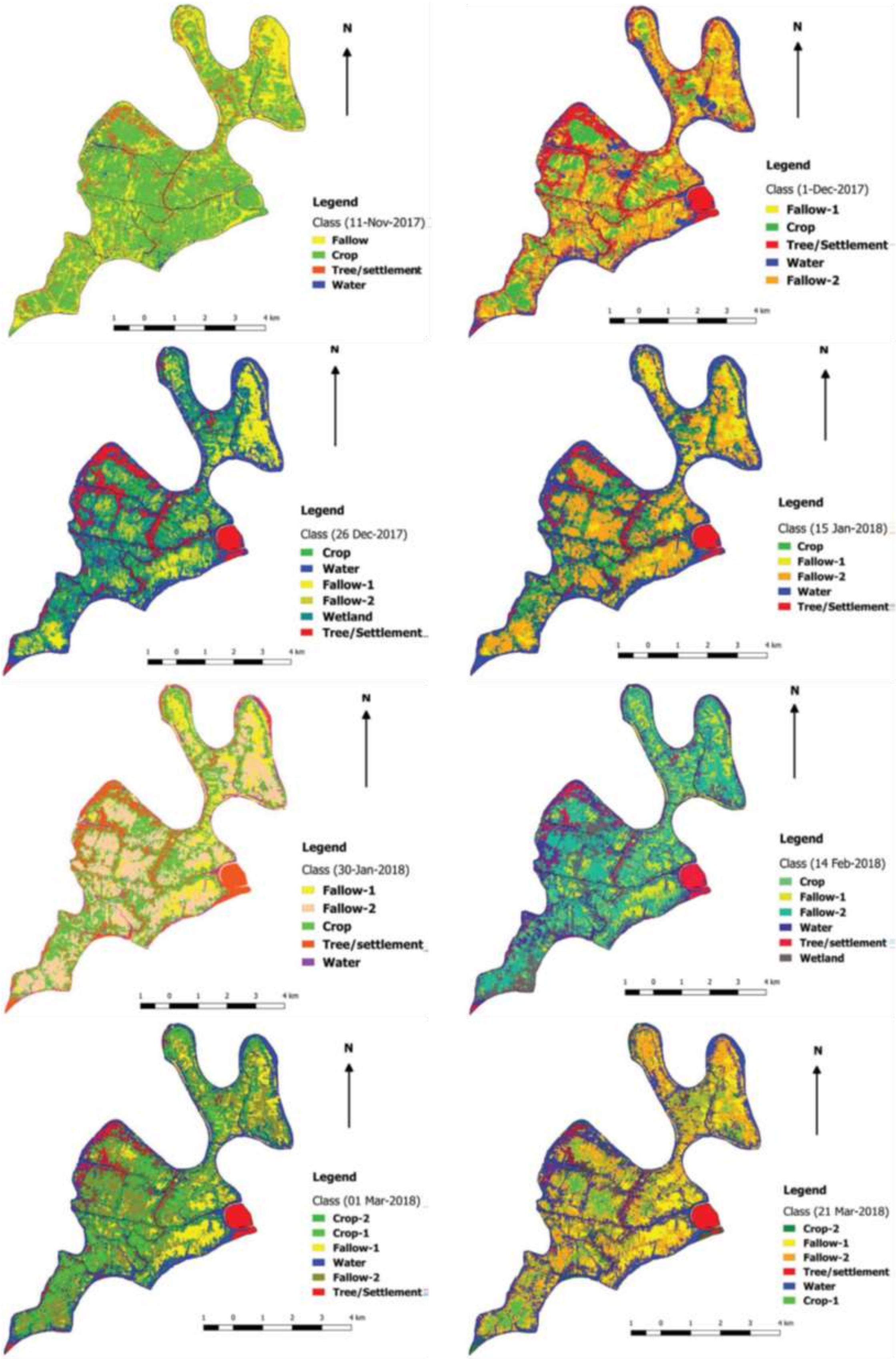

Figure 7.1 Land use map of Gosaba Island between November 2017 and March 2018

7.1.2 Climate

Basic climatic conditions of the six stations are summarised in Table 7.1. For all the stations together, the annual mean daily maximum and minimum temperatures were around 30.8 °C and 22.0 °C, respectively, with small coefficients of variation, indicating similar warm weather across the region.

Table 7.1 Basic temperature and rainfall conditions in the coastal zone

Meteorological station		Canning	Khulna	Mongla	Barishal	Patuakhali	Khepupara
Study Periods		1966-2017	1974-2017	1991-2017	1949-2017	1973-2017	1974-2017
Annual mean daily maximum temperature (°C)	Mean	30.9	31.3	31.1	30.5	30.7	30.5
	CV %	1.08	1.44	1.13	1.38	1.82	1.73
Annual mean daily minimum temperature (°C)	Mean	21.9	21.9	22.5	21.4	22	22.2
	CV %	2.16	2.26	1.56	2.09	1.56	1.28
Annual total rainfall (mm)	Mean	1833	1853	1962	2112	2643	2783
	CV %	19.08	17.6	17.29	19.74	17.58	14.22
Annual numbers of rainy days (count)	Mean	100	112	120	122	123	123
	CV %	11.74	12.41	6.78	21.96	12.57	10.58

The annual precipitation was found varied spatially, which decreasing from more than 2,000 mm in the east (Khepupara and Patuakhali) to 1,800 mm in the west (Canning). Similar spatial variation was found in the number of rainy days, changing from 123 days in the east to 100 days in the west. This implies that the eastern part of the coastal region generally experiences longer and wetter rainy periods. In addition, lower latitudes were found to have larger amounts of total precipitation, as seen by comparing Khepupara with Patuakhali, and Mongla with Khulna. Overall, the precipitation generally increased from west to east, and from north to south (1,853 mm in Khulna and 2,783 mm in Khepupara) within the study area. The annual rainfall differed in different five-year periods, with the period 2008-2012 being the driest at all stations, with a reduction of about 20% compared to other three periods (Please see Annex Report 1 and Yu *et al.* (2019) for more detail). The reduction is attributed to reductions of extreme rainfall events during the kharif season.

About 82-83% of the average annual rainfall occurs in the wet season during the month of May to October (Figure 7.2). Average rainfall during December to February, which is the Rabi season, is about only 5% of the total rainfall.

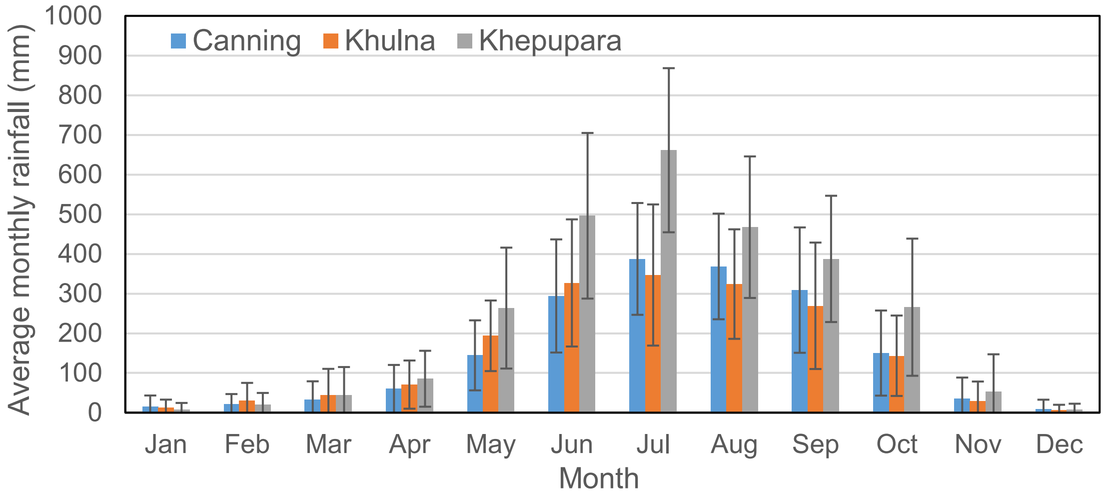

Figure 7.2 Monthly average rainfall for the 3 stations near the selected sites. The error bar shows the standard deviation.

During the Rabi season, it is evident that some sudden heavy rainfalls have occasionally taken place in recent years which affected our experiments in the field. Figure 7.3 shows 10-day accumulated quantity and timing of sudden heavy rainfall at all observatories between December and February over the last two decades. The 10-day accumulated precipitation was generally less than 50 mm in December but could reach approximately 100 mm in January and February. Occurrences of sudden heavy rainfall increased in the early January during the decade of 2008-2017, compared to the previous decade. In addition to quantity and timing of sudden rainfalls, it was also found that despite being the driest location, Canning may receive some of the heaviest sudden rainfall during the Rabi season, such as 30 mm in the mid December and early January, 75 mm in the late January, 90 mm in the late February. Notwithstanding the heavier sudden rainfall, Canning also experienced longer drought periods than the other stations. The median drought periods (consecutive dry days) lasted approximately 80 days, with the 75th quantile of 100 days, and a maximum value of 150 days in Canning.

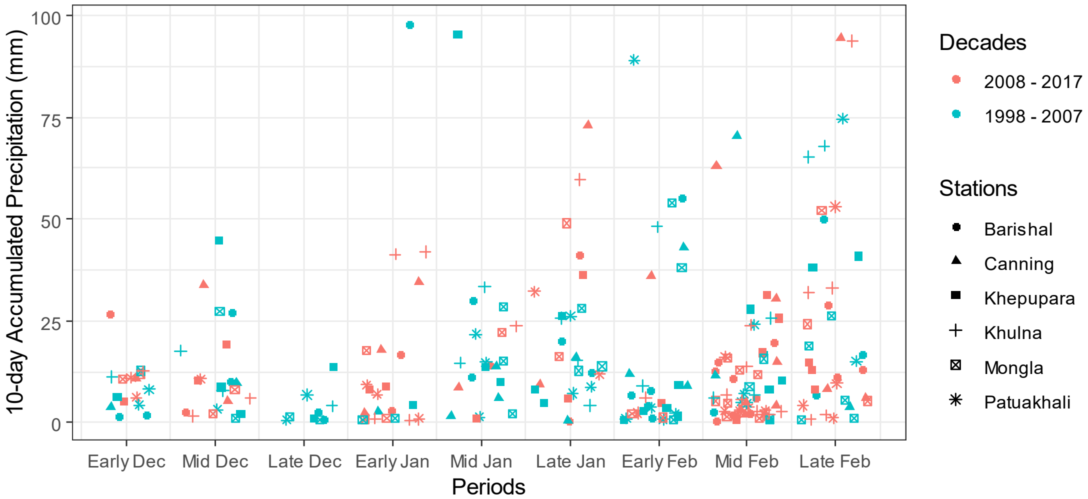

Figure 7.3 Sudden rainfall events during the *rabi* seasons over the last two decades

The annual trends of extreme indices of temperature and rainfall are shown in Table 7.2. The highlighted numbers are statistically significant trends ($p<0.05$). Annual average daily maximum temperature increased at all stations, with average rates of 0.01 °C year^{-1} at higher latitudes (Khulna and Barishal) and 0.028 °C year^{-1} or more at lower latitudes (Mongla, Patuakhali and Khepupara). This finding is consistent with that of other studies (Islam and Neelim, 2010; Mondal *et al.*, 2013; Shahid *et al.*, 2012). The trend was statistically significant at all stations except Canning. Though globally there was increasing trend in air temperature, there was no change in air temperature observed at Canning may be because there was also a decreasing trend of sunshine hour in the region. That might be responsible for compensation of the increasing behaviour of air temperature (Mandal *et al.*, 2019). Stations at lower latitudes in the east, Khepupara and Patuakhali, have longer summer seasons (SU25), increasing at a rate of 0.35 days year^{-1}, and their ranges of daily temperature (DTR) are also rising at 0.03 °C year^{-1}, indicating a larger temperature difference over a day.

In contrast to the trends of increasing temperature, trends in precipitation are less uniform and generally less significant statistically in the study area. At Khepupara, the maximum 5-day accumulated precipitation (RX5DAY) and total precipitation (PRCPtot) both show increasing trends with statistical significance. However, there were no similar long-term trends at other places in the coastal zone. Several other studies found increasing rainfall (Hossain *et al.*, 2014; Mondal *et al.*, 2013; Mukerjee, 2017; Mukhopadhyay *et al.*, 2016; Rahman *et al.*, 2017; Rathore *et al.*, 2013; Shahid and Khairulmaini, 2009; Shahid, 2010; 2011), but some found that there was no significant trend in rainfall (Islam and Neelim, 2010;

Shahid *et al.*, 2014) or that there was a decrease in rainfall accompanied by shift in the timing of rainfall (Hossain *et al.*, 2017). However, many of the studies referred to, while encompassing the coastal zone, covered a wider region such as the whole of Bangladesh or West Bengal. Overall, both annual maximum precipitation and daily temperature generally increased over the years in the coastal zone, associated with longer durations of consecutive wet period.

Table 7.2 Annual trends of the extreme indices of temperature and rainfall in coastal zones

		Canning	Khulna	Mongla	Barishal	Patuakhali	Khepupara
Temperature Indices	TMAXmean	0.01	**0.01**	**0.03**	**0.01**	**0.04**	**0.04**
	TMINmean	0.01	0	0	0	0.01	0.01
	SU25	**-0.21**	-0.05	0.04	0.00	**0.34**	**0.35**
	DTR	0.00	0.01	0.03	**0.01**	**0.03**	**0.03**
Rainfall Indices	RX1DAY	0.19	-0.22	0.09	0.22	-0.79	0.56
	RX5DAY	-0.04	0.55	3.02	0.38	-0.25	3.10
	CDD	-0.31	**0.58**	1.15	-0.11	0.62	0.42
	CWD	-0.03	0.09	0.22	**-0.42**	0.08	0.10
	PRCPtot	-0.88	2.01	10.12	-0.96	-7.59	**9.65**

7.1.3 Characterisation of water resources

Surface water and salinity

Generally, the coastal river water levels and their salinity fluctuate due to tidal conditions and vary during different seasons. Polder 43 in Amtali is surrounded by Buriswar and Takhali River at the west and Dhankhali Don and Nilganj river in the south east side. There are two other rivers; Andharmanik and Payra (Figure 5.2). The water level at the Andharmanik river changes between -0.5 and 2.5 m, while the highest water level in the west of the polder (at Buriswar river) is about 2 m (please see Annex report 1, p 30 – 31; Hossain *et al.* (2019)).

Salinity of the Andharmanik river was measured once in a week (Figure 7.4). The river water salinity increased after November and reached its peak (about 25 dS m^{-1}) in May. After the onset of rainfall in June the salinity level of river water significantly decreased and the river water became fresh from July to November. The canal water was trapped before December with an average salinity about 1.3 dS m^{-1}. Its salinity increased in a slow rate and reached up to 2.7 dS m^{-1} in May due to evaporation (Figure 7.4). This limit was permissible for crop cultivation. The field water salinity varied corresponding to canal water salinity and remained at a low level. The water therefore can be used for crops cultivation in Amtali region. At present the main irrigation canal comes from the nearby river that is saline, but we re-excavated a canal from the non-saline Payra River on the west side to bring major amounts of good quality water for irrigation into the area.

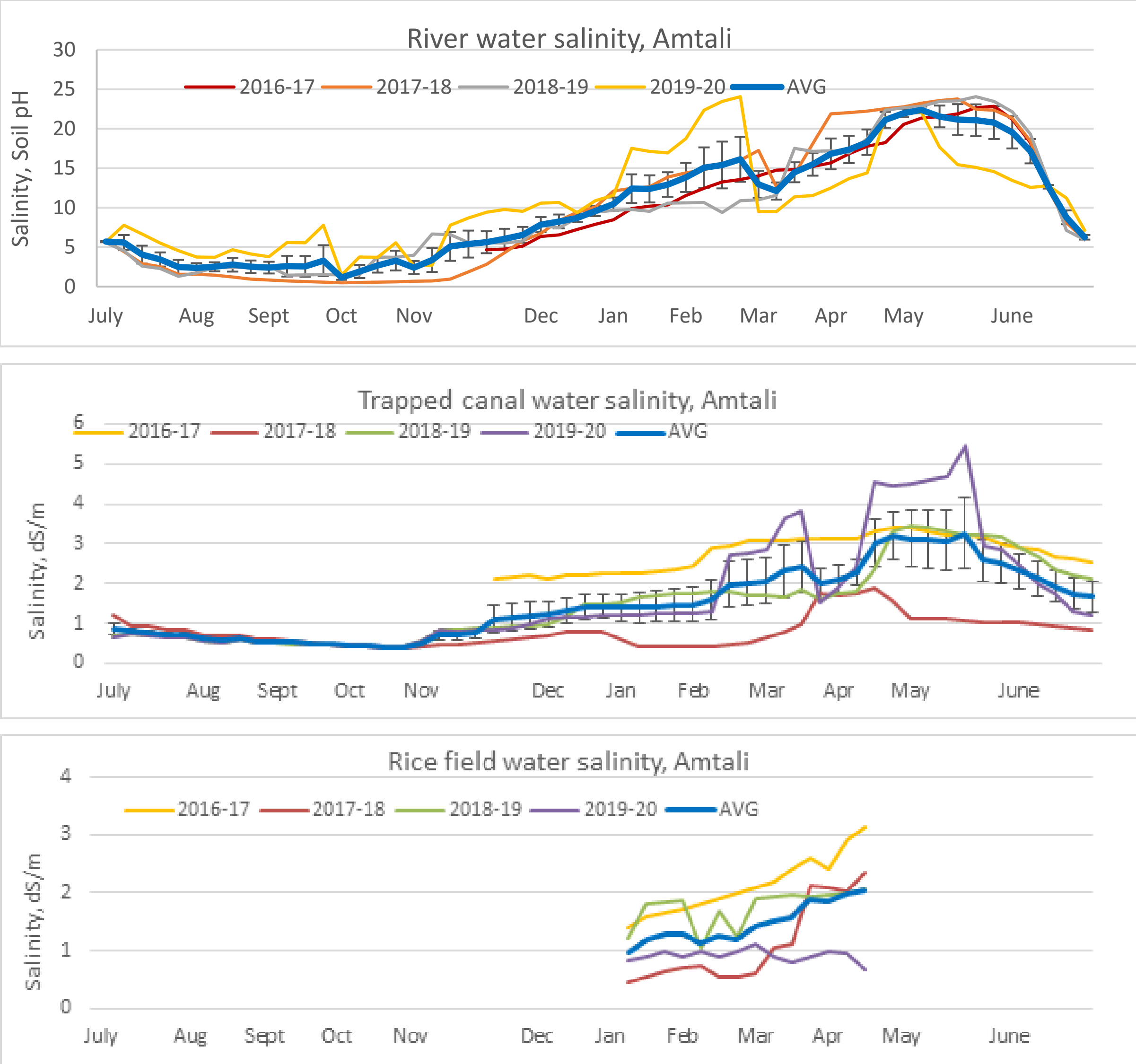

Figure 7.4 Salinity of surface water (river water, canal water and rice field water) at Amtali during 2016 – 2019

In Dacope, the water level in the surrounding river increases from -2 m (a.m.s.l) at low tide to 3 m at high tide. Salinity of the river Jabjapia, Dacope, was measured once in a week at three selected places near the experimental area (Figure 5.2). Based on the four years monitoring data (2016–2020), averaged salinity of the river water remained below 1 dS m^{-1} from August to December, as shown in Figure 7.5 and is therefore considered highly suitable (< 4 dS m^{-1}) for irrigation crops up to end of December. After that the river water salinity gradually increased and it reached up to 24 dS m^{-1} at the end of Rabi cropping season. There is no possibility to directly use river water for crop cultivation after December. The canal water was therefore trapped within December at the period of high tide making canal water salinity of approximately 1 dS m^{-1} (Figure 7.5). Salinity of trapped canal water increased in a slow rate and reached up to 3 dS m^{-1} in May due to evaporation and influence of groundwater flow. This limit was also permissible for crop cultivation. The field water salinity varied corresponding to canal water salinity and successfully grown crops in Dacope region. After the onset of rainy season (i.e. in June) the river water salinity sharply went down and remained at a low level between July and December, and after that it started to increase following the same trend.

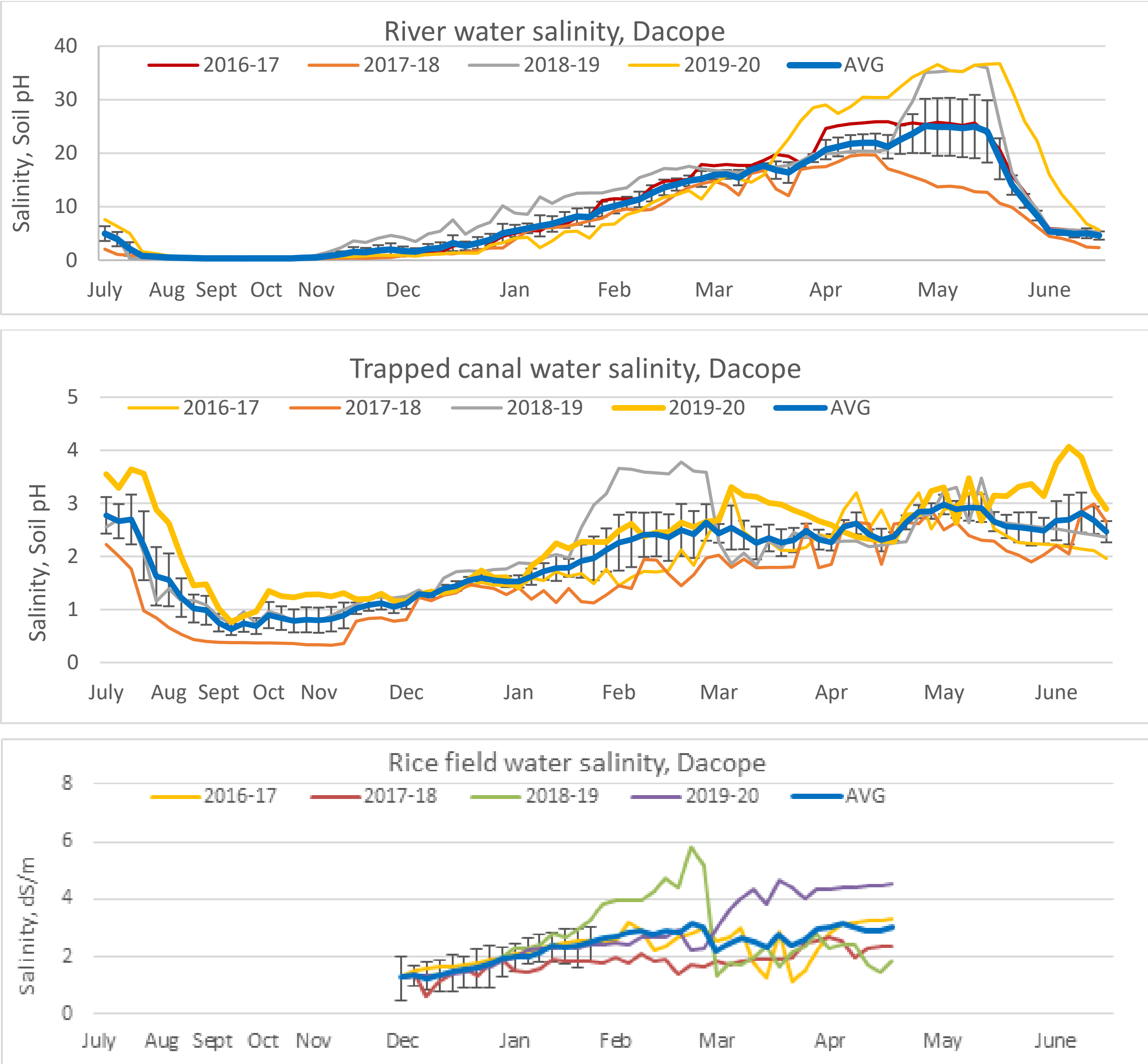

Figure 7.5 Salinity of surface water (river water, canal water and rice field water) at Dacope during 2016–2019

In both Amtali and Dacope, we surveyed the canal networks to determine their water storage potential and quality to estimate the area possible to cultivate different crops with the stored water in the Rabi season. All the canals inside the polder are categorized as good, poor and Bad (almost dead) canals. The canal which has width of 10 m and above and a depth not less than 1 m is called good canal. Basically this type of canals has a good amount of stored water for irrigation. Poor canal has a width of less than 10 m and stored comparatively less water than good canal during dry season. The bad canal may have good width but depth is very low. These canals remained almost dry to small storage which could not use for irrigation. Figure 7.6 shows the different types of canals for Amtali and Dacope.

Total 151 km long primary and secondary canals were surveyed in polder 43/1 at Amtali. Total stored volume of water was 7.415 Mm^{-3} in April. Among the surveyed canal 11.1 km canal was affected by salinity ranges from 1-2.2 dS m^{-1}. Poor maintenance and broken sluice gates are the main causes of saline water intrusion from the river water into the polder area. Water salinity in the remaining canals were found <1.0 dS m^{-1}. About 190, 101, 76 km good, poor and bad canals were recorded in polder 31 (Dacope). In the good canals, total stored water during April was estimated as 502 ha-m. Considering 30%, 50% and 100% excavation of poor and bad canals the water storage was increased to 660, 766 and 1030 ha-m respectively. Crops can be cultivated in large areas using the stored water in the canals (p xx, Annex Report 1, p 64-65, Annex Report 9).

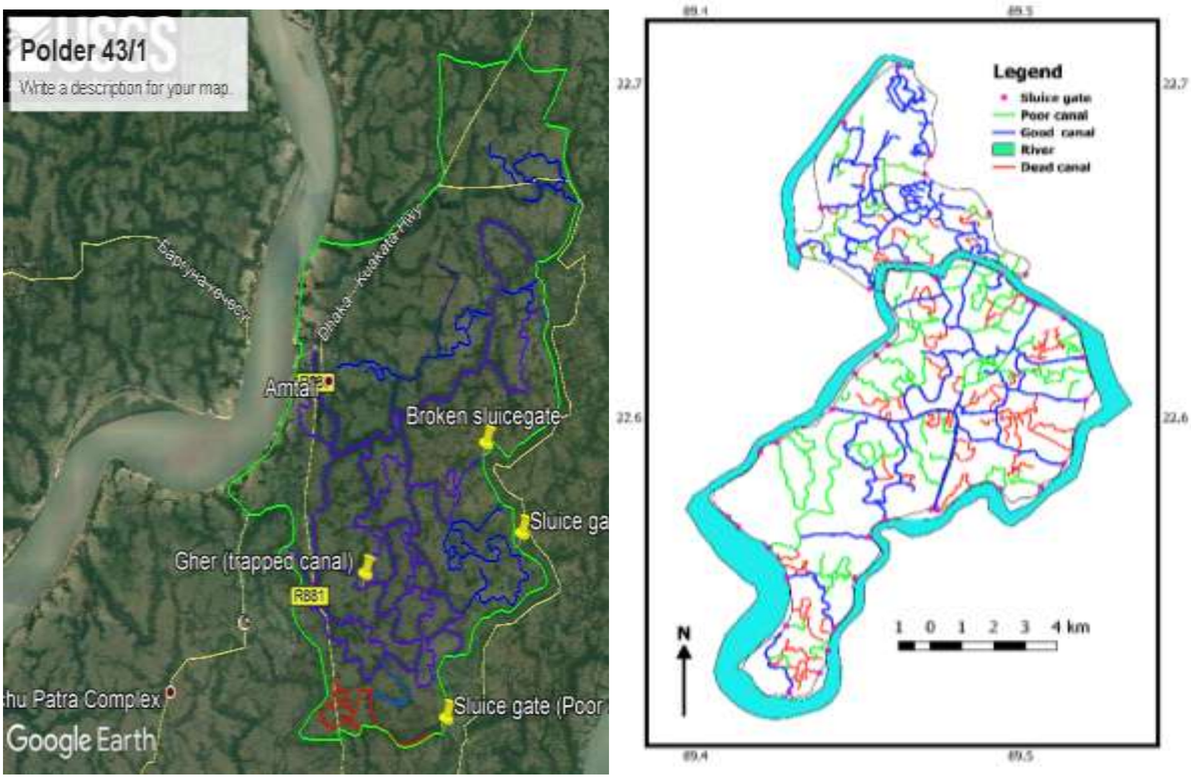

Figure 7.6 Different types of canals (good – blue, poor – green, and dead – red) inside polders at Amtali and Dacope

The water level in the rivers surrounding the Gosaba Island also fluctuates heavily due to tidal effect and water remain saline throughout the year (Figure 7.7). The salinity of the river water was highest during the month of May with maximum of 49.9 dS m^{-1} and minimum of 16.8 dS m^{-1} in the month of August. The average salinity of river water was 32.3 dS m^{-1} and remained saline throughout the year. The salinity of pond water was lowest (average 1.0 dS m^{-1}) among different sources of surface water (Figure 7.7). The pH of the surface water resources was also monitored during the project period. The pH of river water varied between 5.29–8.92, with average pH of 7.73. The pH of Nayanjuli (drainage channel) varied between 5.93-9.24 with average pH of 7.67. The average pH of the water collected from sluice gate was 7.65 with a variation between 6.05-8.79. The average pH of the drinking water sources such as tubewell and tap water was same (8.17) with a variation from 6.31-9.72. The pH of irrigation water (ponds) used by the farmers varied between 5.4-9.3 with average value of 7.64. More details are given in Annex Report 1 (p 36–44), and Annex Report 12 (p 39–42).

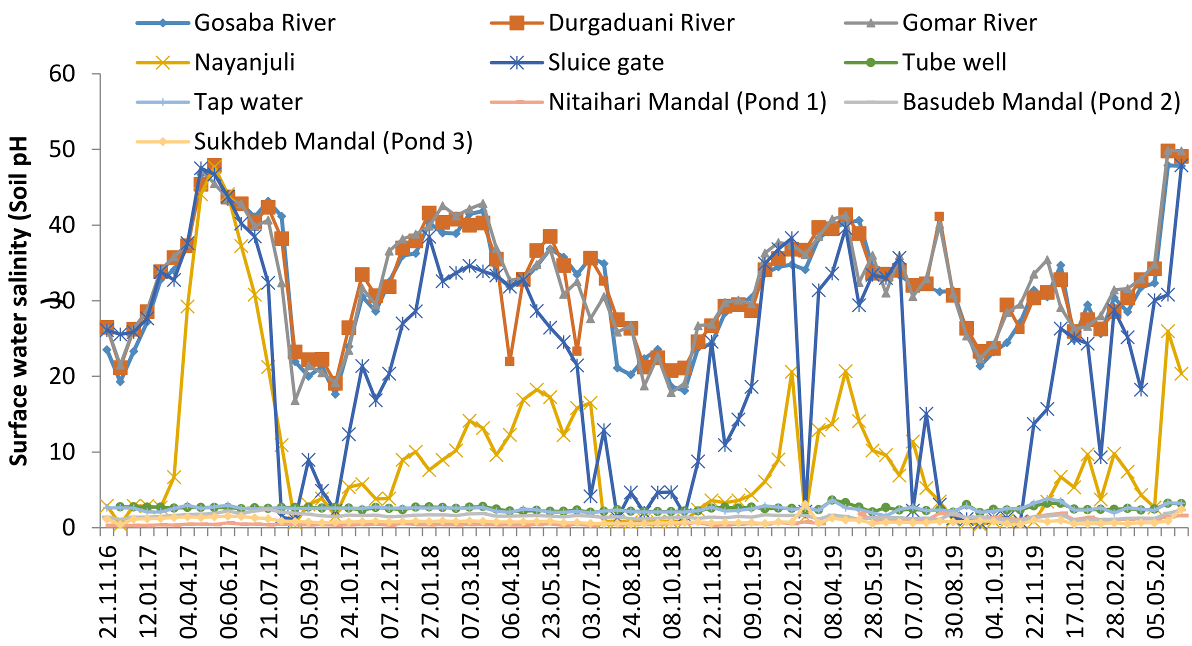

Figure 7.7 Salinity of surface water resources of Sonagaon village in the Gosaba Island during 2016–2020

Groundwater and salinity

Average groundwater level at Amtali varied between 0.8 to 1.8 m from the surface and groundwater salinity increased from 3.2 dS m^{-1} in November and December to 10.8 dS m^{-1} in May and June, implying that the groundwater in the upper aquifer in most cases is not suitable for irrigation (Figure 7.8). Averaged groundwater level and salinity in the experimental field in Dacope varied between 0.04–1.09 m below the field surface and 0.4–2.9 dS m^{-1} respectively (Figure 7.9). Groundwater salinity remained less than 4 dS m^{-1} round the year and was therefore considered suitable for irrigation. However, withdrawal of groundwater from the upper low saline aquifer is a risky for increasing salinity by intrusion of high saline river water during the dry season.

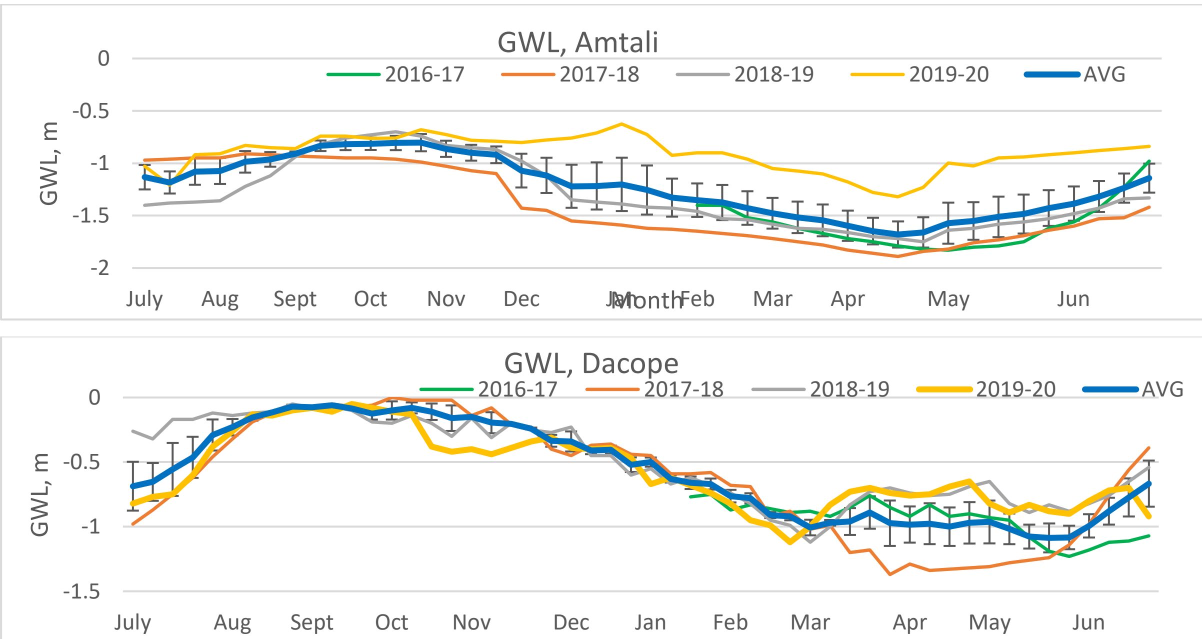

Figure 7.8 Groundwater level at Amtali and Dacope during 2016–2019.

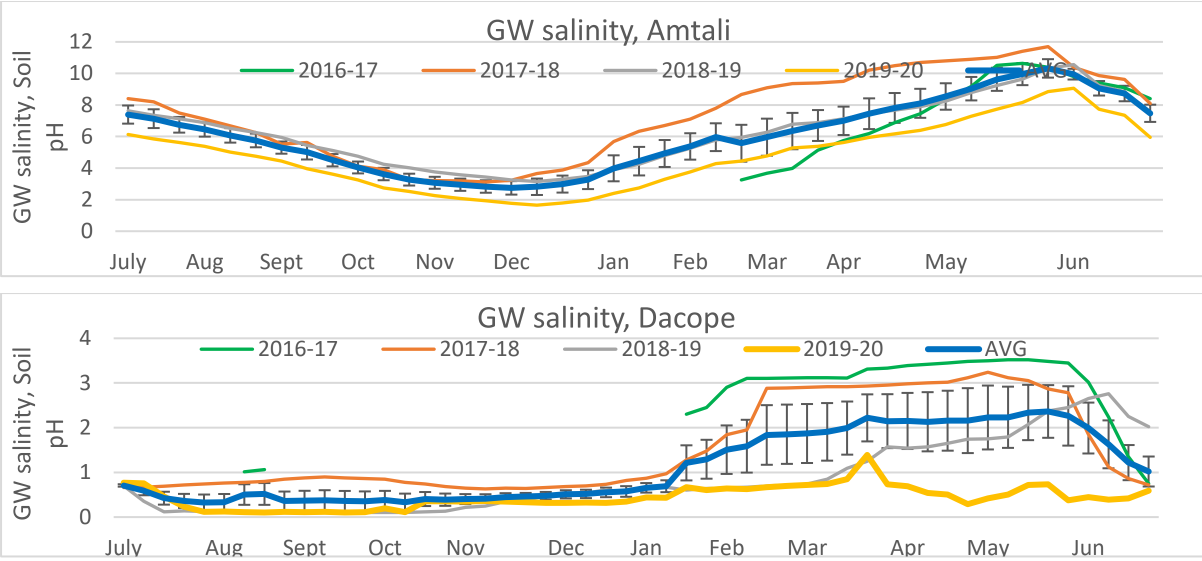

Figure 7.9 Groundwater salinity at Amtali and Dacope during 2016–2019.

Seasonal fluctuation of groundwater depth at Gasaba Island (CSSRI experiment site) is show in Figure 7.10. The depth of groundwater was closest to the surface (+0.05 to -0.54 m) in August and September during the monsoon and the farthest (-1.08 to 1.93 m) during Rabi season. However, the water table never went beyond 2.0 m throughout the year. It was observed that salinity of groundwater varies with the distance from sea (Figure 7.11). The piezometer (Pz1) installed nearest to the sea/river (Figure 5.3) showed highest salinity and the piezometer (Pz 5) that installed farthest from the sea/river had lowest water salinity throughout the study period. The mean salinity of the groundwater is 10.4 dS m^{-1} ranging from 1.2–38.7 dS m^{-1} observed during February 2017 to June 2020 (Figure 7.11). The pH of groundwater varied between 5.21–9.88, with average pH of 7.88. The depth to groundwater table and the salinity at BCKV site in Gosaba Island is given in Figures 7.12 and 7.13 (p 36 - 44, Annex Report 1; p 35-47, Annex Report 13).

A summary of surface water and groundwater condition in the studied polders are shown in Table 7.3.

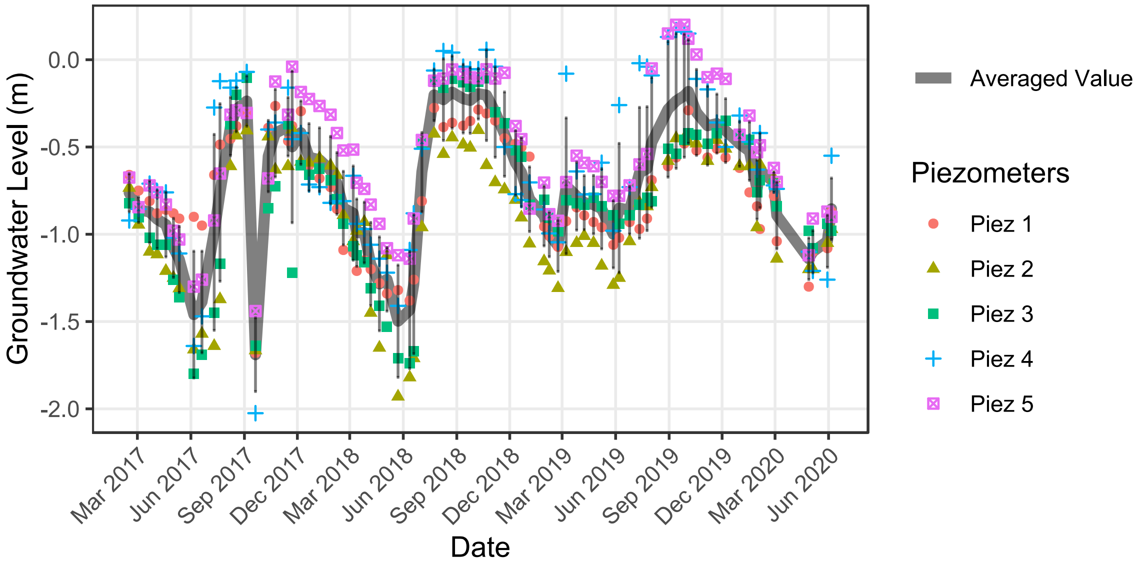

Figure 7.10 Depth of groundwater between 2017 and 2020 at Sonagaon, Gosaba Island

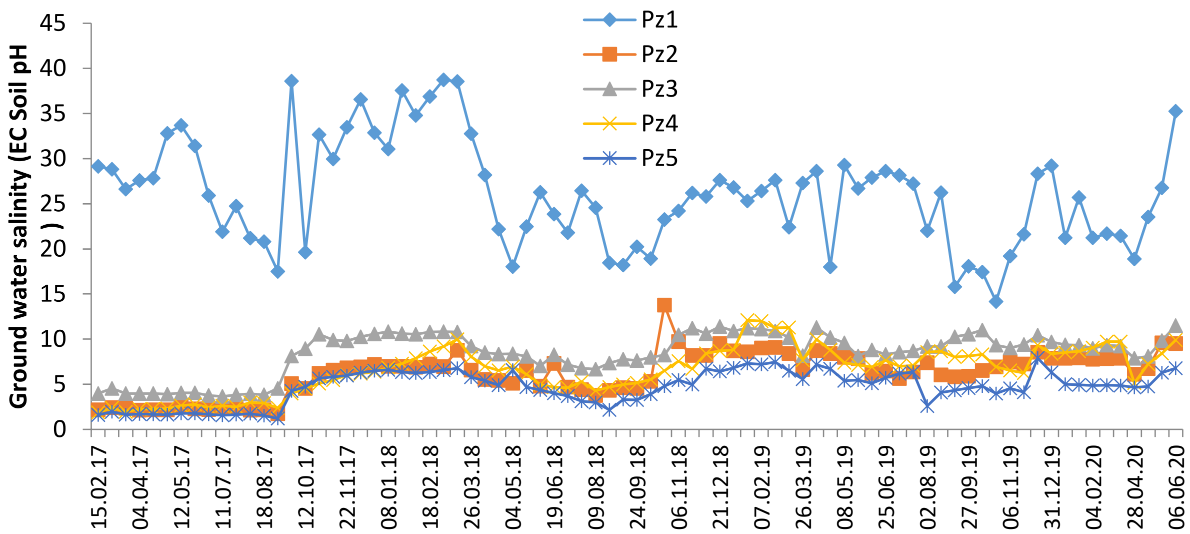

Figure 7.11 Groundwater salinity as observed in five piezometers installed at Sonagaon, Gosaba

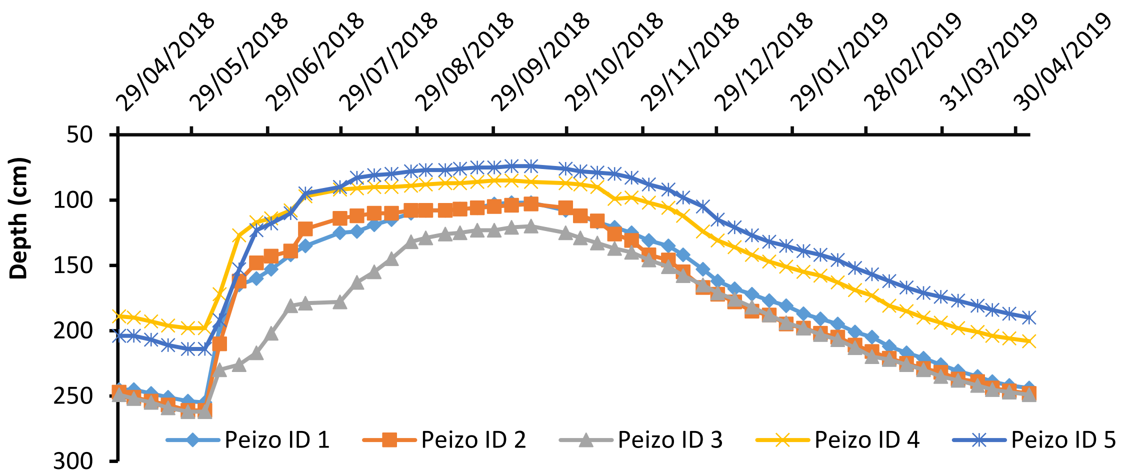

Figure 7.12 Depth to groundwater table at BCKV site in Gosaba in 2018-19

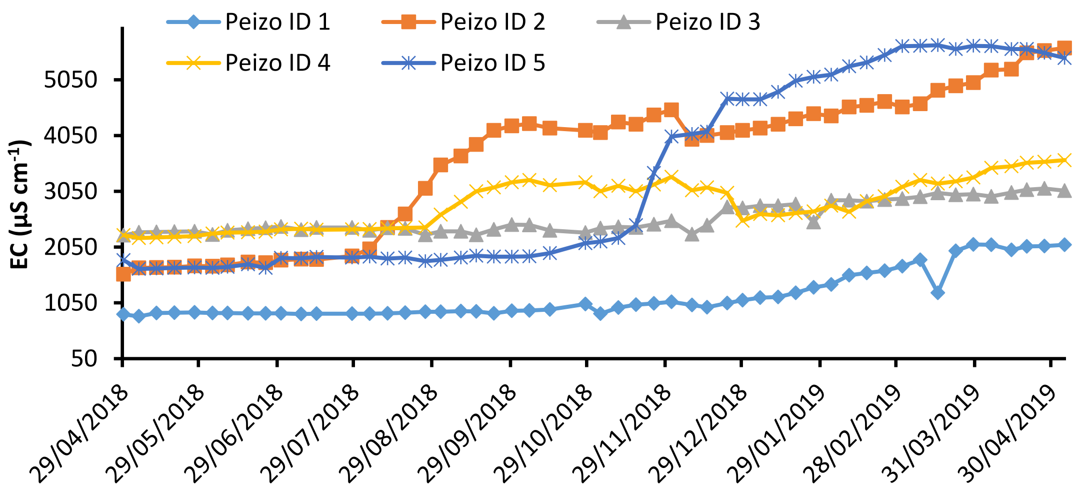

Figure 7.13 Variation of EC of groundwater at BCKV site in Gosaba in 2018-19

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Table 7.3 A summary of surface water and groundwater condition in the studied polders

Studied Polders	Surface Water		Groundwater	
	Water Level	Water salinity	Water Level	Water salinity
Polder 43, Amtali	Coastal river: -0.5 to 2.5 m	River water: Increased after Nov and reached a peak of 25 dS m^{-1} in May Canal water: averaged salinity of 1 dS m^{-1}, suitable for irrigation	0.8 to 1.8m from the field surface	Increased from 3 dS m^{-1} (Nov/ Dec) to 11 dS m^{-1} (May/Jun) non-suitable for irrigation
Polder 31, Dacope	Coastal river: -2 to 3 m	River water: Reached 15 dS m^{-1} and 30 dS m^{-1} in the east and south of polder Canal water: averaged salinity of 1 dS m^{-1}, suitable for irrigation	0.1 to 1.1 m from the field surface	0.4–2.9 dS m^{-1} considered suitable for irrigation development, intrusion of high saline river water during the dry season
Sonagaon, Gosaba Island	Max depth of 3 and 1.5 in ponds and drainage channels	River water: the highest salinity (50 dS m^{-1}) during Mar–May Sluice gate and drainage channels: a wide range of 0–50 dS m^{-1} Pond water: Mean salinity less than 1 dS m^{-1}	1.1–1.9 m from the field surface	Averaged salinity varied from 7.4 to 13.3 dS m^{-1} the highest salinity (38.8 dS m^{-1}) in Mar non-suitable for irrigation
Rangabelia, Gosaba Island	the highest depletion (about 4 m) in Feb	Pond water: Mean salinity less than 1 dS m^{-1}	1–2.5 m from the field surface	Salinity increased to 6 dS m^{-1} during the winter season.

7.1.4 Characterization of soil

Soil samples were collected to determine soil physical and chemical properties after T. Aman or Kharif-II rice harvest. Soil salinity from rice field was measured weekly and non-rice field was measured at 15 days' intervals after transplanting at 0-15, 15-30, 30-45 and 45-60 cm soil depth. In both sites, soils were slightly alkaline in nature and were dominated by clay fraction having bulk density of 1.39-1.42 g cc^{-1} in Amtali and 1.34-1.38 g cc^{-1} in Dacope indicating that the soils are silty clay to clay textured. In Dacope, field capacity moisture level varied from 33.1% to 43.0% and it gradually decreased up to 23.5% to 29.0% in wilting point and its water holding capacity varied from 8.3% to 14.0%. This is an indication of clay dominant poor drainage capacity. In both locations, salinity increased gradually with depth of soil and over time; soil salinity was higher than irrigation water salinity. In non-rice field, soil salinity varied from 4 to 8 dS m^{-1} at varied depth. Dacope area is more saline than that of Amtali areas. The average distribution of soil salinity over the year for Amtali and Dacope is shown in Figure 7.14.

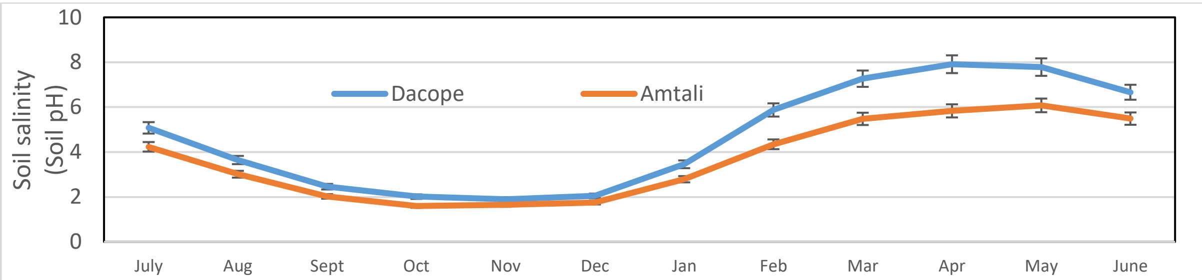

Figure 7.14 The average year round soil salinity in Dacope and Amtali areas, 2016-20

7.2 Polder Salt and water balance

The detail calibration and validation of the model for all 3 polders using experimental results and APSIM simulations are given in the Annex Report 3 and in the published journal papers (Mainuddin *et al.*, 2019b; Mainuddin *et al.*, 2020). Using the model we evaluated 12 scenarios; the first six examining changes in management, the next five examining climate change impacts and the last examining a change in river salinity. The results of the twelve scenarios are shown in Figure 7.15. Here we discuss the management scenarios, shown in green in the figure. More details are given in Annex Report 3 and at Mainuddin *et al.* (submitted).

7.2.1 Impact of a dry season crop

The rice – wheat (RW scenario in Figure 7.15) rotation shows more simulated evapotranspiration than the rice – fallow (RO) rotation, as expected. This leads to somewhat reduced irrigation application for the single crop at Amtali and Dacope, and correspondingly increased runoff. At Dacope, there is less uptake of groundwater when there is no dry season crop, which leads to a less salty soil, and in turn leads to less salty ponds and canals. At Gosaba there is no irrigation, and the saltier soil of the rice – wheat rotation depresses the evapotranspiration; as at Dacope, the lesser uptake of groundwater without a dry season crop leads to a less salty soil, and ponds and canals.

7.2.2 Impact of groundwater pumping

Groundwater pumping (RW-GP scenario in Figure 7.15) results in smaller simulated salt concentrations in the soil and the ponds at Dacope and Gosaba. This is because the groundwater level of the saline deeper groundwater is lowered by pumping. This in turn reduces capillary rise and hence salt transport from the saline deeper groundwater into the soil, and thence via surface field drainage to the ponds. At Gosaba, the less salty ponds and canals leads to them being used for irrigation, which in turn leads to an increase in the evapotranspiration. The salt concentrations at Amtali are low to begin with, and not much affected by the pumping.

7.2.3 Impact of stopping the use of river water

Stopping the use of river water for irrigation (RW-NoR scenario in Figure 7.15) generally results in little simulated difference between this scenario and the base rice – wheat scenario, because the base scenario made little use of river water anyway.

7.2.4 Impact of increasing the area of ponds and canals

The increased area of ponds and canals (scenario RW-MP in Figure 7.15) is simulated to lead to greater use of irrigation at Amtali and Dacope, and somewhat reduced salinities of the soil and ponds and canals at Dacope. However, the evapotranspiration changes very little with the additional irrigation, because the irrigation substitutes for groundwater uptake. The simulated impact at Gosaba is limited.

7.2.5 Impact of using river water for irrigation irrespective of the salt water content

This scenario (RW-RI in Figure 7.15) is essentially a simulation of the breakdown of careful control over the polder sluice gate and irrigation operations. Unsurprisingly, the salt concentrations in some or all of the soil, the ponds and canals, and the groundwater rises at all three locations. The impact on groundwater is significant only at Amtali, where salt reaches the groundwater via irrigation with pond and canal water, followed by downward drainage from the soil. At Gosaba, the soil salinity decreases with the forced use of river water, and the evapotranspiration increases. This is because the river water (the salt concentration of which is diluted by the water in the ponds and canals) results in more water becoming available for irrigation, which substitutes for the uptake of salty groundwater.

Each group of columns shows the average annual water depth (left axis, leftmost four groups of columns) or salt concentration (right axis, rightmost three groups of columns in the shaded region). The average annual water depths are rain, actual evapotranspiration (ETa), applied irrigation (Irrig), and surface drainage from the fields which is equivalent to runoff from the soil to the canals and ponds (Df). The salt concentrations are concentration in the soil water (Csoil), in the pond water (Cpond) and in the fresh shallow groundwater (Cgf). The scenarios are as indicated in the legend in the Gosaba plot; the green bars indicate scenarios with historical climate, and the blue bars indicate climate change scenarios. In order from the left in each group of bars, they are the base rice-wheat scenario (RW), rice but no wheat (no Rabi crop) (R0), groundwater pumping (GP), no use of river water for irrigation (NoR), more ponds and canals (MP), the use of river water for irrigation irrespective of the salt concentration (RI), climate change – average ET change and low rainfall change (RW-CCAELR), average ET change and high rainfall change (RW-CCAEHR), average ET change and average rainfall change (RW-CCAEAR), low ET change and high rainfall change (RW-CCLEHR), high ET change and average rainfall change (RW-CCHEAR), and an increase in salt concentration of the rivers of 5 g L^{-1} (RW-Sr+).

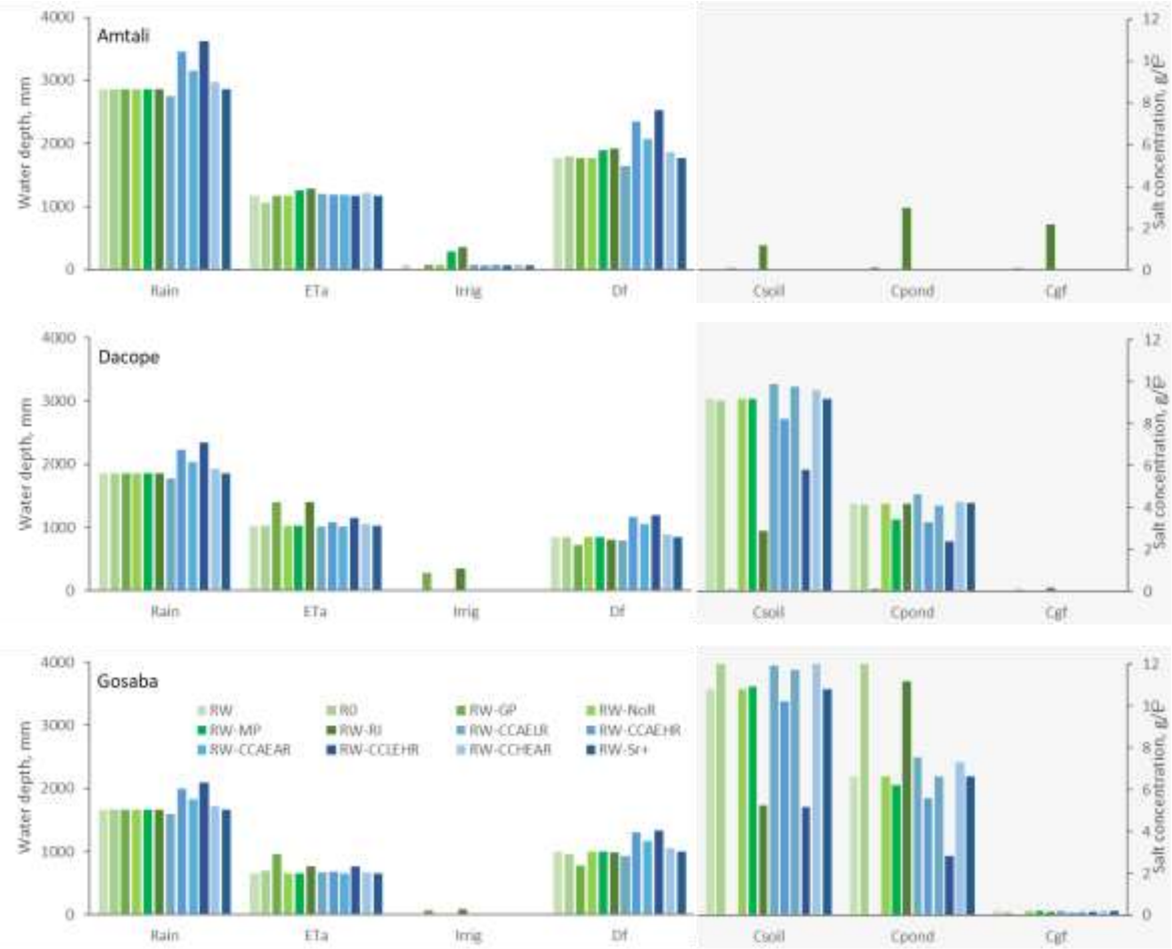

Figure 7.15 Comparison of 12 scenarios for the Amtali (top) and Dacope (middle) polders, and Gosaba Island (bottom).

7.2.6 Impact of climate change

Climate change is projected to affect both the water balance and the salt balance in the polders. Higher rainfall is projected to lead to greater runoff (field surface drainage, denoted Df in Figure 7.15) at all three sites, with the two highest rainfall projections (scenarios RW-CCAEHR and RW-CCLEHR) leading to the greatest runoff. At Dacope and Gosaba, the two high rainfall scenarios lead to projected lower soil and pond salt concentrations than in the base case. At Dacope, the other three climate change scenarios lead to higher soil and pond salt concentrations than in the base case, whereas at Gosaba they are similar to the base case. The salt concentrations at Amtali remains low in all climate change scenarios. Gosaba remains too salty for irrigation under any climate change scenario, whereas the lower salt concentrations at Dacope for the two higher rainfall scenarios leads to somewhat increased irrigation.

7.2.7 Impact of increasing salinity in the rivers

The increasing salinity in the rivers is projected to have little impact on the water and salt balance of the polders, as shown by the rightmost blue bar labelled RW-SR+ in Figure 7.15. At Gosaba, the impact is almost zero, because the rivers are too salty for use as irrigation water, so increasing their salinity results in no change. At Amtali and Dacope, there is a small decline in the applied irrigation water, which also leads to a minor reduction in crop evapotranspiration. At Dacope, this is accompanied by a modest rise in soil water and canal and pond salt concentrations.

The main consideration resulting from the understanding of the polder salt and water balance processes and the model is the importance of strategies to remove salt. These strategies lead to somewhat higher crop evapotranspiration which, all other things being equal, would result in greater crop production. They also lead to long-term sustainability. Lowering of salty groundwater tables, the provision of field drainage to reduce soil salinity, and the management of larger polder drainage canals to remove salt from the polder are all likely to be effective.

While the direct impacts of projected climate changes are to alter the amount of water added to or removed from the polder, this indirectly impacts the removal of salt in the runoff and drainage, and on the requirement to use other, saltier sources of water to satisfy crop water requirements. Thus, salt management strategies are also likely to be important in combatting the impacts of climate change.

7.2.8 Scenario assessment of inundation by major floods

We also used the model to the impact of a single cyclone induced flood event in May, and the way in which the soil and growth of crops recover after the event. We repeated the analysis for another single flood event in November. We compared the flood event with a no-flood scenario as a base case for comparison. The inundation scenarios were:

1. no inundation, to provide a base case for comparison;
2. 1 m inundation by sea water (salt concentration 35 g L^{-1}) in May of the first year; and
3. 1 m inundation by sea water (salt concentration 35 g L^{-1}) in November of the first year.

For each of the three inundation scenarios, we considered two management options. The first option, the mixing parameter was set at a low value to simulate no special action being taken to promote flushing out of the salt and hence a slow recovery from the flood. In the second option, the mixing parameter was set at a high value to simulate action being taken to promote flushing out of the salt and hence a quicker recovery from the flood. The three inundation scenarios each with the two management options leads to a total of six scenarios. Comparison of soil water salt concentration for the scenarios is shown in Figure 7.16. Detail results can be found in Annex Report 3 and at Mainuddin and Kirby (submitted).

The results show that the salt concentration is elevated after inundation (Figure 7.16). This arises because the inundation infiltrates into the soil, immediately saturating it. However, the difference diminishes in year 2, (middle row) and is in some cases insignificant in year 5 (bottom row). The impact diminishes faster in scenarios with a mixing parameter of 1. The results show that impact varies depending on the time of inundation and the location. In high rainfall area, such as at Amtali, the November flooding generally has greater impact on the evapotranspiration and salt concentrations in the soil and shallow groundwater, whereas at Dacope and Gosaba the May flooding generally has the greater impact. The recovery period is largely dependent on the flushing out of the salt from inside the polder. So, the area with higher rainfall recover faster than the low rainfall area. The main conclusion of this study is that with sound maintenance of infrastructure, such as well-maintained embankments elevated as necessary with sea level rise, and sound management, particularly of soil drainage, the polders and islands of the Ganges delta could develop regimes to recover fairly quickly from inundation events. The study is expected to provide valuable information to the policy maker for detailed planning for recovery of the area after any cyclone induced inundation events.

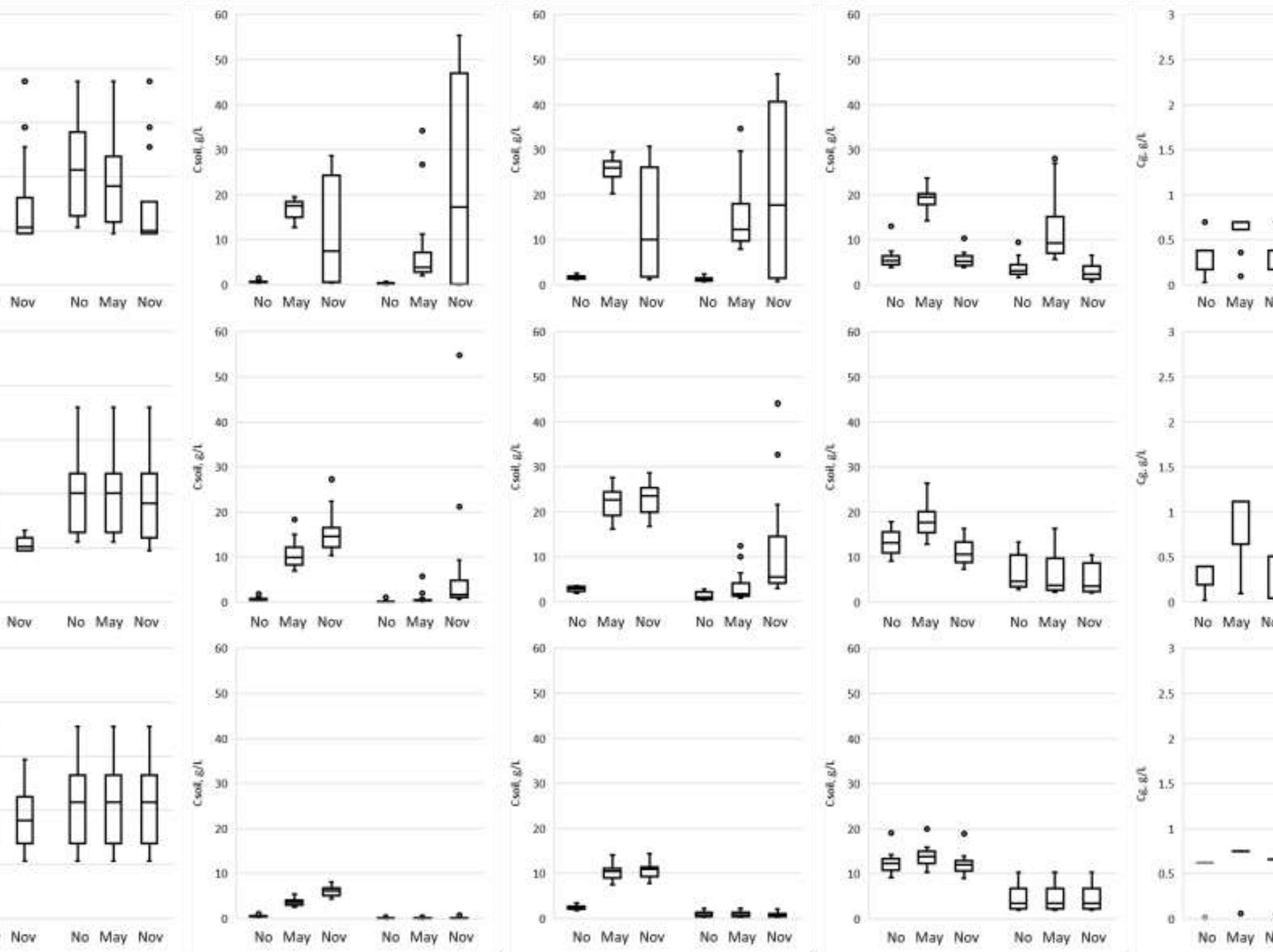

Figure 7.16 Comparison of soil water salt concentration in the scenarios for Amtali (left), Dacope (middle) and Gosaba (right). The results in the first year following the inundation event are shown in the top row, year 2 in the middle row, and year 5 in the bottom row. In each plot, the left hand group of three box plots are for mixing parameter 0.1, and the right hand group of three are for mixing parameter 1, in the order of no inundation, inundation in May, and inundation in November. Each box plot summarises the 12 monthly values for a year.

7.3 Surface water, groundwater and salinity interactions

We developed two separate groundwater models for the two selected polders in Bangladesh to understand the surface water, groundwater and salinity interactions (Annex Report 4). They complement the polder level salt and water balance model described above. The calibrated and verified models have been simulated for a number of scenarios described below:

Base Scenario: Existing hydrological and land cover conditions.

Groundwater withdrawal Scenario: Groundwater has been withdrawn from the shallow aquifer to see the impact on groundwater and effect of salinity intrusion.

Climate Change Scenario: Hydrological condition (rainfall, surface water level and river salinity) for the year 2018 has been predicted considering climate change condition. The river salinity has been increased considering Sea Level Rise (SLR) for climate change.

Brackish water Aquaculture Scenario: The salinity included in the tidal floodplain to see the impact on groundwater salinity intrusion.

The spatial distribution of groundwater level for Polder 31 and Polder 43/1 for the base year along with groundwater withdrawal scenario is shown in Figures 7.17and 7.18, respectively for Amtali and Dacope. Comparing the scenario results with the base condition it may be concluded that due to groundwater withdrawal the groundwater level will be decreased in the areas of pumping in the polders. For pumping the groundwater level decreases up to 4m for Polder 43/1 and 3.6m for Polder 31. The distribution of groundwater salinity due to groundwater withdrawal for vertical movement has been checked transverse to the river alignment. Vertical salinity distribution profile shows that (please see Figures 5.12 and 5.13 in the Annex Report 4) the salinity is propagating inwards for groundwater abstraction. This implies that groundwater withdrawal from near the river boundaries may result in further increase in the salinity of the groundwater over a long period of time.

There is increase in groundwater level due to climate change scenario than the base scenario. There is existing water logging problem in the polders. Due to climate change the problem will further deteriorate in future for this increase in groundwater level. The distribution of groundwater salinity due to climate change shows that the salinity is propagating into the deep region (further from the river inside the polder) due to climate change. There is still fresh water in most of the deep aquifer. So, there is possibility of contamination of the deep aquifer adjacent to river in future due to climate change. The simulation of brackish water scenario shows that the salinity of the shallow aquifer increases rapidly.

A scenario analysis was done using 2D-cross-sectional groundwater flow model of Sonagaon Village of Gosaba Island in Sundarbans by introducing a single, and three equidistant subsurface drains to the study area. The influence of drains on the GW table suggests that the water table is being shifted downwards by almost 0.15 m in the pre-monsoon season while introducing three equidistant drains, but single drain has the lesser impact of 0.03 m lowering only (Figure 7.19). This seems promising for removal of salinity from the crop root zone because the current situation in the study area is that saline ingression in dry seasons is because of the influx of salinity from deeper strata of soil to the top layers, despite tidal influence. The deeper strata up to some depth are already affected with salinity during previous incidents like Aila cyclone and tidal influxes (Haldar and Debnath, 2014). So, as per the scenario analysis, this study suggests that the rise of saline GW could be controlled if three drains are introduced to the area. Then the crop root zone will be free from salinity influx up to some extent which will be very much helpful for the farming sector.

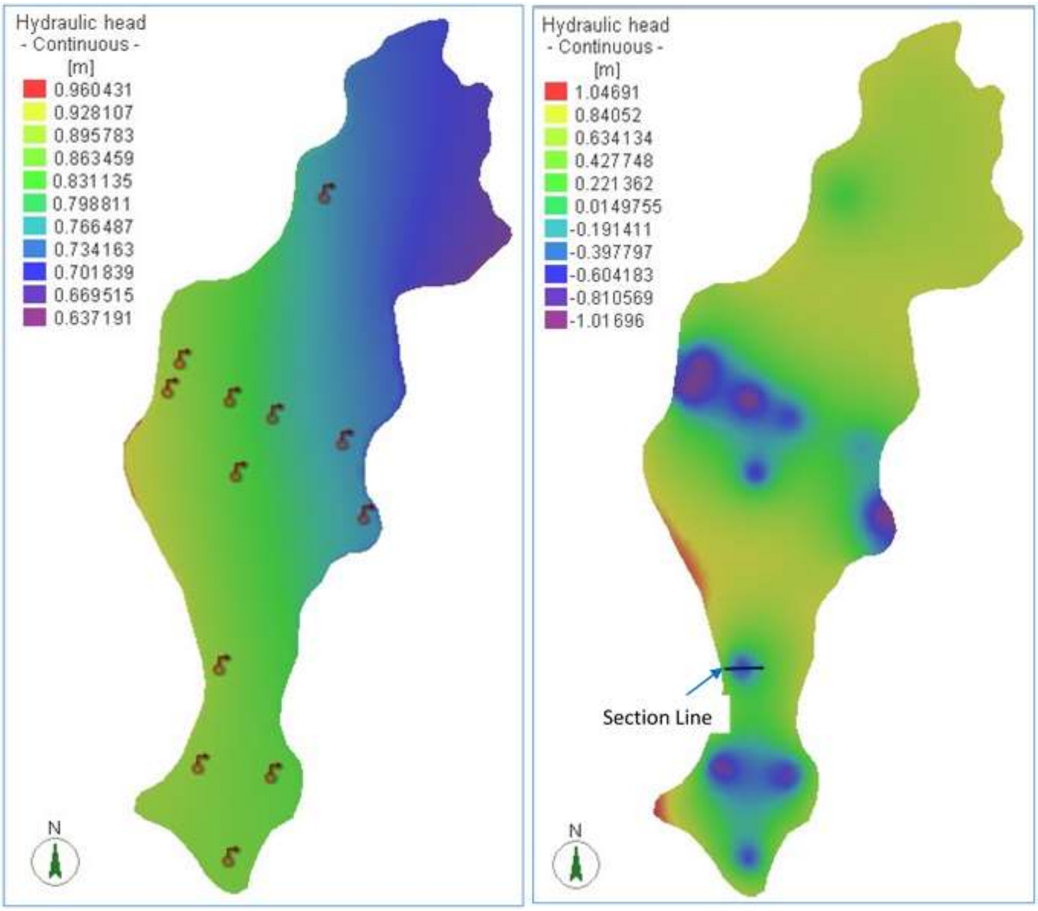

Figure 7.17 Spatial distribution of GWL for base condition (left) with pump and for groundwater withdrawal scenario (right) for Shallow Aquifer of Polder 43/1, Amtali

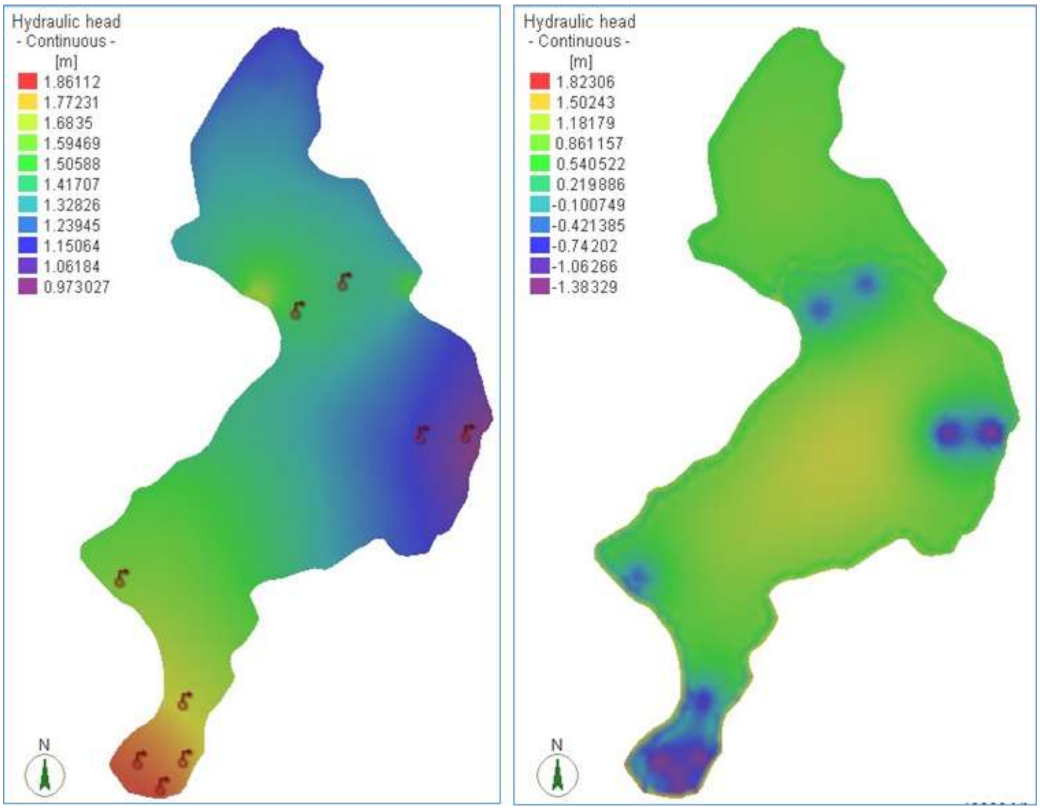

Figure 7.18 Spatial distribution of GWL for base condition (left) with pump and for groundwater withdrawal scenario (right) for Shallow Aquifer of Polder 31, Dacope

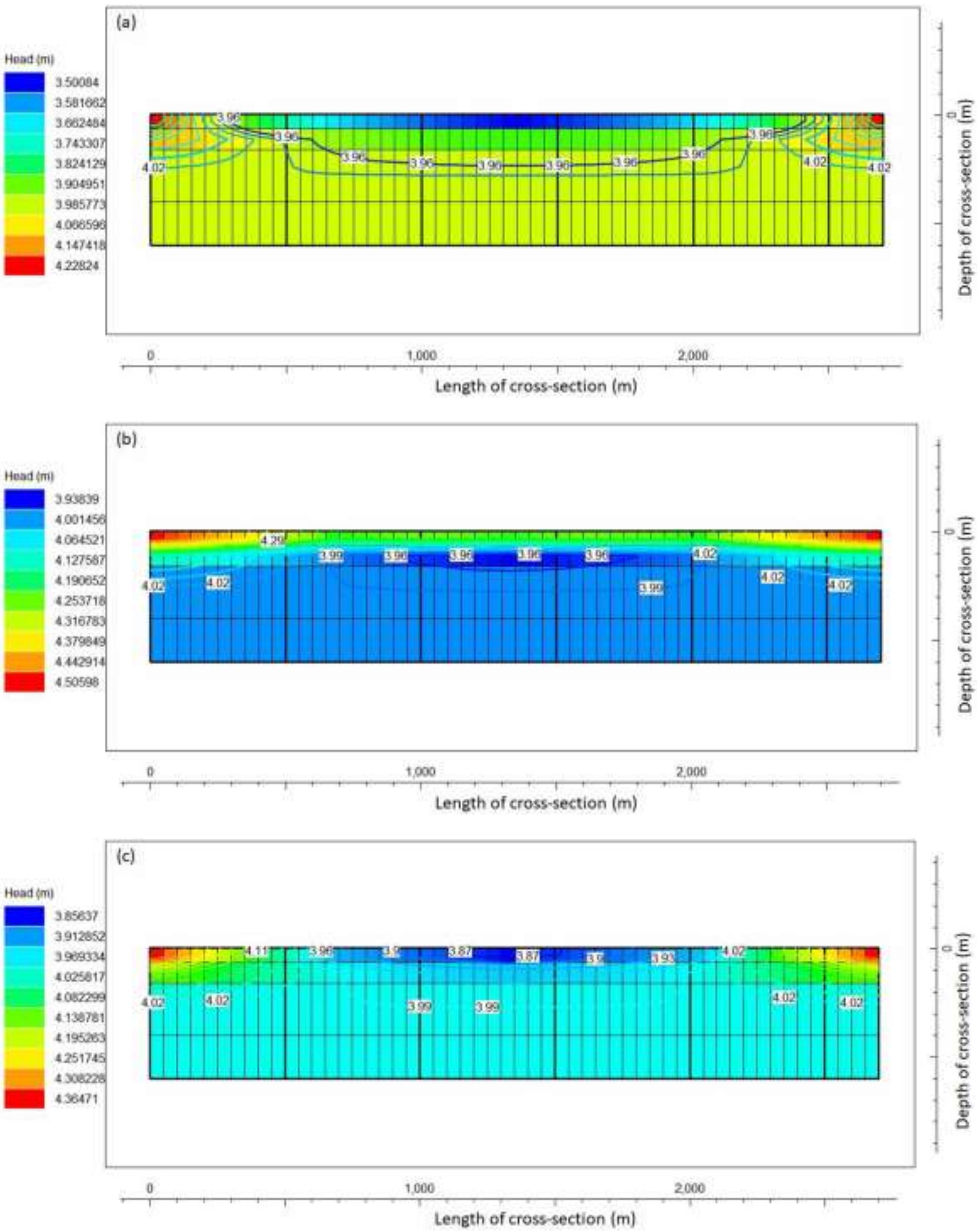

Figure 7.19 Groundwater contours after the addition of 3 drains (3 m wide with a depth of 1.5 m) for (a) Pre-monsoon (b) Monsoon and (c) Post-monsoon seasons

7.4 Crop modelling using APSIM Model

7.4.1 Established APSIM credibility in the CZ

Parameterisation, Calibration and Validation

Parameterisation refers to the process of supplying a model with directly measured or derived input parameters and variables (daily climate data, soil physical and chemical characteristics, management impositions and inputs, etc.), around which there is minimal uncertainty. APSIM was parameterised using the measured soil and environmental characteristics as input parameters, as well as the imposed management details from the experiments. For complex cropping system models like APSIM, there are always some other input parameters which are either difficult to measure or which have a greater degree of uncertainty in estimation, requiring some degree of calibration or adjustment (within reasonable bounds) to achieve accurate output from the model. These include parameters such as those governing crop phenology, biomass partitioning, rooting depth, and soil biological activity. In our simulations, we used the first (2016) year's results to calibrate such parameters – a process by which simulated outputs (for crop development, production, soil water and salt dynamics, or other variables of interest) were compared to the values of those observed from the experiment. If discrepancies were noted, uncertain parameters were re-adjusted, and the process repeated until acceptable model performance was achieved. The overall model setup was then tested (validated) using remaining experiments from 2017-2019 (Figures 7.20Figure 7.20 to 7.23).

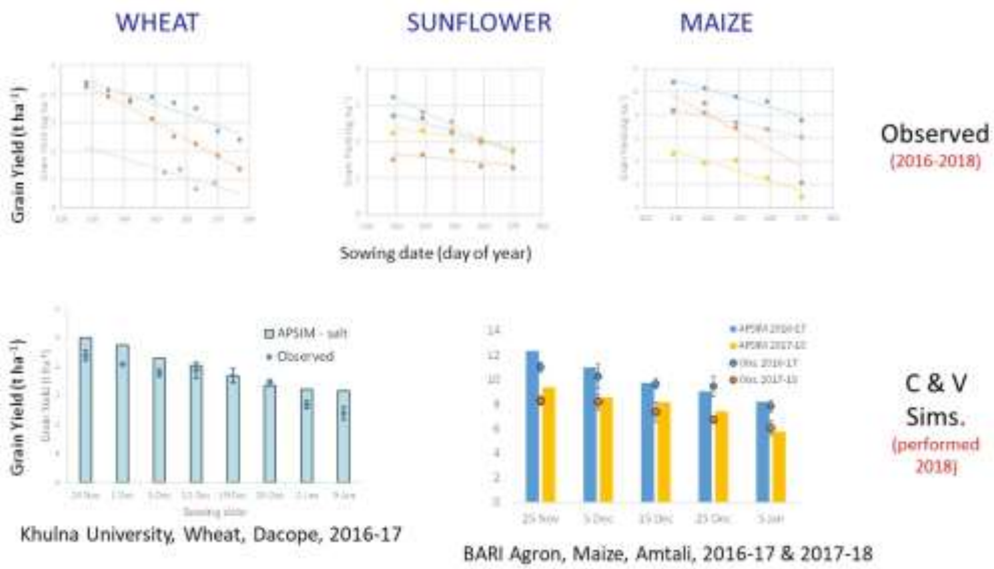

Figure 7.20 Example calibration and validation of APSIM for wheat and maize at Dacope and Amtali, Bangladesh, respectively, focusing on grain yield.

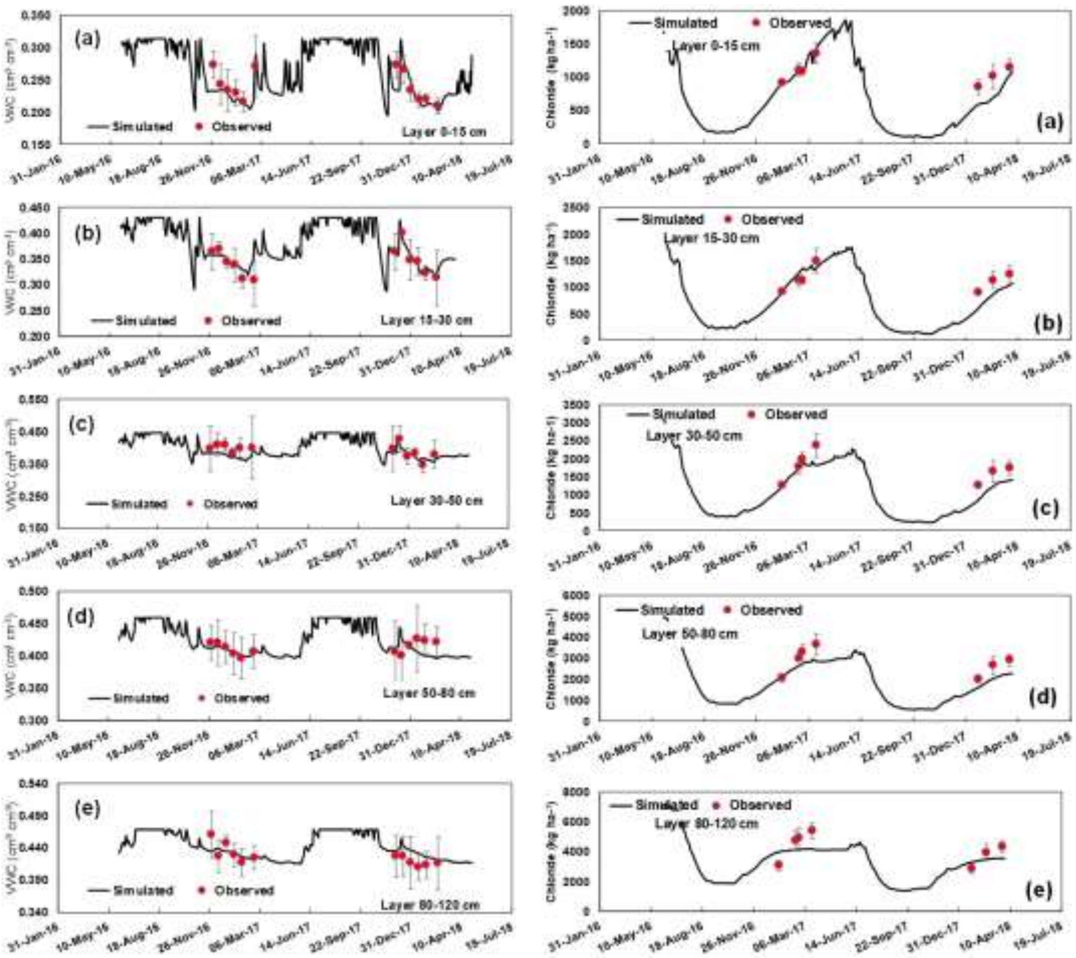

Figure 7.21 Example calibration and validation of APSIM for Gosaba, WB, India, under Rice-Grasspea rotation. Comparison of simulated and measured volumetric soil water content (left-side; cm^3 cm^{-3}) and soil chloride (kg ha^{-1}; right-hand side) in different soil layers (0–120cm) of medium lowland soil of the Gosaba experimental site (Vertical bars are standard error of the means of the observed values)

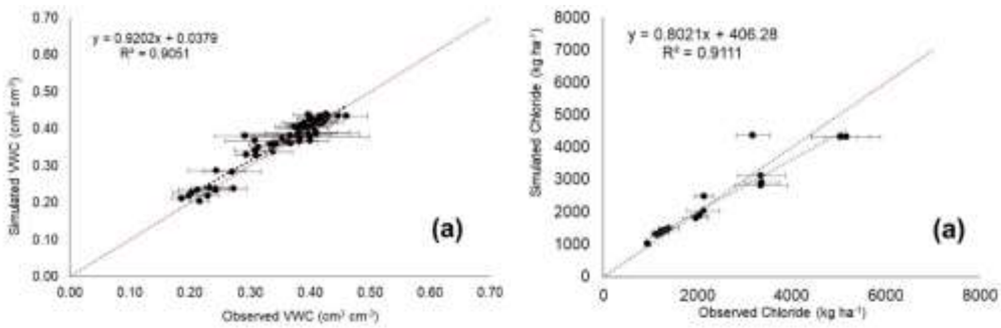

Figure 7.22 Simulated vs observed volumetric soil water content (cm^3 cm^{-3}; left-hand side) and soil chloride (kg ha^{-1}; right-hand side) (Figure 7.22a: Calibration dataset; Figure 7.22b: Validation dataset) across the 0-120 cm soil layer of the experimental site (Lines present the linear relationship between simulated and observed values with intercept at 0)

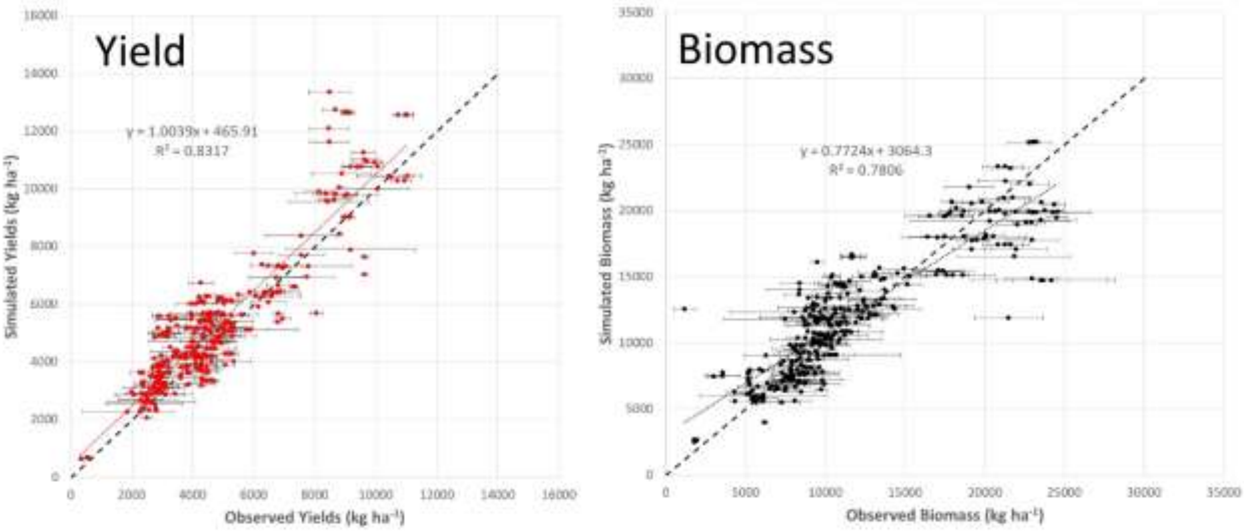

Figure 7.23 Overall performance of APSIM in simulating crop yields and biomass across all cropping systems and treatments at all sites. All crops are included on the same graph.

APSIM simulated grain yield, crop biomass, soil salinity, and soil moisture with a RMSE (between simulated and observed values) which was of the same quantum as the standard deviation of the observed values, thereby indicating that the model was effectively simulating the observed behaviour within the bounds of experimental uncertainty (Table 7.4). This is all you can possibly expect a model to do and is a reliable measure of acceptable model performance (Gaydon *et al.*, 2017). The simulation of soil salinity build-up and crop water-use under different irrigation salinity applications was similarly acceptable. In addition, APSIM has been used to successfully simulate the impact of sowing date on rice crop performance in this region (see Fig 5–8 in Gaydon *et al.*, 2017). For these reasons, we felt comfortable with model credibility at the case-study location, and in using the model for our subsequent scenario analyses.

Table 7.4 Statistical analysis of APSIM performance against CSI4CZ experiments and on-farm trials. The units of X_{sim}, X_{obs} and RMSE is kg ha^{-1}.

Model	Variables	n	X_{obs} (sd)	X_{sim}	P(t*)	β	α	R^2	RMSE %
Calibrate	Chloride (kg ha^{-1})	20	2371 (274)	2308	0.88	443	0.80	0.91	19.5
	VWC (cm^3 cm^{-3})	60	0.352 (0.030)	0.37	0.45	0.04	0.92	0.90	6.6
	Grain yield (kg ha^{-1})	26	2819 (230)	3012	0.76	33.2	1.05	0.99	10.2
	Biomass (kg ha^{-1})	26	6953 (442)	7314	0.77	655	0.96	0.99	7.7
Validate	Chloride (kg ha^{-1})	20	2193 (356)	2315	0.79	315	0.91	0.89	18.0
	VWC (cm^3 cm^{-3})	60	0.356 (0.290)	0.37	0.64	0.01	1.00	0.93	6.07
	Grain yield (kg ha^{-1})	56	2723 (234)	2972	0.91	82.3	0.8	0.78	6.61
	Biomass (kg ha^{-1})	56	8065 (416)	8274	0.92	466	0.78	0.82	7.01

X_{obs}, mean of observed values; **X_{sim}**, mean of simulated values; **SD**, standard deviation; **n**, number of data pairs; **P(t*)**, significance of Student's paired t-test assuming non-equal variances; **α**, slope of linear regression between simulated and observed values; **β**, y-intercept of linear regression between simulated and observed values; **R^2**, square of linear correlation coefficient between simulated and observed values; **RMSE**, absolute root mean squared error (percentage in brackets of observed mean)

7.4.2 APSIM model improvements have been made

Process developed for simulating soil salinity from inputs of daily climate, water-table height and salinity, plus irrigation source salinity

To maximise the flexibility in applying the APSIM model under saline soil conditions, we have developed a novel technique for simulating surface-soil salt build-up and the associated Rabi crop response. In this technique, we simply provide the model with daily water table depth and salinity data, daily climate, and daily salinity dynamics of the water sources being used for irrigation, and the surface soil salinity dynamics area an emergent variable resulting from the simulation of capillary rise, percolation, crop water uptake, and soil evaporation. This is in contrast with previous cropping systems modelling salinity studies where the crop response is driven by soil salinity that has been input directly into the model. We have developed a technique to actually simulate soil salinity build-up, in response to the other previously mentioned environmental variables. This has positioned us well to explore the performance of farmer management adaptations under both historical and future climate scenarios, as future climate modelling exercises can supply APSIM with changes in river water salinity, water tables height and salinity etc., but cannot give us soil salinity dynamics. For all future applications in saline region crop modelling – we don't need to be given soil salinity dynamics – we can now simulate them. This has been a major step forward for cropping systems modelling in saline zones in general – not just for this project.

Adding sensible simulation of osmotic potential

APSIM-Swim already accounted for solute concentrations in the soil, but during CSI4CZ we have implemented a new osmotic algorithm into APSIM, to ensure that the rate of osmotic potential rise with solute concentration rise is correctly specified for our target environments. Ed Barrett-Lennard has conducted a comprehensive investigation into the ratio of key soil salts at project sites, and this information informed modification of this key rate factor in APSIM. Selected field trials simulation has been the avenue to test APSIM performance with new rate constants, and the results are reflected above in the acceptable model performance in validation datasets.

New APSIM modules – APSIM-Grasspea and APSIM-Lentil

Apart from regular APSIM crops which we have calibrated and tested, this project has also developed and tested two brand new modules as part of Mr Sukamal Sarker's PhD work. These are APSIM-Grasspea and APSIM-Lentil. The development of new models in APSIM requires high-quality experimental data over different sowing dates, different fertiliser amounts, and ideally a couple of different locations to check geographical response. The broad geographical nature of this project has provided these, but also additional non-project datasets were sought and collated from drastically different environments in India. Sukamal is preparing an international journal paper on the development and testing of these models and their incorporation into the standard APSIM release package, which will make them available to researchers internationally.

7.4.3 Scenario Analyses and findings

We conducted a range of scenario simulations using the validated model to help understand crop responses to management change and environmental drivers in the coastal zone. The model has been particularly useful in understanding the risk, or variability in crop performance as driven by environmental constraints.

Sowing date is critical to yield and water-productivity

Our long-term simulations at each site have confirmed the general nature of the pattern we have observed in our field experiments over a limited number of years. The highest crop yields are achieved by sowing as early as possible following the cessation of the Kharif season to allow drainage/preparation of land for Rabi cropping. Although it was impossible to establish crops in the field prior to 15 Nov due to flooding and water issues, the model revealed that there would not be much point anyway – crop yield for sowings prior to 15 Nov experience dangerous levels of cold stress around flowering (time and degree vary between species) and exhibit lower average yields with very high season-season variability (Figures 7.24 and 7.25)

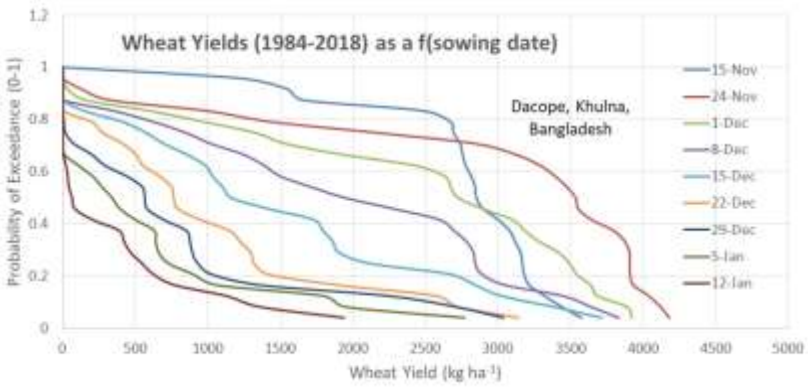

Figure 7.24 Simulated Wheat yields Dacope, Bangladesh, as a function of sowing date.

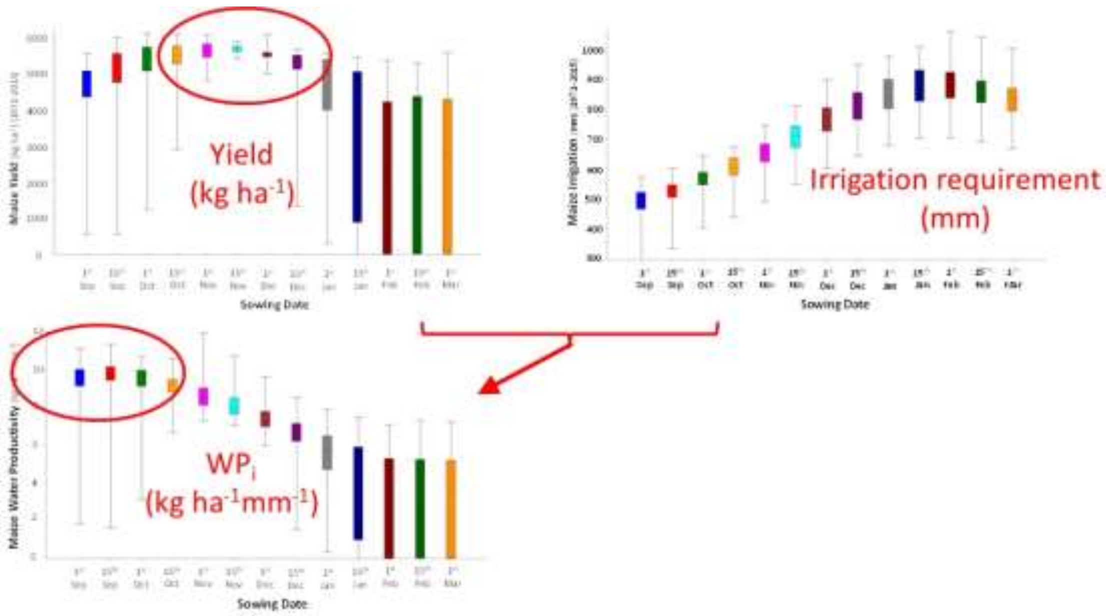

Figure 7.25 Simulated Maize yields, irrigation water requirement and resulting water productivity for Dacope, Bangladesh.

Across all crops and sites, the modelling revealed that crop yields were highest and irrigation water requirement lowest for early sowings – resulting also therefore in maximal water productivity (WP; kg grain yield mm^{-1}). The model also indicated that the operating point for maximising grain yield and maximising WP may not always be the same, however operationally for crops in the CZ they are.

How much of yield decline is due to salt and how much to climate?

APSIM scenarios allow us to ‘play’ with factors that are impossible to ‘play with’ in the field, in order to understand various system processes. For the Rabi cropping, delayed sowing date reduces potential crop yields simply due to climatic factors (temperature and radiation), however salt plays an even greater part in yield decline. This is illustrated in Figure 7.26, where the grain yield in the real environment (blue bars: with salt) are compared to the grain yields in the same location if we could magically remove salt from the system. It became clear that the saline conditions not only decrease the average yields, they introduce a large degree of risk and variability, due to the fact that not all years become equally salty. This is illustrated in the December and January sowing graphs (Figure 7.26), which show that in some years (a decreasing number of years with advancing sowing date) ‘salty’ crop yields are not greatly different from ‘non-salty’ crop yields. This phenomenon is largely driven by the amount and timing of Rabi season rainfall and its variability. Figure 7.27 illustrates how cropping becomes increasingly risky with later sowing dates, and this is driven mostly by salinity.

Figure 7.26 The variability in wheat grain yields at Dacope, Bangladesh (1995–2018) for different sowing dates, for the natural, saline environment (blue bars) compared with a simulated environment, magically free of salt (red bars)

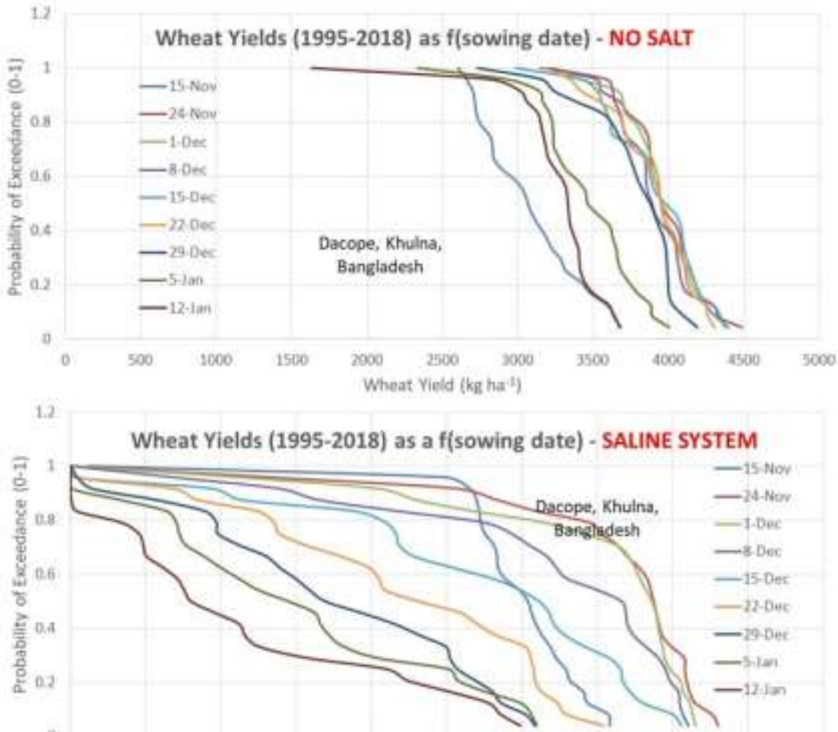

Figure 7.27 The probability of exceedance for wheat grain yields at Dacope, Bangladesh (1995–2018) illustrating the effect of sowing date, for the natural, saline environment (bottom graph) compared with a simulated environment, magically free of salt (top graph)

Sowing date and waterlogging risk

The soils of the CZ are prone to waterlogging during the Rabi season as a result of unseasonal rainfall events. Although the chance of in-crop rainfall during Rabi is highest later in the season (Figure 7.28), the chance of ponding and problematic waterlogging is highest early in the season (Figure 7.29). This is driven by two factors – (i) early in the season the soils are already wet post monsoon; and (ii) the small crops at that stage have a lower water extraction capability and tolerance to waterlogging. The modelling has illustrated the importance of in-field drainage capability in capitalising on the benefits of early sowing.

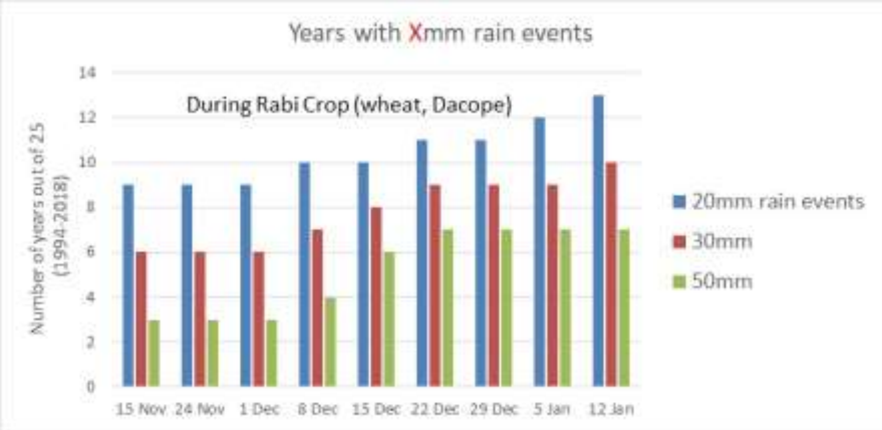

Figure 7.28 The probability of in-crop Rabi season rainfall events of different sizes at Dacope, Bangladesh (1995-2018)

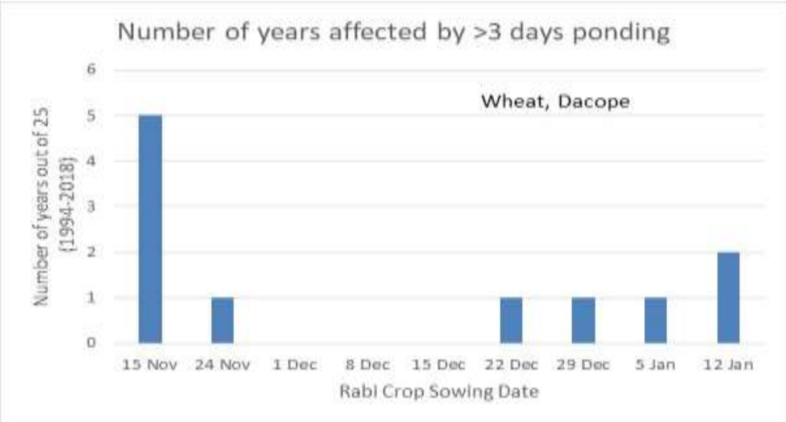

Figure 7.29 The probability of greater than 3 days in-crop ponding during the Rabi season at Dacope, Bangladesh (1995-2018)

Mulch is good news for Rabi crops in the saline zone – but how much is best?

APSIM modelling, in combination with project field trials, has illustrated that retaining crop residues in the field during Rabi crops has a number of significant advantages in the CZ: (i) soil moisture is conserved through reduced soil evaporation; (ii) capillary rise is reduced for the same reason, hence salt deposition in the surface soil is reduced and the crop experiences less salinity; and (iii) there are soil health benefits from increased C and N incorporation in the soil. Figure 7.30 illustrates that the biggest benefits for Rabi crops are for those sown after December, as it is under these sowing dates that the impacts of drought and salinity are the highest. This is seen in Figure 7.30 by the much higher proportion of low-yielding crops under current farmer management (no residues). A possibly unexpected insight provided by the modelling is that at the high end of yields, there is a slight reduction in the few highest yielding crops, driven by nitrogen immobilisation in the decomposition process for surface residues. This could easily be managed with slightly higher N fertiliser application, however we have not investigated this with APSIM.

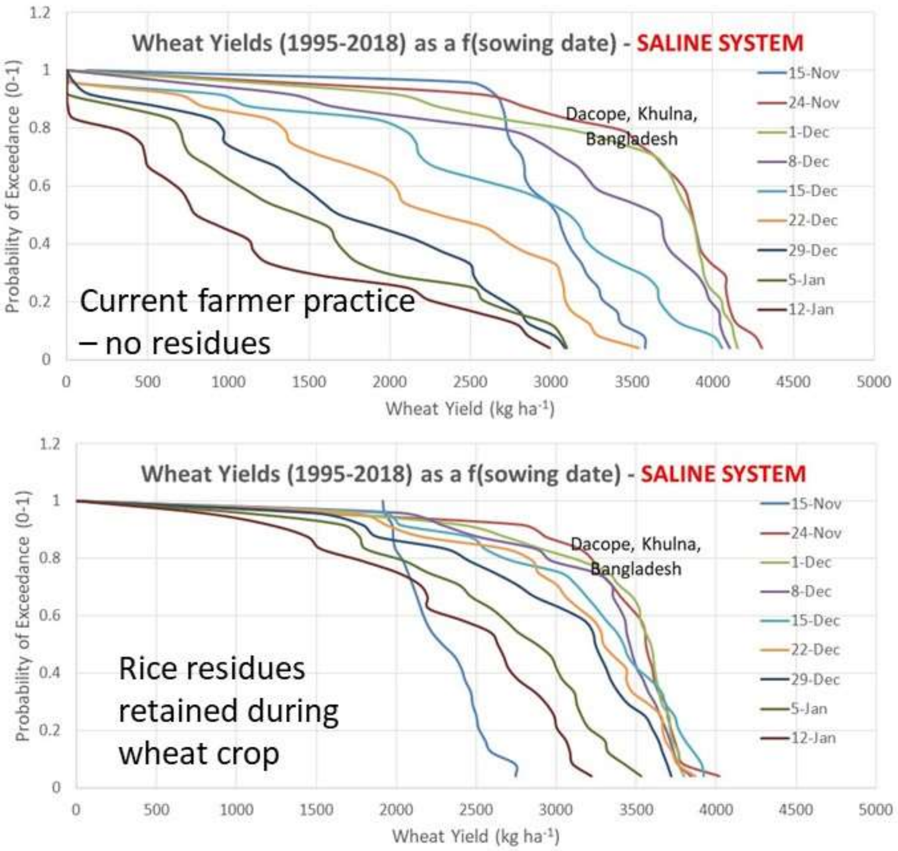

Figure 7.30 The probability of exceedance for wheat grain yields at Dacope, Bangladesh (1995-2018) illustrating the effect of sowing date and crop residues

Another key insight from the modelling is just what proportion of crop residues should be retained? After all, in conventional management the farmer feeds residues to livestock and also uses for domestic purposes such as heating and cooking. By accounting for the opportunity costs of leaving different percentages of residues in the field, we found that the optimal percentage varied, depending on (i) the time of Rabi crop sowing and (ii) between sites with different salt and water dynamics. For example, at Amtali, early Rabi crop sowing (15 Nov) achieves highest GM's when no (0%) residues are retained (Figure 7.31). As the sowing date becomes later, the negative effect of salinity plays a larger part and by January sowings, the best GM's are considerably lower and achieved with full (100%) maintenance of the kharif rice crop residues during the Rabi crop. This pattern was evident at all sites, but stronger at Amtali compared with Dacope, due to prevailing salinity dynamics. At Dacope, Rabi crop sowing (15 Nov) is best conducted with no residue retained, however by 15 Dec, around 50% is optimal (Figure 7.32). For later sowing dates, as long as 50% or more residue is retained the system GM is maximised. For both Amtali and Dacope (but more so at Amtali), the effect of salt dynamics in the system is significant – illustrated by the use of 'no salt' simulations in APSIM (Figures 7.31 and 7.32). Notably, if there were no salt in the system, our analyses indicate that residue is best used for off-field purposes in terms of the farmer's economic outcomes.

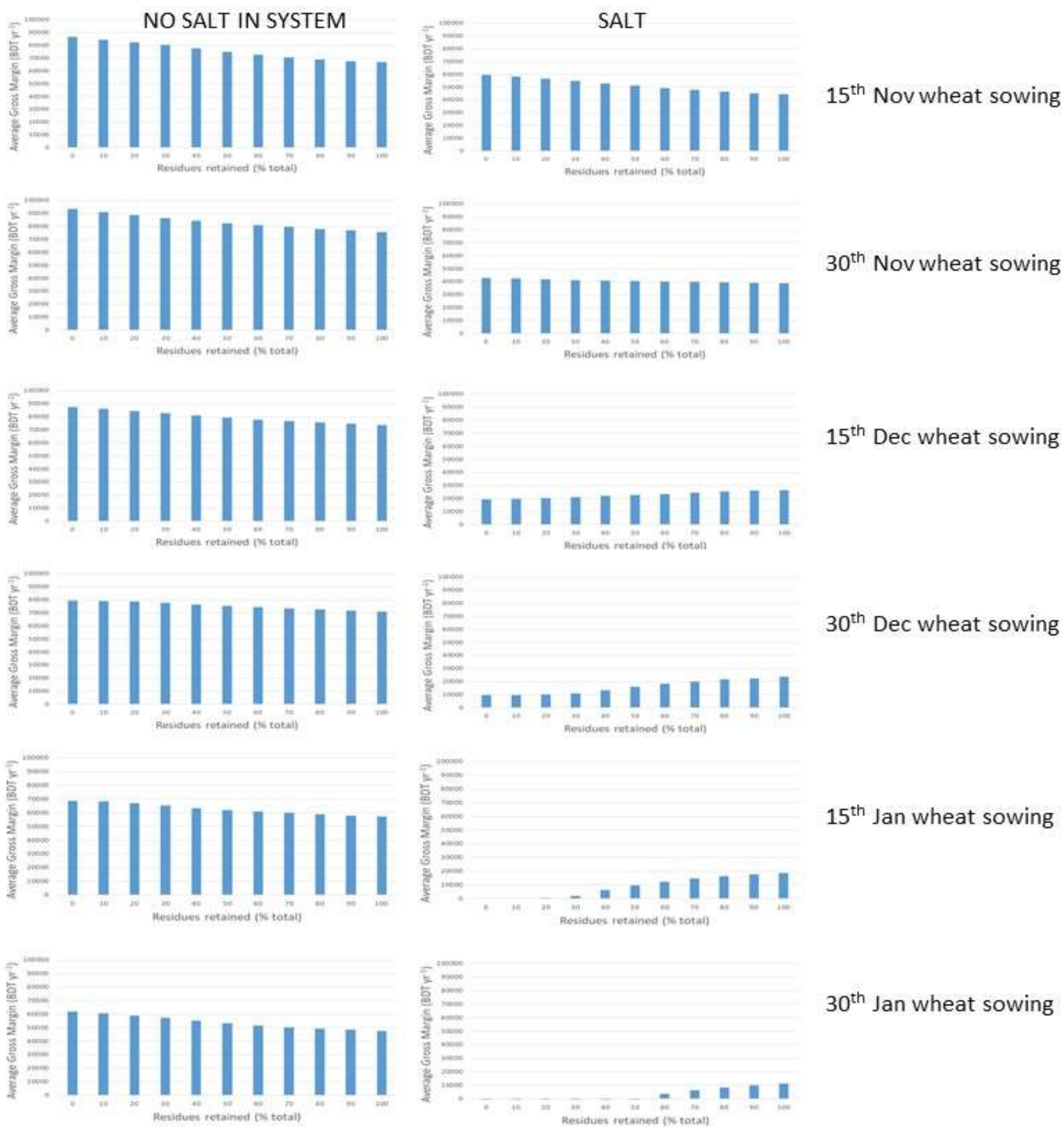

Figure 7.31 Long-term comparison (1984-2018) of average system gross margin (BDT ha^{-1}) achieved at Amtali for different percentages of kharif rice residues retained during the following wheat crop. Results are presented for wheat crops sown yearly on a.) 15th Nov, b.) 30th Nov, c.) 15th Dec, d.) 30th Dec, e.) 15th Jan, and f.) 30th Jan. The graphs on the right illustrate performance of the natural system, with dynamically-saline water table of fluctuating depth; the graphs on the left remove the effect of salt in the system (i.e. the water-table and irrigation water are both 0 dS m^{-1}).

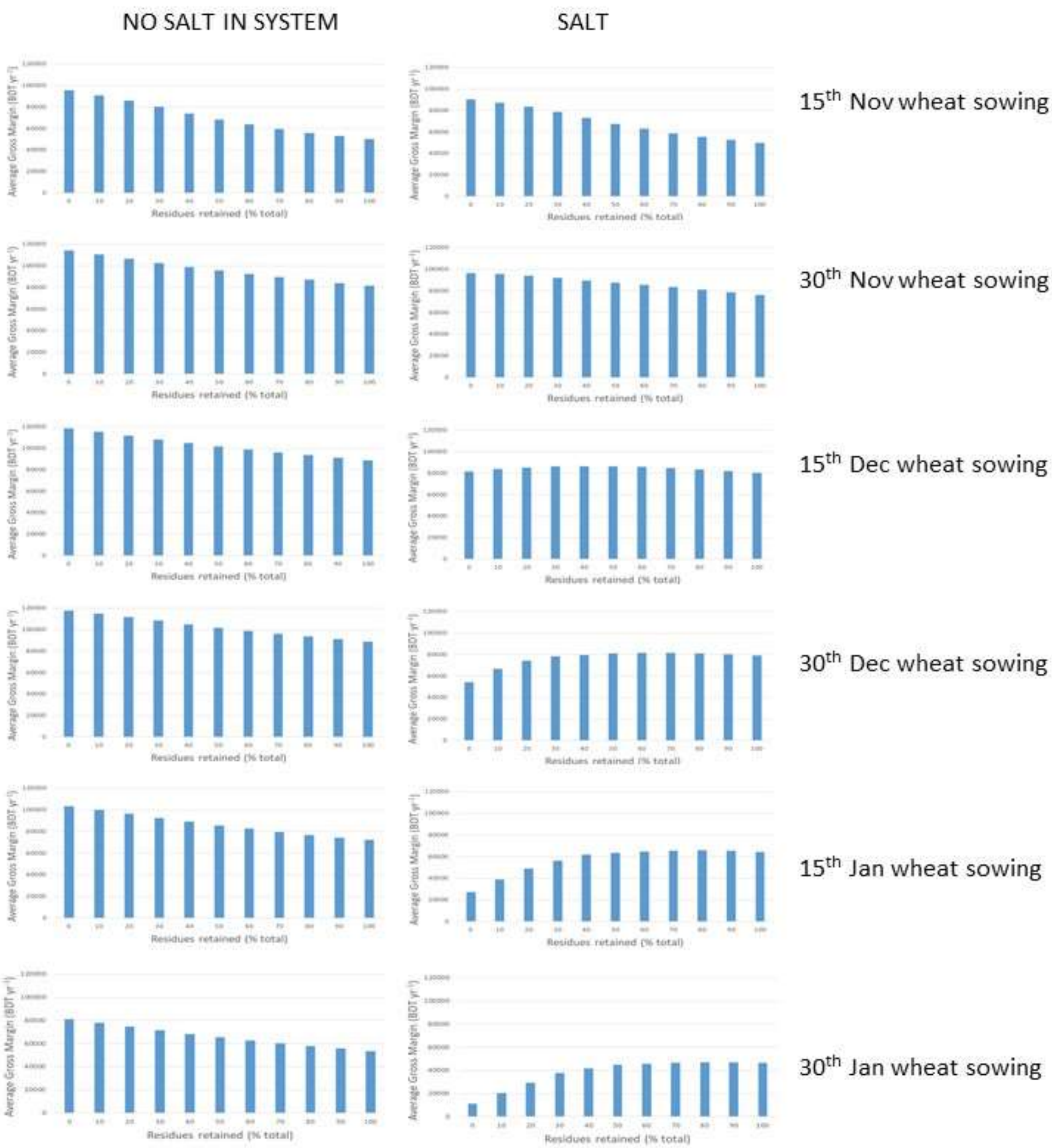

Figure 7.32 Long-term comparison (1984-2018) of average system gross margin (BDT ha^{-1}) achieved at Dacope for different percentages of kharif rice residues retained during the following wheat crop. Results are presented for wheat crops sown yearly on a.) 15th Nov, b.) 30th Nov, c.) 15th Dec, d.) 30th Dec, e.) 15th Jan, and f.) 30th Jan. The graphs on the right illustrate performance of the natural system, with dynamically-saline water table of fluctuating depth; the graphs on the left remove the effect of salt in the system (i.e. the water-table and irrigation water are both 0 dS m^{-1}).

Pumping to lower water tables – reduces salinity build-up, but introduces water-stress

Salinity build-up in the surface soil during Rabi cropping is primarily driven by capillary rise from shallow saline water tables in the CZ. We used APSIM to artificially lower the water tables by varying degrees and examine the impact on crop performance, with the aim of potentially decreasing surface soil salinity from capillary rise and thereby increasing crop yields. We found that lowering the water table has impacts on decreasing the salinity to which crop roots are exposed, but also has the unexpected negative impact of increasing the crop water stress (Figures from 7.33 to 7.35) and requiring significantly more irrigation water to achieve comparable yields. Overall, lowering the water table decreased crop yields at all sites, in addition to incurring the costs of pumping. We found that a such a significant increase in irrigation was required to overcome the crop water stress (due to lowering of the WT; green bars in Figures from 7.33 to 7.35) that it negated any real benefits and significantly decreased irrigated water productivity. There was no large differential outcomes between sites or sowing dates – pumping water (lowering water-tables) to increase crop productivity does not appear to be a useful idea and modelling has indicated there is much more value in focussing on early sowing, drainage capability implementation, and appropriate use of mulch.

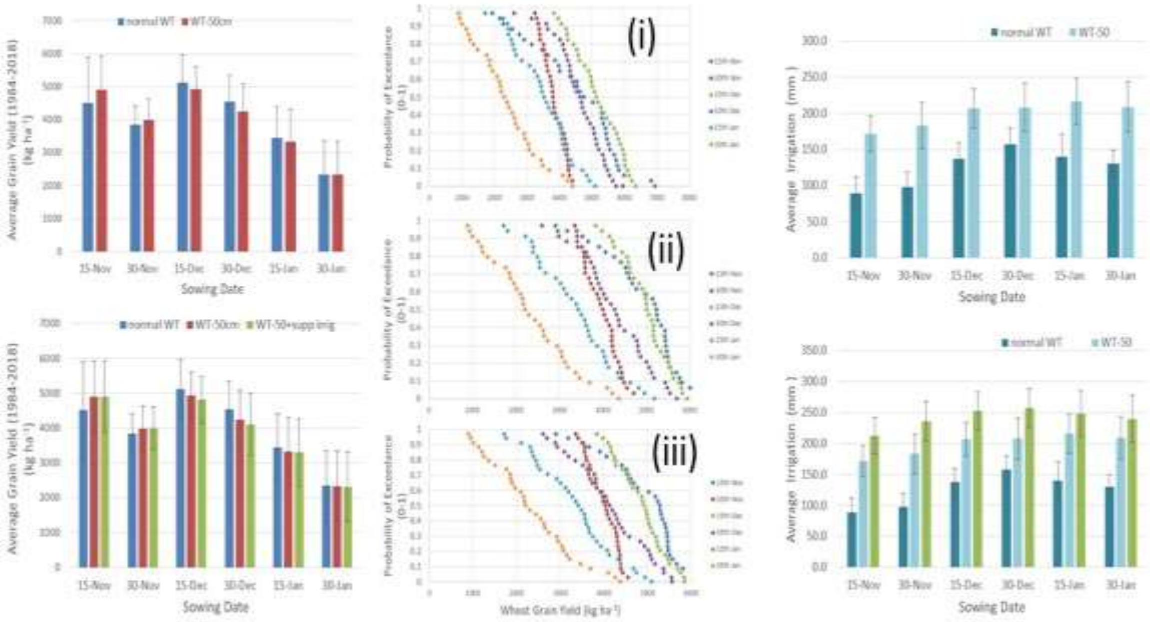

Figure 7.33 Wheat grain yields and water requirement at Dacope, Bangladesh (1984-2018) illustrating the effect of (i) sowing date; (ii) pumping to lower the water table (WT) by 50cms during crop growth; and (iii) pumping plus supplementary irrigation

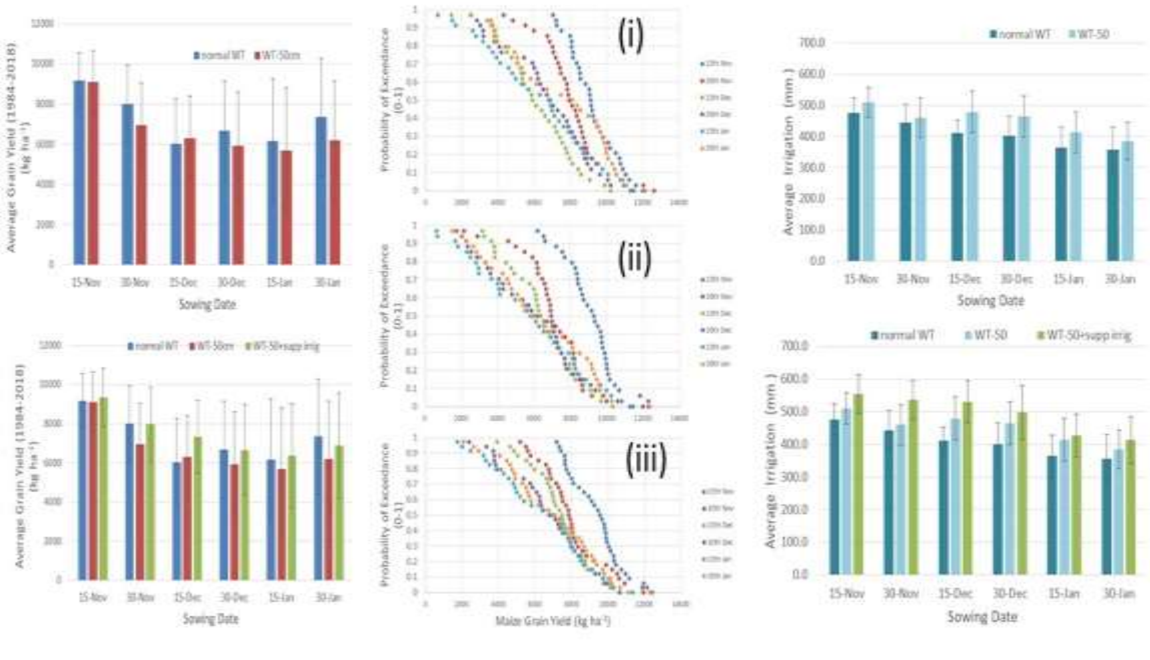

Figure 7.34 Maize grain yields and water requirement at Amtali, Bangladesh (1984-2018) illustrating the effect of (i) sowing date; (ii) pumping to lower the water table (WT) by 50cms during crop growth; and (iii) pumping plus supplementary irrigation.

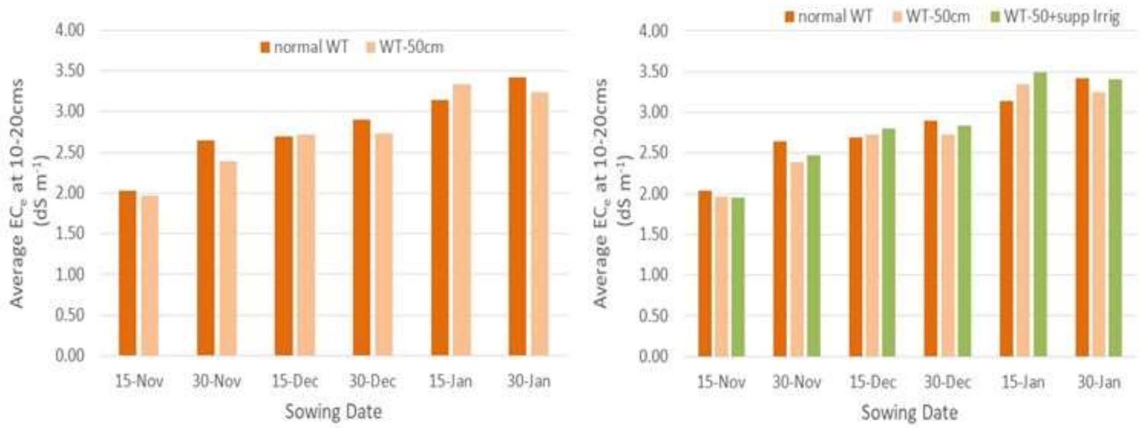

Figure 7.35 Average crop soil ECe during maize crops at (10-20cms depth) at Amtali, Bangladesh (1984-2018) illustrating the effect of (i) sowing date; (ii) pumping to lower the water table (WT) by 50cms during crop growth; and (iii) pumping plus supplementary irrigation.

7.5 Understanding spatial variability in soil salinity through use of EM survey

We used EM techniques to reduce the effects of soil factors (salinity, water logging) and optimize cropping experiments in the projects study areas to improve trial site selection processes, investigate relationships between ECa, Soil EC1:5 and soil water content and develop models at field or plot scale, and to understand when & how to use ECa in covariance analysis to improve trial results.

7.5.1 Use EM techniques to improve trial site selection processes

In the first field trials conducted with the DualEM1HS instrument in Bangladesh in 2017, we established a continuous (walking) survey method with the capacity to quickly highlight the spatial variability of ECa across the flat landscape. Plotting these data in EM4Soil or in QGIS allowed us to quickly identify sites with homogenous or highly variable ECa responses and target appropriate trial site locations (Figure 7.36).

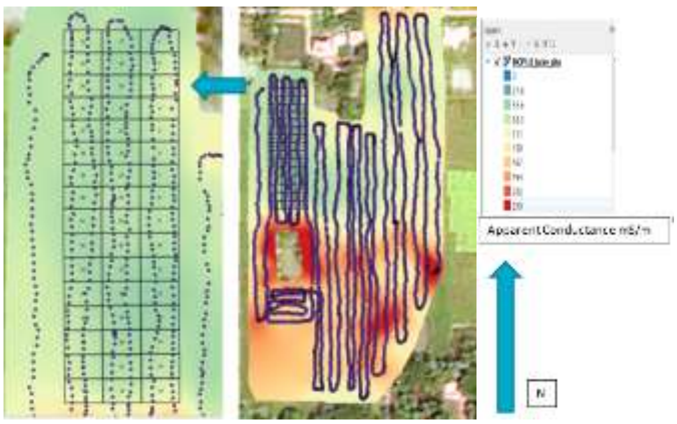

Figure 7.36 Homogenous Soil properties identified at the BCKV Site Gosaba Island West Bengal 2019

7.5.2 Investigate relationships between Eca, Soil EC1:5 and soil water content and develop models at field or plot scales

Relationships between ECa or inversion modelled ECa with Soil EC 1:5 and soil water content have been established and used to model the soil parameters spatially. Unfortunately, there are few of these models where the relationship is statistically significant. Typically, the R^2 of statistically significant models explain less than 70% of the variance of the Soil EC1:5 and rarely is the soil moisture content relationship with ECa significant. We believe that this is a function of the size of the instrument footprint compared to the size of a smaller soil auger hole used to sample the soil material. The number of soil samples that can be collected and analysed may also improve these statistics however the logistical value of such an exercise needs careful assessment with consideration to covariance results presented in the following section. In Table 7.5 a significant (p = 0.021) model states - EC1:5 (0-15cm) = - 0.1044 + 0.799 * PRP 0.5 (mS m^{-1}) from three straw mulch potato trials surveyed at Dacope in 2020. This model could be projected to an adjacent area where ECa data was also acquired, based on this ECa/Soil EC 1:5 relationship, effectively out-scaling Soil EC 1:5. The raw PRP 0.5m ECa explains 69% of the variance in Soil EC1:5 at this site in this example.

Table 7.5 Model Coefficients Predicting EC1:5 (0-15cm) using Raw ECa data from the PRP 0.5m Coil (0-30cm depth of enquiry) with an R^2 = 0.688

Model coefficients - EC 1:5 (0–15)

			95% Confidence interval				
Predictor	Estimate	SE	Lower	Upper	t	p	Stand. Estimate
Intercept	-0.1044	0.3932	-1.1151	0.906	-0.265	0.801	
PRP 0.5 mS m^{-1}	0.0799	0.0241	0.0181	0.142	3.324	0.021	0.830

7.5.3 Understand when & how to use ECa in covariance analysis to improve trial results

We used a digital layout that defines a spatial entity or polygon for each plot in a cropping trial. The ECa data can be sampled directly within these polygons are then averaged to represent the ECa value for each depth interval at each plot. Alternatively, the data can be spatially interpolated using a Kriging technique which projects data in a distance weighted analysis between data points. The kriged data is then gridded in raster format and the digital layout is used to calculate the zonal mean of the rasters which fall within with in each plot in the digital layout. The plot based ECa data are then matched with the cropping trial data for statistical analysis using Jamovi software.

Agronomic trials are generally assessed using Anova statistics to test the statistical significance (P value) of the treatment factors in relation to yield. P values <0.05 are generally accepted as significant in most instances.

The test in Table 7.6 shows the variety (P 0.086 > 0.05) has insignificant impact on tuber yield while the mulching rate (P 0.023 < 0.05) has significant impact on yield. To improve the significance of the variety impact in this trial we have used the ECa data from the HCP 0.5 (depth 0–0.8 m) as a covariate to tuber yield (Table 7.7).

Table 7.6 Anova analysis of straw mulch potato trial assessing variety and mulching rate Dacope in 2020

ANOVA - Tuber yield (t ha^{-1})

	Sum of squares	df	Mean square	F	p	$\eta^2 p$
Rep	11.82	2	5.91	1.269	0.323	0.202
Variety	16.90	1	16.90	3.627	0.086	0.266
Mulch rate	52.09	2	26.05	5.592	0.023	0.528
Variety * mulch rate	3.11	2	1.56	0.334	0.724	0.063
Residuals	46.58	10	4.66			

Table 7.7 Ancova - Covariance Analysis of straw mulch potato trial assessing the variety and mulching rate at Dacope in 2020

ANCOVA - Tuber yield (t ha^{-1})						
	Sum of squares	df	Mean square	F	p	η^2p
Rep	11.819	2	5.909	3.986	0.058	0.470
Variety	16.897	1	16.897	11.399	0.008	0.559
Mulch rate	52.094	2	26.047	17.571	< .001	0.796
HCP0.5	35.435	1	35.435	23.904	< .001	0.726
Variety * mulch rate	0.917	2	0.458	0.309	0.741	0.064
Residuals	13.342	9	1.482			

Linear regression analysis and model development can be used to predict tuber yield from the same ECa data that was used as a co-variate analysis above (Table 7.6) using the trial treatment as factors. This process can be used to out-scale yield from a trial site to a surrounding area with ECa measurements.

A predictive model ((Eq. 1) using the coefficients from Table 7.8, can be developed to out-scale the potato tuber yield (Figure 7.37) to areas outside the trial with an R^2 = 0.757.

$$Tuber\ yield = 31.956 + (-0.143) \times HCP0.5 + Para_1 + Para_2,$$

$$with\ Para_1 = \begin{cases} 0, & if\ mulch\ rate = 1 \\ 3.788, & if\ mulch\ rate = 2 \\ 3.258, & if\ mulch\ rate = 3 \end{cases} \ and\ \ Para_2 = \begin{cases} 0, & if\ variety = 1 \\ -2.201, & if\ variety = 2 \end{cases} \quad \text{(Eq. 1)}$$

Table 7.8 Model Coefficients of Tuber Yield with ECa from HCP 0.5m (0–0.8m depth) and treatment factors

Model coefficient - Tuber yield (t ha^{-1})				
Predictor	Estimate	SE	t	p
Intercept*	31.956	6.1563	5.19	< .001
HCP0.5	-0.143	0.0410	-3.49	0.004
Mulch rate				
2 - 1	3.788	0.9027	4.20	0.001
3 - 1	3.258	0.9057	3.60	0.003
Variety				
2 - 1	-2.201	0.7405	-2.97	0.011

*Represents reference level

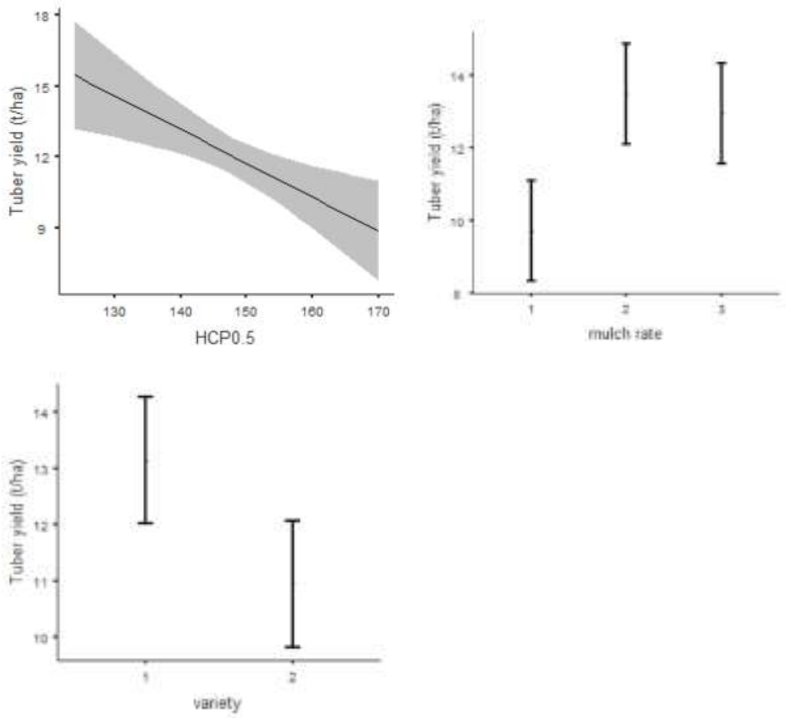

Figure 7.37 Estimated marginal means regression outputs for Tuber yield vs ECa HCP 0.5, mulch rate and variety from the straw Mulch Potato Trial at Dacope in 2020

In conclusion, the EM approach has been an outstanding success to date and there appear to be enormous scope to spatially extrapolate trial results based on this work and that of the GIS team at BCKV into the future.

7.6 Selection of suitable wet season rice verities for improving productivity and facilitating Rabi crops

Traditionally, farmers cultivate low-yielding local and long duration high yielding rice varieties under rainfed conditions in wet season (Kharif-II) (Karim, 2006; Rashid *et al.*, 2014). Due to late harvest, cultivation of following Rabi crops is delayed and exposes crops to shortage of irrigation water, increasing soil salinity, heat stress and early monsoon winds at the later stages. The objective was to find suitable rice varieties which give more yield and also mature 15-30 days earlier.

In Bangladesh, over the study period we introduced and tested 11 high yielding, short duration, and early establishing new varieties (BRRI dhan49, 53, 54, 62, 66, 71, 73, 75, 76, 77 and 87) alongside 8 existing varieties (BR 11, BR 23, Boran, BRRI dhan34, Sadamota, Swarnamushare, Tapu, Vogon) (Figure 7.38). Growth duration and yield of these varieties are given in Tables 7.9 and 7.10. Detail are given in Annex Report 10 (p 24-29) and at Maniruzzaman and Kabir (2019). Four years of research findings show that BRRI dhan87, BRRI dhan77, BRRI dhan76 gave higher grain yield than existing varieties (BR11, BR23 and all local varieties) in both Amtali and Dacope (Table 7.9). The average yield of the promising varieties was 5.47 t ha^{-1} and 5.03 t ha^{-1}, respectively for Amtali and Dacope compared to the average yield of existing varieties of 4.27 t ha^{-1} and 4.10 t ha^{-1}. Economic analysis shows that gross income (or net benefit) from new varieties were Tk.32,656 ha^{-1} and Tk.38,070 ha^{-1} compared to Tk.21,106 ha^{-1} and Tk.23,820 ha^{-1} from the existing varieties, respectively in Amtali and Dacope (p 36, Annex Report 10). By cultivating new varieties, farmers can increase their gross income or net benefit by 55% and 60%, respectively in Amtali and Dacope.

Table 7.9 Performance of high yielding new varieties at Dacope, Khulna and Amtali, Borguna during Kharif/Aman season, 2016–19

Variety	Sowing date	Growth duration (days)	**Dacope, Khulna**					**Amtali, Borguna**				
			2016	2017	2018	2019*	Average	2016	2017	2018	2019	Average
BRRI dhan49	26 July	125				3.6c	3.6					
BRRI dhan53	12–14 Aug	118	4.2a				4.2	4.57a	4.78ab			4.67
BRRI dhan54	8–14 Aug	119	3.5b				3.5	4.13ab	4.51bc	4.35c		4.33
BRRI dhan62	10–25 Aug	93						3.82b				3.82
BRRI dhan66	5–13 Aug	114	4.3a				4.3	4.21ab	4.65abc	2.6d		3.82
BRRI dhan71	26 July	115				3.5cd	3.5					
BRRI dhan73	25 Jul–11 Aug	117	4.5a	4.3ab	2.3c		3.7		4.67abc			4.67
BRRI dhan75	26 July	105				3.2d	3.2					
BRRI dhan76	25 Jul	151		4.6ab	5.6a	4.1b	4.8		4.5bc	5.6a	5.6a	5.23
BRRI dhan77	25 Jul	145		4.7a	5.8a	4.2b	4.9		4.9a	5.45ab	5.5b	5.28
BRRI dhan87	26 July	126				5.4a	5.4					
BR23 (improved management)	15–25 Jul	148	4.2a	4.4ab	5.5ab	4.4b	4.6	4.56a	4.37c	5.23b	5b	4.79
BR11 (improved management)	15–25 Jul	145		4.15b	5.2b		4.6		4.5bc	5.04b		4.77
CV			8.89	6.6	6.7	4.0		10.5	4.6	6.0		

Table 7.10. Performance of farmer's variety at Dacope, Khulna and Amtali, Borguna during T. Aman, 2016–19

			Dacope, Khulna					**Amtali, Borguna**				
Variety	Sowing date	Growth duration (days)	2016	2017	2018	2019*	Average	2016	2017	2018	2019	Average
BR 23	15–25 Jul	149	3.9a	3.9a	5.1a	4.0a	4.2	3.9a	4.3a	4.8a	4.7	4.42
BR11	15–25 Jul	146	4.1a	4.1a	4.7b	3.7a	4.1			4.6a	4.7	4.65
Sadamota	25 Jul	153		3.1b	4.4b	2.5b						
Vozon	15–30 Aug	148							3.6b	4.4b	4.6	4.2
Shwarnamoshure	15–30 Aug	147						3.6ab	3.8b	4.3b	4.4	4.03
Tapu	15–30 Aug	146						3.6b	3.8b		4.7	4.03
Boran	12–23 Aug	161	4.0a				4.0					
BRRI dhan34	11–12 Aug	136	3.78a									
CV (%)			6.8	3.3	4.0	10		4.68	4.7	6	11.4	

Preference analysis (p 37- 49, Annex Report 10) was conducted every year (2016-2019) to identify the best suited new crop varieties for large scale dissemination in the farmers' fields. The result show BR23 and BRRI dhan76 were most preferred varieties at Amtali area because of the potentiality of the variety for transplanting in the fields with over a feet depth of water, higher growth rate of the plants, longer growth duration so that matured for harvesting after drainage out the stagnant water from the fields, less or no infestation of disease and long panicle with large number of grain. BRRI dhan77 was second most preferred variety in Amtali mainly because of its suitability for planting in fields with stagnant water, matured for harvesting after drainage out stagnant and long panicle so that expected higher yield. Newly introduced variety BRRI dhan87 was the most preferred variety at Dacope followed by BRRI dhan76 and BRRI dhan77. The main feature of BRRI dhan87 was 20-25 days earlier harvest with good yield than local varieties, long panicle with large number of glossy colour medium slander grain that might be tested good to eat and higher yield.

Short duration Binadhan–7 (life cycle 110–120 days) was cultivated in both 2016 and 2017 Kharif/Aman season at Dacope (p 5, Annex Report 11). In 2016, Binadhan–7 was transplanted on 7 July and harvested on 6 October; in 2017 it was transplanted on 25 July and harvested on 7 November (usual harvesting time of any Aman rice is December in this area). The grain yield of rice was 3.5 t ha^{-1} and 3.0 t ha^{-1} in 2016 and 2017, respectively, which is approximately equal to the average rice yield in Aman season in Bangladesh. Usually the land remains excessively wet after rice harvest. As this variety was harvested far ahead of usual harvesting time (December), the land was wet because of the growing rice fields surround the harvested land.

In this situation, early variety of rice can vacant the land early (than the late one) and drainage of land just after rice harvest helped quick drying of excess moisture. However, early cultivation of HYV rice and winter crops face rodents, birds and domestic animal damage because of small area coverage by early rice and the subsequent winter crops (one/few farmers). These damages may potentially be overcome by community approach: cultivating early varieties of approximately similar duration and cultivating winter crops in a vast area by many farmers.

In Gosaba, CSSRI introduced and tested 5 varieties of rice (Pratikshya, CR 1009, CR 1017, CR 1018, MTU 1075) along with three indigenous cultivars (Jatayu, Amal-Mana, Swarna-Sub 1). Among the 5 rice varieties tested over the three years, varieties CR 1009, CR 1017, CR 1018 and Pratikshya performed better with grain yields above 6.0 t ha^{-1} (Table 7.11, also see p 7 Annex Report 12). However, the rice variety Pratikshya matured earlier by about 15 days which is very significant in earlier establishment of second crop. The crop duration for Pratikshya was 132 days while the duration of other varieties was about 150 days.

CSSRI also used 4 different crop establishment methods viz. conventional puddled transplanting (PTR), non-puddled transplanting (NPTR), drum seeding (DRUM) and direct seeding (DSR) with two varieties (Figure 7.38); Pratikshya and CR 1018. In 2016, the highest grain yield of 4.09 t ha^{-1} obtained under PTR, while drum seeding resulted in the lowest grain (3.09 t ha^{-1}). In 2017, DSR resulted in similar grain yield of rice (6.47 t ha^{-1}), compared to PTR (6.52 t ha^{-1}). In 2018, DSR yield was significantly higher than PTR as well as NPTR (p 7, Annex Report 12 and Sarangi *et al.*, 2019a). The DSR crop was harvested earlier by more than one week, which may facilitate earlier establishment of subsequent rabi crops. The two varieties did not differ with respect to grain yield; however the straw yield was highest in CR 1017. The grain and straw yields were comparable in DSR (6.47 and 8.35 t ha^{-1}, respectively) and PTR (6.52 and 8.39 t ha^{-1}, respectively). The soil moisture was better distributed in soil profile under DSR with less moisture in the upper layer facilitating earlier establishment of subsequent Rabi crop.

Based on three years of study, it is concluded that alternative rice establishment methods such as dry direct seeded rice or non-puddled transplanted rice may be suitable for the submergence-prone lowlands of the coastal region of the Ganges delta. Pratikshya was a promising rice variety with suitable plant height to avoid submergence in medium to low land type and it has lodging tolerance that is favoured by farmers. By maturing at least by 15 days earlier, Pratikshya creates opportunities for cropping system intensification in the coastal zone by earlier establishment of Rabi season crops.

Figure 7.38 High yielding and early-maturing Aman rice at the field of Amtali along with local rice (left), established direct-seeded (DSR) rice at Gosaba (right)

Table 7.11 Yield and duration of tested Kharif-II rice cultivars at Gosaba

Variety	Crop duration	Average grain yield (t ha^{-1})				
		2016	2017	2018	2019	Average
Gosaba (pre-existing varieties), BCKV						
Dudershar	130		4.09	3.83		3.96
Dud Shal	128		3.88	-		3.88
SR 26B	140		4.87	-		4.87
Lal Minikit	120		2.33	-		2.33
Patiksha	135	4.93	5.33	5.24		5.29
Gobindobhog	130			2.93		2.93
CSSRI						
Jatayu	148				4.82	4.82
Amal-Mana	163	4.19				4.19
Swarna-Sub 1	143	2.93				2.93
Gosaba (introduced varieties), BCKV						
Amalmana	150		5.18	4.93		5.06
Canning 7	140		5.32	5.01		5.17
CR 1017	150	5.35	5.31	5.24	5.39	**5.32**
Gitanjali	145		5.26	5.20		5.23
Koushlya	145		4.84	4.27		4.56
Jatayu	142	-	-	5.40	5.42	**5.41**
Santoshi	135			5.63		**5.63**
CR1009	155			5.31		5.31
Super Shamoli	140			4.93		4.93
Swarna Mashuri	130			4.52		4.52
Muktoshri	130			4.11		4.11
BN20	128			4.69		4.69
Sabita	150		5.20	5.29		5.25
Sujala	150		5.72	5.03		5.38
Swarna Sub 1	135		4.56	4.80		4.68
CSSRI						
CR 1009	150	3.86	6.18			5.02
CR 1017	150		6.19		5.37	5.78
CR 1018	155			6.09		**6.09**
MTU 1075	144				5.21	5.21
Pratikshya	134			6.07	5.41	**5.74**

At the BCKV site at Gosaba Island, we evaluated 15 high yielding varieties and compared the results with 6 other existing varieties (Table 7.11, and p 20 Annex Report 13) for yield, salt tolerance and other yield attributing characters. The results clearly indicate that introduced rice cultivars performed significantly better in the farmers field than the production of old pre-existing cultivars. From this demonstration trails farmers selected three rice cultivars i.e. CR1017, Jatayu and Santoshi based on the duration, constant yield performance and cooking preferences.

7.6.1 Optional planting and harvest dates of T. Aman and effects on yield

The study on T.Aman at Rangabelia in Gosaba Island (p 18, Annex Report 13) considered six planting times and two varieties of T.Aman. From the yield of two varieties of T.Aman, SwarnaSub1 (orange dots, Figure 7.39a) and CR1017 (blue dots, Figure 7.39a) it is clear that best seed yields were achieved with early sowing in mid-June. This was especially so in the higher-yielding line Swarnasub1 for which yield declined from 6.0 to 4.0 t ha^{-1} (around 40%) by delaying planting by 5 weeks from 15 June to 19 July. Almost 60 kg ha^{-1} of rice was lost per day delay. Though the overall trend is clear it would be interesting to know why low yield occurred from a 27 June sowing. Maybe increased water flooding at a critical stage reduced leaf area exposure to radiation which in turn reduced carbon fixation. Straw yield (Figure 7.39b) followed a more curvilinear relationship with planting date possibly associated with the continuing accumulation of biomass as the season progressed and linked changes in radiation levels. CR1017 produced equivalent straw yield from early and late plantings.

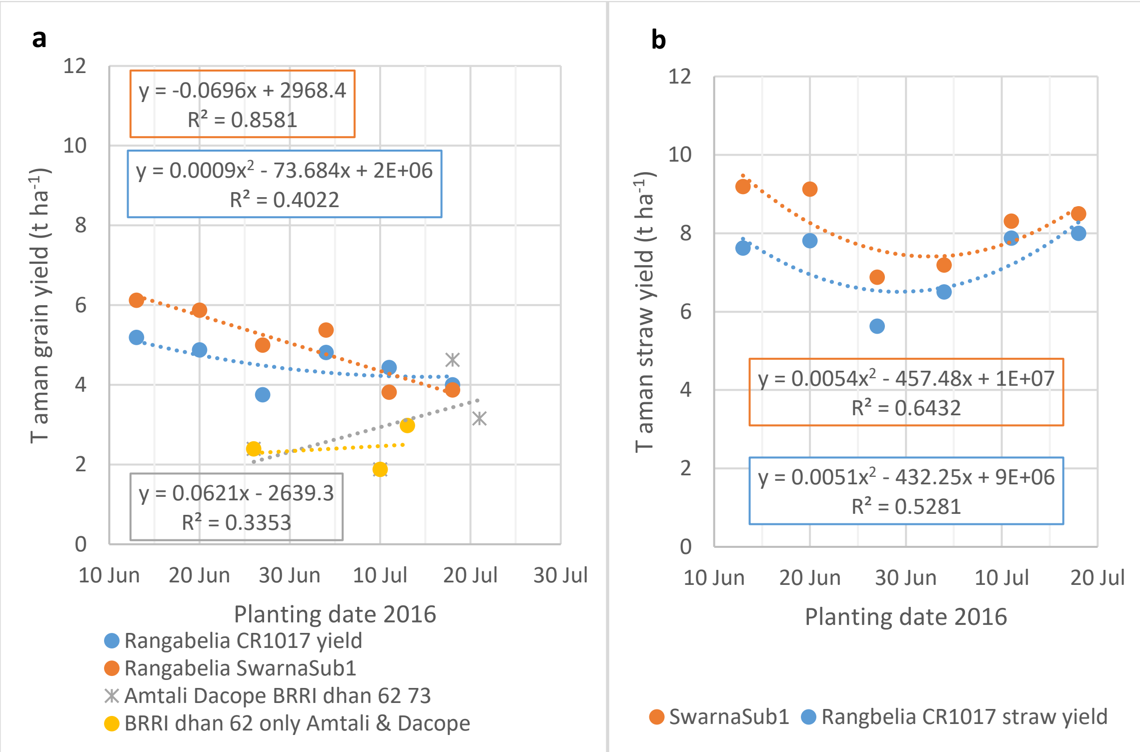

Figure 7.39 Grain (a) and straw (b) yields of Kharif or T. Aman rice at different sowing dates

The conclusion may be that if planting dates must be delayed till mid to late July until the previous crop has been harvested, then T.Aman yields will be limited to 3.0 to 4.5 t ha^{-1} dependent on the variety chosen. BRRI dhan 62 was not acceptable to farmers primarily because of its low yield but also because of earlier maturity it attracted bird damage. There was no trend in the Amtali and Dacope data indicating that high yields would result from very early plantings in mid-June as the Rangabelia data had demonstrated. Indeed there was an insignificant reverse trend.

Transplanting time for T.Aman in Amtali was 16 August for the preferred BRRI dhan 73 (Table 7.9), a tight but possible fit with harvesting time of previous T. Aus crops. Its harvest date was 12 November, so early enough to allow the cultivations required for a following dry season Rabi crop and early enough to capture the full fresh water soil profile remaining from the monsoon.

7.7 Growing vegetables with wet season rice under waterlogged lowland condition

Due to high water levels in the field and around households during the monsoon season, it is very difficult to grow vegetables in this area. The prices of vegetables are comparatively higher in the market at this time. In 2016 wet season in our project's two Bangladesh sites, we tested growing vegetables in bags over the highly water-logged rice fields (Figure 7.40, left). It was a new concept and initially farmers could not believe that vegetables can grow in waterlogged situation. Therefore, it took lot of convincing by our BRRI colleagues to get one farmer agree to do this in each site.

Figure 7.40 Growing vegetables in bags of soil in the wet season (Aman) rice in Amtali (left) and at Gosaba (right)

In 2016, additional income was Tk.7,074 ha^{-1} and Tk.8,375 ha^{-1} respectively from Amtali and Dacope (p 53, Annex Report 10). This was insignificant compared to initial investment required. We repeated this in 2017 and 2018 (p 53-57, Annex Report 10). While some farmers gained additional benefit some farmers also lost due to loss in rice yield and higher initial investment. Farmers reported about 10% yield loss or rice due to placement of the bag. The bag is also not durable for multiple season which increase the cost of this technology. We tested by replacing the bag with plastic drum and analysed 3 scenarios considering the durability of the drum as 10, 12 and 15 years. The net income was in the range between Tk. 38,220 ha^{-1} to Tk. 71,242 ha^{-1} across the three scenarios under the modified method. The results indicate that the integrated rice/vegetable system would economically profitable to farm households. Farmers commented that the technology is highly potential for large-scale adoption. However, the initial investment for the system was behind the investment ability of the most farm households, including large farmers.

We introduced cultivation of vegetables in paddy field in Gosaba in Kharif season of 2018 with 3 farmers at the CSSRI site. In 2019, 12 farmers showed interest and adopted this technology. Farmers cultivated bitter gourd and cucumber. In 2018, the average net additional income from 48 m^2 area was Rs.985. This is equivalent to Rs.194,000 ha^{-1} compared to the net income of Rs. 27,701 ha^{-1} only with rice cultivation. In 2019, average net income from 12 farmers was Rs.175,308 ha^{-1} against Rs.10,368 ha^{-1} from solo rice cultivation (p 35, Annex Report 12). While we are struggling to make this technology profitable in Bangladesh, the results of the two-year study in the Gosaba island reveal that cultivation of vegetables in bags along with low land paddy is a profitable technology with higher net return and benefit cost ratio compared to sole cultivation of paddy. This technology should be demonstrated in more locations and other island for wide spread adoption.

7.8 Introduction of Aus rice in the cropping pattern in the sites of Bangladesh

Even though rice is the major crop of the southern coastal regions of Bangladesh, from our farmer focus-group discussions, there appears to be significant unmet demand for rice in the study areas. The dominant crop grown in the saline areas is transplanted Aman rice which is grown during the Kharif-II season as discussed earlier. Transplanted Aus is usually cultivated in the Kharif-I season. Based on farmers' interest, we have introduced Aus rice in the project area. Aus rice is an alternative to Kharif-I upland crop cultivated in rainfed condition in nearby areas. The main problem with Aus rice is seedling raising and transplanting. Seedlings are raised where water is available and transplanting start with on-set of seasonal rainfall. So, area coverage of Aus rice vary in the years with time of rainfall starting and quantity in the region. Soil salinity of the coastal region peaks during April-May, which is the time for seedling raising and transplanting. Most of the area faces serious water shortages in this period. So, development of irrigation facilities may help to intensify the fallow lands with Aus rice during Kharif-I season in the project site.

In 2017, we started cultivation of Aus rice with 11 farmers in Amtali and 1 farmer in Dacope using BRRI dhan48 (most popular variety of Aus) (Figure 7.41). The average yield was 4.1 t ha^{-1} and 4.6 t ha^{-1} respectively in Amtali and Dacope (p 106, Annex Report 10). The country average yield of Aus rice was 2.25 t ha^{-1} in 2015-16. Aus rice was also found to be highly profitable with gross income over Tk. 20,000 ha^{-1} (p 107, Annex Report 10). Aus rice was new to the farmers particularly in the Dacope area. Farmers have never seen such production in the Aus season. Farmers showed high interest to grow Aus rice by conserving fresh water in the canal. In another area within Amtali, another 3 farmers cultivated Aus rice and achieved yield of 3.79 t ha^{-1}, 4.01 t ha^{-1} and 4.19 t ha^{-1}. Gross margin or net benefit varied from 75,800 Tk. ha^{-1} to 80,800 Tk. ha^{-1} (p 36, Annex Report 7).

Figure 7.41 Cultivated Aus (left) Boro (right) rice in Bangladesh

Following the interests of the farmers, we set up experiments to find the suitable planting time for Aus rice in 2019. We used seven seeding (to prepare seedlings in the nursery) dates at 10 days interval starting from 01 April. Two varieties were used; these were BRRI dhan48 (popular but non-saline tolerance Aus variety) and BRRI dhan67 (saline tolerance Boro variety). Twenty days-old seedlings were transplanted with 20 cm x 20 cm hill spacing – following BRRI recommendation at each location. The results showed that 10 April to 30 April sowing date performed better irrespective of varieties and locations (p 104, Annex Report 10). The average yield was above 4.5 t ha^{-1} in both locations. After that, the yield declined for both varieties. The irrigation water salinity varied from 4.0 to 6.4 dS m^{-1} at Dacope and 2.38 dS m^{-1} to 4.24 dS m^{-1} at Amtali during the season (p 104, Annex Report 10). The experiment was supposed to be conducted in 2020 but that was not possible due to COVID-19 lockdown.

Production of Aus rice in the coastal area is an option for cropping intensification. The seedling raising period and the crop establishment period is the critical time due to water shortage. In most years, monsoon rainfall stars early in coastal region. On the basis of yield performance April 10-30 is the optimum window for Aus growing in the coastal areas. Delay in transplanting may hamper the timely transplanting of Aman rice.

7.9 Selection of suitable variety and sowing time for Boro (dry season) rice

The dry season irrigated rice i.e. Boro rice requires a large volumes of irrigation water. The water requirement is greater in the coastal region due to the need for salt flushing. But the fresh water resource in dry season is limited in the coastal region. The objective of this study was to find out the potential of growing Boro rice in this water-constrained environment, it's response to salinity and to find out a suitable planting time through APSIM modelling. The modelling facilitates exploration of the crop's potential in a wide range of coastal environments and to determine the optimum methods for Boro rice cultivation in coastal regions of Bangladesh as discussed in Section 7.5. We set up experiments in both sites in Bangladesh and a mirror site in a non-saline condition in the Regional Research Station of BRRI in Barishal (p 73, Annex Report 10; Yesmin *et al.*, 2019).

In each site, we used 3 varieties of Boro rice. These are BRRI dhan28 (popular but non-saline tolerant Boro variety), BRRI dhan67 and BINA dhan10 (saline tolerance Boro varieties) with six sowing dates (date the seeds were sown in the nursery) at 15 days interval starting on 15 October. The experiment was conducted in consecutive 2 years 2016-17 and 2017-18.

Among the six sowing dates 30 November and 15 December sowing dates gave highest yield in the field irrespective of varieties. In Dacope, BINA dhan10 produced highest yield (6.03 t ha^{-1} and 6.41 t ha^{-1} respectively in 2016-17 and 2017-18) followed by BRRI dhan67 (5.88 t ha^{-1} and 6.17 t ha^{-1}) (p 75-76, Annex Report 10). The result was similar in Amtali. The yield of BINA dhan10 sown on 15 Dec was 6.17 t ha^{-1} and 5.0 t ha^{-1}, respectively in 2016-17 and 2017-18 (p 79-80, Annex Report 10). The yield is much higher than the country average yield of Boro rice (~4.0 t ha^{-1} in 2015-16). In the non-saline condition (on-station trial in Barisal), BRRI dhan28 produced the highest yield among the 3 varieties (6.09 t ha^{-1} for 15 December sowing) in 2016-17 (p 83, Annex Report 10). In 2017-18, the highest yield was 6.45 t ha^{-1} for BRRI dhan28 sown on 30 October (p 84, Annex Report 10).

Economic analysis carried out for 2016-18 shows that Boro rice is highly profitable. The gross income or net benefit gained was Tk.41,155 ha^{-1} at Amtali and Tk.46,675 ha^{-1} at Dacope (p 86, Annex Report 10). However, this varies from year to year due to the fluctuation of rice price in the market but is always profitable.

The performance of Boro rice in saline coastal locations such as in Dacope and Amtali was consistent with the potential yield of modern cultivars. The grain yield of salt-tolerant cultivars was better than non-salt tolerant varieties in saline soil of Dacope and Amtali. The results stipulate that there is potential for cropping rice in the dry season in saline coastal Bangladesh where there is water for irrigation.

The irrigation requirement of Boro rice at Amtali was 560-970 mm in 2016-17 and 730-850 mm in 2017-18 depending on the time of transplanting and rainfall during the growing period (p 81, Annex Report 10). In Dacope, these were 600-988 mm and 656-910 mm (p 77, Annex Report 10). In fresh-water scarce environment this is quite high. So, we tested water saving irrigation technologies in both sites during 2018-20. We used continuous standing water and alternate wetting and drying (AWD) though AWD was not suggested in saline prone areas due to leaching requirements of salt. There were two varieties; BRRI dhan81 (latest non-saline tolerance HYV Boro variety) and BRRI dhan67 (saline tolerance

Boro variety). In 2019-20, we replaced BRRI dhan81 with BRRI dhan89 as the performance of BRRI dhan81 was very poor in 2018-19. In 2019-20, the yield of BRRI dhan89 was highest (7.0 t ha^{-1}) with AWD at Dacope compared to 6.8 t ha^{-1} with continuous standing water. At Amtali. The yield was almost similar (about 6.7 t ha^{-1}) for both AWD and continuous standing irrigation. The yield of BRRI dhan67 was lower than BRRI dhan89 in both places (p 89, Annex Report 10).

The irrigation water use varied from 678 to 906 mm based on water management in both the locations. Compared to the continuous standing water, AWD method of irrigation required 20-24% less water in both the locations for the tested varieties (p 91, Annex Report 10). Though in saline belt, AWD was not recommended earlier for increasing the salinity level of soil in the rice field, in this case, low salinity (< 4 dS m^{-1}, p 91, Annex Report 10) of trapped canal water did not have any adverse impact of rice growth and yield.

We also experimented use of mulch to reduce water requirements and to find out the reduction rate of salinity in water. Four different types of mulch (ash, saw dust, rice husk, and rice straw) was used along the no mulch condition in both location during 2018-19 and 2019-20. The combined statistical analysis revealed that the yield significantly varied among the treatments, locations and tested years (Figure 7.42). Mulching in the rice field is not common practice in Bangladesh. But the results indicated that application of ash mulching gave the yield advantage and also reduce the salinity level in the field (p 93, Annex Report 10).

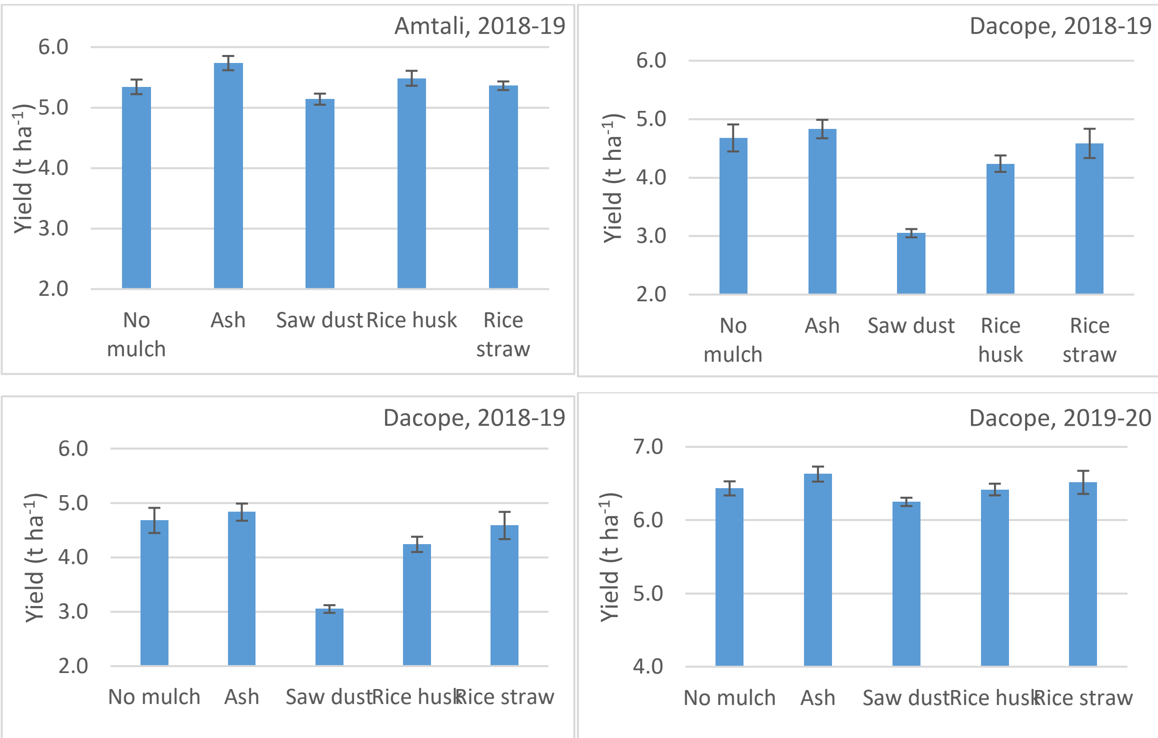

Figure 7.42 Yield of Boro rice with different mulching materials at Amtali and Dacope

The highest grain yield was found in ash mulching and the lowest grain yield was found in saw dust mulching in both the locations and years. It was observed that the fresh saw dust might have developed some toxicity resulting in water colour became red and crop appeared to be stunted. Ash mulching treatment produced comparatively higher yield in both the locations and years (Figure 7.42). It may be due to higher potassium content in ash, which reduced the salinity effect from rice field. Ash mulching showed 1.28 to 7.35% yield advantage over the conventional no mulching treatment over the locations and years.

In West Bengal, we set up on-station experiments (at CSSRI Canning Town) to select the salt tolerant variety and the suitable sowing time with 3 rice varieties (WGL 20471, Bidhan 2 and IET 4786) with 6 dates of sowing at 15 days interval starting on 01 October (p 18, Annex Report 12). The mean grain yield was lowest when sown earliest on 1st October, which was may be due to the incidence of diseases under low temperature regime. However, the yield also declined due to delay in sowing in December. There was a significant interaction between dates of sowing and varieties. The grain yield varied from 2.74 t ha^{-1} to 7.08 t ha^{-1}, 2.66 t ha^{-1} to 7.19 t ha^{-1}, and 2.08 t ha^{-1} to 4.25 t ha^{-1} for WGL 20471, Bidhan 2 and IET 4786, respectively in 2017-18. In 2016-17, yield was lower (p 19, Annex Report 12). In case of varieties WGL 20471 and Bidhan 2, sowing can be delayed even up to early December but there was yield reduction beyond 15th December sowing. However, in case of variety IET 4786, early sowing is beneficial and delay in sowing resulted in significant yield loss.

Production of Boro rice in the coastal area is an option for cropping intensification in the comparatively low land areas where water levels recede slowly after T. Aman harvest and there is limited option for accelerated drainage (Figure 7.42). But Boro rice needs more water than other crops. So Boro rice may be grown where the fresh water resources are available during crop growing season. The enterprise budget indicates that dry season rice cultivation at current price is profitable based on gross margin and return.

7.10 Screening of suitable crops for coastal region

We started our activities in the field in the Kharif/Aman season of 2016 with the introduction of some new varieties of Aman/Kharif rice along with existing varieties. For the following Rabi season, we initiated our activities by selecting some crops (such as Boro rice, wheat, maize, sunflower, etc.) based on the literature, experience of our local team members, and discussion with the farmers in the project sites. From the following years we started introducing new crops and set up crop cafeteria where we tried to grow different crops in small plots to see their performance.

At Amtali, we established a crop cafeteria in farmers' field during Rabi season of 2018-2019. Suitability of growing different crops like maize, barley, wheat, millet, field pea, cowpea, mustard and sunflower were observed against salinity and inherent soil conditions of coastal region. For each crop, we also used different varieties. For example, for Barley we used 7 barley varieties released by BARI. Unit plot size was 8m×5m. In the field all the varieties did not performed well. The performance of cereals (maize, barley, millet) was better than pulses (filed pea, cow pea) and oil seeds (mustard and sunflower). Among the tested cereals foxtail millet (Kaon) performed better than others (Figure 7.43). The yield of BARI Kaon-2 (1.15 t ha^{-1}) was higher than BARI Kaon-1 (p 41, Annex Report 9). The yield of maize was not up to the mark due to lack of irrigation facilities. Though maize is suitable to be grown in the area if there is irrigation facilities. Barely also performed well and looked promising. In case of pulses, germination was good but in later stage maximum plants damaged due to soil moisture stress as well as soil salinity. During crop growing period salinity ranges from 2.4-7.2 dS m^{-1} in the field (Fig. 1). Yield of mustard and wheat was not satisfactory due to delayed sowing (land was not suitable for earlier sowing).

Figure 7.43 Foxtail millet (left) and English spinach (right) cultivated at Amtali and Dacope

In Dacope, there were experiments on several crops (wheat, mustard, garden peas, sunflower, maize, etc.) used in the crop cafeteria of Amtali. So in 2017-18 we introduced and tested zero tillage potato (described later) and in 2018-19 we introduced English spinach (Figure 7.43). Average yield was recorded 17.28 t ha^{-1}. Estimated gross return or net benefit was Tk.108,440 ha^{-1} and marginal benefit cost ratio was 2.68, which indicated spinach cultivation is profitable (p 50, Annex Report 09). In the following year, we set up experiments to find out suitable sowing and harvesting time of spinach which is described in Section 7.11.

At Gosaba, we introduced and tested sunflower, linseed, mustard, Indian spinach, broccoli and capsicum during 2017-18 (p 22, Annex Report 12). Results shows that broccoli and Indian spinach are suitable vegetable crops for rabi season. One of the women farmers Mrs. Sumitra Giri was very successful in the cultivation of Broccoli crop. She got net income of Rs. 1,192 from an area of 70 m^2 (Rs.170, 357ha^{-1} ~ 3,800 AU\$ha^{-1}) apart from meeting home consumption. This crop not only increased her income, but also she could provide nutritious vegetables to her family. She continued cultivation of broccoli for the next years. Mustard can be grown with early sowing and sunflower with effective control measures to protect from the damage by parrots. Linseed was found to be least suitable as a rabi crop in the Gosaba island. In the following years, we also tested more crops (onion, garlic, okra, French bean, tomato, pumpkin, bitter gourd, snake gourd, cucumber, chilli, mung bean, mustard, cabbage, cauliflower, knol-khol, beetroot) with paddy straw mulch which are discussed later in Section 7.13.1.

7.11 Finding suitable time of sowing for different crops

Time of sowing experiments have been conducted in two years with wheat, maize, sunflower, mustard and spinach.

Wheat: In Dacope, we tested 8 sowing dates for wheat (BARI Gom 25) at 1 week interval starting from 24 November (p 13-14, Annex Report 11; Kabir *et al.* (2019)) in 2016-17. But in 2017-18, due to late rainfall on 8-9 December, we were able to test only 4 sowing dates (starting from 19 December). In 2016-17, the grain yield was the highest in 1st and 2nd sowing dates (4.4 t ha^{-1} and 4.1 t ha^{-1}, respectively). After the 2nd sowing, the yield started to decline. From the 3rd to 5th sowing, the grain yield was statistically at par (3.7 to 3.9 t ha^{-1}). With the delay of sowing, the grain yield further declined and the lowest yield (2.4 t ha^{-1}) was found with the 8th sowing (45 days later than the 1st sowing). From 1st sowing to 8th sowing, the grain yield declined by about 50%. In 2017-18, the 1st sowing gave the highest yield (2.72 t ha^{-1}) which was statistically similar to that of 2nd sowing (2.50 t ha^{-1}) while the 4th sowing gave lowest yield (1.34 t ha^{-1}) (p 13-14, Annex Report 10). Generally, long winter season is required for higher production of wheat as found in northern Bangladesh. The cost benefit analysis showed that in a good (no late rain, no infestation of pests, etc.) year (e.g., 2016-17), net profit of ~60,000 Tk ha^{-1} can be obtained from early wheat. But the net profit could be zero or even negative for wheat in an adverse year such as in 2017-18. In Amtali, wheat cultivation was not profitable. So wheat is a very risky crop.

Sunflower: Two varieties of sunflower (Hysun33, i.e. hybrid variety, and BARI Surjomukhi-2, i.e. open pollinated variety) were tested in both Dacope and Amtali with 5 different sowing dates 10 days apart starting from 25 November (p 9, Annex Report 08). The two year's experimental results revealed that the optimum sowing time for sunflower ranged from 25 November to 5 December in southern coastal region of Bangladesh (p 12-13, Annex Report 08). Further delay in sowing reduces the yield. The yield of Hysun33 was higher compared to the BARI Surjomukhi-2 due to the hybrid vigor of this variety. For example, the average yield of Hysun33 was 3.11 t ha^{-1} compared to 2.30 t ha^{-1} for BARI Surjomukhi-2 in Amtali for 25th November sowing. At Dacope, the interaction effect of variety and sowing date exerted significant influence on yield. Hysun 33 on 5 December sowing gave the highest seed yield (2.44 t ha^{-1}), which was statistically similar to that of Hysun 33 on 25 November, 15 December and 25 December sowing. The lowest seed yield (1.17 t ha^{-1}) was obtained from BARI Surjomukhi-2 on 5 January, which was statistically similar to those of BARI surjomukhi-2 on 25 December sowing (1.21 t ha^{-1}), 15 December (1.45 t ha^{-1}) and 25 November (1.50 t ha^{-1}) (p 12-13, Annex Report 08).The yield decreased remarkably with delaying of the sowing date in both years. The local farmers are very much interested to cultivate sunflower as the crop fits well with their existing cropping system and ago-ecosystem. Farmers usually extract oil from the sunflower seeds by using local expeller machine and consume oil by themselves.

Maize: Maize was tested in both Amtali and Dacope in Bangladesh (p 4, Annex Report 8) for two years (2016-18 considering 5 sowing dates (25 November, 5 December, 15 December, 25 December and 5 January) and 2 varieties (NK-40, i.e. commercial variety, and BARI Hybrid Maize-9). The grain yields obtained from two varieties (NK-40 and BARI HM-9) were statistically similar in 2016-17. Therefore, in second year (2017-18), only one variety (BARI Hybrid Maize-9) had been sown. Crop sown on 25-November gave the highest grain yield (11.02 t ha^{-1} for NK-40 and 10.62 t ha^{-1} for BARI HM-9) at Amtali. In Dacope, yield was lower than Amtali, 8.64 t ha^{-1} and 8.21 t ha^{-1}, respectively fir NK-40 and BARI HM-9 in 2016-17. The yield decreased remarkably with delaying of the sowing date in both years (p 6-7, Annex Report 08). At Amtali, the yield decreased from 11.02 t ha^{-1} sown of 25 November to 7.83 t ha^{-1} sown on 05 January for NK-40 in 2016-17. At Dacope, yield decreased from 8.64 t ha^{-1} to 2.16 t ha^{-1} during that period. The highest crop duration was 135 to137days from seed to seed in both varieties of maize at 25 November sowing. Timely establishment of winter crops is possible through hand dibbling method. The optimum sowing time for maize is ranging from 25 November to 5 December in southern coastal area of Bangladesh. The local farmers are reluctant to grow maize for grain production. They usually cultivate maize for selling the green cobs at local market as there is no formal marketing system of maize grain in this area. The green cobs of maize are roasted and sold at the local market for direct consumption by the local people.

Mustard: We tested 5 sowing dates 10 days apart starting from 25 November with two varieties (BARI Sarisha-11, i.e. drought and salt tolerant, and BARI Sarisha-14, i.e. short duration variety) in 2017-18 season at Amtali (p 14, Annex Report 08). It was observed that the plant characters namely, plant height and seed yield varied significantly due to different sowing dates. BARI Sarisha-11 sown on 25 November gave the highest yield of 1.12 t ha^{-1} (p 16, Annex Report 08). For BARI Sarisha-14 the highest yield was 533 kg ha^{-1} sown on 15 December. With the advancement of sowing dates, yield decreased gradually mainly due to increasing of soil salinity and temperature. Crop grown on 5 January exhibited the lowest performance in terms of yield components and yields. As BARI Sarisha-11 is a saline tolerant variety and gave higher yield, therefore, farmers of that locality showed their interest to cultivate this variety. The variety can be fitted well with the farmers' existing cropping systems.

In Dacope, Mustard was only cultivated in 2016-17 considering 3 sowing dates (24 Nov, 01 Dec, 08 Dec). The corresponding yields were 0.7 t ha^{-1}, 0.6 t ha^{-1}, and 0.3 t ha^{-1} (p 18, Annex Report 11). Although the 1st sowing produced the maximum seed yield but it was the half of the average seed yield of this variety which indicates that sowing on 24 November was also the late sowing. Thus in the subsequent years (2017-18, 2018-19 and 2019-20) mustard was excluded from Dacope.

English spinach is grown as winter vegetable in other region of Bangladesh. In 2018-19, we set up crop cafeteria (where different crops are grown in small plots to see their performance). In Dacope, we found that spinach performed very well and can be grown in fallow lands after T. Aman. It is a short duration crop and could escape high heat and high soil salinity of summer season. But it is important to find out their sowing time and harvest interval which determines spinach yield, quality and market price. In 2019-20, we set up an experiment with 3 sowing dates 10 days interval starting from 16 January and 4 different harvest dates (10 days interval starting at 30 days after sowing) (p 35, Annex Report 09). Fresh yield of spinach was significantly highest (27.81 t ha^{-1}) in 16 January sowing followed by 5th February (14.09 t ha^{-1}) and 26 January (12.41 t ha^{-1}) (p 36, Annex Report 09). Fresh yield of spinach was highest when harvested at 60 DAS (29.67 t ha^{-1}) and lowest in 30 DAS (5.98 t ha^{-1}) (p 37, Annex Report 09). However, taste quality was reduced due to accumulation of salt in leaf, which ultimately reduced taste score. So, it is suggested that spinach should be harvested within 40 DAS and sown as early as possible in January.

Indian spinach: Indian spinach was evaluated under three dates of sowing 15 October, 7 November and 3 January with both non-mulching and mulching at Gosaba (p 22, Annex Report 12). The highest yield (vegetative part) was obtained when sown in mid-October (13.35 t ha^{-1} with mulch and 12.13 t ha^{-1} without mulch) and lowest yield was recorded when sown in first week of November (7.26 t ha^{-1} with mulch and 6.05 t ha^{-1} without mulch) (p 23, Annex Report 12). The reduction in yield of Indian spinach when sown in the month of November may be due to low temperature induced growth restrictions during the months of December and January.

Synthesis of Sowing Date Trials (for Kharif and Rabi crops)
Looking across all the trials mentioned above, and plotting crop yield against sowing day (Julian day), we observed some clear trends. Plotted all together these are difficult to discern (Figure 7.44), however we can clearly see the reducing grain yield trend with sowing date for Kharif rice (2016-17), Gosaba, West Bengal (BCKV) by adding a trendline (Figure 7.45) and then by adding trendlines to all the Rabi crop experiments (Figure 7.46).

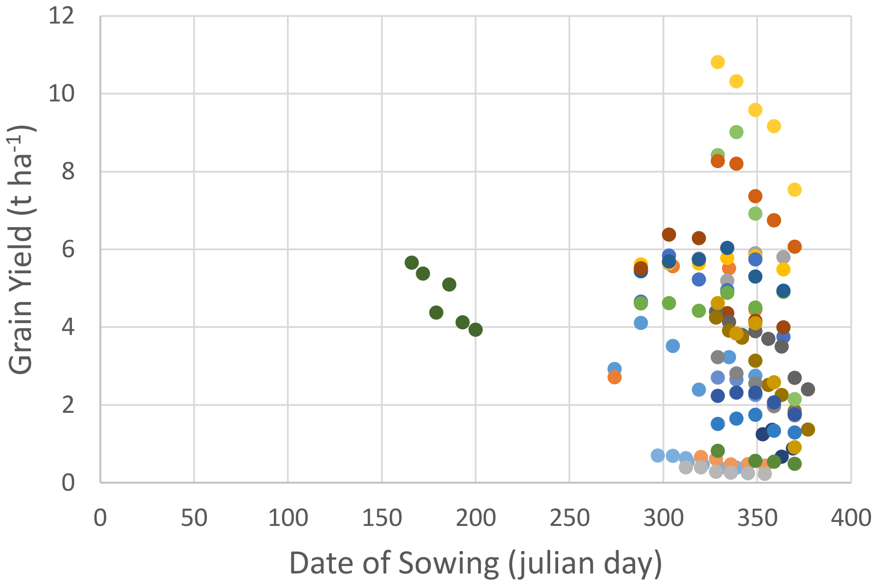

Figure 7.44 Response of Kharif and Rabi crops to date of sowing, across project experiments all sites and two seasons (2016-2018)

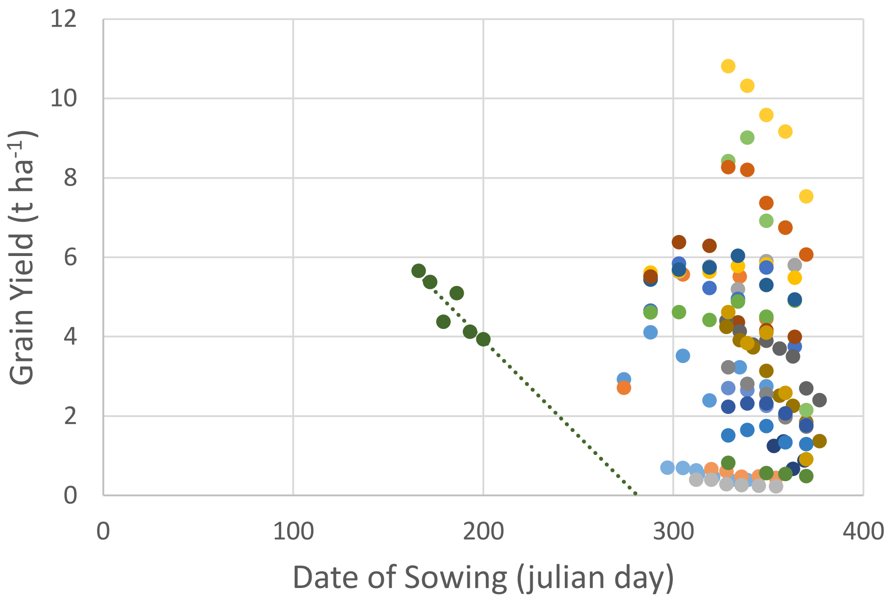

Figure 7.45 Response of Kharif and Rabi crops to date of sowing, across project experiments all sites and two seasons (2016-2018), indicating trendline for sowing date trial of Kharif-II rice crop at Gosaba, West Bengal, India.

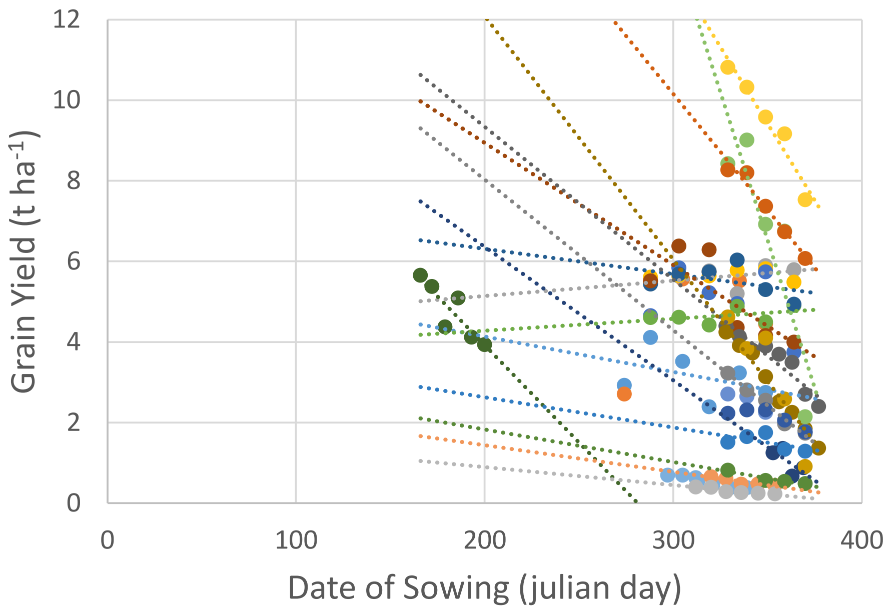

Figure 7.46 Trends in crop grain yield response to date of sowing, across project experiments all sites and two seasons (2016-2018)

By disentangling all the different Rabi crops, locations and seasons, some further trends emerged. For example, both wheat and maize are strongly negatively impacted by delay in sowing date after mid-November (Figure 7.47). This is due to a combination of increasing salinity and also moving into sub-optimal sowing dates for physiological development.

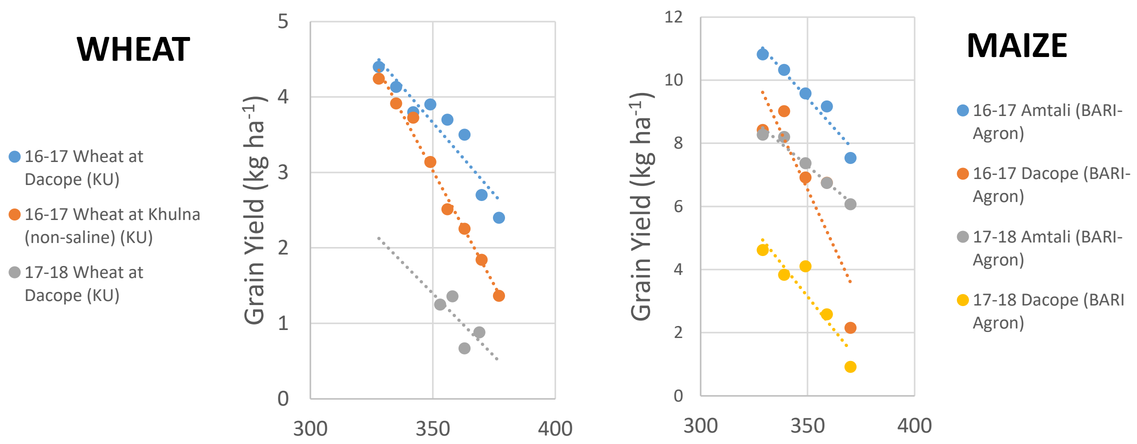

Figure 7.47 Disentangling the trends in crop grain yield response to date of sowing, across project experiments all sites and two seasons (2016-2018) for maize (Annex Report 08) and wheat (Annex Report 11)

The trend in Boro rice yields was not so clear, particularly at Amtali and Dacope (Annex Report 10, Figure 7.48) which showed an opposite trend, contrasting with the non-saline site (Barishal). The Boro rice sowing date trial at Canning Town, WB (CSSRI) indicated an ambiguous trend (Annex Report 12), however for all the Boro rice trials it is important to note that the first sowing date was considerably earlier than the other Rabi crop trials (15 Oct cf 15 Nov) hence all exhibited a fairly similar optimum sowing date (around 15 Nov) which is strongly supported by literature. However clearly from our experiments the rate of yield decline after optimum sowing date is less for Boro rice than for the other Rabi crops (like wheat, maize etc.). This is likely due to increased irrigation flushing which keeps salinity levels down.

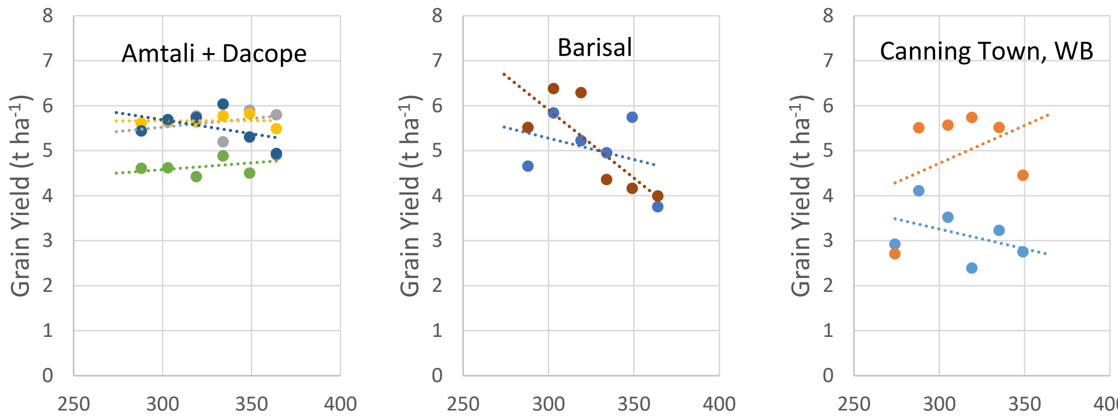

Figure 7.48 Disentangling the trends in crop grain yield response to date of sowing, across project experiments all sites and two seasons (2016-2018) for Boro rice (Annex Report 10)

Sunflower trials also indicated a fairly steep decline in grain yields achieved after 15 Nov sowings (Figure 7.49), however it was steeper at Amtali compared to Dacope. This is likely driven by more intransigent heavy soil conditions at Dacope, which limited the yield potential of early-sown crops.

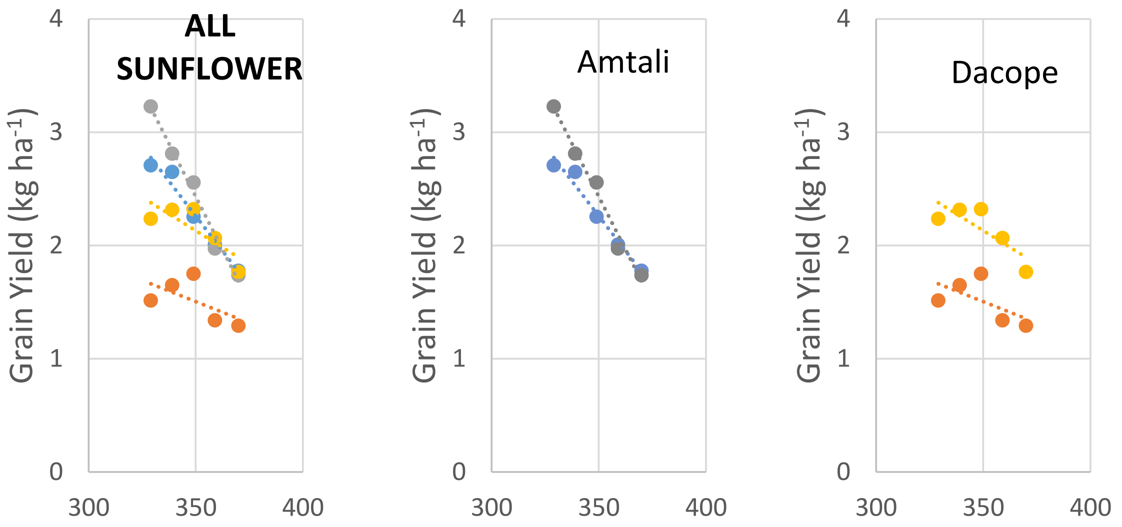

Figure 7.49 Disentangling the trends in crop grain yield response to date of sowing, across project experiments all sites and two seasons (2016-2018) for sunflower (Annex Report 08)

Similarly, mustard and small legumes like grasspea, greengram and lentil all revealed a marked decrease in grain yield with delay in sowing date after optimal time (Figure 7.50).

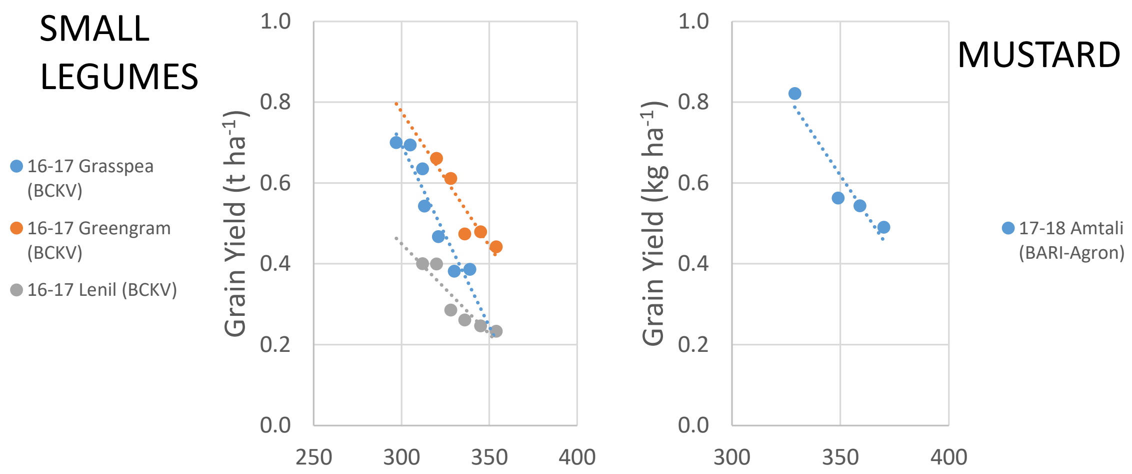

Figure 7.50 Disentangling the trends in crop grain yield response to date of sowing, across project experiments all sites and two seasons (2016-2018) for mustard (2017-18 Amtali, Annex Report 08) and small leguminous crops, grasspea, greengram and lentil (Annex Report 13)

In summary, the synthesis of project sowing date trials has revealed clear trends, indicating that in all project sites the prospects for good yielding Rabi crops (non-rice) are significantly enhanced by early sowing. Given the results which also indicate Kharif (T. Aman) crops also respond positively to early sowing, this suggests that farmers should possibly aim for early-establishment of high-yielding, early-maturing Kharif rice crops, and follow as soon as possible with early-established Rabi cropping. Since Boro rice appears less influenced by delays after optimal sowing time (15 Nov) due likely to enhance flushing of salts in comparison with Rabi crops, it may present a better option for later sowing opportunities.

However, there is an important additional finding from the 2017 early plantings. Their yields were generally depressed compared to 2016, which we attribute to heavy late monsoon rainfall on 9-11 December. This was sufficient to depress wheat yield from over 4 t ha^{-1} (which was highly profitable) to about 1 t ha^{-1} which was not profitable) (Figure 7.47). Maize yields were depressed from 8-9 t ha^{-1} to 4-5 t ha^{-1} (Figure 7.47). In other cases where standing water remained in fields for several days severe crop damage occurred. By contrast, when surface water was drained immediately in one experiment, sunflower survived and substantially recovered to produce about 2.0 t ha^{-1}. Hence there are significant risk with early sowing in the Rabi season, and further research needs to focus on risk alleviation strategies for the early-sown Rabi crops.

7.12 Crop establishment in the Rabi season

As discussed earlier, the optimum sowing time for many Rabi crops is mid-November to early December. Through early establishing of crops, it is possible to use the existing soil moisture in the field resulting in less or no irrigation and avoid damages due to soil salinity at the late stages of the crops. But due to late harvest and high soil moisture in the field, farmers need to wait to establish Rabi crops using traditional method delaying sowing. So to start Rabi crops early in the field, we studied different methods of establishing Rabi crops in the field. These are:

1. Zero tillage and minimum tillage
2. Transplanting
3. Dibbling, and pit establishment

7.12.1 Zero tillage and minimum tillage

Potato

Zero tillage (AT) or growing crops without or minimum tillage is being practiced in Bangladesh and India for various crops (such as maize, wheat, etc.) and is not new. Potato has been grown in Gosaba in limited scale using traditional ridge and furrow method which was sown late requiring irrigation. So only farmers who has adequate stored fresh water for irrigation could grow this crop. We developed an innovative technology in 2016-17 for cultivation of potato after kharif rice under zero tillage condition and the findings were validated in the farmers' fields during 2017-18. With this technology, potato is sown on the same day after harvest of rice in the wet soil compared with conventional tillage (CT) practice of sowing potato in ridge and furrow method. The details are given in (Sarangi *et al.*, 2018a).

ZT potato cultivation is the breakthrough technology of the project which has been taken up by the farmers in Gosaba rapidly (Figure 7.51). We started ZT potato with 23 farmers in 2016-17. The number of farmers increased to 44 in 2017-18, 121 in 20189-19 and 208 in 2019-19. While demonstrating the technology to the farmers field we also carried out experiments on the selection of suitable variety and to find out optimum agronomic management.

Figure 7.51 ZT potato along with ridge potato in the field (left), ZT potato before harvest (right)

After the success of the technology in 2016-17, we initiated experiment to find out optimum thickness of paddy straw mulching (PSM) and nutrient management options along with conventional ridge and furrow cultivation which was carried out for consecutive 3 years (2017-18 to 2019-20) (p 25, Annex Report 12). There were six treatments on ZT by combining 3 different thickness (15 cm, 20 cm, 25 cm) and 2 types of application of fertilizers (broadcasting and foliar spray of water soluble fertilizers) along with the control treatment of ridge and furrow cultivation with soil application of nutrients. Potato variety Kufri Pukhraj was used in this experiment. Highest tuber yield of 20.71-37.94 t ha^{-1} was recorded in the treatment of ZT with 20 cm PSM with foliar spray of soluble fertilizers which was at par with ZT with 25 cm PSM with foliar spray of nutrients). The tuber yield of conventional ridge cultivation varied from 16.73 t ha^{-1} to 21.24 t ha^{-1} (p 28, Annex Report 12). There was significant reduction in irrigation water requirement due to ZT potato cultivation with PSM. About 17 cm of irrigation water can be saved due to this technology compared to the conventional practice (p 28, Annex Report 12). Similarly, the irrigation water productivity increased from 396 kg ha^{-1} cm^{-1} under conventional practice to 873.63 kg ha^{-1} cm^{-1} of irrigation water under ZT sowing with PSM technology (p 28, Annex Report 12). Average cost of cultivation of potato reduced by about 27% due to zero tillage sowing (US$ 1211.6 ha^{-1}) compared to conventional tillage intensive ridge sowing practice (US$ 1660.4 ha^{-1}). The net benefit of ZT cultivation varied from 1,398 US$ ha^{-1} in 2016-17 to 2,498 $ ha^{-1} in 2019-20. The net benefit of ZT cultivation with foliar spray of fertilizers is several times higher than the conventional cultivation due to higher yield and low cost of cultivation. For example, in 2018-19, the net benefit of ZT treatments varied from 1,025 US$ ha^{-1} to 2,766 US$ ha^{-1} compared to only 481 US$ ha^{-1} for the conventional practice (Sarangi *et al.*, submitted). More detail can be found in Annex Report 11, Sarangi *et al.* (2018b) and Sarangi *et al.* (submitted).

At Gosaba, we also studied the effects of different foliar nutritional management with macro and micronutrients on growth, yield and quality of potato grown under ZT condition considering 9 different treatments (p 28, Annex Report 12). These are: T_1: Zero Tillage + Mulching (control), T_2: Zero Tillage + Mulching + 2% Urea @ 30 DAP (Days after planting), T_3: Zero Tillage + Mulching + 2% Urea @ 30 & 50 DAP, T_4: Zero Tillage + Mulching + 2% MOP @ 30 DAP, T_5: Zero Tillage + Mulching + 2% Urea @ 30 & 50 DAP + 2% MOP @ 30 DAP, T_6: Zero Tillage + Mulching + 0.1% Boron@ 30 DAP, T_7: Zero Tillage + Mulching + 2% Urea @ 30 & 50 DAP + 0.1% Boron @ 30 DAP, T_8: Zero Tillage + Mulching + 0.5% Zn @ 30 DAP, T_9: Zero Tillage + Mulching + 2% Urea @ 30 & 50 DAP + 0.5% Zn @ 30 DAP replicated thrice (p 30, Annex Report 12, BCKV). Nutritional supplementation through foliar spray significantly influenced the potato growth parameters like plant height, and LAI. The application of 2% Urea @ 30 & 50 DAP along with 0.1% Boron @ 30 DAP (T_7) not only increased tuber number (2.92×10^5 ha^{-1}) and yield (26.4 t ha^{-1}) but also quality parameters of potato tuber such as total soluble solid (TSS), tuber hardness, vitamin C etc. were significantly increased (p 28, Annex Report 12). It may thus be concluded that 2% Urea @ 30 & 50 DAP along with 0.1% Boron @ 30 DAP as foliar application is the best foliar nutrient management option for potato grown under zero tillage and mulching as it registered the highest yield attributes, yield, uptake of nutrients and better tuber quality in coastal saline soils of West Bengal.

We also tried to find out the suitable variety of potato (p 24, Annex Report 13). We have tested 5 varieties; Kufri Chandramukhi, Kufri Jyoti, S-52, S-6 and local. Potato was cultivated under two methods of cultivation: zero tillage and conventional ridge and furrow system. The maximum tuber yield (22.45 t ha^{-1}) was obtained from the S-6 hybrid potato cultivar which was statistically at par with Kufri Chandramukhi, Kufri Jyoti and S-52 (Table 7.12; please also see p26, Annex Report 13). The yield of local variety was the lowest (12 t ha^{-1}). On the other hand, conventional line sown potato (local cultivar) recorded a tuber yield of 19.94 t ha^{-1}. A marked variation was observed amongst different potato cultivars with respect to quality attributes. Local varieties are comparatively poor with reference to most of the quality parameters. But other potato cultivars used in this experiment are more or less identical in terms of various quality parameters assessed.

Table 7.12 Production of tested potato cultivars at Gosaba

Variety	Crop duration	Average grain yield (t ha^{-1})				
		2016	2017	2018	2019	Average
Gosaba (pre-existing varieties)						
Local	100-110		11.97	12.65	14.63	13.08
Gosaba (introduced varieties)						
K. Chandramukhi	95-105		19.63			19.63
K. Jyoti	110		19.38			19.38
S-52	108		18.09			18.09
S-6	115		22.45			22.45
K. Pukhraj	75-80		-	23.52	22.53	23.02

Potato usually not grown in the coastal saline soils of Bangladesh earlier because of high salinity and increasing air temperature. Recently, BARI has developed some heat and salt tolerant potato varieties (e.g. BARI Alu-72), which is salt tolerant (up to 8 dS m^{-1}) as well as heat tolerant. So, following success of ZT potato at Gosaba, we initially set up zero tillage experiments using BARI Alu-72 with 3 different types of mulch (compost mulch, rice straw with 15 cm thickness, and rice husk with 7.5 cm thickness) in 2017-18 which was continued in 2018-19 (p 23, Annex Report 09). In 2017-18, tuber yield among mulch materials did not vary significantly. However, highest tuber yield (10.46 t ha^{-1}) was produced from rice husk. The yield was also highest with rice husk in 2018-19 (13.99 t ha^{-1}) in 2018-19, which was significantly higher than other mulch treatments (Figure 7.52). However, because of lowest total variable cost net benefit or gross margin was from rice straw mulch (Tk. 53,633 ha^{-1}) in 2017-18. The lowest (Tk. 10,319 ha^{-1}) was from the treatment with rice husk. Similar result was also found in 2018-19 (p 25, Annex Report 09). So ZT potato with rice straw mulch was found to be highly suitable and profitable at Dacope. However, it was necessary to determine appropriate amount of mulch for higher production.

In 2018-19 and 2019-20, we used 3 different straw mulch rate (4 t ha^{-1}, 7 t ha^{-1} and 10 t ha^{-1} which corresponds to 9 cm, 12 cm, 15 cm in thickness) and two varieties of potato (BARI Alu-72 and BARI Alu-73) (p 27, Annex Report 09). In 2018-19, the spacing was 60 cm x 25 cm and in 2019-20, 40 cm x 20 cm spacing was followed. In both years, mulch rate had significant effect on different soil and crop parameters, however there was no significant effect observed in variety and variety vs mulch rate (p 29, Annex Report 09). In 2018-19, treatment with 10 t ha^{-1} mulch rate produced highest yield (15.62 t ha^{-1}) followed by treatment with 7 t ha^{-1} mulch rate (14.41 t ha^{-1}) though they were statistically similar. In 2019-20, the yield was slightly higher with 7 t ha^{-1} mulch rate (13.33 t ha^{-1}) than that with 10 t ha^{-1} mulch rate (13.18 t ha^{-1}) (p 29, Annex Report 09). So, it is observed that rice straw @ 7 to 10 t ha^{-1} is the most suitable for zero tillage potato cultivation in the coastal area of Bangladesh. We estimated that, dry rice straw from about 3.18 ha land is needed to meet 10 t ha^{-1}.

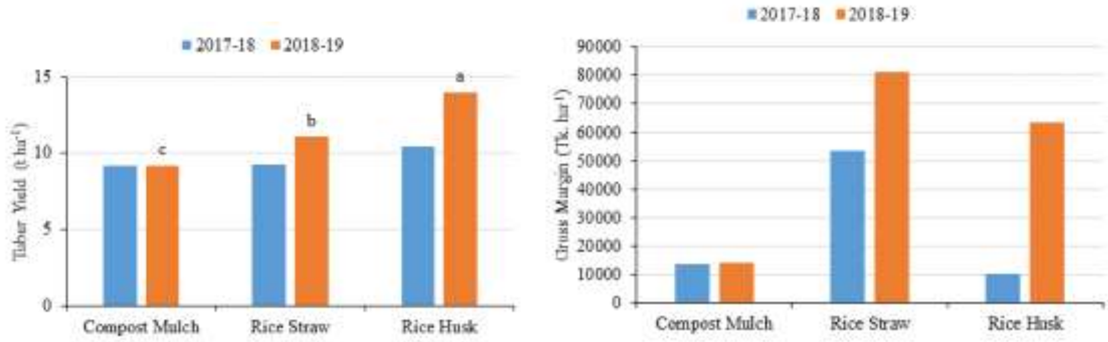

Figure 7.52 Tuber yield and gross margin of zero tillage potato grown at Dacope during 2017-18 and 2018-19

Garlic

Garlic is one of the important and expensive spice crops in Bangladesh. Garlic can be cultivated under zero tillage condition on the muddy soil surface through straw mulching to reduce the turn-around time. This practice also encourages deeper and denser rooting. BARI has developed a number of modern varieties of garlic in the recent years. However, they were not tested or cultivated in the coastal saline condition. The success of ZT potato encouraged us to test ZT garlic with straw mulch. We carried out experiments in both Amtali and Dacope for consecutive two years (2018-20) to understand their performance and to find out the suitable variety(ies) for cultivation in southern coastal region of Bangladesh. We tested 4 BARI developed varieties (BARI Rasun-1 to 4) along with a local variety (p 42, Annex Report 08; Figure 7.53).

In both locations, the highest bulb yield (4.74 t ha^{-1} at Amtali and 6.85 t ha^{-1} at Dacope) was obtained from BARI Roshun-4 (p 44-45, Annex Report 08). The lowest yield was from BARI Rasun-1 at Amtali and BARI Rasun-3 at Dacope. Economic analysis (p 45, Annex Report 08) shows that farmers can gain net benefit of 294,586 Tk ha^{-1} by cultivating BARI Rasun-4 with a BCR of 3.18. The local farmers had no idea about the cultivation of garlic under zero tillage along with straw much. When the experimental results were demonstrated and discussed about the technology to the farmers gathering during Field visit and Field Day then they were very much impressed and interested to grow garlic.

Figure 7.53 Garlic under zero tillage with mulch at Dacope and maize with different types of tillage at Amtali

Maize

At Amtali, we tested 4 different methods of sowing for maize in 2016-17 and 2018-19 (p 9, Annex Report 09; Figure 7.47). These are; seed sown using Power Tiller Operated Seeder (PTOS), strip tiller, bed planter and by conventional tillage. Significant variations were found among the treatments in terms of plant height and yield. The highest grain yield (7.06 t ha^{-1} and 6.58 t ha^{-1}) was obtained from seeding by PTOS during 2016-17 and 2018-19 respectively followed by bed planter and conventional tillage. The lowest grain yield 3.65 t ha^{-1} and 3.75 t ha^{-1} was obtained from seeding by strip tiller in both the years. It is due to lower growth and plant populations in the treatment (p 10, Annex Report 09). On the basis of cost and return (p 10, Annex Report 09) it was observed that seed sown by PTOS was the best option for maize cultivation as it return the highest (Tk.158,620 ha^{-1}) followed by Bed planting (Tk.135,740 ha^{-1}). Farmers showed their interest on PTOS as it save times and labour. In 2019-20, we set up demonstration with both PTOS and conventional tillage method at Amtali in 2019-20. The average yield was 7.51 t ha^{-1} with PTOS compared to 6.32 t ha^{-1} with conventional tillage. The gross margin was comparatively higher (Tk.99,370 ha^{-1} against Tk. 42,320 ha^{-1}) with PTOS due to 16% higher variable cost of cultivation in conventional method (p 49, Annex Report 09).

Strip tillage opens up new fertilizer placement options. During the tillage operation, plant nutrients can be placed several inches deep directly below the seedbed. This can be an economical and agronomically efficient way of supplying some of the crop’s nutrient requirements, particularly nutrients with limited mobility like phosphorus and potassium where deep placement can enhance positional availability. In 2016-17 at Amtali, we tested 4 different doses of fertilizer such as recommended dose (RD) and 10%, 20% and 30% less than the RD (p 10, Annex Report 09). The highest grain yield (6.10 ha^{-1}) was found for treatment with 10% less than the RD and the lowest (4.68 ha^{-1}) was from 20% less than the RD. However, there was no significant difference in yield and other plant parameters. Considering cost and return application of fertilizer 10% less than the RD was found the most beneficial as it returned the highest amount (Tk. 134,200 ha^{-1}) over other treatments (p 11, Annex Report 09).

7.12.2 Transplanting

Sunflower

Sunflower is usually grown by sowing seeds. For that the land should be in a suitable condition. Due to delay in harvesting of Aman/Kharif rice and waterlogging in the field sowing of seed is often delayed. Delayed sowing not only causes reduction in yield (Bell *et al.*, 2019; Paul *et al.*, 2020b) but also sometimes plant dies due to salinity in the soil at the later stages. To establish sunflower timely (by December) in the field during winter, raising sunflower seedling in the seedbed and transplanting them just after rice harvest could be a potential option. Transplanting might also shorten the lifespan of this crop in the main field thus may avoid stresses (waterlogging and salinity) and reduce yield reduction due to dibbling after late harvest of rice. Thus two field experiments were conducted in the farmer’s field in Dacope, Khulna during winter (2018-2019 and 2019-2020) to evaluate the possibility of sunflower transplanting, suitable seedling age and transplanting dates and the grain yield (p 20, Annex Report 11).

We transplanted 14 days (S1) and 21 days (S2) seedlings at 3 different transplanting dates; 25 December (T1), 05 January (T2) and 15 January (T3) (Figure 7.54). The result of the 2018-19 experiment showed that individually 14-day-old seedling and early transplanting produced more seed yield than that of older seedling (21-day-old) with late transplanting. The combined effect of seedling age and transplanting date showed that younger seedling with early transplanting (25 December) realized the maximum seed yield followed by younger seedling with 2nd sowing (5 January). Younger aged seedling (14-day-old) with early transplanting also produced ~ 54%, and ~ 25% more seed yield, respectively, over later transplanting and older seedling. In general, the yield was higher in 2019-20 then in 2018-19 (Figure 7.55).

Figure 7.54 Seedlings of sunflower and the established field

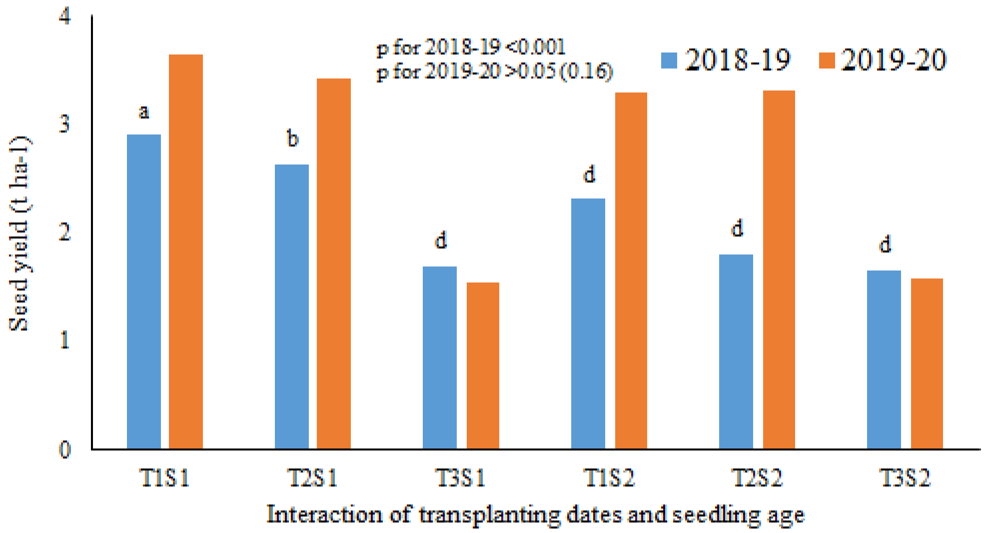

Figure 7.55 Grain yield of sunflower influenced by seedling age and transplanting dates interaction

The results suggest that if farmers cultivate moderate or longer duration rice that usually they harvest in December can use 21-days-old seedlings without compromising the grain yield of sunflower (p 23-24, Annex Report 11). The findings of the experiments revealed that transplanting of sunflower is possible and may be a better intervention of sunflower establishment in the coastal wet soil of southwestern Bangladesh. Even if the farmers harvest rice late, sunflower cultivation will be possible with seedlings thus the cropping intensity will be increased. The study showed that timely sowing and crop establishment were the principal factors and excess soil moisture/wetness is governing the fitting of a second crop (winter crop) after single Kharif-II rice.

Maize

We also tested transplanting of 14 days old seedings of maize under zero tillage condition and compared the results with dibbling under zero tillage condition, seeding with minimum tillage; and seeding with conventional tillage (2-3 pass by power tiller) in both Amtali and Dacope (p 29, Annex Report 08). In both locations, transplanting seedlings provided highest yield (8.83 t ha^{-1} in Amtali and 6.64 t ha^{-1} in Dacope) (p 32, Annex Report 08). Transplanting facilitated early establishment of the crop which enabled escaping the soil salinity stress during the cropping season. The lowest yield was with seeding with conventional tillage (4.37 t ha^{-1} in Amtali and 4.23 t ha^{-1} in Dacope). The main reason was this is the delay in sowing. While transplanting of 14 days old seedlings was done on 29 November the sowing with conventional tillage was done on 17 December.

7.12.3 Dibbling and pit establishment

In both locations in Bangladesh, we tested crop establishment by dibbling of sunflower and maize and pit cultivation of pumpkin and water melon in the moist soil under zero tillage condition during 2016-17 to 2017-18 (p 107, Annex Report 10). The highest yield (2.33 t ha^{-1}) of sunflower was obtained from Amtali in the year 2017-18 and the lowest (1.96 t ha^{-1}) was also in the same location in the year of 2016-17. The yield of sunflower is more or less similar with national average yield (2.5 t ha^{-1}) for both the location under favourable condition (p 110, Annex Report 10).

The highest yield (8.51 t ha^{-1}) of maize was found at Dacope during 2017-18 which is statistically similar with the yield of previous year (8.46 t ha^{-1}) at the same location. In Amtali there was no statistical difference in case of maize yield but location wise yield varied significantly. The average yield was found 8.46 t ha^{-1} and 7.62 t ha^{-1} in Dacope and Amtali (p 110, Annex Report 10), respectively while the national average yield of maize is about 10 t ha^{-1} (BBS, 2011).

The yield of sweet gourd or pumpkin varied significantly over the location in every year. The highest yield (13.5 t ha^{-1}) was found in Dacope during 2017-18. The average yield of sweet gourd is 12.08 t ha^{-1} and 8.58 t ha^{-1} in Dacope and Amtali, respectively. This yield is much lower than the national average yield (20-25 t ha^{-1}) of sweet gourd under recommended condition (p 110, Annex Report 10). Some adverse factors like salinity and lack of irrigation may be the cause for this yield reduction.

Performance of watermelon was comparatively poor than the other three crops in both locations over two consecutive years. The highest yield (7.53 t ha^{-1}) of watermelon was found in Amtali during 2017-18 which is much lower than the national average (18-22 t ha^{-1}).

Although the national average yield of sweet gourd and watermelon are found higher but it is remarkable that sweet gourd and watermelon were cultivated under stress conditions like salinity and lack of irrigation water where the land remains fallow during Rabi season in this area.

Economic analysis shows that among the potential dry season crops, pumpkin was more profitable followed by sunflower in Dacope. On the other hand, sunflower was more profitable followed by pumpkin in Amtali (Table 7.13; p111, Annex Report 10).

Table 7.13 Costs and returns (Tk. ha^{-1}) of dry season crops in Amtali and Dacope, 2016-18

Crop	Amtali			Dacope		
	Total paid-out cost	Gross benefit	Gross income	Total paid-out cost	Gross benefit	Gross income
Sunflower	77,826	118,750	40,924	79,414	108,775	29,361
Maize	76,964	114,300	37,336	82,254	126,900	44,646
Pumpkin	71,328	111,540	40,212	74,818	134,960	60,142
Watermelon	88,987	116,400	27,413	91,578	106,920	15,342

Following success with dibbling cultivation of sunflower, we conducted experiments during 2018-19 and 2019-20 on optimum fertilizer requirements for maximizing yield and profit (p 119, Annex Report 10). Three fertilizer placement methods were considered for basal dose of fertilizer. These are furrow placement, hole placement, and broadcasting. Interaction effect of basal fertilizer application methods and topdressing showed statistically non-significant effect on yield among the treatments. The highest yield (1.94 t ha^{-1}) of sunflower was found when basal fertilizer applied at furrow and top dressing was done before irrigation and the lowest yield (1.45 t ha^{-1}) was found in broadcasting of basal fertilizer and top dressing after irrigation treatment combination (p 124, Annex Report 10). The economic benefit was also highest (Tk.9,854 ha^{-1}) when basal fertilizer applied at furrow and top dressing (p 125, Annex Report 10). Gross margin was significantly lower compared to that presented in Table 7.13 due to the lower yield due to adverse weather condition (heavy rainfall during the seasons). Although furrow placement of basal fertilizers costs a little bit more but due to higher yield than other methods economic returns was also higher compared to other methods. It assumed that good crop establishment will provide better economic returns under this method of fertilizer management.

7.13 Crop management

7.13.1 Use of mulch

Crop cafeteria including sunflower and maize

In addition to the testing and screening of different Rabi crops described in Section 7.10, we also studied feasibility of new Rabi crops with and without mulching in the coastal saline areas of West Bengal during 2017-18 to 2019-20. In this experiment 6 crops (sunflower, linseed, mustard, Indian spinach, broccoli and capsicum) were grown in 2017-18, 8 crops (broccoli, knol-khol, cabbage, cauliflower, sweet potato, chilli, Indian spinach and sunflower) in 2018-19, and 19 crops (broccoli, onion, garlic, okra, French bean, Indian spinach, tomato, pumpkin, bitter gourd, snake gourd, cucumber, chilli, mung bean, mustard, cabbage, cauliflower, knol-khol, beetroot) were grown in 2019-20 (p 21, Annex Report 12). The experiment was conducted in a split-plot design with crops in main plot and mulching treatments (no-mulch and paddy straw mulch) in sub-plot. Highest BEY was recorded in case of Indian spinach (10.51 t ha^{-1}) followed by broccoli (2.67 t ha^{-1}) and lowest in case of linseed (0.43 t ha^{-1}) in 2017-18. In 2018-19, the highest BEY yield was for chilli (72.6 t ha^{-1}) followed by knol-khol (28.13 t ha^{-1}). However, in 2019-20, the BEY of chilli was much lower (24.72 t ha^{-1}). The highest yield in that year was for pumpkin. There is significant variation in the equivalent yield of different crops in different years (p 21-25, Annex report 12). This is because of the variation in the market price of the crops. Irrespective of crops, mulching with paddy straw increased the yield by 11% over non-mulching. The advantage of mulching may be due to suppression of weeds, conservation of soil moisture and nutrients for better growth of plants and grain formation. A preference analysis on the farmers reveals that broccoli, Indian spinach, mung bean, mustard, and other vegetables are preferred by the farmers. The preference for sunflower, maize and capsicum was low.

Mung bean was evaluated considering five treatments viz. farmers practice of broadcasting the seeds without any treatments, line sowing, line sowing + Rhizobium seed treatment, line sowing + Rhizobium seed treatment + paddy straw mulching and line sowing + paddy straw mulching in a randomized complete block design with three replications (p 25, Annex Report 12). Rhizobium seed treatment along with paddy straw mulching produced highest yield of 1.95 t ha^{-1}. The yield at farmers practice was 0.98 t ha^{-1}.

We have tested different maize cultivars with and without mulching in Gosaba (p 31, Annex Report 12). The experiment was conducted with four maize types viz. popcorn, baby corn, sweet corn and hybrid corn combined with liming, paddy straw mulching and both. Highest kernel yield of about 4.0–4.5 t ha^{-1} was recorded in all the corn types with application of lime and straw mulching which is at par with straw mulching alone (3.5–4.0 t ha^{-1}) (p32, Annex Report 12). Economics of maize showed, given the price available to the farmers, maize cultivation can be a good option for the study area, providing a profitable cropping system intensification option.

Potato

Zero tillage potato was found suitable and very promising in Bangladesh following our initial trial in 2017-18. So in 2018-19, we initiated experiments to understand the optimum management practices for potato under zero tillage condition in coastal saline soil. In one experiment (p 33, Annex Report 08), we tested 4 treatments combining fertilizer doses with different types of tillage (zero tillage, minimum tillage, and conventional tillage) and mulch thickness (8 cm and 10 cm). The results show that management practices had significant effect on all the plant characters of potato (p 36-37, Annex Report 08). The treatment of recommended nutrient (RN) with 10 cm straw mulch and 20% extra potassium produced the highest tuber yield (24.65 t ha^{-1} at Amtali and 11.67 t ha^{-1} at Dacope). Only application of the recommended nutrient gave the lowest yield (16.57 t ha^{-1} at Amtali, 8.89 t ha^{-1} at Dacope) of potato (p 36-37, Annex Report 08). Application of straw mulch can conserve the soil moisture and extra potassium lowers down Na^+ uptake by plants and increases K^+ uptake (Haque, 2006). As a result, the soil salinity stress could be reduced through using straw mulch during cropping season in southern coastal region.

From the previous trials on zero tillage potato cultivation it was observed that at conventional spacing (60 cm X 25 cm) maximum canopy coverage remains less than 60%. As a result, a significant space between two rows remains open. So in 2019-20, we studied (p 37, Annex Report 08) the plant spacing for ZT potato considering 4 different plant spacing treatments (T1 = 60 cm ×25 cm, T2 = 50 cm ×25 cm, T3 = 40 cm ×25 cm and T4 =30 cm ×25 cm). The plant spacing had significant effect on all the plant characters of potato except plant height (p 40-41, Annex Report 08). The highest tuber yield (15.20 t ha^{-1} at Amtali and 20.38 t ha^{-1} at Dacope) were obtained from the treatment T4 (30 cm × 25 cm). Net economic benefit (92,582 Tk ha^{-1} and 160,252 Tk ha^{-1}) and benefit cost ratio (1.86 and 2.10) were also highest for this treatment. Closer plant spacing (30 cm×25 cm) was found suitable because of zero tillage (no ridge formation is required) for higher tuber yield and economic benefit.

In another experiment in Dacope, we tested another four spacing treatments viz. 60 cm x 20 cm, 50 cm x 20 cm, 40 cm x 20 cm and 30 cm x 20 cm (p 33, Annex Report 09). These spacing were tested on two potato varieties viz. BARI Alu-72 and BARI Alu-73 (Figure 7.56). Highest tuber yield (23.6 t ha^{-1}) was found from spacing of 40 cm x 20 cm, which was identical with 30 cm x 20 cm (22.1 t ha^{-1}) (p 33, Annex Report 09). Statistically identical and lowest tuber yield was recorded from 60 cm x 20 cm (15.7 t ha^{-1}) and 50 cm x 20 cm (16.3 t ha^{-1}). Gross return followed the similar trend of yield, highest (Tk. 246,778 ha^{-1}) was from the spacing of 40 cm x 30 cm (p 34, Annex Report 09). From benefit cost analysis it was apparent that major expenditure was in purchasing seed potato. As spacing decreased seed rate also increased. Other operation cost was similar in all spacing treatments. As a result total variable cost was highest from narrow spacing (Tk. 129,722 ha^{-1}) and lowest from wider (Tk. 84,722 ha^{-1}).

60 cm X 20 cm

50 cm X 20 cm

40 cm X 20 cm

30 cm X 20 cm

Figure 7.56 Plot view of different spacings treatments on zero tillage potato at Dacope during 2019-20 (p 33-34, Annex Report 09)

Tomato

In Dacope, we compared the performance of rice straw mulch and black polythene mulch with no mulch for tomato cultivation in Dacope in 2017-18 (p 19, Annex Report 09). Highest yield of tomato was observed in polythene mulch (50.67 t ha^{-1}) followed by rice straw (53.93 t ha^{-1}). The lowest yield was found in no mulch (30.80 t ha^{-1}). Economic analysis shows that highest net benefit (Tk. 332,698 ha^{-1}) can be obtained from Polythene mulch followed by Rice straw mulch (Tk. 152,381 ha^{-1}) (p 20, Annex Report 09). In 2018-19, we combined the mulch treatment with two different treatments (prilled urea and urea super granule, USG). Results showed that there was no interaction effect of mulch and nitrogen treatments. Better performance of rice straw and prilled urea may be due to better aeration and readily availability in coastal clay soil than other treatments. Highest net benefit (Tk. 152,715 ha^{-1}) was found from rice straw and prilled urea (p 23, Annex Report 09). Similar experiment was also carried out at Amtali in 2017-18. The highest gross margin (Tk.300,000 ha^{-1}) was from polythene mulch+USG application of fertilizer. The lowest was (Tk.220,000 ha^{-1}) was from the conventional practice (p 46, Annex Report 09).

Pumpkin

We also tested different types of mulching (rice husk, rice straw, polythene, and rice straw at bottom and above the pit) with pumpkin (p 112, Annex Report 10). The yield varied significantly due the different mulch material in year to year and also in location to location. During 2016-17, mulching with rice straw, and rice husk) produced significantly higher yield (13.47 t ha^{-1} and 13.05 t ha^{-1}, respectively) over all the treatment in Dacope, Khulna (p 113, Annex Report 10). In the following year, yield (6.44 t ha^{-1}) reduced significantly with mulching with rice husk. In Amtali, mulching with rice straw, and mulching with rice straw at above and bottom of the pit produced statistically similar yield (10.7 t ha^{-1} and 11.2 t ha^{-1}, respectively) during 2016-17. In 2017-18, mulching with rice straw at bottom and above the pit) and mulching with polythene sheet gave the highest yield (10.70 t ha^{-1} and 10.80 t ha^{-1}, respectively) (p 113, Annex Report 10). It is observed that mulching has significant effect on the yield of pumpkin in both years at every location but the treatment impact differs from location to location and also in year to year. Location wise average yield indicates that when rice straw used as mulch material at the bottom and above the pit then sweet gourd produced better yield than other treatments. Economic analysis shows that farmers can get net benefit of Tk.51,835 ha^{-1} and Tk.41,025 ha^{-1}, respectively from Amtali and Dacope by cultivating pumpkin with rice straw mulch at the bottom and above the pit (p 114, Annex Report 10).

7.13.2 Cover crop

In coastal areas, sunflower cultivation is expanding in some pocket areas where irrigation facilities are available. For higher yield sunflower requires at least three irrigations. So, moisture conservation is a primary concern for crop production in coastal area. For conservation of moisture, we used rice straw mulch in the field. However, we hypothesized that short duration green leafy vegetables could be used as cover crops in between sunflower rows, which could conserve soil moisture as well as reduce soil salinity. Moreover, farmers could get extra income from cover crops, thereby system productivity would be increased. So, in 2019-20, we conducted an experiment at Dacope considering 5 treatments (p 38, Annex Report 09). These treatments are: sunflower with rice straw, sunflower + Spinach, Sunflower + Ghee Kanchan (Shobuj Shak), sunflower + red amaranth and Sunflower without mulch (control). Highest sunflower equivalent yield (2.95 t ha^{-1}) was calculated from the treatment sunflower + spinach), which ultimately brought highest gross return gross margin (Tk. 106550 ha^{-1}) with BCR (4.10) (p 39, Annex Report 09). The gross margin of sunflower with spinach was 46% higher than sunflower with rice straw mulch. Cover crop did not affect sunflower yield, hence there was no significant yield variation in sunflower. However, yield of vegetables were far lower than expected because of poor tillage. Among the vegetable varieties spinach yield was highest.

7.14 Amendment of soil, utera system, relay cropping

7.14.1 Soil amendment

Soil acidity along with salinity prevails in many fields in Gosaba. To find suitable soil management for achieving higher yield of Kharif rice we tested different soil amendment methods such as green manuring (GM), use of lime, and rock phosphate (RP) (p 9, Annex Report 12) for 3 years (2017-2019) with rice variety CR 1018. In 2018, mean grain yield was lowest (3.79 t ha^{-1}) under control and highest (5.66 t ha^{-1}) with GM+L+RP, which was at par with GM+L and GM+RP (p 10, Annex Report 12). The same experiment was continued during Kharif 2019, the soil pH before the experiment varied from 5.0-5.65. Highest grain yield (5.90-5.97 t ha^{-1}) was recorded in the treatment where GM as well as at least one amendment or both was followed. Therefore, GM and application of soil amendments can produce higher yield of Kharif rice in these poor quality soils of Sundarbans.

After rice, during Rabi seasons of 2016-17 and 2017-18, hybrid maize crop grown in these acid saline soils with four treatments viz. control (no amendment), lime, rock phosphate, and lime + rock phosphate. The Average (over two years) kernel yield was increased in all the treatments over control. Highest mean kernel yield of 5.75 t ha^{-1} was observed due to application of rock phosphate in acid saline soils, which was at par with application of lime (5.65 t ha^{-1}), however there was no advantage due to application of both lime and rock phosphate (p 11, Annex Report 12). There was significant improvement of soil pH due to GM and application of rock phosphate. Soil pH increased from about 5 to more than 5.5 due to these treatments (Figure 7.57).

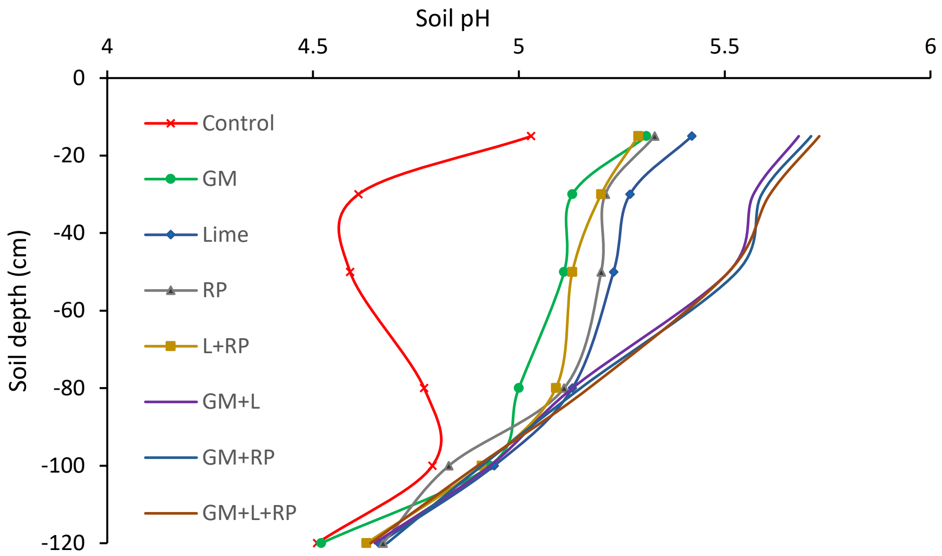

Figure 7.57 Effect of green manuring and amendments on soil pH

In another field trial on maize grown in an acid soil with pH 5.1 in 2018-19 under four treatments viz. control (no amendment), lime (@1.5 t ha^{-1}), straw mulch and lime + straw mulch, significantly higher kernel yield was obtained under application of lime combined with paddy straw mulching over control. The results were compared with that of maize grown in normal soil with pH 6.5. Highest kernel yield of maize was observed due to application of both lime and use of paddy straw mulching (3.45 t ha^{-1}), however the yield was lower than that observed under normal soil (3.66 t ha^{-1}) (p 12, Annex Report 12).

In both sites in Bangladesh, we tested the influence of bio-organic amendment in saline soil for Boro rice cultivation during 2017-20 (p 95, Annex Report 10). Bio-organic fertilizers were used as 2 t ha^{-1} (dry weight basis) with 70% chemical N, 0% TSP and 100% MoP. BRRI dhan67 was used as test crop. The treatment combinations were: T_1= bio organic fertilizer + 70% N + 100% K, T_2 = full chemical fertilizer (N-P-K-S @ 140-20-80-10 kg ha^{-1}). In both sites, application of bio-organic fertilizer at 2 t ha^{-1} (dry weight basis) along with 30% reduced urea and 100% removal of TSP increased rice yield by about 0.5 t ha^{-1} compared to use of full chemical fertilizer (p 97, Annex Report 10).

7.14.2 Utera system

In Gosaba, inclusion of pulses, as utera crop, is a potential option in rice-fallow areas with a dual advantage of crop diversification for sustainable production and area expansion of pulses for human nutrition. But the effective utera management practices is not standardized so far. To address this issue, a field experiment was conducted in Rabi seasons of 2016-17 and 2017-18 in the farmers' fields to standardize the management practices of utera crops lathyrus (cv. Bio-L 212) and lentil (cv. Maitree) in rice-fallow system (p 23, Annex Report 13). Five management practices were tested on utera crops: sowing of dry seed 2 weeks before harvest of rice + no fertilizer, water soaked seed sown 1 week before harvest of rice + no fertilizer, water soaked seed 1 week before harvest of rice + foliar application of 2% DAP (di-ammonium phosphate), water soaked seed 1 week before harvest of rice + Rhizobium inoculation and sowing of seed by reduced tillage. In both years of experiment, although different utera management practices have beneficial impact of yield and yield attributes of pulse crops, but the maximum seed yield (649 kg ha^{-1} and 914 kg ha^{-1}, respectively for lentil and lathyrus in 2017-18) was obtained when pulse crops received 2% DAP as foliar spray (p 23-24, Annex Report 13). Rest other utera management treatments were statistically at par except dry seed sowing just two weeks before harvesting of kharif rice. Thus, foliar applications of 2% DAP may be advocated for better yield and growth of utera lentil and lathyrus in rice-fallow areas under coastal saline zone of West Bengal.

For lentil, we also conducted net house experiment on the influence of stress mitigating chemicals on growth and yield of lentil gown on different soil type (coastal saline soil with $EC_{1:5}$ = 2.1 and new alluvial soil, $EC_{1:5}$ = 0.19) using 5 different treatments of two foliar spray of Seaweed Sap, Salicylic acid (1.0 mM), proline (50 mM), Abscisic acid (ABA) (250 ppm) with control (water spray only). Significant variation in main yield attributing traits (Branch/plant and Pod/branch) of lentil was found with foliar spray of different salt mitigating chemicals (p 28, Annex Report 13). Salicylic acid treatment was the best in producing 37.60 times higher branch per plant and 34.78 % higher number of pods per branch over control. New alluvial soil proved to be more productive than coastal soil as the earlier soil type produced 19.4% more branch per plant and 23.7% more pod per branch than the latter on. Based on that results the experiment was discontinued for later years.

7.14.3 Relay cropping

Relay cropping of grasspea (lathyrus) was also trialled in Dacope in 2016-17 (p 13, Annex Report 09). Two grasspea varieties viz. BARI Khesari-2 and BARI Khesari-3 were relayed on three sowing dates before T. Aman rice harvest viz. 20 days before (25 November 2016), 15 days before (30 November 2016) and 10 days before (5 December 2016). Highest grain yield and harvest index were recorded from BARI Khesari-2 when sown on 25 November i.e. 20 days before rice harvest. However, there was no significant variation between BARI Khesari-2 and BARI Khesari-3 sown on 30 November and 25 November sowing, respectively (p 14, Annex Report 09).

7.15 Irrigation and water management of Rabi season crops

Due to limited availability of freshwater for irrigation during the Rabi season, we have conducted several studies on irrigation and drainage water management and methods. These are:

- Conjunctive use of fresh and saline water for irrigation
- Development of drainage facilities for non-rice crop cultivation during Rabi season
- Use of storage pond for water harvesting in the wet season and using the stored water in the Rabi season
- Drip irrigation for high value crops

7.15.1 Conjunctive use of fresh and saline water for irrigation

There are many sources of water in the coastal area i.e. pond, canal, groundwater through tube well etc. which contains various degrees of salinity. After January availability of fresh water reduces. But there is possibility to grow some salt tolerant crops (sunflower, maize) with slightly to moderate saline water. So, to find out the effective use of saline and non-saline sources of water for sunflower production, we used different treatment combining fresh water with slightly saline water (5 treatments) in a trial at Amtali in 2016-17 (p 12, Annex Report 09). There was significant variation in yield. The highest seed yield (2.33 t ha^{-1}) was found from treatment of 3 irrigation with pond water having salinity of 0.8 dS m^{-1}, 0.9 dS m^{-1}, and 1.1 dS m^{-1}, respectively for 1st, 2nd, and 3rd irrigation (p 13, Annex Report 09). The results show that use of saline water up to 4 dS m^{-1} in 2nd and 3rd irrigation does not hamper sunflower yield and salinity did not developed too much.

Conjunctive use of fresh (low-saline: pond water) and saline water (medium saline: canal water) was used for growing sunflower in both locations in Bangladesh over two Rabi seasons during 2016-17 and 2017-18) (p 44, Annex Report 07). Six irrigation treatments with different combination of fresh water and saline water irrigation (2 to 3 irrigation) at different growth stages (vegetative, flowering and grain filling) of the sunflower crops were studied (p 45, Annex Report 07). The variation in yield for the treatments are shown in Table 7.14(p 59-61, Annex Report 07).

Table 7.14 Variation in yield (for sunflower with conjunctive use of fresh and saline water for irrigation

Treatments	Amtali, yield ($t\ ha^{-1}$)		Dacope, yield ($t\ ha^{-1}$)	
	2016-17	2017-18	2016-17	2017-18
2 irrigations at vegetative and flowering stages with fresh water (T1)	1.87bc	1.33c	2.47a	1.24c
1 irrigation at vegetative stage with freshwater and 1 at flowering stage with saline water (T2)	1.76bcd	1.32c	2.39a	1.40bc
1 irrigation at vegetative stage with freshwater and 1 at grain filling stage with saline water (T3)	1.74cd	1.20d	2.47a	1.4bc
3 irrigations at vegetative, flowering and grain filling stage with freshwater (T4)	2.07a	1.50ab	2.33a	1.64a
1 irrigation at vegetative with fresh water and 2 at flowering and grain filling with saline water (T5)	1.65d	1.55a	2.52a	1.71a
2 irrigations at vegetative and flowering with fresh water and 1 at grain filling with saline water (T6)	1.93ab	1.43bc	2.53a	1.61ab

The results (Table 7.14) shows that total seed yield was higher in treatment T5 compared to other technique of T1, T2, T3, T4 and T6 at both locations during the crop growing season of 2017-2018. In 2016-17, the highest yield was from the treatment T4 at Amtali and that was significantly different from the other treatments. But at Dacope though T6 produced highest yield, the difference among treatments was not statistically significant. The results indicated that yield increased with increased number of irrigations with fresh or saline water and irrigation affected the yield in both locations. The response of plant growth and sunflower yield to the conjunctive use of fresh water (pond water: ≥ 0.5 and ≤ 1.2 dS m^{-1}) and saline water (canal water ≥ 1.2 dS m^{-1}) could be used for developing better irrigation practices in coastal areas of Bangladesh. Irrigation water with EC of ≥ 0.5 and ≤ 2 dS m^{-1} (pond water) at earlier growth stages and EC of ≥ 1.2 dS m^{-1} had no significant effect on seed yield of sunflower in both locations of Dacope and Amtali during 2017-2018.

A similar experiment was also conducted for growing maize with similar irrigation applications at vegetative, tasselling and grain development stages (p 64, Annex Report 07). There was no significant difference in yield among the treatments. The yield of maize grain ranged from 6.55 t ha^{-1} to 7.7 t ha^{-1} at Dacope and 6.4 t ha^{-1} to 7.67 t ha^{-1} at Amtali (p 73, Annex report 07). Yield slightly increased with increased number of irrigations but there was no significant differences among the treatment in both locations. Irrigation water with EC of ≤0.5 dS m^{-1} (pond water) at earlier growth stages and EC of ≥ 1.5 dS m^{-1} at Dacope had no significant effect on grain yield of maize. The results indicated that when slightly high saline water was applied, Maize yield had insignificantly reduced in both locations. The technique of conjunctive use of fresh water (pond water: ≤0.5 dS m^{-1}) and saline water (canal water:≥ 1.5 dS m^{-1}) could maintain approximately similar trend of grain yield.

Based on two years (2017 and 2018) studies on sunflower and maize, the technique of conjunctive use of fresh water (EC ≤ 1.2 dS m^{-1}) at early crop growth stages and saline water (EC ≥1.2 and EC ≤ 5 dS m^{-1}) at later growth stages of these crops could be an alternative irrigation method for increasing yield and water productivity with a little reduction in crop yield compared to the no crops (fallow lands) during rabi season.

During 2018-20, we experimented conjunctive use of fresh and saline water on wheat, barley (Figure 7.58) and mustard using 4 treatments of 1 to 3 irrigations at different growth stages of the crops (p 76, Annex Report 07). Irrigation had a significant positive effect on the growth, yield and yield contributing parameters of wheat (p 81, Annex Report 07). Three irrigations; one at crown root initiation with fresh water and the other two at the booting (55-60 DAS) and grain filling stages (75 - 80 DAS) with saline water produced highest yield of 2.53 t ha^{-1} at Amtali and 1.78 t ha^{-1} at Dacope in 2018-19. In 2019-20, the highest yield was also from the same treatment (1.83 t ha^{-1} at Amtali and 2.51 t ha^{-1} at Dacope).

For Barley, one irrigation at 17-21 DAS with FW and two irrigations at booting (55-60 DAS) and grain development stages (75-80 DAS) with saline water produced highest yield in both years (2.56 t ha^{-1} and 1.82 t ha^{-1}, respectively in 2018-19 and 2019-20) at Amtali. At Dacope, yield varied from 1.44 t ha^{-1} to 2.22 t ha^{-1} in 2018-19 and 1.85 t ha^{-1} to 2.47 t ha^{-1} in 2019-20 (p 82-83, Annex Report 07). In 2018-19, highest yield was from the same treatment as Amtali but in 2019-20, the yield was highest from the treatment of one irrigation at 17-21 DAS with freshwater and one irrigation at grain development stages (75 - 80 DAS) with saline water. But the different was not significant.

Mustard was only studied at Amtali. The yield significantly varied from 0.63 t ha^{-1} to 1.16 t ha^{-1} in 2018-19 and from 0.78 t ha^{-1} to 0.94 t ha^{-1} in 2019-20 (p 84, Annex Report 07). The trend of yield among the treatments was exactly similar in both years. The highest yield was from the treatment with two irrigations, one at pre-flowering with freshwater and the other at siliqua filling stage with saline water. The lowest yield was from the treatment with no irrigation.

Based on the results of wheat, barley and mustard, it can be concluded that conjunctive use fresh water (low saline) at early growth stages and saline water (medium saline) at later growth stages of crops have the potential to sustain irrigated agriculture to intensify the cropping systemin the coastal salt-affected areas of Bangladesh.

Figure 7.58 Barley grown using conjunctive use of fresh and saline water in Dacope and sunflower sown by dibbling at Amtali

Crack formation in clay soils presents a major difficulty for movement of water, conserving soil moisture and the accumulation of salts on the soil surface through capillary from saline groundwater which restricts the crop growth and yield in no-tilled systems of coastal saline soils of Bangladesh. Field experiments were conducted to evaluate the effect of straw and irrigation frequency on growth and yield of maize (at Dacope) and sunflower (at Amtali, Figure 7.58) during 2018-19 and 2019-20 (p 90, Annex Report 07). There were two rice straw treatments (with or without straw), and 4 irrigation frequencies (at intervals of 5-7 days,10-12 days,15-17 days or 20-25 days). Maize and sunflower seeds were sown by dibbling in no-tilled systems. The results showed that rice straw significantly affected the yield, increasing the yield of maize and sunflower by 22% and 4.3% compared to treatments of without residue (p 94, Annex Report 07). The yield of sunflower significantly varied from 1.35 t ha^{-1} to 1.57 t ha^{-1} with straw and 1.31 t ha^{-1} to 1.47 t ha^{-1} without straw in 2018-19. In 2019-20, yield varied from 2.10 t ha^{-1} to 2.48 t ha^{-1} with straw and 1.33 t ha^{-1} to 1.90 t ha^{-1} without straw. The average yield of maize was 5.03 t ha^{-1} and 8.51 t ha^{-1}

with straw and 4.12 t ha^{-1} and 7.72 t ha^{-1} without straw, respectively for 2018-19 and 2019-20 (p 95-96, Annex Report 07). The results indicate that residue management and frequent irrigation techniques minimize soil moisture, cracks, salinity, osmotic potential and yield reductions by reducing evaporation in coastal eco-system.

We also tested irrigation method (flood irrigation and furrow irrigation) for sunflower, maize and sweet gourd in 2018-19 (p 116, Annex Report 10). Result shows that there was no significant difference in between flood irrigation and furrow irrigation. However, furrow irrigation required 31% and 51% less water than flood irrigation method respectively for Amtali and Dacope (p 118, Annex Report 10).

7.15.2 Use of drainage

Unexpected heavy rainfall in March 2017 damaged most of the Rabi crops in both locations. To overcome this situation, we designed a drainage system i.e. excavation of a drainage canal along the length of the plot of size 50 cm in width and 30 cm in depth (p 115, Annex Report 10). This created a facility to drain the excess rain water rapidly from the field and to protect the Rabi crops from damage due to waterlogging. Later in 2017, there was heavy rainfall at the beginning of the Rabi season during 9-11 December which severely damaged early season planting of Rabi crops. At the later part of Rabi crops i.e. some rainfall occurred, but due to the drainage facility, there was no damage to the crops such as sunflower, maize, sweet-gourd (also called pumpkin) and watermelon.

Following repeated unusual heavy rainfall in the Rabi seasons of 2016-17 and 2017-18, we realized that waterlogging and poor surface drainage are becoming a major constraint to the production of Rabi crops in southern coastal saline soils of Bangladesh. Hence, we set up field experiments to understand the effect of surface drainage on crop growth and yield at both Amtali (maize) and Dacope (sunflower) during 2018-19 and 2019-20 (p 100, Annex Report 07). The 4 treatments consisted of (i) single row raised bed with 30 cm drain, (ii) double row raised bed with 40 cm drain, (iii) triple row raised bed with 40 cm drain, and (iv) random field ditches (scattered)–pothole in 2018-2019 and one extra treatment of four row raised bed with 40 cm drain in 2019-2020 (p 102, Annex Report 07). The yield of sunflower and maize grain varied from 1.53 t ha^{-1} to 2.34 t ha^{-1} and 7.16 t ha^{-1} to 8.04 t ha^{-1}, respectively. The treatment of single row raised bed with 30 cm drain produced (8.04 t ha^{-1}) significantly greater yield than other drainage treatments. The results was similar for sunflower in 2018-19. In 2019-20, triple row raised bed with 40 cm drain produced the highest yield. In general, the results indicate that drainage can not only saves the crop it can also provide higher yield for both maize and sunflower.

7.15.3 Use of storage pond for water harvesting

We created two mini-ponds at Dacope, Khulna in a participatory way with two farmers for conserving rainwater and multi-purpose use of ponds for fish culture and supplemental use of high value crops (p 127, Annex Report 10). Based on the service area of crop field only 3-6% area was used for mini-pond (Figure 7.59). By using the mini-pond water, during Rabi 2017-18, Mr. Akhil Haldar got a bumper crop of watermelon and sweet gourd from his land and earned about Tk.81,000 from watermelon and about Tk.3,000 from sweet gourd with a total expense of Tk.30,000. He earned about Tk.8,000 from fish rearing in his excavated mini-pond. In 2019, during Kharif/Aman season, he cultivated off-season water melon on the bank of the pond (Figure 7.59) and earned about Tk.30,000 with the expense of Tk.15,000.

Figure 7.59 Excavated mini pond (left) and off-season watermelon on the bank of pond during Kharif II season at Dacope in 2019

He pointed out that by excavating a mini-pond he was able to cultivate the high value non-rice crops and he got additional benefit from his land, whereas most of the lands remain fallow during Rabi season due to shortage of fresh water. It also increases the total land productivity and income and a meet up the need of vegetables and fish requirement for family consumption. Off-season water melon cultivation has the potential to increase farm income in the coastal region.

7.15.4 Drip irrigation

We introduced and tested different types (solar powered, low-cost, indigenous) of drip irrigation in the field. Solar powered drip irrigation system (SPDIS) was introduced for the first time in the Gosaba Island under this project (p 13, Annex Report 12). In this system solar pump was used to pump water in the tank placed over a concrete platform (Figure 7.60). Due to high initial cost (Rs. 1,66,382), we also introduced low-cost (Rs. 45,000) drip irrigation system (LCDIS) without solar pump and using tank over a metal frame (Figure 7.60). The system was installed as a permanent system in an upland plot where rice cannot be grown even in the Kharif season. Using drip irrigation farmers are able to grow several vegetables such as okra, bitter gourd, cucumber, cabbage, broccoli, cauliflower, knoll-khol and chillies round the year; 3 to 4 crops per year. So, the cropping intensity was 300% or higher.

Figure 7.60 Solar powered drip irrigation (left) and low cost drip irrigation (right) set up in Gosaba

Economics of SPDIS and LCDIS and has been calculated based on input-output data from actual cropped area under the system in the experimental field during 2017-18 and 2018-19. The results show that both SPDIS and LCDIS indicated that the cropping system under the experiment was profitable in terms of gross return, net return and output-input ratio (p 65–66, Annex Report 12; Mahanta *et al.*, 2019; Mandal *et al.*, 2020). Average net return for SPDIS was Rs. 200,593 ha^{-1} from the SPDIS and Rs. 292,280 ha^{-1} from the LCDIS. After analyzing the economics of the cropping system, based on the annual cost and return, financial feasibility of the SPDIS was examined following discounted financial analysis criteria such as Internal Rate of Return (IRR), Benefit-cost ratio (BCR), Net present value (NPV) and un-discounted criteria, payback period. The financial feasibility on such system was not so encouraging due to high initial investment required for the system, particularly under the investment made through own capital. The system would be financially viable if the area under operation is doubled or subsidies (80%) for the installations are available. Since there are high dividends from micro irrigation, there is a need for larger quantum of subsidy especially for the small and marginal farmers. The output input ratio of the low-cost drip irrigation system has been found very encouraging (3.12). Also due to the reduced cost on the system, the financial feasibility of the low-cost drip irrigation system become good proposition with favorable IRR (33%), BCR (1.52), NPV (Rs. 42,308) and payback period of 1.91 years. Thus, this low-cost drip irrigation system can be promoted in other similarly plots in the region for achieving higher cropping system intensification and profitability.

We have also tested the performance of different water saving options including drip system in high value post-monsoon crop (Tomato) in Gosaba (p 20, Annex Report 13; Samui *et al.*, 2020) using five treatments such as surface irrigation (at critical growth stages), surface irrigation (at critical growth stages) with straw mulching, drip irrigation at 100 % ETo, drip irrigation at 80 % ETo, drip irrigation at 80 % ETo with straw mulching during 2016-17 and 2017-18. Amongst the treatments, the maximum number of fruits per plant (49.9) was recorded from the plants receiving drip irrigation 80 % ETo with straw mulching. As a result, significantly higher fruit yield (60 t ha^{-1}) was also recorded from the same treatment (p 22, Annex Report 13). Water use efficiency of tomato varied significantly due to adoption of different water saving options. The highest water use efficiency was recorded (182.03 kg ha^{-1} mm^{-1}) from the plots receiving drip irrigation at 80 % ETo along with straw mulch (p 22, Annex Report 13).

In 2018-19, we applied drip irrigation at 80 % ETo along with straw mulch to six different crops i.e. okra, tomato, onion, knolkhol, beet and chilli in Gosaba Figure 7.61; p 29, Annex Report 13). It was observed that, cultivation of tomato under drip irrigation system is most remunerative (benefit: cost (B:C) ratio: 2.52) followed by knolkhol (1.91) and beet (1.31). All the crops under experimentation except onion showed positive net return and B:C ratio (p 29, Annex Report 13).

Figure 7.61 Low cost drip irrigation in Gosaba (left) and damaged drip experiment at Dacope, Khulna (right)

We also tested solar powered drip irrigation for growing vegetables in Dacope during 2018-19 (p 109, Annex Report 07). But, due to heavy rainfall, the experiment was damaged (Figure 7.61). In 2019-20, we set up drip irrigation again at Dacope with water melon. The yield was 26.23 t ha^{-1}. The unit fruit per plant and unit weight per fruit were 2.36 and 4.5 kg, respectively (p 110, Annex Report 07). Due to COVID-19, the price of watermelon was very low. However, it was technically feasible and most probably economically profitable as well.

7.16 Out-scaling and demonstration of different crops

7.16.1 Amtali and Dacope

On the basis of the result of our experiments in 2016-17, some up-scaling program was carried out during Rabi season of 2017-18 at Amtali, Borguna (p 42, Annex Report 09). Thirty three farmers including 5 women were involved in up-scaling program covering 3.5 ha of land. The program was carried out for wheat, grasspea, cowpea (relay with Aman rice), pumpkin and potato. As discussed earlier, wheat is a risky crop and farmers were not impressed with the yield. The yield of potato was far below the potential yield of the variety (BARI Alu-72) but was profitable. However, farmers were not optimistic with the production of BARI Alu-72 against the heat and salt stress condition. Farmers were very much satisfied for getting higher yield of sweet gourd or pumpkin and it looked promising for the area. Grasspea and cowpea were damaged due to excessive rainfall.

We continued upscaling with maize and sunflower in the following year as well due to their good performance in the field as discussed earlier. On basis of our results in 2019-20, we set up out-scaling and demonstration of sunflower (24 farmers, 3.24 ha), maize, and foxtail at Amtali (our project site) and also at the neighboring Upazila of Kalapara of Patuakhali district (Table 7.15; p 47, Annex Report 09).

Table 7.15 Out-scaling of different crops at Amtali with number of farmers, area and yield (2019-20)

Crop	No of farmers involved	Area (ha)	Yield range (t ha^{-1})	Average Yield (t ha^{-1})
Sunflower	24	3.24	1.20–1.85	1.48
Maize by PTOS	12	1.62	6.73–8.37	7.51
Millet	6	0.81	0.80–1.13	1.05

We gathered farmers' opinion on the demonstrated crops. For sunflower, there was massive bird attack. As there are not many fields in the area with crops, the sunflower fields at the maturity stage became magnet for birds. So effective bird control measures are necessary. Untimely rainfall affected the yield as there was unfilled grain of 20-40%. Farmers faced difficulty in threshing and there is less demand for the seed in the market. Access to threshing machine and good market condition are necessary to promote this crop to the farmers.

For maize, farmers were highly satisfied with PTOS as it saves time and seed and reduce labour cost. So, to popularize and increase maize area in the region PTOS should be available locally. Foxtail millet is a new crop in the region so seeds are not easily available. Farmers faced increased production cost due to weeding, severe bird attack, lower yield, difficult in di-husking, and less demand in the market. If these limitations can be minimized then the crop can be incorporated in the farmers existing pattern.

Following success of ZT potato in Dacope, out-scaling and demonstration program of zero tillage potato cultivation with rice straw mulch was undertaken in 2018-19 and 2019-20. In 2018-19, eight farmers cultivated five decimal (41 m^2) lands each. In 2019-20, we introduced zero tillage potato in three upazilas viz. Dacope, Koyra and Batiaghata. Average yield of potato in 2018-19 from eight farmers' field was 13.43 t ha^{-1} (p 50, Annex Report 09). Economic analysis on average tuber yield and average total variable cost shows that gross return was Tk. 134,338 ha^{-1} (p 50, Annex Report 09).

In 2019-20, highest yield was recorded from the variety BARI Alu-72 (18.76 t ha^{-1}) from Koyra followed by BARI Alu-78 (14.98 t ha^{-1}) from the same location. Lowest yield was recorded from BARI Alu-73 (4.18 t ha^{-1}) from Dacope (p 51, Annex Report 09). It was observed that late sowing and thin mulch coverage reduced the yield of potato of one farmer. Sometimes heavy rainfall and rat attack aggravated the situation and reduced expected yield. However, farmers reported that this technology is easier to implement and almost without any care a reasonable harvest can be achieved.

We also demonstrated spinach (BARI Spinach-1) in about 33 decimals (0.14 ha) of land. Average yield was recorded as 17.28 t ha^{-1}. Gross margin was Tk.108,440 ha^{-1} which indicates spinach cultivation is profitable (p 52, Annex Report 8, OFRD).

We also conducted block demonstrations of Boro rice with 6 varieties (BRRI dhan28, BRRI dhan58, BRRI dhan67, BRRI dhan74, BRRI dhan89, and BINA dhan10) using canal water in Amtali and Dacope for 3 years (2017-18 to 2019-20) (p 98, Annex Report 10). In both sites, the tested variety was transplanted at middle to later part of January and harvested at late April to early May in every season. The area coverage and the number of farmers are given in Table 7.16.

Table 7.16 Area Coverage and number of farmers cultivated different varieties of Boro rice

Location	2017-18		2018-19		2019-20	
	Area (ha)	No. of Farmers	Area (ha)	No. of Farmers	Area (ha)	No. of Farmers
Amtali, Borguna	4.12	26	12.5	41	20.2	58
Dacope, Khulna	2.99	9	18.6	35	9.0	28

In Amtali, the area and the number of farmers increased significantly over the years. In Dacope, while there was 4 fold increase in the number of farmers from 2017-18 to 2018-19, there was a reduction of 20% in 2019-20 compared to the previous year. The canal which was being used to irrigate the rice fields were leased out by the government for fish production in 2019-20. The farmers were afraid to use the fresh water from the canal for rice production. So, farmers choose not to cultivate.

All the tested rice varieties performed well. In Amtali, rice yield varied from 4.68 t ha^{-1} to 5.17 t ha^{-1} in 2018-19 and 5.52 t ha^{-1} 5.84 t ha^{-1} in 2019-20. The yield in Dacope varied from 5.10 t ha^{-1} to 6.05 t ha^{-1} in 2018-19 and 5.80 t ha^{-1} to 6.34 t ha^{-1} in 2019-20. In 2017-18, the average yield was 5.0 t ha^{-1} and 5.88 t ha^{-1} respectively for Amtali and Dacope. In Dacope, all the tested varieties produced the highest grain yield compared to Amtali in both year (p 100, Annex Report 10).

Gross income or net benefit of Boro rice at average yield (5.4–5.7 t ha^{-1}) were between Tk. 55,030 ha^{-1} to 59,385 ha^{-1} in Dacope and Amtali respectively (p 102, Annex Report 10). Farmers were satisfied with the yield of Boro rice over the last couple of years. They reported that Boro rice is more resilient to extreme weather events, in particular torrential rain than the non-rice crops that are highly vulnerable to stagnant water. Therefore, most participant farmers are willing to continue Boro rice cultivation, and they preserved seed. Many new farmers also showed interest to cultivate. It is likely that Boro rice area may increase in both locations in the future. However, farmers have apprehension about the availability of freshwater for irrigation, and they are concern about the high seasonal fluctuation of the price of paddy rice in particular at harvesting time. Thus, strengthening policy supports for enhancing access to freshwater for irrigation and fair price of paddy rice is very important for sustainable intensification of Boro rice cultivation in the region.

Following introduction and high yield of Aus rice in 2017, many farmers came forward to cultivate in both locations (p 104, Annex Report 10). The area cultivated and number of farmers are given in Table 7.17. Three varieties were tested (BRRI dhan48, BRRI dhan67 and BRRI dhan82).

Table 7.17 Area Coverage and number of farmers cultivated different varieties of Boro rice

Location	2017		2018		2019		2020	
	Area (ha)	No. of Farmers	Area (ha)	No. of Farmers	Area (ha)	No. of Farmers	Area (ha)	No. of Farmers
Dacope, Khulna	0.2	1	2.0	10	4.2	29	4.0	19
Amtali, Borguna	1.7	11	19.2	88	19.1	74	14.6	40

In both locations, BRRI dhan48 performed better than the other varieties. In Dacope, the yield was higher than that of Amtali for all varieties. The yield in Dacope varied from 4.12 t ha^{-1} to 4.67 t ha^{-1} in 2018 and 4.09 t ha^{-1} to 4.47 t ha^{-1} in 2019. In Amtali yield varied from 3.86 t ha^{-1} to 4.30 t ha^{-1} in 2018 and 3.92 t ha^{-1} to 4.30 t ha^{-1} in 2019 (p 106, Annex Report 10). Harvesting was not done this year (2020) yet at the time of preparation of this report. The gross income or net benefit per hectare of Aus rice at average yield (4.1–4.2 t ha^{-1}) were in the range between Tk.20,522–23,353 ha^{-1} (p 107, Annex Report 10). The yield of Aus rice in the demonstration plots was stable than non-rice crops as the non-rice crops wilted with stagnant water in the fields for couple of days. Famers are willing to cultivate Aus rice in the larger area subject to ensure access to (i) fair price of the paddy rice and (ii) freshwater for raising seedling in the nursery.

7.16.2 Gosaba

In Gosaba, the main out-scaling activities was on the ZT potato cultivation. The technology is being adopted by the farmers and the number of farmers are increasing rapidly every year as shown in Table 7.18. The main reason for its adoption is the ease of cultivation and economic profitability. The quality of ZT potato is better than the traditionally cultivated potato (Sarangi *et al.*, submitted) and they can be stored for longer period at home. A detail analysis of the adoption of ZT potato is given in Section 7.18.

Table 7.18 Number of farmers, area under field experiment and net benefit due to zero tillage potato cultivation with paddy straw mulching at Gosaba

Year	Number of Farmers			Area in ha	Net benefit (US$ ha^{-1})
	Male	Female	Total		
2016-17	20	3	**23**	1.53	1,398
2017-18	38	6	44	3.52	1,540
2018-19	88	34	122	4.90	1,991
2019-20	138	70	**208**	6.91	2,213
Total	284	113	397	16.86	1,785

7.17 Suitable and profitable cropping patterns

Several suitable and profitable cropping patterns have emerged based on our research over the last four years for the study areas (Figures 7.62 and 7.63).

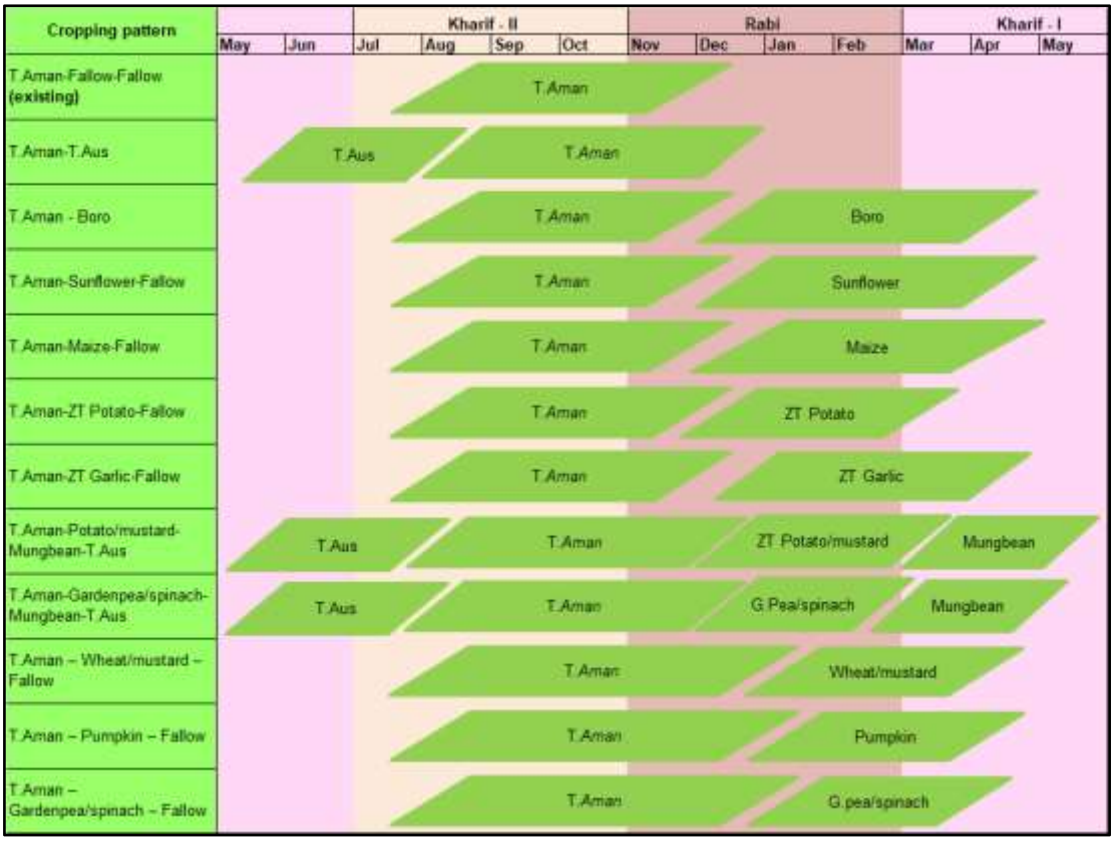

Figure 7.62 Suitable and profitable cropping patterns along with existing pattern for Bangladesh

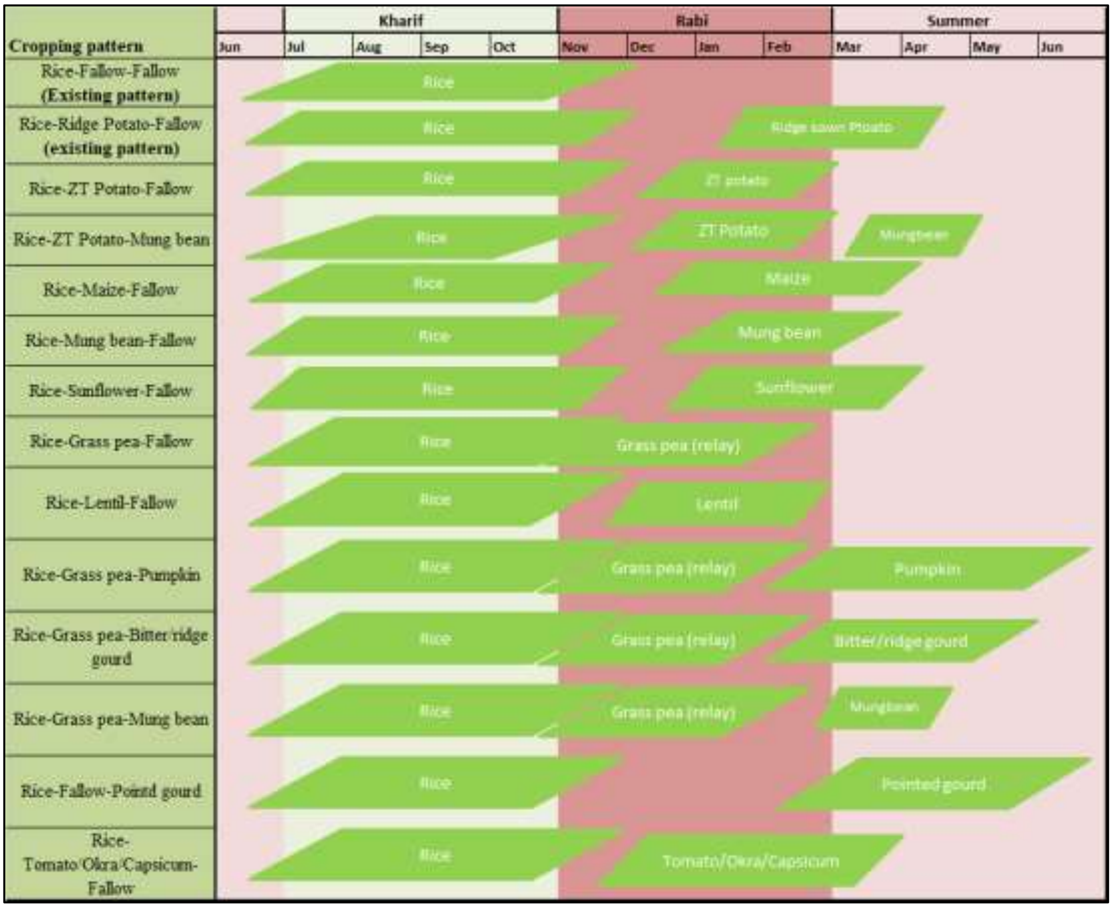

Figure 7.63 Suitable and profitable cropping patterns along with existing pattern for Gosaba Island, West Bengal

Table 7.19 shows the profitability of different cropping patterns tested by the Agronomy Division of BARI at Amtali and Dacope during 2016-17 and 2017-18 (p 18, Annex Report 08; Saha *et al.*, 2019). In Amtali, T.Aman - Potato - Mungbean - T.Aus showed the highest gross return, total variable cost and net return followed by T.Aman - Spinach - Mungbean - T.Aus. The later cropping pattern gave the highest benefit cost ratio (1.91). T.Aman - Garden pea - Mungbean - T.Aus also gave comparatively higher gross return, net return as well as benefit cost ratio (Table 7.19; p 27, Annex Report 08). However, cropping pattern with 4 crops is possible in comparatively upland areas adjacent to homestead. On the other hand, T.Aman - Fallow - Fallow (Farmers' practice) contributed the lowest gross return, total variable cost, net return and benefit cost ratio. In Dacope, the highest gross return, net return and benefit cost ratio were obtained from T.Aman - Spinach - Fallow cropping pattern followed by T.Aman - Potato - Fallow (Table 7.19).

Table 7.19 Profitability of different cropping patterns in Amtali, Borguna and Dacope, Khulna

Cropping pattern (Kharif-II-Rabi-Kharif-I)	Gross return (Tk. ha^{-1})	Variable cost (Tk. ha^{-1})	Net return (Tk. ha^{-1})	Benefit cost ratio
Amtali, Borguna				
Rice - Potato - Mungbean - T.Aus	454,050	258,762	195,288	1.75
Rice - Mustard - Mungbean - T.Aus	318,600	187,623	130,977	1.70
Rice - Garden pea - Mungbean - T.Aus	293,400	157,631	135,769	1.86
Rice - Spinach - Mungbean - T.Aus	452,925	236,591	216,334	1.91
Rice – sunflower- fallow (OFRD)	170,600	113,500	57,100	1.47
Rice – foxtail millet- fallow (OFRD)	116,660	73,370	43290	2.11
Existing patterns				
Rice - Fallow - Fallow (Agro)	98,775	64,285	34,490	1.54
Rice - Fallow - Fallow (OFRD)	67,200	43,350	23,850	1.82
Rice - Fallow - Fallow (OFRD), different variety of T. Aman	64,300	48,600	15,700	3.09
Dacope, Khulna				
Rice - Wheat - Fallow	114,750	87,467	27,283	1.31
Rice - Mustard - Fallow	111,600	76315	35,285	1.46
Rice - Garden pea - Fallow	142,425	82,871	59,554	1.72
Rice - Spinach - Fallow	242,100	93,,719	148,381	2.58
Rice - Potato - Fallow	190,,350	121,823	68,527	1.56
Rice - Fallow - Fallow (Farmers' practice)	90000	65,136	24,864	1.38

Note:1 US Dollar = 85 Bangladeshi Taka (Tk)

Farmers in Amtali, Borguna opined that the tested cropping patterns have created an opportunity to cultivate more crops in a year. Earlier farmers of this area had no idea about the improved cropping pattern and that is why they used to cultivate only single rice crop (T.Aman rice) in monsoon and the land remained fallow during rest period of the year. The improved cropping patterns will increase their total crop production and economic return which will ultimately improve their livelihood. Farmers in Dacope, Khulna opined that potato, garden pea, wheat, mustard and spinach gave the satisfactory yield. Therefore, the farmers are interested to cultivate this winter crops after harvest of T.Aman at that location.

OFRD Division of BARI, two profitable cropping patterns at Amtali. These are T.Aman – sunflower- fallow and T.Aman – foxtail millet- fallow for Amtali (p 6, Annex Report 09). The gross margin or net benefit of these two patterns were Tk 57,100 ha^{-1} and Tk. 43,290 ha^{-1}, respectively against existing pattern of T.Aman-fallow-fallow, the gross margin of which varied from Tk. 15,700 ha^{-1} to Tk. 23,850 ha^{-1} (p 7, Annex Report 09). The results indicate that farmers can increase their income more than 2-fold by practicing improved cropping patterns. This will need additional investment as well as shown in the total variable costs of Table 7.19.

Five different cropping patterns for Amtali were also tested (by IWM Division of BARI) during 2016-18 (p 12, Annex report 7; Sarker *et al.*, 2019). The economic analysis of these patterns are given in Table 7.20; p 30-32, Annex Report 07). In terms of crop yield, rice equivalent yields, production efficiency, total system of crop and water productivity, profitability of economics and reducing the risk of soil salinity, osmotic pressure and scarcity of available water, the improved cropping systems were: T.Aman - mustard - T.Aus, T.Aman - sunflower - T.Aus, and T.Aman- maize - T.Aus.

Table 7.20 Profitability of yearly total system based on variable cost, gross margin and benefit-cost ratio (BCR) of different cropping system

Cropping pattern (Kharif II- Rabi-Kharif I)	Total variable cost (Tk. ha^{-1})	Total gross return (Tk. ha^{-1})	Total gross margin (Tk. ha^{-1})	Marginal benefit cost ratio
T. Aman - Mustard -T. Aus (Optional)	132,206	206,300	74,094	1.56
T. Aman - Sunflower -T. Aus (Optional)	165,095	253,050	87,955	1.53
T. Aman - Maize -T. Aus (Optional)	188,607	258,900	70,293	1.37
T. Aman - Wheat – Mung bean (Optional)	104,275	107,750	3,475	1.03
T. Aman - Fallow-Fallow, Farmers' practice)	46,650	71,225	25,450	1.52

Table 7.21 summarises existing and potential cropping systems for the coastal area in particular for Amtali and Dacope studied by BRRI (p 130, Annex Report 10). Rice-fallow-fallow is the most dominant cropping pattern, covering about 80-90% of total arable areas in the study areas. Only few plots were under pattern rice-fallow-rice. All other patterns were identified as potential. The profitability of existing and potential cropping patterns for Amtali and Dacope are given below (p 131-134, Annex report 10).

Table 7.21 Gross income or net benefit (Tk. ha^{-1}) from existing and potential cropping patterns in Amtali and Dacope, 2017-18 to 2019-20

Cropping pattern (Kharif-II-Rabi-Kharif-I)	Amtali		Dacope	
	2017-18	2019-20	2017-18	2019-20
Rice- fallow-fallow, farmers' practice	34,951	37,180	34,361	35,911
Rice - fallow-rice	60,786	65,702	70,668	62,464
Rice-sunflower-rice	101,710	108,248	100,029	120,610
Rice-sunflower-fallow	75,875	79,726	63,721	94,057
Rice-maize-fallow	74,387		72,106	80,384
Rice-maize-rice	100,222		108,414	106,937
Rice-Pumpkin-fallow	73,223	83,785	74,543	89,606
Rice-pumpkin-rice	99,057	112,307	110,850	116,159
Rice-rice-fallow	78,829	92,210	79,910	95,296
Rice/vegetables- Vegetables-fallow	8,012		27,422	

Note: Gross income or net benefit = Gross return – cost of production (without including the cost of farmers' own labour)

As shown in Table 7.21, all potential cropping systems under recommended practice were profitable. However, there was substantial variation in gross return due to mainly to high seasonal fluctuation of the price of paddy rice. The variation in yield of the rice and non-rice crops due to seasonal weather variation also affected the seasonal changes of return per hectare land between the seasons.

The economic analysis of the current and the evolved/improved cropping system for Gosaba is given in Table 7.22. Current cropping system is dominated by Kharif rice-fallow (86%) followed by Kharif rice-Rabi rice, Kharif rice-mixed vegetables, Kharif-rice-potato (ridge) and homestead production system (p 64, Annex Report 12). All the improved and evolved cropping systems provided higher profitability as compared to the existing cropping systems. The proposed cropping system intensification has the potential to increase the cropping intensity to 200 to 300 percent in the study area as compared to the existing 123 percent (p 64, Annex report 12).

Table 7.22 Cropping system intensifications and profitability for Gosaba, West Bengal

Sl. no	Cropping system (Kharif-Rabi)	Total Cost (Rs ha^{-1})	Gross Return (Rs ha^{-1})	Net Return (Rs ha^{-1})	Output-input ratio
A. Existing: currently practiced by the farmers					
(i)	Kharif rice-fallow	38,393	52,350	13,957	1.36
(ii)	Kharif rice-Rabi rice	93,110	139,294	46,184	1.50
(iii)	Kharif rice-ridge potato	171,905	225,150	53,245	1.31
B. Improved: Replacing existing varieties with the improved varieties of Kharif rice and potato					
(i)	Kharif rice-fallow	38,046	80,835	42,789	2.12
(ii)	kharif paddy-ridge potato	159,824	257,415	97,591	1.61
C. Evolved: Replacing existing varieties with new technologies					
(i)	Kharif paddy-green gram	63,384	115,635	52,251	1.82
(ii)	Kharif paddy-ZT potato (Farmers adopted plot)	142,990	246750	103760	1.73
(iii)	Kharif paddy-ZT potato (Experimental plot)	122,125	284,415	162,290	2.33
(iv)	Kharif paddy-ZT potato-green gram (experimental plot)	160,171	365,250	205,079	2.28
(v)	Kharif paddy-maize	95,031	162,278	67,247	1.71
(vi)	Vegetable-vegetable-vegetable through Solar drip irrigation system (per 1000 m^2)	15,360	35,419	20,059	2.31

Note: 'Net return' here is the same as 'gross income' described in Table 7.21.

The economics of different rice-based systems for the BCKV site in Gosaba revealed that rice-vegetable systems were much remunerative for the study area (Table 7.23) (p 60, Annex Report 13, Ray et al., 2020). Among different rice-based systems, rice-bitter gourd had the highest net return (Rs. 501,570 ha^{-1} $year^{-1}$) and B:C ratio (3.92). However, rice-fallow-fallow systems recorded the lowest net return and B:C ratio.

We further analysed the risk of 11 of the cropping systems below (Table 7.23) to evaluate the current viability and future sustainability of the rice-based systems (Kabir *et al.*, 2017)considering three different situations for the individual crops viz. best (high yield and high price), normal (average yield and average price) and worst (lowest yield and lowest price) seasonal conditions over the last 5 years (p 65, Annex Report 13). Among the different rice-based systems, rice-tomato-fallow followed by rice-chilli-fallow and rice-potato-greengram were less risky under changed yield and selling price situation (Figure 7.64).

Table 7.23 Cost of cultivation, gross return, and net return in thousand Rs. ha^{-1} year^{-1} and benefit:cost (B:C) ratio of different rice-based cropping systems

Systems	Cost of cultivation	Gross return	Net return	B:C ratio
Rice-lathyrus-fallow	57.50	83.12	25.62	1.45
Rice-potato-fallow	124.95	255.00	130.05	2.04
Rice-sunflower	84.00	121.92	37.92	1.45
Rice-fallow-fallow	40.50	58.32	17.82	1.44
Rice-potato-ladies finger	194.70	328.60	133.90	1.69
Rice-lentil-fallow	69.00	110.82	41.82	1.61
Rice-potato-rice	177.45	337.94	160.49	1.90
Rice-lentil-rice	121.50	193.76	72.26	1.59
Rice-rice	93.00	141.26	48.26	1.52
Rice-potato-pumpkin	199.95	497.40	297.45	2.49
Rice-pointed gourd	166.50	339.57	173.07	2.04
Rice-potato-ridge gourd	208.58	510.00	301.43	2.45
Rice-bitter gourd	171.75	673.32	501.57	3.92

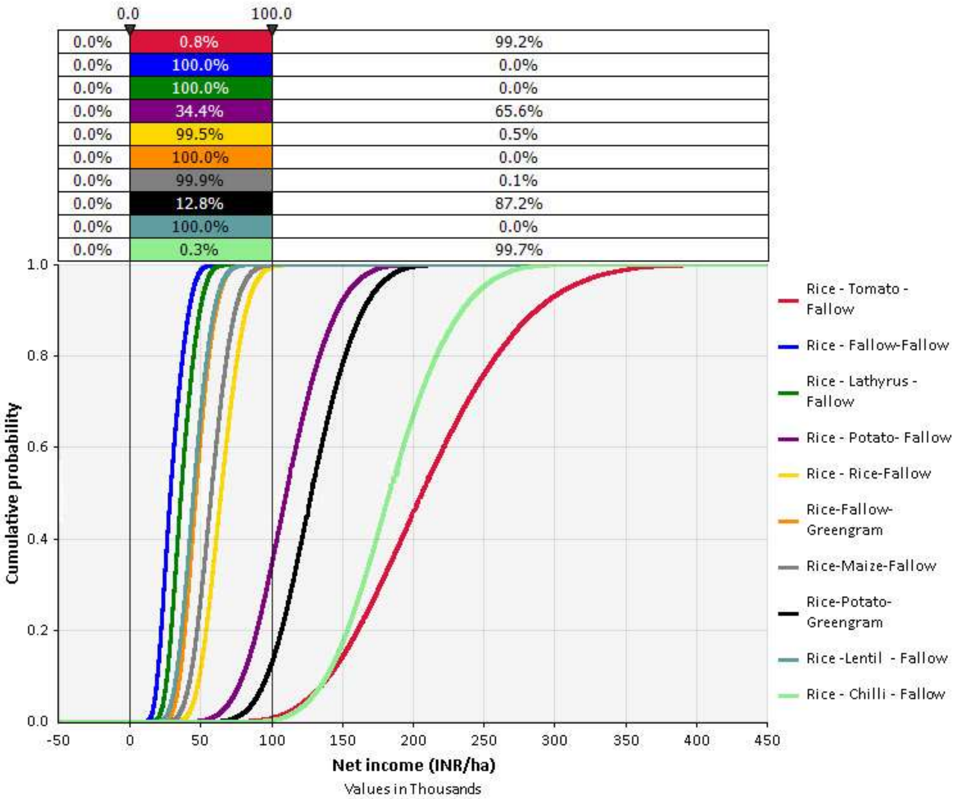

Figure 7.64 Cumulative probability distribution (CDF) of net income per ha of different existing and potential rice-based cropping systems based on current prices and historical yields

The cropping system intensification has been quite successful and there are several opportunities to achieve higher cropping intensities with substantially higher returns as compared to the existing practices. The experiments have showed that there are number of feasible options can be promoted and also some existing options can be improved through suitable technological interventions like soil and water management. Such interventions can increase farmers' income substantially by reducing the yield gap.

7.18 Baseline condition, adoption and community perceptions

At the beginning of the project in 2016, we conducted baseline survey in the selected areas. The general objective of benchmark surveys was to obtain an understanding of the present status of farmer communities with respect to their resources, constraints and possibilities in agricultural production. Based on these benchmark surveys, researchers, extension workers, development partners and policy makers are able to develop programs to address farmers' problems and to optimize utilization of available farm resources.

Table 7.24 present socio-demographic feature of households in the 3 trial villages in Bangladesh. Nearly one third of the households in the villages were landless labourer. Most farm households were small (68-91% of total farm households) semi-subsistence and resource poor owner/tenant farmers. On average size of small farm in the trial villages was less than half hectare. Only 9-27% of total farm households were medium farm type. On average size of medium farm was just over one and half hectare. Family size (4.2-4.8) of small and medium farm families is consistent with national average family size of rural households (4.6), indicates that most are nuclear family consist of husband, wife and their children (for detail please see p 3-5, Annex Report 10).

Table 7.24 Socio-demographic features of households in trial villages in Amtali and Dacope 2016

Features	Dacope		Amtali
	Pankhali	Khatail	Sekandarkhali
Number of total households	131	143	113
Non-farm households (%)	34	31	29
Farm households (%):	66	69	71
Large farm	2	0	5
Medium farm	24	9	27
Small farm	73	91	68
Farm size (ha): LF > 3ha	5.1	-	5.8
MF >1 -3 ha	1.6	1.6	1.7
SF < 1 ha	0.4	0.4	0.5
Family size (no.): LF	6.5	-	5.6
MF	4.7	4.3	4.8
SF	4.2	4.6	4.5

The baseline survey identified the constraints and opportunities for cropping system intensification in the study area. The constraints of cropping system intensification included inadequate access to fresh-water for irrigation, high soil salinity, excess soil moisture at sowing time of dry season crops, lack of soil moisture at sowing time of Kharif-I crops, lack of farmers' knowledge, inadequate access to suitable technologies at local level, lack of stress tolerant varieties, technologies and extension supports and price volatility. The survey identified the opportunities to increase cropping intensity in the area through improving linkages between cropping choices and polder level water and salinity management, in particular judicious use and management of reserved fresh-water, improving farmers' knowledge on crop management and increasing adoption of stress tolerant variety and management. Re-excavation of canal, repairing and/or establishing a new sluice gate between canal and rivers and farming friendly sluice gate management, increased extension supports, dissemination of stress tolerant varieties and stress management technologies together with increasing access to soft credit, quality inputs may jointly facilitate increased cropping intensity and/or ensure agricultural sustainability in the coastal areas of Bangladesh.

In Gosaba, we conducted baseline survey to collect primary data during 2017-18 from 90 collaboratives farmers in the CSSRI study area (p 61, Annex Report 12). Responses of 304 non-collaborative farmers were recorded to understand their response to cropping intensification interventions while they managed farm lands by themselves. During 2019-20, an end line survey was conducted covering 230 farmers (90 collaborative farmers and 140 non-collaborative farmers) and the data were compared (before and after the project) to analyse the socio-economic impact of the various interventions made during the project and farmers response to adoption of these technological interventions. Key findings from this are given below. The details are given in Annex Report 12 (p 67-77).

1. The impact of the project interventions was visible in case of rabi season cultivation. Significant change in area and production was observed for the rabi crops. All these expansion in area was influenced by the project interventions and successfully reduced the extent of rabi fallow area (30-35%) in the coastal zone. More number of crops was taken during rabi season with higher cropping system intensification, resulted into higher production and income. Overall, the interventions have been successful to increase the cropping intensity to around 202% after the interventions, substantially higher as compared to the before interventions (145%) situations.
2. The impact of the project was also analyzed through estimating the change in expenditures and returns from the cultivation practices, before and after the project for both kharif and rabi season crops. Overall, it indicated, with 19% increase in expenditures, average gross return from the cultivation (per households) increased by 46%. Out of this total increase, higher return was obtained from rabi cultivation (88% increase) as compared to kharif cultivation (42%). In both the seasons expenditures and return was increased but incremental return was higher in rabi season as compared to kharif season, also indicated that interventions in the project were successful.
3. During the project period, several interventions have been attempted and demonstrated with the active participation of the farmers. Most preferred interventions reported by the farmers were, ZT potato, vegetables in bags along with kharif paddy, straw mulching, green manuring, lime applications and growing new crops like broccoli, moong, mustard, sunflower, maize and other vegetables. Low cost drip irrigation method, direct seeded rice and drum seeded rice method was also preferred by the farmers in the coastal zone but not quite sure whether to adopt in large scale, primarily due to erratic rainfall pattern and operating very small area of land. Overall, it was realized that farmers prefer interventions that reduces water use, increase production with less resources (labour, fertilizer), conserve moisture, improves soil quality and can provide vegetables throughout the year. Key reasons for not able to adopt the new interventions despite they liked some, was mainly due to the lack of suitable land area and uncertainty of availability of quality inputs.
4. Several constraints still remain critical for decision making by the farmers. Some of these critical constraints need attention for larger policy interventions and some can be mitigated through the knowledge gained from the project experiences. Key constraints, as perceived by the farmers were, more water in kharif (waterlogged situation), less water in rabi (good quality), soil salinity, water salinity, input unavailability in time and quality, high

input cost, disposal of crops with remunerative price, limited access to technical know-how, risk in agriculture and insufficient capital.

Baseline survey was also conducted in the study areas (2 villages) of BCKV at Gosaba (p 47, Annex Report 13). Most of the respondents (88.5%) rely on agriculture as their primary occupation followed by 11.5 % other than agriculture (Figure 7.65). Regarding their secondary occupation, 67.3% depends on other activities (Rickshaw-van pulling, wholesale shop, labour in man days etc.) followed by 3.8% in agriculture and rest 28.8% do not participate in any secondary occupation. Through the survey participants' caste, family type and size, educational status, social participation, economic information, land holdings, house type, farm power, material possession, irrigation availability status and farm mechanization status were collected. The details can be found in the Annex Report 13 (p 48).

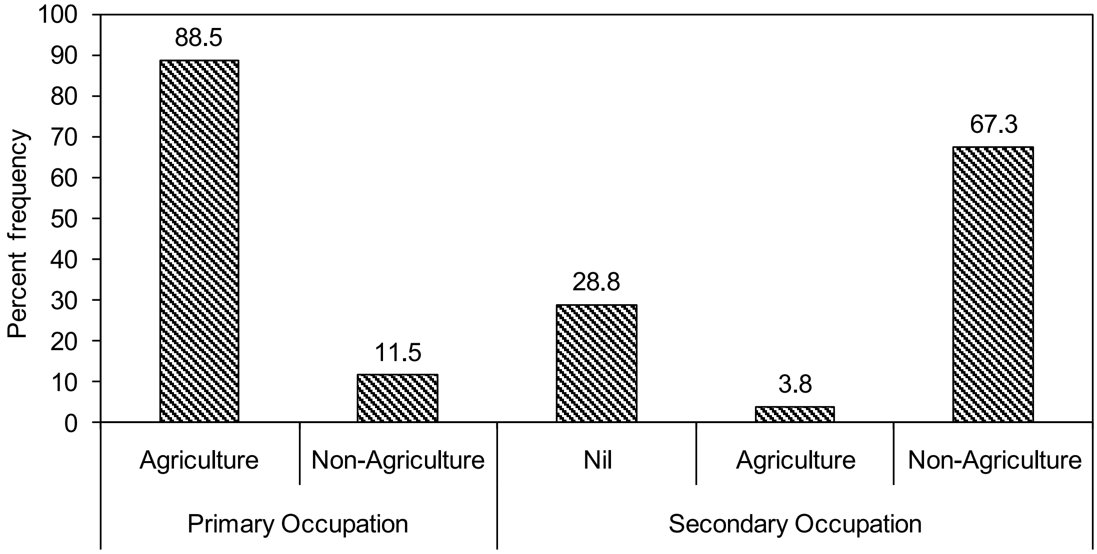

Figure 7.65 Occupation status of the villagers

We also studied socio-economic impact of their different technological interventions such as relay cropping of lentil, lathyrus, cultivation of green gram, tomato cultivation using drip irrigation and zero tillage potato at Gosaba (p 53, Annex Report 13). Relay cropping of lentil and cultivation of green gram resulted in limited adoption in the study area. The other 3 are being adopted by the farmers and their diffusion pathway and adoption were studied further (p 53-54, Annex Report 13; Ray *et al.*, 2019). The pathway of dissemination of ZT potato technology is shown in Figure 7.66. The flow of technology was both direct and indirect. The accrued profit of one farmer in first year was a crucial factor for dissemination of technology in the second year.

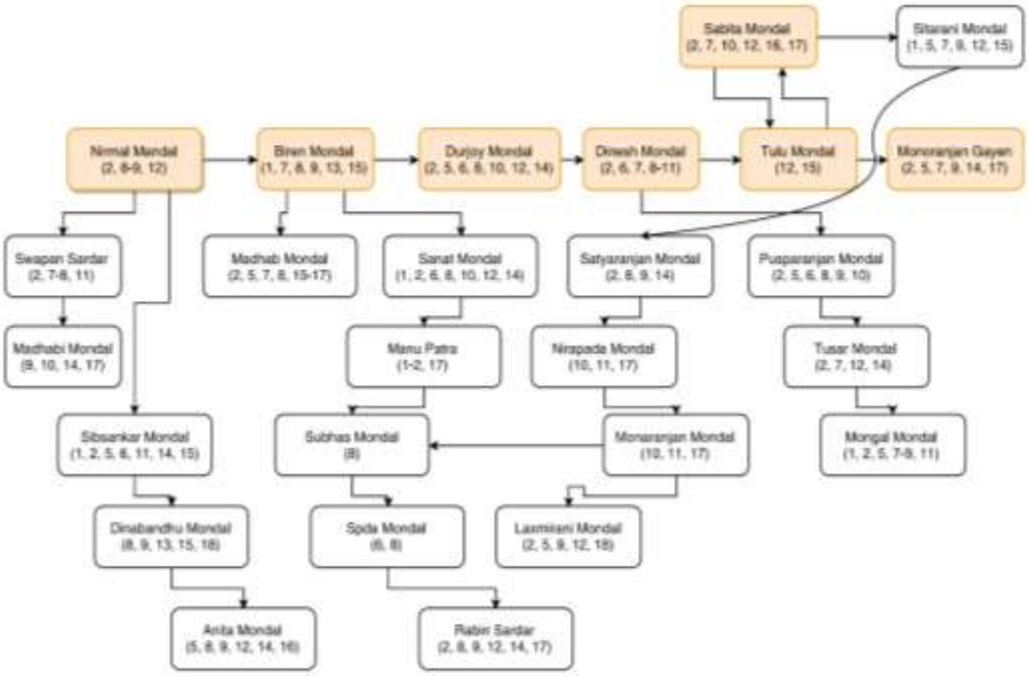

Figure 7.66 Participatory Innovation Tree for zero-tillage potato with straw mulch within parenthesis, the numbers denote impact indicators affecting adoption of technology. The impact indicators are 1-less fertilizer, 2-less water, 3-less pest, 4-less fallow, 5-less cost, 6-better plant growth, 7-better size product, 8-better yield, 9-better profit, 10-less labour, 1-child education, 12-buying farm implements, 13-growing next crop, 14-buying medicine, 15-repairing home appliances, 16-pond cleaning, 17-pisciculture, and 18-own consumption

For each technology, impact indicators were given a score for each farmer (N=60). For this, 0 (benefit not perceived) and 1 (benefit perceived) score for each indicator was used. Mean score for each indicator was scaled in 0-1 range, and finally the mean total impact for each technology was assessed in 10 scales. Figure 7.67 revealed that the requirement of less water (indicator 2), better yield (indicator 8) and profit (indicator 9), respectively influenced the adoption of ZT potato cultivation. More detail can be found in Ray *et al.* (2019) and in Annex Report 13 (P 55-56).

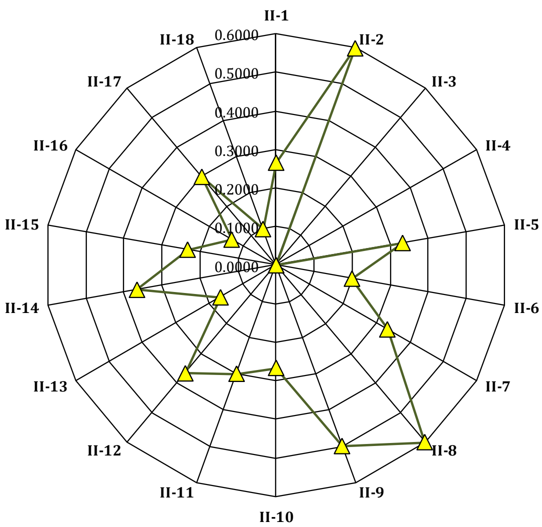

Figure 7.67 Spider diagram showing the sensitivity of different impact indicators towards adoption of ZT potato cultivation

7.19 Discussion

Currently, a range of constraints are perceived to limit the options for cropping intensification by growing additional crops in the dry season (Rabi) and early wet season (Kharif-I). The major constraints are perceived to be soil salinity and the apparent lack of fresh surface water for Rabi season crop production (Humphreys *et al.*, 2015). However, the collective work reported here and in related papers (Humphreys *et al.*, 2015) challenge those perceptions and present the evidence for realistic and profitable cropping systems intensification opportunities. Having said that there are constraints that limit the success of a crop. These are:

1. Will the crop complete its life cycle within the allocated season?
2. Does the grower or the market have a use for the crop?
3. Will the chosen crop's yield be profitable for the grower?
4. Will aspects of the season's environment prevent acceptable or profitable yield?
5. Can environmental constraints be sufficiently controlled economically by agronomy or engineering?

These questions differ depending on the country and its seasons. The studies reported in this document focus on the coastal regions of Bangladesh and West Bengal. The farmers and other people that live in these regions are generally poor.

These regions have potentially three cropping seasons as discussed earlier.

1. A pre-monsoon or Early Wet Season called Kharif I that is humid, hot and has variable rainfall (April to July).
2. The Monsoon or Wet season called Kharif II during which rainfall can cause widespread flooding to 1m depth in low-lying terrain (July to November)
3. The dry season or Rabi (November to March) has very limited unreliable rainfall.
   At the start of Rabi, which follows the monsoon, coastal soil rooting profiles are still full of fresh water. Continuing drainage from higher lands into rivers and the sea can maintain this state for a few weeks. But then, and certainly by February to March, salt has risen into the soil rooting profiles by capillarity, often to finally leave salt crystals on the soil surface as free water evaporates. By this time the tidal rivers are saline at their lower reaches while canals are partially saline unless managed.

Historically, the crops that naturally fitted these three seasons were rices, in Kharif I and Kharif II, followed by fallow in Rabi. Fallow was widely the preferred option for Rabi because the important Kharif II rices were long season thus delaying Rabi crop plantings beyond their optimum dates; the soil profiles by then were drying down and salts were rising through the root zones. Farmers then commonly took up other means of employment until Kharif I came around again.

Clearly, what needed to be managed to achieve at least three major crops per year was water, both its availability at appropriate times and its drainage to minimise waterlogging. Additionally, crops/varieties needed to be chosen that would suit the length and conditions of each season so there would be no delays past optimal planting dates. And finally there needed to be an understanding of the cycles of salinity within soil profiles and their differences between locations, so as to choose the best sowing to harvest time-window for the particular crop species and variety. Other variable major events like cyclones, accompanied by tidal surges, and often in November, would also have to be factored in for exposed regions.

7.19.1 Understanding the coastal zone environment and hydrology

Climate and trends

Across the Ganges delta, climate varies sufficiently to alter profitability and suitability of cropping choices and patterns across the region (Yu *et al.*, 2019). In Patuakhali, Bangladesh, annual rainfall is 2,643 mm but only 1,833 mm in Canning Town. The decrease in rainfall from east to west was associated with a decline in rainy days from 123 to 100. Rainfall increases from north to south: for example annual rainfall is 2,112 mm in Barisal but 2,783 mm at Khepupara (Yu *et al.*, 2019). Regardless of location, the total rainfall is relatively high, suggesting that the region should be able to take advantage of the available water for crop production. However, because the rainfall is mostly compressed into 3-4 months, storage of the excess fresh water is critical.

The climate in the coastal zone has shown a general warming trend in the last 40 years, equivalent to 0.04 ^{o}C year^{-1} (Yu *et al.*, 2019). Only the Canning Town station avoided the increase in temperatures which is attributed to a decrease in sunshine hours there, possibly due to an increasing air pollution plume from Kolkata. No general trend could be discerned in the rainfall records of the last 40 years for the coastal zone. However, since the 1960s, there has been an increase in the maximum rainfall over a 5-day period suggesting that rainfall is becoming more intense.

Rainfall in the dry season could be beneficial to crop production by alleviating drought stress. However, the dry season rainfall often occurs in a few heavy events. The likelihood of heavy rainfall events and their timing in the Rabi season is particularly important as a determinant of the riskiness of dry season cropping in the coastal zone. Events > 20 mm are not likely in December and January, but in November almost 50% of years may experience events of 20 mm and 25% of years, experience 50 mm events. These events can hamper timely early sowing or cause crop failure at establishment unless there is adequate drainage. Similarly, from February to April the likelihood of 20 mm rainfall events increases from 25 to 65 %, while for 50 mm events the increase in likelihood is from 5 to 30 % of years. These heavy rainfall events tend to coincide with rising soil salinity and may create the combination of waterlogging and salinity conditions in the root zone which are particularly damaging to most crops (Barrett-Lennard and Shabala, 2013).

Polder scale hydrology

Polders (also called islands in West Bengal), are surrounded by river water that can vary from continually fresh (especially to the north of the coastal zone) to continually saline (especially closer to the Bay of Bengal and in the southwest of the Delta) (Mainuddin *et al.*, 2019b). Most previous research in this region has focused on experimental field plots that cover small areas within polders: Mainuddin *et al.* (2019b; 2020) developed a polder scale water and salt conceptual model to provide greater clarity about the distinctive water and salt dynamics at polder scale. The low-lying land within polders has a shallow, variably saline water table (2.3–3.5 dS m^{-1} at Dacope and 3.12–11.7 dSm^{-1} at Amtali as reported in Sarker *et al.* (2019); 2.3–5.7 dS m^{-1} at Dacope as reported in Jahan *et al.* (2020); 0.8–30 dS m^{-1} at Gosaba in this report) that is rarely deeper than 2.5 m (Hossain *et al.*, 2019; Schulthess *et al.*, 2019). Annual rainfall in the coastal zone ranges from 1,800-2,800 mm and the recharge of this rainfall in the monsoon season creates a fresh water lens on top of the saline groundwater. The fresh water lens is a resource for crops to use, but during the course of the dry season, it becomes contaminated by capillary rise of salts from the groundwater and from salts released by the dominant clay loam soils, which also act as temporary salt stores. Capillary rise of salts from these sources also increases surface soil salinity during the Rabi season.

The excess of rainfall over evaporation in the coastal zone is 500-1300 mm annually, so that there are opportunities for leaching and dilution of salt, provided the drainage system allows flushing of the salt. Without removal of salts, the polder model suggests that salts recycle from the groundwater to the upper soil layer and then back to the groundwater

(Mainuddin *et al.*, 2019b; 2020). In addition, through the irrigation of crops with water from canals and ponds, salt re-circulates to the soil and groundwater. Episodic storm surges that breach the embankments surrounding polders can cause catastrophic input of salt into the soil and groundwater system in the polder. Under the existing drainage infrastructure, the natural rate of flushing of salts by wet-season rains means that these events can take viable land out of production for up to 5 years (Mainuddin *et al.*, 2020; Annex Report 3). However, with well-designed drainage, the polder-scale modelling suggests that most of salt can be removed within 2 years.

For cropping systems intensification, the polder-scale model suggests that early sown Rabi crops should have access to a significant store of reasonably fresh water. Later sown crops will also have access to stored water but of increasing salinity as the season progresses. The second major learning from the polder scale model is the importance of a drainage systems within the polder that allows saline waters to drain out of the polder and to ensure that only fresh water is permitted into the polder from river systems. A third implication is that the water in canals and ponds generally remains low enough in salinity to be used for irrigation (e.g. Saha *et al.*, 2019), but the quantity is currently not large. Hence the presently available pond and canal water needs to be used strategically for high value crops. Drip irrigation systems are a promising water saving technology for the coastal zone (Mahanta *et al.*, 2019; Samui *et al.*, 2020). Alternatively, investment into expanding the volume of storage in ponds and canals could broaden access to irrigated Rabi season crops.

7.19.2 The environmental benefits and constraints of the coastal regions

The monsoon

Though the timing, amount and frequency of the rainfall can be erratic it generally is sufficient to flood many areas with fresh water, and fill and flush the rivers, canals and ponds. Most importantly, many soils are filled with fresh water and the salts are leached down and out of the profile used by crops. The coastal region is the lowest drainage point of the sloping lands of Bangladesh and West Bengal so is the last part of the country to dry sufficiently after the monsoon to allow surface soil cultivation to occur. The land is refreshed. Though where water has ponded and land sits waterlogged, high salt levels can prevail and prevent germination of many crops.

The dry season of Rabi

It is relatively cool to begin, even called winter by some, farmers have harvested their T.Aman rice crop, and can now benefit from full fresh water soil profiles for their next chosen crop. Temperatures rise and because of the relatively high water table, unlike in the north where water tables drop rapidly as Boro rice is continuously serviced from tube wells, crops can develop deepening root systems. By February it is hot and often humid because of mists and fogs. Good for reducing crop water use but not for some diseases. Soil salinity has increased as it rises vertically by capillarity towards the surface. In sensitive crops this can be flushed down again by an irrigation. This one irrigation can save the crop salinity-growth-reductions for maybe one week to ten days. Again, depending on the species, this could be a sensitive developmental period leading up to seed or grain filling, making that one irrigation critical for yield.

The early wet season

The early wet or Kharif-I season with its occasional rains boosts growth of the species sown on fortuitous rain, or planned irrigation in late Rabi. Historically a time for T.Aus rice, and the once important crop Jute, used for carpets, ropes, bags, sacks, exported around the world from factories in Kolkata. But not a crop for the coastal region. Temperatures are now declining.

7.19.3 What determines crop choice? Some general comments

6. Will the chosen crop's yield be profitable for the grower? Wheat for example must yield greater than 0.5 t ha^{-1} just to cover inputs.
7. Can pests such as rats and birds excessively reduce harvestable yield? Is there a later or earlier planting date than can avoid damage from these pests?
8. Is the farming community familiar with how to grow and harvest the selected crop? New crops can be distrusted and for poor farmers present an unwelcome risk.
9. Does the farmer or the local market have a use for the crop? If not, avoid the crop.
10. Will the harvested crop depreciate in quality and salability with keeping (potatoes)?
11. Does the crop sown at a selected date have enough days to establish and then complete its full life cycle? It might require sowing in the dry season immediately following the monsoon when the soil profile is still full of fresh water though no longer waterlogged? Check its heat sum (^{o}Cd) requirement or determine it by experiment
12. Will soil salinity at planting reduce yield to unprofitable levels? Check before planting maybe using the taste test.
13. Will aspects of the season's environment like low or more likely high temperature and humidity prevent acceptable or profitable yield? Can the crop growing window be adjusted to avoid such problems? Choose a variety with a different duration.
14. Can environmental constraints such as salinity and waterlogging be sufficiently controlled economically by agronomy (pre sowing cultivation like ridging, use of mulches, irrigation, drainage) or engineering (use of walled Polders/enclosures with sluice gates to manage influx and efflux of fresh or saline water)?
15. Do you know the optimal time of planting for the crop, i.e. that will produce the highest yield in the location chosen?
16. Do you know when it will be ready for harvest if planted at the optimal sowing date? Check its heat sum.

Selecting desirable crops to yield well and sequence with others over a whole year through a changing environment is a seriously difficult jigsaw. And the required jigsaw will change for different locations and will change with expected and unexpected changes in the environment. There are many unknowns. However, describing and understanding the components of the general environment and the characteristics of the crop species and their varieties will get us close. Dynamic modelling progressively cycling with experimentation as in this project is the route.

Coastal farmers are rice farmers first and foremost and that means T.Aman is the crop that frames the cropping jigsaw. If they could choose, they would, like the northern farmers, grow more rice like Boro during the dry season. We also know that to use the dry Rabi season most efficiently the crops that follow T.Aman must be planted as soon as the monsoon waters have drained sufficiently to allow cultivation and before salinity begins to creep upwards into the rooting profile.

7.19.4 Opportunities

To make cropping systems intensification a reality, we proposed that a number of systems changes need to be made in the coastal zone of the Ganges delta (Mainuddin *et al.*, 2019a) as follows:

- surface drainage of excess water at the end of the wet season,

- planting of earlier maturity and shorter duration rice varieties during the monsoon season to provide for early sowing of Rabi crops so that maximise access to fresh stored soil water while avoiding later season salinity stress,
- increased use of salt tolerant Rabi cultivars,
- better understanding and use of the limited fresh groundwater (after investigating potential acid sulphate soil problems),
- increased surface water storage capacity, and better maintenance, management and use of the existing limited storage,
- optimising areas of cropping in relation to areas devoted to surface storage,
- separation of lands of higher and lower elevation taking advantage of existing infrastructure (e.g. roads) to manage salt, water resources and drainage;
- strategic construction of small levees,
- pumping to lower saline water tables during Rabi season, and reduce salt build-up in surface soil, and
- use of mulches to reduce Rabi season soil evaporation and hence reduce salinity build-up in surface soil.

Investigations into many of these opportunities are reported in this Report and discussed below.

Early Kharif rice harvest

Traditional Kharif rice varieties for the coastal zone are relatively low yielding but well adapted to the wet season water regimes. They have been selected for tall stature to cope with deep standing water level and to mature in December when flood water recedes. In both Bangladesh and West Bengal, recently released cultivars with tall stature that mature 15-30 days earlier than traditional varieties have 0.5-1.0 t ha^{-1} higher yield than existing cultivars (Maniruzzaman and Kabir, 2019; Sarangi *et al.*, 2019a). Direct seeding was also advantageous for early harvesting and crop tolerance to deep flooding. In West Bengal, cv. Pratikshya was the most promising rice variety with 20 days earlier maturity, tall stature and lodging resistance. In Bangladesh, three promising cultivars with increased yield and 30 days earlier maturity were selected by farmers (Maniruzzaman and Kabir, 2019). The traits preferred by farmers were high yield potential, taller plants, strong stem, more tillers per hill, increased panicle length and longer grain size. Hence there were win-win solutions for Kharif rice varieties with 15-30 days earlier harvest, and 0-5-1.0 t ha^{-1} yield increases. After early harvest of Kharif rice, the crop straw was in high demand for cattle and attracted a higher price among local farmers. However, to capture the benefits of early maturity and early sowing of the Rabi season crops, coordinated planting of the improved cultivars is needed over a sizable block of land. Otherwise there will be increased bird attack on the ripening grain of the early variety, and conflict among farmers since some will want to retain flood water for long duration varieties while others need early drainage of excess standing water to prepare land for Rabi season crops.

Early sowing of Rabi season crops

Provided early maturing rice varieties are grown, and early drainage of excess water can be effectively managed, early sown Rabi season crops out yield those sown after the natural recession of the flood waters (see above). Wheat produced a maximum yield of 4.2-4.4 t ha^{-1} when sown between 25 November and 1 December (Kabir *et al.*, 2019). Delay in sowing decreased wheat yield. Similar benefits with early planting (late November to mid December) are being found in experiments for yield of sunflower (Paul *et al.*, 2020a), maize, lentil, grass pea (see above). For crops like wheat and sunflower, early sowing delays flowering which lengthens the vegetative growth period: the longer vegetative growth together with higher level of soil water and lower soil salinity appear to explain why the early sown crops have higher yield potential in the coastal zone.

Schulthess *et al.* (2019) reported that maize and wheat crops on clay-textured soils with a shallow water table could produce satisfactory yields in the coastal zone of the Ganges delta without irrigation except in the driest of winters when supplementary irrigation during early growth was sufficient. In their studies, wheat was sown in the latter half of December and maize on around 01 January after the recession of flood waters. Jahan *et al.* (2020) harvested yields of 1.7-1.8 t ha^{-1} from sunflower sown on 30 November or 15 December and grown without irrigation at Dacope on clay-textured soils with a shallow water table. The highest yields with full irrigation in the experiment were 2.7 t ha^{-1}.

Crop modelling with APSIM showed that for simulations over the period 1995-2018, the optimum period for establishment was 15-30 November. Earlier sowing apart from being more difficult to manage due to excess standing water and heavy rainfall risk, exposes crops to greater winter chilling which decreased yield potential. Delayed sowing after 15 November increased the risk of salinity damage to crops. Interestingly, APSIM modelling suggests that salinity had minimal effects on crops sown on 15 November, but thereafter the longer the delay in sowing the increased the probability of low yield due to salinity.

Boro and Aus rice

Despite the range of Rabi season cropping options found to be profitable in the coastal zone (see below), farmers at Amtali and Dacope expressed a strong preference to grow more rice. This suggests that current Kharif season rice supplies are not sufficient to meet food security needs. When fresh water is available, farmers in Dacope, Khulna and Amtali, Borguna have preferred Boro rice even though it has very high water requirements. The optimal period for establishing seedling nurseries for Boro rice was mid-November to mid-December. The salt-tolerant cultivars, BRRI dhan67 and BINA dhan10, produced the highest yield (about 6 t ha^{-1}) in Bangladesh (Yesmin *et al.*, 2019). For the low lying areas in the coastal zone where adequate water is available, Boro rice is an option. Further evaluation of the reliability of Boro rice over the long term in the coastal zone is being carried out using APSIM modelling. Alternate-wetting and drying as a water-saving option for growing Boro rice was examined. Yields with AWD were comparable to the standing water irrigation, but 20-24 % less water was required to growth the rice crop. The AWD practice is still new to the coastal zone and is a promising opportunity for those farmers who choose to grow rice. Further testing of the AWD system is needed to confirm that soil salinity levels remain within crop limits across a range of sites.

As an alternative to Boro rice where water is more limiting, Aus rice is an option since it needs less irrigation water. Transplanting from 10 to 30 April was optimal for Aus rice. With later transplanting, the Aus rice harvest interferes with the Aman rice crop. Aus rice in Amtali, Borguna averaged 3.8-4.0 t ha^{-1} (Saha *et al.*, 2019; Sarker *et al.*, 2019; Section 7.9 of this report). Lack of water to establish the rice seedling nursery may hamper Aus rice in some years. Further evaluation of the reliability of Aus rice over the long term in the coastal zone and optimum sowing time can be assessed using APSIM modelling. This may depend on being able to develop Aus rice nursery systems that have low water requirements and are protected from soil salinity.

Soil management

Early establishment of the Rabi season crops will inevitably involve sowing into wet soils. Mechanised seeding can reduce the labour requirements for rapid crop establishment after rice harvest. Experiments at Dacope indicate that high levels of mechanical soil disturbance are more effective for crop yield in this environment than minimum soil disturbance (Paul *et al.*, 2020a). Full rotary tillage and planting on shallow beds resulted in highest yield of sunflower, even though emergence of plants was delayed relative to strip planting and zero tillage. The high level of soil disturbance decreased the accumulation of salt in the upper soil layer and maintained higher soil water levels, both of which ensured higher solute potential in the upper root zone. However, mechanized zero tillage or strip planting delays sowing until soils are firm enough for trafficking.

Dibbling of seeds into a shallow hole formed in the soil enabled earlier sowing and was effective for crop establishment (Paul *et al.*, 2020c; Rashid *et al.*, 2014). Crop establishment and soil disturbance requirements vary with type of crops, e.g. maize sown on raised beds and rapeseed sown as dibbling following zero tillage resulted in better yield and economic returns compared to conventional practice (Sarangi *et al.*, 2019b).

Mulching the soil surface consistently increases crop yields in the Rabi season (Paul *et al.*, 2020b; Sarangi *et al.*, 2018a; 2018b). In the coastal zone, there is generally a surplus of rice straw even though cattle graze on it during the dry season. Hence, 5 t ha^{-1} of rice straw is generally available provided the area of Rabi crops is less than the area of Kharif rice. Paul *et al.* (2020b) found that rice straw mulch at 5 t ha^{-1} increased sunflower seed yield by 14-26% and this was associated with higher soil water content and solute potential in the 0-15 cm soil layer. White and black plastic sheet mulch also showed promising effects on yield of a range of crops in Gosaba Island, 24 South Parganas, West Bengal (Mahanta *et al.*, 2019), although it would be desirable to identify bio-degradable forms of plastics if they become more popular and affordable.

Further research is needed to develop best management practices for fertilizer application in the coastal zone. Sowing into wet soils is a challenge for placement of fertilizer close to the seed. Broadcast fertilizer is likely to have poor availability due to drying of the soil surface. Applying fertilizer to transplanted Aman rice in the coastal zone when water level is 30-50 cm deep is challenging. In-season application of nitrogen fertilizer needs to coincide with irrigation events in the Rabi season otherwise there will be poor positional availability of N to crop roots.

Tolerance of salinity

For Rabi season cropping, increased salt tolerance of crop cultivars seems an obvious solution to the salinity constraint but this opportunity is being examined for wheat and pulses by a companion project in the coastal zone (CIM/2014/076 Incorporating salt-tolerant wheat and pulses into smallholder farming systems in southern Bangladesh). Crop tolerance, however, should not focus on salt tolerance alone. The Rabi season in the coastal zone involves other crop stresses in addition to salinity. In addition to rising salinity, drought, heat stress, waterlogging and the waterlogging-salinity interaction need to be considered. Solute potential is a useful concept to link the combined stresses of salinity and drought or soil dryness (Paul *et al.*, 2020a; 2020b). Salt concentrations in the soil solution rise as the soil dries, and the resulting increase in soil solution salt concentration (i.e. decrease in solute potential) limits crop water uptake at higher levels of soil water and lower levels of salinity than are normally considered a risk. Paul et al. (2019a,b), Sarker *et al.* (2019) and Kabir *et al.* (2019) have all shown that solute potential is more closely related to crop response than either electrical conductivity or soil water content.

A further challenge for screening for salt tolerance and assessing crop response to treatments in the field is the variability of salinity levels (Rawson *et al.*, 2013). Intensive soil sampling and laboratory analysis of EC could quantify the variability of salinity and enable it to be used as a co-variate in statistical analysis. A less tedious approach is to use EM sensing with the Dual EM (Annex Report 06). Several case studies have demonstrated Dual EM readings are an effective, rapid method of quantifying salinity variation across experiments. In several experiments, adding EM values as a co-variate in analysis of variance enable significant treatments effects to be demonstrated while the conventional ANOVA suggested the effects were not significant. The Dual EM is an opportunity to enhance the returns on research investment in the coastal zone by overcoming the influence of spatial salinity variability on the measurement of crop performance.

Increase surface water storage

Another opportunity for cropping system intensification is to create more surface water storage capacity to enhance the supply of irrigation water for the Rabi season. Monitoring to date indicates that water stored in ponds and canals remains of acceptable quality throughout the dry season for irrigation, but the volume available is limited and insufficient for major expansion of irrigated Rabi season cropping. Economic analysis is needed to determine the optimum proportion of farms for surface water storage. Due to the high initial investment cost of digging water storage ponds and canals, co-investment of government agencies and engagement of banks to provide finance on favourable terms are likely to be essential to accelerate the increase of water storage capacity.

Drainage

More effective surface drainage is essential to decrease the risk of crop failures or delayed sowing due to heavy rainfall events in the early Rabi season. Rainfall trend analysis suggests these events are increasing in frequency. Kabir *et al.* (2019) describe the steps that they took with surface drains to remove excess water in paddy fields after harvest of the Kharif season. Further research is underway to determine the effectiveness of sub-soil drainage (50 cm deep) and surface drains (10-20 cm deep) to drain soils for early season planting and to protect crops from episodic heavy rainfall during the growing season (Md Nazrul Islam, personal communication). After two consecutive years, sunflower with the combination of sub-surface and surface drains had 90 % yield increase compared to crops on undrained soils and the combination was significantly more effective than either of the drainage methods alone. The optimum depth and spacing between surface drains is still to be defined. While 30 cm deep drains 40 cm apart were most effective for maize and sunflower yield in one year, a triple row raised bed with 40 cm deep drain gave highest yield in the following year. As surface drains require significant manual labour to construct each Rabi season, benefit cost analysis is needed together with farmer preferences to make a final selection of drainage configurations.

Drip irrigation

Considering the shortage of fresh water storage in the coastal zone, water-saving irrigation by drip technology should be an attractive option. Mahanta *et al.* (2019) and Samui *et al.* (2020) demonstrated that drip irrigation even by low cost technology was highly profitable for high value vegetables such as tomato, chilli, knoll-khol, okra and bitter gourd in the Rabi season and cucumber, bitter gourd and okra in the Kharif season. Benefit-cost ratios (BCR) ranged from 1.26 to 6.4. Drip irrigation also decreased the EC in the upper part of the root zone compared to non-irrigated soil. Decreasing irrigation applied to 80 % of ET and applying straw mulch further improved the water use efficiency of drip irrigation. The solar powered drip irrigation was also highly effective for growing high value vegetable crops, but the initial investment cost is not affordable to smallholder farmers without up to 80 % subsidy on the purchase price, and it needed a larger area to be economically viable.

7.19.5 Risks

Early maturing Kharif rice

Individual farmers growing early maturing rice cultivars will experience a number of new risks that need to be clearly disclosed to farmers so that they are well prepared to manage the risks (Kabir *et al.*, 2019). Firstly, bird and rat damage may be severe unless precautions are taken. Secondly, rapid drainage of excess flood water after rice harvest can be hampered by the need of neighbouring farmers to retain that water as long as possible, highlighting the need for an equitable water management strategy involving community engagement based on social inclusion principles.

Late monsoon rain

As noted above, heavy rainfall events in November are relatively common (Yu *et al.*, 2019). This will delay the sowing of Rabi season crops unless effective surface drainage systems are set up. Flooding in fields or waterlogging can only be tolerated by the Rabi season crops like sunflower for 1-2 days. Other crops are even more sensitive to flooding/ waterlogging. Hence rapid responses are needed to heavy rainfall events or else crop failure is likely. The likelihood of heavy rainfall events declines in December (Yu *et al.*, 2019). Further research is needed on the relative tolerance of Rabi season crops to waterlogging and flooding during the crop establishment phase. However, drainage in fields for Rabi crops should be either be installed as a standard feature at planting or rapidly installed when heavy rain is forecast. Boro rice has the obvious advantage over Rabi crops in tolerating heavy rainfall events.

Mid-season rain

From mid-January onwards the probability of heavy rainfall events increases progressively (Yu *et al.*, 2019). Moreover, the frequency of such events appears to have increased over the last 40 years. The positive effect of these events is to replenish stored soil water and increase solute potential of soil water. However, because of the rising soil salinity levels from February onwards, there is a risk of crop stress from the salt-waterlogging interaction. Crops generally have reduced tolerance to salinity if the root zone is waterlogged (Barrett-Lennard and Shabala, 2013). If adequate drainage is installed, the risk of damaging salt-waterlogging interactions on crops is diminished.

Kharif rain and storms

The pre-monsoon storms in April-May are accompanied by strong winds and heavy rainfall which can cause lodging of crops. Early sowing of crops in late November to mid-December decreases this risk because generally the early-sown crops mature and are harvested before these storms occur.

Heat stress

There has been limited study of heat stress per se, although it is recognized as a likely crop stress in the coastal zone. Early sowing reduces the exposure of crops to heat stress since crop flowering is largely completed before the high temperatures in March (e.g. sunflower in Paul *et al.*, 2020c). However, climate trend analysis indicates that maximum temperatures have been rising over time by 0.04 ^{O}C year^{-1}. Hence, even with earlier sowing there is increasing risk of heat stress. Crop simulation modelling with APSIM could provide useful insights into the magnitude and frequency of heat stress events and their likely change over time (Gaydon *et al.*, 2017).

8 Impacts

8.1 Scientific impacts – now and in 5 years

The project made considerable scientific advances in understanding and modelling the crop systems and hydrology of the Ganges Delta. We developed a unique time-stepping model of water and salt stores and flows in an idealised polder (Mainuddin *et al.*, 2019b; Mainuddin *et al.*, 2020; Annex Report 03). As far as we know, it is the only model which deals with the transfers of water and salt amongst the soil – plant continuum, the atmosphere (with which water only is exchanged), the groundwater (idealised as a two component system with a shallower, fresh lens overlying a deeper, salty regional groundwater), the ponds and canals which drain the polder (and may also be used in reverse for irrigation), and the surrounding rivers. It is thus the only model known to us which can be used to assess a wide range of crop, soil, water and salt management strategies from the level of the crop to the level of the whole polder. We used it to analyse the impact of climate change, flood inundation, and management strategies on water and salt balance of the polders and islands in the Ganges delta (Mainuddin *et al.*, submitted; Mainuddin and Kirby, submitted). The model can be used by the policy makers for future planning of the coastal polders to understand the impact of cyclone induced flood inundation on soil salinity, the possible water management practices, and recovery period for resuming crop cultivation. The model can be used in similar coastal environments particularly in the Pacific Island countries to investigate the impact of climate change, water and salt management strategies, cyclone-induced flood inundation and recovery, etc.

The salt and water balance model was supplemented by a detail surface water, groundwater and salinity interaction model for the polders in Bangladesh (Annex Report 04). We simulated salt movement between polders and the surrounding rivers impacted by various polder management strategies such as increased cropping, pumping of freshwater for irrigation from deeper aquifer (if there is fresh water available), pumping of saline groundwater for lowering the groundwater table thus preventing capillary rise of saline groundwater to the crop root zone in the Rabi season using a 3-D model. As described in the results section, the outputs of the model provide spatial movement of salinity through water interaction and how they can be affected in the future by climate change and sea level rise. To our knowledge, there is no such modelling and analysis done in the Ganges Delta. We are in the process of writing this up for a journal.

We have proven that DuelEM data can be used as covariates to improve clarity of treatment effects in field trials (Annex Report 06). One of the major issues with landscapes affected by salinity is that soils are highly spatially variable. On such soils, a cultivar may appear to be salt tolerant (for example) due to high yields at a given location. This might be because that cultivar is more salt tolerant (a good outcome) but it might also be because the soil at the location of those plots was less saline (a confusing outcome). We have used experimental results and the EM survey to disaggregate the spatial variability from treatments effects which brought new capabilities to the crop related experiments done by our partners. We developed a procedure to integrate the experimental results with EM survey data using GIS which is expected to be a significant contribution in the area of crop and soil interaction in saline environment.

We developed a better understanding of the effects of soil salinity and water content on crop growth by overturning the current belief that crop growth is affected by the salt concentration of the soil rather than the salinity of the soil solution: the ratio of salt to water in the soil. We have examined the relationships between water potential, the concentration of different salts and soil water content. Interestingly the relationship between EC, water content and solute potential is strongly affected by the type of salt in the soil and its concentration. Based on that we proposed a new equation to estimate the solute potential (Paul *et al.*, 2020a; 2020b).

We made significant advancement in APSIM modelling by: modifying the model to accept daily inputs of groundwater depth and salinity; validation of the inclusion of osmotic potential approach to simulate the effects of soil salinity on crop growth; validation of SWIM3 within the APSIM environment, and; introduction, calibration and validation of new pulse (grass pea and lentil) models in APSIM. We have learnt how to simulate the dynamics of salt in the upper soil layers by giving APSIM input information only about daily water table depth and salinity level, plus daily climate data. This is something we have never done before – adequately simulating the dynamics of the saline soil environment rather than just re-setting soil salt levels as inputs from measured data. This positions us well to investigate the effect of different irrigation strategies on keeping salt levels down, or polder-scale groundwater pumping to reduce local groundwater levels and hence possibly reduce salt build-up in soil. One paper is under review (Sarkar *et al.*, submitted) from these works and at least 4 others are being prepared for submission to relevant journals (i.e., Field Crop Research).

Over the last four years of experiments with a range of Kharif and Rabi crops, we found conclusive evidence on various issues such as finding suitable and early maturing Aman rice varieties (Maniruzzaman and Kabir, 2019; Sarangi *et al.*, 2019a), finding suitable and high-yielding Aus and Boro rice (Saha *et al.*, 2019; Yesmin *et al.*, 2019), growing vegetables with Aman rice, early establishment or different Rabi season crops using different techniques such as zero tillage, relay cropping, dibbling, mulching, etc (Kabir *et al.*, 2019; Paul *et al.*, 2020a; 2020b; 2020c; Samui *et al.*, 2020; Sarangi *et al.*, 2018b; Sarangi *et al.*, submitted; Sarkar *et al.*, 2019; Sarkar *et al.*, 2020a; Sarkar *et al.*, 2020b; Sarkar *et al.*, submitted; Sarker *et al.*, 2019; Shahadat *et al.*, 2019), use of irrigation (Mahanta *et al.*, 2019; Sarker *et al.*, 2019), limiting the harmful effects of waterlogging on crops in saline soils, selection of suitable cropping patterns (Mandal *et al.*, 2020; Ray *et al.*, 2019; 2020; Saha *et al.*, 2019), and use of storage ponds for water harvesting and irrigation in the Rabi season. These are helped by the underpinning model assessments (Ghosh *et al.*, 2019; Hossain *et al.*, 2019; Mainuddin *et al.*, 2019b; 2020; submitted; Mainuddin and Kirby, submitted). We have demonstrated strategies that are likely to increase productivity, cropping intensity and profitability. Several suitable and profitable intensified cropping patterns have emerged from our research (Mandal *et al.*, 2020; Ray *et al.*, 2019; 2020; Saha *et al.*, 2019). There is clear evidence that productivity of the crops is improving and cropping intensity is increasing in the project areas due to the project's engagement with farmers (Bell *et al.*, 2019; Mandal *et al.*, 2020; Ray *et al.*, 2019).

As shown in the list of publications, so far, we published 26 journal papers, 4 currently are under journal review and many more (at least 10) are under preparation. This does not include the publications expected from the Ph.D students working with the project. We expect that these significantly contribute to the science literature on the management of water and salinity, improving crop productivity and cropping intensity in saline conditions, and management of the coastal delta and similar environments (such as islands in the Pacific). They are likely to be used in the future by other researchers around the world in similar environments.

8.2 Capacity impacts – now and in 5 years

The project is having positive capacity impacts both for the farmers and the scientists. Many farmers in the project area were not used to the cultivation of Rabi crops. So, farmers did not have the technical knowhow to grow different Rabi crops such as potato, maize, sunflower, wheat, spinach, water melon, garlic, mustard, pumpkin, tomato, and different types of vegetables. Through our activities, they are learning how to grow Rabi crops (including crops they have never seen in the area), use advanced machinery (e.g. drum seeder, PTOS, drip irrigation installation, etc.), incorporate different cultivation practices (e.g. raised bed cultivation, dry direct seeding, zero tillage cultivation, use of mulch, growing vegetables with Aman rice, etc.), treat seeds with Rhizobium inoculum, and the application of lime and rock phosphate in the field. During our field experiments in the 4th year, we found that many farmers are growing crops where previously they grew none. This is having a motivational impact on the farmers and helped increase cropping in the Rabi season in the last year. Many farmers requested and received information from our scientist on the availability of the seed and other inputs. The project was initiated during 2016-17 with 384 farmers (46 women) (Kharif + Rabi), which increased to 511 farmers (36 women) in 2017-18, 934 farmers (118 women) in 2018-19 and 1,204 farmers (226 women) in 2019-20. Aus and Boro rice were not grown in the project sties of Bangladesh earlier. We introduced these crops in the area and every year the area of cultivation is increasing.

We also organized formal and informal training for the farmers in the field and at the Farmers' Academy and Convention Centre (FACC) at BCKV. For example, BARI organized a training on the awareness of climate change and production technology of wheat, maize, garden pea, sunflower and lentil in the project site in Dacope on 19 January 2017, CSSRI organized several training events in 2016- 2018 on the use of drum seeder for sowing of pre-germinated rice seeds (21 June 2016), application of lime and rock phosphate (17 November 2016), rhizobium inoculation in mungbean seeds (8 January 2016), cultivation of Rabi and Kharif crops and green manuring. TSRD organized/facilitated the exposure visits/training for 360 farmers (including 260 women farmers) from this area in six batches to BCKV. The training was conducted by BCKV at Kalyani. More details are given in the partners' Final Reports (Annex Reports 7-14).

A five days residential training programme on "Economic Development and Empowerment of Farmers and Farm Women through Adopting Improved Agro-techniques" was organized at FACC, BCKV during 12 -19 February 2018 (Figure 8.1). Sixty men and women farmers of Gosaba block (including all partner farmers of this project) attended the workshop. The program aimed at motivating farmers to develop a sustainable agricultural system through adopting integrated farming practices. BARI organized a training on "Modern production technology of zero tillage potato cultivation in coastal saline area of Bangladesh" at the Union Parishad Conference Hall, Pankhali, Dacope, Khulna on 27 February 2018. Thirty farmers (24 man and 6 women) participated in the training.

Figure 8.1 Prof. Koushik Brahmachari of BCKV Inspiring the farmers and farm women towards integrated farming system for better income and sustainable rural development.

The Australian team visits the project sites to work with the local partners in the field once in every season. Local scientists accompany the Australian team during the field visits. This gives the team opportunities to share their experience, work together, and learn from each other. This is having some significant capacity impacts on the local scientists particularly exposing them to the various aspects of the agricultural system outside their area of expertise. This is also a good opportunity for the Australian scientists to understand the complexity (bio-physical, social, and political) of managing polders and growing crops in such a constrained environment. This is having significant capacity impacts. The project is probably one of the very few initiatives (perhaps only) where various partner organizations (BARI, BRRI, IWM, and Khulna University in Bangladesh; CSSRI, BCKV and TSRD in West Bengal) having different background and expertise (agronomist, soil scientists, hydrologist, irrigation engineer, pathologist, on-farm research specialist, socio-economist, etc.) are working together. Our multidisciplinary and integrated approach in the project is greatly enhancing the research capacity for the whole project team. This will have long lasting impacts beyond the life of the project as the scientists will be able to apply their acquired knowledge in doing research for their organization in the future.

We also organized 4 formal trainings for the in-country researchers to enhance skill level on monitoring, evaluation and impact pathways for the research project focusing on this project, use of ground based EM techniques for assessment of agricultural trial areas (Figure 8.2, left), affected by salinity, use of APSIM modelling and on advanced data analysis for journal paper writing (Figure 8.2, right). During DualEM survey, the participants were given 'Hands-on training' on the use of QGIS and SAGA for digital layout preparation, kriging of and zonal mean analysis of ECa from DualEM reading. This helped in studying covariance of ECa in field experiments using Jamovi. The local partners now have capability to use GIS independently. We have a team in both Bangladesh and India to carry out EM survey and associated data analysis without any help from the Australian counterpart. These teams are competent to independently acquire EM data to meet the needs of cropping trial assessments. Spatial data analytical capacity in our team in Bangladesh has progressed tremendously. Cropping trial data analytical capacity has also increased across the broader group of researchers using Anova analysis to interrogate the significance of cropping trial responses.

Figure 8.2 Participants in the EM training conducted during 12-14 February in Khulna Bangladesh in the field (left) and training organized on “Data: organising, analysing, interpreting and presenting” at Khulna during 15-17 June 2019 (right)

To facilitate and guide them to write journal papers, we negotiated to publish papers from the project in a special issue of the journal of the Indian Society of Coastal Agricultural Research (ISCAR). Australian team closely guided the local scientists to write these papers. Seventeen papers have been published in the special issue and we have been working together to write more papers; some of these are submitted and some are under preparation. The project provided opportunities to the local scientist to enhance their capacity in advanced data analysis, modelling and writing papers for international journals. This will have a long lasting impact. It is expected that the scientists involved with the project will be able to improve the quality of their research and publish their work in international journals.

Probably, the most significant capacity impact is the 16 Ph.D students currently working with the project. Four of them are John Allwright Fellows (JAF) enrolled at Murdoch University and the Australian National University (Table 8.1). Three of them have been working with the project team at the Dacope site for their experiments. The other started in January 2020 and will work on the southwestern part of the coastal region of Bangladesh (Khulna and Satkhira districts) on understanding the salinization in groundwater of coastal aquifer under future climate change. They are from our partner organizations BARI (Afrin and Rahena) and BRRI (Priya Lal and Nazrul). In addition, 10 KGF funded Ph.D students (7 women and 3 men), who are scientists from BARI, commenced their study in 2018 and 2019. The other two students are enrolled for Ph.D at BCKV and are also working as Senior Research Fellow with the project team. The name and topic of their Ph.D study are given in Table 8.2. One Ph.D student of BCKV (Sukamal Sarkar) spent about 2 months at CSIRO in Brisbane, Australia (in two occasions in 2018 and 2019) to work on APSIM modelling. After completion of their study, these students will be able to lead team for doing research on the issues related to the cropping intensification in the coastal zones. This will be a significant boost to the capacity of their respective institutions for doing research in the coastal zone.

In addition to these students, 12 master students received support and completed their thesis works based on the project activities (Table 8.3). One of them, spent two weeks at CSIRO, Brisbane to work for the model he developed for groundwater and salinity modelling for Gosaba Island.

Table 8.1 List and detail of the John Allwright Fellows working with the project

Name	Thesis title	Start date	University
Priya Lal Chandra Paul	Crop establishment in wet soils of the coastal zone of Bangladesh to alleviate soil salinity risk in the Rabi season	July 2016 (completed August 2020)	Murdoch University
Afrin Jahan Mila	Efficient use of non-saline (ECw< 0.7 dS m^{-1}) and saline water irrigation in southern Bangladesh on sunflower	June 2017	Murdoch University
Md. Nazrul Islam	Effectiveness of Subsoil Drains in Wet Coastal Soils	June 2018	Murdoch University
Rahena Parvin Rannu	Managing salt and water in the polders of Bangladesh: a model study of options and uncertainty	Jan 2020	Australian National University

Table 8.2 List and detail of the Ph. D students working with the project in India and Bangladesh (All Bangladeshi students are funded by KGF as part of the co-funding of the project)

Name	Thesis title	Start date	University
Sukamal Sarkar	Cropping system intensification through inclusion of pulses in rice based system in the salt-affected coastal zone of West Bengal	August 2016	BCKV, India
Argha Ghosh	Trend analysis of water resources vis-a-vis cropping system of Gosaba polder of Indian Sundarban using satellite and co-lateral in-situ observations	August 2017	BCKV, India
Subarna Kundu	Effect of different agronomic management practices in potato production and its influence on system productivity of potato-maize-T.Aman cropping pattern in coastal area of Bangladesh	July 2018	Bangladesh Agricultural University (BAU)
Md. Shahidul Islam	Adaptive Responses of Barley (Hordeum vulgare L.) Genotypes for Salinity Tolerance	July 2018	BAU
Sujan Mahmud	Productivity of sunflower-legume intercropping as influenced by agronomic practices in the coastal saline area of Bangladesh	July 2018	BAU
Md. Afzal Hossain	Screening of suitable sunflower varieties for increasing and sustaining crop production in the salinity affected polder area in Khulna	July 2018	BAU
Shamima Akhtar	Effect of different management practices on growth, yield and quality of maize cultivar in coastal region of Bangladesh	January 2019	BAU
MST. Majida Khatun	Surveillance, bio-ecology, molecular identification and assessment of bio-rational based management of fall armyworm, of maize in south coast area of Bangladesh	January 2019	BAU
Mosammat Nazia Akhter	Screening of different salt tolerant garlic lines in coastal region under saline condition	January 2019	BAU
Nazmun Naher	Salt tolerant field pea genotypes and characterization	January 2019	BAU
Nazneen Ara Sultana	Disease control of maize	January 2019	BAU
Hosna Kohinoor	Collection and characterization of salt tolerant linseed/mustard genotypes	January 2019	BAU

Table 8.3 List and detail of master students (8 men and 4 women) working with the projects in Bangladesh and India

Name	Thesis title	Completion date	University
Md. Majharul Islam	Evaluation of sowing dates of wheat grown in a medium high land of southwestern Bangladesh	2017	Khulna University
Md. Hamidul Islam	Evaluation of sowing dates of mustard in southwestern coastal soil of Bangladesh	2019	Khulna University
Arjun P	Quantification of surface water–groundwater interactions in sundarbans delta: a study on Gosaba Island	April 2019	Indian Institute of Technology, Kharagpur
Deepak Sahoo	Effect of Foliar Nutrient Management on Potato Grown under Zero Tillage and Mulching in Coastal Saline Soil of West Bengal	June 2019	BCKV
Debolina Sarkar	Analysis of land use and water resources in Rangabelia island of Indian Sundarban using remote sensing and open source GIS tool	June 2019	BCKV
Mainak Brahmachari	Socio-economic impact of technological interventions for cropping system intensification in the salt-affected coastal zone of West Bengal		Ramakrishna Mission Vivekananda Educational and Research Institute (RMVERI)
Piyali Sen	Estimation of economics, energetics and GHGs emission of different cropping systems in Gosaba block, West Bengal	June 2019	RMVERI
Suman Mandal	Assessment of economic sustainability of cropping systems in salt-affected coastal zone of West Bengal	June 2019	RMVERI
Anubha Saha	Qualitative analysis for evaluating the dissemination of technologies for cropping system intensification in the coastal saline zone of West Bengal		RMVERI
Piyali Sarkar	Geospatial analysis of mangrove changes in Sundarbans region using google earth engine data products		BCKV
Pankaz Kumar Sarker	Effect of seedling age and transplanting dates on establishment and yield of sunflower (Helianthus annuus l.) in coastal region of southwestern Bangladesh	January 2020	Khulna University
Amit Kumar Ghosh	Evaluation of sowing Dates on Wheat Grown in a typical coastal soil of Southwestern Bangladesh	Waiting for final thesis defence	Khulna University

We organized and supported participation of 10 scientists (which includes 4 senior level officials) from the project team of KGF, BARI, BRRI, CSSRI and BCKV to attend the 'Third International Tropical Agriculture (TropAg) Conference organized during 11-13 November 2019 at the Brisbane Convention & Exhibition Centre in Australia. Prior to the conference, CSIRO organized a day-trip to the Lockyer Valley for the participants to show them agricultural practices in the region. The visit gave them the opportunity to enhance their knowledge in latest advances in tropical agricultural research. A large number of participants in the conference were from Australia which is one of the world's leaders in research and development in agriculture. So the participants particularly the women participants had the opportunity to exchange views with the researchers from Australia and the world. This would have given them the voice to communicate their knowledge in their own organizations. There are large number of women scientists working in these organizations. The women participants would be able to encourage and mentor their colleagues to assume leadership roles in their organization in the future. Their participation would also encourage their male and female colleagues to excel in their knowledge and skill.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The main outputs of this project are profitable technologies that are expected to enable farmers to increase agricultural productivity and income thus improving their food security and livelihoods. These technologies are ways of increasing productivity and benefit for the Aman/Kharif season and increasing cropping intensity in the Rabi season. There is evidence that farmers are getting increased income by adopting improved water management and modern cropping technologies, with indirect benefits for landless labourers and marginal farmers, through employment generation due to increased cropping.

In both Bangladesh and West Bengal, we introduced high yielding varieties of Aman/kharif rice. The yields of these varieties are higher than the local verities. In Bangladesh, farmers can get about 0.8 t ha^{-1} to 1.0 t ha^{-1} of extra yield by cultivating newly released HYV of rice which will give them extra income of Tk.12,900 ha^{-1}. Aman rice is grown by about 25,000 households in about 10,000 ha in Amtali and Dacope. If we consider that 25% of this area will adopt new varieties in the next 5 years, the total extra rice production will be about 1,800 t year^{-1}. The net benefit will be over AU$500,000 year^{-1}. Around 6,000 households will be benefitted. In Gosaba, the average yield of introduced varieties with soil amendment was 5.25 t ha^{-1} against current yield of 3.79 t ha^{-1}. The cultivable area of the West Bengal site is about 3,000 ha supporting around 8,000 to 10,000 households. If 25% of the cultivable area adopt the new technology over the next 5 years (5% increase per year), there will be additional 1,100 t of rice per year for the 2,000 to 2,500 households.

We introduced Aus rice in the two project areas of Bangladesh in 2017 with 12 farmers covering 3 ha land. Farmers attained net benefit of Tk. 35,000 ha^{-1}. So, each farmer in that year had additional average income of Tk. 8,750 from Aus cultivation. This is not a small income for a poor farmer in the region. Motivated by the success of Aus rice, in 2019, 103 farmers cultivated Aus rice on 23.2 ha of rice and achieved net benefit of Tk.21,938 ha^{-1}. The average yield was about 4.1 t ha^{-1}. The total income was about Tk. 509,000 (AU$9,000); average income per farmers was about Tk.4,940. Again if even a very modest 10% of the area (1,000 ha) can be brought under Aus cultivation in these two selected areas over the next 5 years, the total production of rice will be 4,100 t year^{-1} which will have significant impact on the local food security. The total benefit will be about $366K year^{-1} which will be shared by 2,000 to 2,500 households. This will have significant economic impact on the livelihoods of the farmers. Similarly, the area of Boro rice is also increasing every year. In 2017-18, area under Boro rice was 7.12 ha (35 farmers). Due to low risk, good yield and higher net benefit, this year (2019-2020), 97 farmers cultivated Boro rice in 31.7 ha. This is obviously providing extra economic benefit to the farmers.

Akhil Haldar and his mini-pond

Like 2018-19, this year (2019-20) Akhil Haldar got high production of watermelon from his land by using water stored in the mini-pond. He earned about 200,000 Taka with the total expense of 50,000 Taka. Besides, he expects to earn about 30,000 Taka from fish from the mini-pond He pointed out that by excavating a mini-pond he was able to cultivate high value non-rice crops and he got additional benefit from his land, whereas most of the lands remain fallow during Rabi season due to shortage of fresh water.

We introduced a range of crops and found zero-tillage potato, sunflower, maize, mustard, pumpkin, water melon, lentil, grass pea, spinach are suitable and economically profitable. Among these crops, zero-tillage (Z-T) potato is getting very popular and being adopted by the farmers in Gosaba and Dacope. In Gosaba, there were 23 farmers in 2016-17 season who achieved net benefit of about Rs. 85,000 ha^{-1} (about 2,000 AU$ ha^{-1}). In 2019-20, 208 farmers grew Z-T potato. They achieved net benefit of about Rs. 115,600 ha^{-1} (about AU$ 2,500 ha^{-1}). The number of farmers growing Z-T potato continues to increase every year. If we can achieve Z-T potato on only 5% of the land (150 ha) in Gosaba, then the total benefit will be about AU$ 400,000 $year^{-1}$ (based on the benefit attained in 2019-20). The approximate number of households benefited will be 800 to 1000. Z-T potato is also getting very popular with the farmers in Dacope. The benefit cost ratio of Z-T potato in 2018-19 was 1.96 with net benefit attained at Tk.84,722 ha^{-1} in Dacope. If only a small fraction (5%) of 5,000 ha of cultivable area in Dacope can be brought under Z-T potato cultivation over the next 5 years, then the total income for the farmers will be about AU$400,000 $year^{-1}$ (based on the estimates of 2019-20). So the investment in this project can be recovered in 6 years only by growing Z-T potato in Dacope. The number of farmers growing Z-T potato has been increasing every year and is expected to continue.

Z-T potato -Rabindra Nath Dhali, Khulna

A farmer couple named Rabindra Dhali and Krishna Rani Dhali, live in the remote Koyra upazila of Khulna district. The location is near the Sundarban forest, where farmer usually cultivate only T. Aman rice during the monsoon season and for the rest of the year land remains fallow. Scientists from BARI motivated the Dhali couple to cultivate Z-T potato with his unused rice straw as mulch. This couple have a good reputation for their farming practice and have faith on scientists and new findings. However, he never heard about potato cultivation without any tillage, which was unimaginable for them. Initially, his neighbours and other farmers called them insane when he was planting whole tubers on the ground. They planted three potato varieties viz. BARI Alu-72, 72 and 78 on 11 December 2019 on 10 decimal of land. The yields were 18.76 t ha^{-1}, 9.00 t ha^{-1} and 14.98 t ha^{-1}, respectively. He earned about Tk. 6,170 in 90 days. Mr. Dhali reported that this amount of money is like a gift because there is hardly any effort needed except planting and harvesting. Mrs. Dhali also added that this practice is a fun, anybody can do it, especially for household women and children can take care of the crop easily out of their regular work. Many farmers became inspired from their success. Different local and national news media reported their success.

In Gosaba, the project has been quite successful in developing new or improving existing cropping systems suitable in the study area and there is evidence that these systems increased the farmer’s income from agriculture compared to the existing cropping system

(Mandal *et al.*, 2020). Kharif rice followed by Z-T potato can be one of the best cropping system intensification options in the study area with net benefit of Rs.103,760 ha^{-1}. In some areas it is also possible to grow a green gram crop after Z-T potato with estimated net benefit of Rs.205,079 ha^{-1}(Mandal *et al.*, 2020). Ray *et al.* (2020) compared thirteen rice-based cropping systems at the BCKV site of Gosaba in terms of productivity, profitability, energetics, and emissions. Information on the crop management practices of these systems was collected on 60 farms through a questionnaire survey. Rice-bitter gourd system was observed to have the highest system yield (49.9 ± 4.34 $tha^{-1}yr^{-1}$) followed by rice-potato-ridge gourd (37.8 ± 2.77 $tha^{-1}yr^{-1}$) and rice-potato-pumpkin (36.8 ± 2.04 $tha^{-1}yr^{-1}$) systems. The rice-bitter gourd system also recorded the highest benefit:cost ratio (3.92 ± 0.061). The lowest system yield and economics were recorded in the rice-fallow-fallow system. Several suitable and profitable cropping patterns have also emerged for Bangladesh sites. Some of the highly profitable cropping patterns for Bangladesh sites are sunflower-rice-rice (Rabi-Kharif I-Kharif II), Z-T Potato-rice-rice, maize-rice-rice, pumpkin-rice-rice, etc. (Saha *et al.*, 2019; Sarker *et al.*, 2019). The current dominant (80 to 90% of the area) cropping pattern is fallow-fallow-rice.

Success story of Mrs. Sumitra Giri

Mrs Sumitra Giri, having a land holding of 0.53 ha, adopted various crops during the Rabi season after the Kharif rice. She also adopted the rice + vegetable cultivation in bags during the Kharif season. During the summer season she grown mung bean by adoption of improved package of practices. There was tremendous success in cultivation of different crops by following the cropping system options and improved package of practices suggested by the scientists. Mrs. Sumitra Giri incurred expenditures of Rs. 13,100, Rs. 12,400 and Rs. 5,575 during Kharif, Rabi and summer seasons respectively. The season-wise gross returns were Rs. 24,850, Rs. 26,500 and Rs.1,7720. The average net income from her farm after meeting the household consumption was Rs. 37,995. Cultivation of these crops not only increased her income, but also provided nutritious vegetables to her family.

Mrs. Sumitra Giri and her broccoli and vegetables with rice (photo taken with permission)

Ray *et al.* (2019) studied the adoption of improved technologies for cropping intensification in Gosaba and observed impacts for the farmers in terms of better yield and profit due to adoption of the improved technologies. There is clear evidence that the cropping is increasing in the area due to our engagement with the farmers. Due to strengthening of the project activities and social engagement, the farmers have started to realize the benefits of improving cultivation practices. Our research has clearly showed visible impact over the conventional agricultural practices of the farmers. Therefore, farmers are adopting and expanding our technologies for intensification of crop (Figures 8.3 and 8.4) and increase their income from their land.

Figure 8.3 Left photo was taken on 9th April 2016 at Khatail, Dacope during the project team's visit including ACIAR Program Manager, Evan Christen, to the site after the Inception workshop. The same fields on the right 3 years later – photo taken on 12 February 2019.

Figure 8.4 Visible increase in Rabi cropped area in the project site Left: March 2016 Right: February 2019, in Gosaba

During 2019-20, an end line survey was conducted covering 230 farmers (90 collaborative farmers and 140 non-collaborative farmers) in Gosaba by CSSRI to understand the farmers response/perception of all different interventions made during the project period. The feedback survey was conducted through four Focused Group Discussions (FGD) as well as personal interview methods with the key informants. The baseline and end line survey data were compared (before and after the project) to analyse the socio-economic impact of the various interventions made during the project and farmers response to adoption of these technological interventions. Comparing the farm-level cropping area before and after the project, there was no significant change in area under Kharif crops, but due to the introduction of better varieties, establishment methods, quality seeds and vegetables in Kharif paddy, higher net return was realised (p 63-64, Annex Report 12). Average net return of Rs. 20,206 was obtained from 1153 m^2 cultivated area due to paddy + vegetable cultivation in sack (bags) as compared to Rs. 1195 from conventional paddy cultivation alone in same area.

The impact of the project interventions was visible in case of Rabi season cultivation. Significant change in area and production was observed for the Rabi crops, such as potato, mung bean, lathyrus and vegetables. All these expansions in area were influenced by the project interventions and successfully reduced the extent of Rabi fallow area (30-35%) in the coastal zone. Greater numbers of crops was grown during Rabi season with higher cropping system intensification, which resulted in higher production and income. Overall, the interventions have been successful to increase the cropping intensity to around 202%, substantially higher as compared to intensity before interventions (145%) situations.

8.3.2 Social impacts

After the 1st year (2016-17) of our activities, our local team reported that "*the key social impact of the project so far is that the local farmers have increased confidence that it is possible to increase cropping intensity by growing Rabi crops despite apparent constraints* *of soil salinity and lack of fresh water for irrigation*". After four years of engagement with the farmers in the study area, it is evident that farmers are confident in cultivation of a range of crops in the Rabi season. In addition, farmers now believe that it is also possible to increase the production and profitability of the current wet season crops (Aman or Kharif rice). At the Bangladesh sites, we have demonstrated that it is not only possible to grow 2 crops (Aman rice in the wet season and other crops in the Rabi season) in a year but also possible to grow 3 crops including two rice (including Aus in Kharif-I season) in a year. There are clear signs that the cropping is increasing in the area due to our engagement with the farmers. So, our activities are having social impacts.

In Dacope, farmers were reluctant to grow Rabi crops due to lack of fresh water for irrigation. The project team motivated the farmers for the development of water sources in the canal for crop cultivation. Farmers willingly participated in making an embankment across the canal for trapping fresh water and preventing salt water intrusion. The farmers wanted to resolve the conflict between shrimp and crop farmers for canal water management and they were advised to solve the problem locally. The project team also discussed the issue with local administration. Through involvement of local leaders, and active participation of the farmers, our sister SIAGI project facilitated formation of a water management committee for managing the sluice gate and stored water in the canal for irrigation. However, intervention from the project was needed to construct a temporary bund across the canal to store water in 2016. In 2017 and onwards, farmers assumed the responsibility and organized the construction of the bund in the canal without any help from the project team. Some female farmers also participated. Farmers are very happy to see the crops in this area in the Rabi season. They did not see any crops in the dry season in this area for the last 20 years (during 1987 to 2009, the area was under shrimp farming). Earlier the area was under shrimp farming and farmers were in dispute over land use conflicts. Now they are keen to grow another crop in this area in the dry season. Farmers are seeking technological help from the project team.

Similarly in Amtali, a Water and Silt Management Committee (WSMC) has been formed to re-excavate a 2-km long canal for storing freshwater for irrigation. In 2018, the canal was re-excavated (Figure 8.5). The local Union Parishad (UP) Chairman, the Upazilla Chairman, the local farmers (through their own labour) and the two projects (LWR/2014/072, and LWR/2014/073) shared the cost of re-excavation. Farmers think as canal was renovated, there will be unlimited water for irrigation of 80% of the present fallow land and a likely shift to Boro rice cultivation on a large percentage of the fallow land. WSMC regulates allocations of water to ensure equity among farms. The detail about the formation of the committee, the process and implementation of re-excavation, and the constitution for the management and operation of the canal is given in the sister SIAGI project report.

During harvesting of Rabi crops, many farmers visited the sites, and became confident that a second crop is possible. That had positive impacts during this year (2019-20) Rabi season as the team observed that many farmers have cultivated a range of crops including Boro rice in the study area.

Zero tillage potato, which is an invention of this project in Gosaba, West Bengal is being adopted by the farmers rapidly. The number of farmers increased from 23 (3 women) in 2016-17 to 49 (6 women) in 2017-18, 116 (49 women) in 2018-19, and 208 (70 women) in 2019-20. We tested this with one farmer in Dacope site of Bangladesh in 2017 which was successful. In 2018, 10 farmers cultivated this. More farmers were interested but we could not provide enough seed.

Figure 8.5 Re-excavated canal at Amtali. At the top corner there are rice field (Aus rice) grown using canal water.

We supported gender equity and women's empowerment through deliberately working with increasing number of women farmers in the project sites. For example, in Gosaba, we started ZT potato with 23 farmers in 2016-17 of which 3 (13%) were women. In 2017-18, there was 6 (14%) women farmers out of 44, in 2018-19, 34 (28%) and in this year (2019-20) the number of women farmers grew to 70 (34%) out of 208. It should be noted here that the proportion of women farmer is less in the overall population. So in terms of percentage of total population, the number of women farmers would be significantly higher than the men farmers as we have deliberately targeted them. In response to interest shown by women farmers, and to increase their participation in agricultural activities, 3 women's groups were formed in Gosaba site, and provided with small irrigation pumps to be utilised on a sharing basis. With the help of the pumps these women farmers grew additional crops and generated additional income. Creation of such interest group with more women farmers can be engaged gainfully in the region to increase the agricultural production and income. There are not many women led farming household in Bangladesh sites. However, in terms of percentage of total available, their rate of participation would be higher.

Through project activities, we managed to bring confidence among the farmers that higher productivity of Kharif rice and increasing cropping intensity by growing Rabi crops are possible if they adopt new agricultural technologies, and if the community works together to manage the water resources and sluice gate operations. In all sites, it is evident that the project team's intervention is having significant social impacts as many farmers have already adopted the demonstrated technologies. This will help improving their income and livelihood and have positive follow-on social impacts as well. This impact is not limited only to the study area. It may also be having impacts on the other areas in the coastal zone through widespread reporting of the project's successes in stories through TV, radio and newspapers (described in Section 8.4).

8.3.3 Environmental impacts

There are a few positive environmental impacts to report. These are mainly related to the storing of fresh water in the canals in our sites in Dacope and Amtali. In both sites with the active participation of the farmers and local leaders, we constructed temporary bunds and re-excavated the canal to store fresh water for irrigation in the Rabi season. Without that, saline water would have entered the canals during the Rabi season. Saline water in the canal may contribute to the field soil salinity in the surrounding fields as discussed in the modelling results in Chapter 7. Storing of freshwater in the canals may have other benefits to the environment as well.

We studied greenhouse gas (GHG) emission (CO_2, N_2O, and CH_4) from different cropping system in Gosaba and published in Ray *et al.* (2020). With the increasing cropping intensity, we found that GHG emission will increase as well. The rice-potato-ladies finger, being at par with rice-potato- rice, recorded the highest emission of CO_2. The rice-fallow-fallow system, followed by the rice-sunflower system, experienced the lowest emission of CO_2. An almost similar trend was observed for N_2O emission. The rice-potato-ladies finger system was observed to have significantly ($p<0.05$) highest emission of N_2O, followed by the rice-potato-pumpkin and the rice-potato-ridge gourd system. However, rice-sunflower, rice-fallow-fallow, and rice-rice systems were at par in terms of the lowest system N_2O emission. Three double rice systems *viz*. rice-potato-rice, rice-lentil-rice, and rice-rice recorded the highest emission of CH_4. Apart from this, we could not find any adverse direct environmental impacts in the project area.

8.3.4 Policy impacts

We achieved considerable policy impacts mainly through our local partner organizations. These are Bangladesh Agricultural Research Council (BARC), BARI, BRRI in Bangladesh and BCKV and CSSRI in West Bengal India. BARC, BARI and BRRI are the organizations under the Ministry of Agriculture, which formulate and update policies on agriculture. These organizations regularly communicate achievements to the Ministry; this information is influential in setting or updating policies. There is evidence of such impact from the project. The success of cultivation of sunflower in the farmers' field as part of our project attracted the attention of the government policy makers in Bangladesh. The Ministry of Agriculture (MoA) of the Government of Bangladesh (GoB) provided funds (equivalent to AU$425K) to our partner BARI for a project on "Production, dissemination and postharvest technology development of sunflower for saline lands of coastal region" during July 2018 to June 2021.

We organized communication workshops at BARC in Bangladesh on 01 March 2020 which was attended by the high level officials of the relevant government organizations including the officials from the MoA, international organizations, and non-government organizations (NGO). In West Bengal, we organized a workshop on 05 March 2020 with the Department of Agriculture (DoA) officials to communicate our achievements to the Agriculture Advisor to the Chief Minister of the Government of West Bengal (Figure 8.6). The advisor attended the workshop and promised assistance for the project and follow-up with DoA officials for supporting program/projects.

Figure 8.6 Workshop at Kolkata with the Agriculture Advisor to the Chief Minister of West Bengal

In addition, media coverage on the project achievements also generates awareness and inquiries from the policy makers which is an effective channel of influencing policy as is evident in our current works. As mentioned earlier, our achievements in the project have been widely reported in the national newspapers and TV channels. These attracted the attention of the MoA officials and they contacted our partners (BARI and BRRI) to know more about the project. The Minister of Agriculture wished to visit the project site in Dacope which was arranged by our partners on 12 March 2020 (Figure 8.7). In his interview with the journalist of the media, the minister spoke highly about our activities in that area. He was surprised that so many crops can be grown in that area which no one has thought before. In his speech and interview, he pledged to initiate and fund follow-up projects from the MoA on extension, seed availability and canal re-excavation so that farmers can take the full benefit of these technologies. He also guided the BRRI authority to take initiative to expand more area under Boro rice by conserving fresh water in Dacope region during next season (2020-21). In this year's (2020-21) MOA budget there is special allocation for the farmers of the coastal zone. In his news conference on the budget on 12 June 2020 (https://www.banglanews24.com/economics-business/news/bd/793693.details, in Bangla) the minister mentioned about the Rabi crops currently grown in the coastal area where earlier only one crop (Aman rice) was grown. The budget will be used to provide free seed, fertilizers and technologies for the farmers to grow Rabi crop in the upcoming season. Considering the minister's statement during our field visit on 12 March and his speech at the news conference on 12 June, a direct link between this two cannot be proven. However, it is likely that the field visit influenced the minister to arrange a special allocation for the coastal farmers.

Figure 8.7 Visit of the Minister of Agriculture of Bangladesh to the project site in Dacope (top left: Minister is checking the ZT potato, top right: Khokan Kumar Sarker of BARI explaining Barley experiment, bottom left: minister is talking about sunflower experiment of Khulna University and bottom right: minister is speaking to the media after visiting the BRRI Boro rice demonstration)

The Minister of Agriculture of the Government of West Bengal was the Chief Guest in the opening session of our annual meeting at BCKV in April 2017 (Figure 8.8). He was accompanied by the Director of the DoA. They are aware of our work and the Minister expressed his desire to visit our activities in the field. But the minister could not visit the site as he moved to another ministry soon after the annual meeting. Throughout the duration of the project, we maintained good communication with the DoA of West Bengal. The Additional Secretary, and Deputy Director of the DoA and many other districts officials of South 24 Parganas and Sundarbans regions have expressed their satisfaction after visiting our activities at Gosaba on 24th January 2019.

Figure 8.8 Annual meeting at BCKV in 2017; at the centre is the Minister of Agriculture

8.4 Communication and dissemination activities

8.4.1 Communication with other projects and organizations working in the region

We maintained regular communication with our sister project (LWR/2014/072) which is co-located in the same sites in Bangladesh allowing closer integration of research activities. The two project leaders have been maintaining a close communication and discussion of relevant issues, and informing of events such as visit to the countries, meetings, etc. In addition, the local partners of the projects also informed each other while visiting the field and visited the field and organized the meetings together. We also closely worked with and funded the canal re-excavation at Amtali site in Bangladesh. The mid-term review of the projects organized together provides significant evidence that the two sister projects (CSI4CZ and SIAGI) have been collaborating and working together.

CIM (CIM/2014/076) project had a much delayed start (started in July 2017). However, we have been also maintaining close communication. We presented our activities in each other's annual meetings. There are scientists from BARI who are member of the both project teams which provided additional closer cooperation. 'Nutrient management for diversified cropping in Bangladesh (NUMAN, LWR/2016/136)' project also co-located some activities in the same sites. The project leader of the NUMAN project, Prof. Richard

Bell, is a leading member of this project team as well which facilitated joint field visits, discussion and smooth flow of information.

We also had communication and information exchanged with two other ACIAR funded project with a common team member (Ed Barrett-Lennard); one in Pakistan ('Improving salinity and agricultural water management in the Indus Basin of Pakistan) and the other in Vietnam (Crop diversification challenges in the changing environment of the Mekong Delta, Vietnam). Both these projects have strong 'living with salinity' and 'future of deltas' components. Michael Mitchell of Charles Stuart University, who was leading the Indus project joined the mid-term review meeting in Khulna during 29 July to 03 August 2018 to know more about our activities and find synergies with their proposed project's activities.

We also maintained close communication with the other international organizations who are working in the regions particularly with IRRI and CIMMYT informing them about our major activities in the field, trip to the country, and have taken the opportunity to meet and discuss the progress, issues, and explore synergies. We actively participated in the workshops 'Towards better integrated of R4D for improved food production systems in coastal zone of Bangladesh' organized by IRRI in 2016 in Bangkok and in 2017 in Dhaka. The objective of the workshop was to establish a platform for improved sharing, networking, complementarities, and synergies, across the many R4D projects on production system and water management in the Ganges coastal zone, with the ultimate goals of improved livelihoods, productivity, resilience and sustainability. Representatives from various government and international organizations involved in the coastal zone of Bangladesh attended the meeting and presented their works.

To communicate the scientific output of the project, we negotiated with the Indian Society of Coastal Agricultural Research (ISCAR, http://www.iscar.org.in/) to publish a special issue of its journal (Journal of the ISCAR) with title 'cropping system intensification in the salt-affected Ganges Delta' (http://www.iscar.org.in/urls/publication.html) based on the research carried out under this project. The Society has large number of members (scientists) who are working on the coastal issues in India and Bangladesh. We published 17 papers in the special issue in September 2019. We have also published another 8 papers in international journals, 4 are in journal review and at least another 10 are at different stages of preparation. There were another 30 conference presentations. The details are given in Section 10.1.

Achievement and award

Our local project team members received several awards for the presentation of the works in international forum. There are:

1. The paper "New cropping systems and management options to face the emerging challenges in the salt affected coastal zones" by Sarangi, S.K., Maji, B., Mahanta, K.K., Mandal, U.K., Digar, S., Burman, D., Mandal, S., Sharma, P.C. and Mainuddin, M. 2019 received the Best Poster Award – 1st Prize at ICAR-CSSRI Golden Jubilee International Salinity Conference on "Resilient Agriculture in Saline Environments under Changing Climate: Challenges and Opportunities" organized by Indian Society of Soil Salinity and Water Quality held during 7 – 9 February, 2019 at ICAR-CSSRI, Karnal, India.
2. Mr Sukamal Sarkar (Senior Research Fellow and Ph.D student) has received the International Plant Nutrition Institute (IPNI) – Scholar Award 2018 for his Ph.D research work based on the project.
3. Mr. Indranil Samui (MSc Scholar working in the project) got best poster award in International Conference on "Agriculture and allied sciences.......Ecology" 13-14th August 2018, BCKV, WEST BENGAL.

8.4.2 Communication with the stakeholders and policy makers

Our local partners have formal channel of communicating the research outputs to the policy makers. These are already described in Section 8.3.4. In addition, we organized two special workshops; one in Dhaka on 01 March 2020 (Figure 8.9) and the other in Kolkata on 05 March to communicate the project outputs to the policy makers and wider stakeholders. The workshop in Dhaka was organized in collaboration with the BARC which is at the apex of the national agricultural research system (NARS). The Chief Guest at the Workshop was the Additional Secretary (Research) of the Ministry of Agriculture. Executive Director of KGF, ACIAR Program Manager and the representative from the Australian High Commission in Dhaka attended the workshop as special guests. The workshop was chaired by the Executive Chairman, BARC. About 100 high level officials from the relevant organizations attended the workshop. In his speech, the chief guest provided the details of some of the initiatives taken by the government for the development of agriculture sector. He expressed his satisfaction for the achievements of the project over the last 4 years and hoped that the outcome of the project will increase the land productivity and income of the vulnerable farmers of the coastal zones. He also mentioned that the Ministry will explore possible ways of extension of these technologies for wider adoption.

Figure 8.9 Workshop organized at BARC, Dhaka

The workshop in Kolkata was organized at the State Agricultural Management and Extension Training Institute (SAMETI) at Ramakrishna Mission Ashram Narendrapur (Figure 8.6). The Honourable Agriculture Advisor to the Chief Minister of West Bengal Dr. Pradip Mazumdar was the Chief Guest in the workshop. Many high level officials of the DoA, West Bengal and the project team of BCKV, CSSRI and TSRD attended the workshop. The project leader in his presentation mentioned the meeting of the Australian team including then ACIAR Program Manager Evan Christen and Regional Manager Kuhu Chatterjee with the Advisor in his office during the scoping study of this project in October 2014.

In July 2018, we had the first opportunity to communicate our activities to the high level stakeholders in Bangladesh through the showcase event organized by ACIAR and KGF at BARC (Figure 8.10). The Minister and Secretary of Agriculture, Australian High Commissioner, Executive Directors of ACIAR and KGF and the Executive Chairman of BARC were the guests in the event. The achievements of 3 ACIAR funded projects (LWR/2015/073, LWR/2016/136, and CIM/2014/076) were presented in the showcase event.

Figure 8.10 Guests and participants at the ACIAR-KGF showcase event on 29 July 2018

One the most effective ways of communicating the project outputs and outcomes is broadcasting and publishing stories in electronic and print media. The activities of the project are widely and prominently reported in the national and local newspapers and national TV channels every year (described later in Section 8.4.4). Our scientists were interviewed and participated in the Talk Show program of the TV channels and Radio regularly to speak about the project. In addition, two TV channels in Bangladesh made and broadcasted special program based on the activities of the project. ATN Bangla, a national TV channel, made 3 episodes (about 25 min each) of their agriculture based regular program called ‘Sonali Din (Golden Days)” based exclusively on the activities and successful technologies of the project. They were broadcasted on 14 and 15 September 2019, 14, 15, 21, 22 March 2020. Episodes 46 and 47 include interview with the ACIAR Program Manager of Water and Climate was as well. The You Tube links of these episodes are given below.

Episode 22: https://www.youtube.com/watch?v=MGIQvz4GoSU

Episode 46: https://www.youtube.com/watch?v=tBezEICMER4

Episode 47: https://www.youtube.com/watch?v=Q3dxwaXM_fE

The national government TV channel “Bangladesh Television (BTV)” made a program (22 min) based on our zero tillage potato in Dacope to broadcast in their flagship agriculture related program called “Mati O Manush” (People and Earth) and another episode of the program on the visit of the Minister of Agriculture to our project site in Dacope on 12 March 2020. The links of these two episodes are given below.

BTV - ‘Mati O Manush’ on Zero tillage potato

https://www.youtube.com/watch?v=EAapF91tLaw&feature=share

BTV - ‘Mati O Manush’ on the visit of the Minister to project site in Dacope

https://www.youtube.com/watch?v=PSmdfQAJcf4&feature=share

Millions of farmers in Bangladesh, agricultural scientists and extension workers, and policy makers watch these programs which is a very effective ways of communication of the project outputs and outcomes.

We opened a Facebook page https://www.facebook.com/CSI4CZ/ for the project. We regularly update the Facebook with the activities that are going in for the project. As of 06 June 2020, there were 600 likes on the page.

8.4.3 Communication with the farmers and dissemination of the project outputs

We set up field experiments in the farmers’ fields with direct collaboration of the farmers. Scientists involved with the projects including the scientists from Australia have regular communication with the farmers. We are not only working with the famers involved with the experiments, we also have communications with other farmers while visiting the field through community meetings, formal and informal discussion, visiting the experiments together and discussing the issues, etc (Figure 8.11).

Figure 8.11 Meeting of the project team with the farmers; left- meeting in February 2018 at Amtali and right – meeting at Gosaba on 06 March 2020

The communication and dissemination of the project output to the farmers and local extension officials is done through organizing Field Days, focus group discussions, community gatherings, and visits to the field sites. At the national level, communication and dissemination of the project output are done through the electronic and print media. Local scientists are invited to speak about the project activities in the TV and radio channels. Local and national newspaper published stories on the project activities. Annex reports from the local partners (Annex Reports 7-14) give detail of these activities. The summary list is given below.

CSSRI prepared an audio-visual program of 12 min on the activities of the project titled "Farming the Fallows" in English and Bangla to promote the cropping intensification practices in the region. We also prepared and distributed leaflets in Bangla on various aspects of the project and distributed to the farmers and stakeholders. The list of leaflets are given in Section 10.2.

Field days and Focus Group Discussions

2019-20

1. A Farmers Participatory Variety Selection Program was organized on 10 December 2019 at Amtali, Barguna by BRRI in collaboration with DAE, Amtali and BARI for T. Aman rice cultivation in that location. Twenty-one male farmers, 23 female farmers, 3 DAE official and 6 scientists from BARI and BRRI participated in the event. A similar program was organized at Dacope on 29 November 2019. 34 farmers (19 male and 15 female), 3 DAE official and 5 scientists participated the event.
2. BRRI organized a Field Day on 28 October, 2019 at Pankhali, Dacope, Khulna in collaboration with DAE, Dacope for growing off-season watermelon on the bank of pond and gher under lowland rice conditions. Goal of the field day was to show farmers how to generate additional income and improve land productivity and human nutrition through the cultivation of watermelon under waterlogged coastal zones in Khulna and Barisal regions of Bangladesh. About 150 (100 men and 50 women) participated in the Field Day including two scientists from Australia.
3. TSRD organized farmers meet awareness camps, visit of the interested and progressive farmers to the project experiments, organized community meeting similar to the other years in Gasaba where in total 1,849 farmers (905 men, 945 women) participated at BCKV site in Jatirampur and 1,860 farmers (1,051 men and 809

women) participated at the CSSRI site at Sonagaon. Please see Annex Report 14 for more detail.

2018-19

1. A Farmers Participatory Variety Selection Program was organized on 12 November 2018 at Amtali, Barguna by BRRI in collaboration with DAE, Amtali and BARI for T. Aman rice cultivation in that location. Twenty-nine male farmers, 14 female farmers, 4 DAE official and 7 scientists from BARI and BRRI participated in the event. A similar program was organized at Dacope on 11 November 2018. 36 farmers (23 male and 13 female), 3 DAE official and 5 scientists participated the event.
2. BARI organized a Field Day on 10 March 2019 at Dacope (Figure 8.12). The goal of the field day was to show farmers different Rabi crops grown in the site such as zero tillage potato, garlic, potato and maize. About 100 farmers (30 women) participated in the field day.
3. Khulna University organized a Field Day at Dacope on 23 March 2019. Students and faculty member of Khulna University and 25 farmers (10 women) participated in the field day along with local DAE officials.
4. BRRI organized Field Day on 31 July 2018 at Amtali, Borguna by in collaboration with DAE, Amtali for Aus rice cultivation in that location. Local leaders and farmers (about 100) attended the Field Day (Figure 8.13).

Figure 8.12 Field Day organized by BARI on 10 March 2019 at Dacope

Figure 8.13 Field day organized by BRRI on Aus rice (left) and meeting with the farmers for selection of suitable Aman varieties (right)

5. CSSRI organized a day long Stakeholders' Consultation Workshop on “Upscaling technologies for cropping system intensification in coastal zone of West Bengal” under the project on “Cropping system intensification in the salt affected coastal zones of Bangladesh and West Bengal, India” on 05 September 2018 (Figure 8.14, left). The objective of this workshop was to create awareness on cropping system intensification and to discuss strategies for upscaling of suitable technologies. There were 46 registered participants (35 men and 11 women) in this workshop, including Assistant Director of Agriculture (ADA) from Canning I, Canning II, Agriculture

Extension Officer (AEO) from Gosaba, farmers and farm women from project sites, project implementing partners etc.

6. Farmers Field Day was organized by CSSRI & TSRD on 21 February 2019 at Sonagaon, Gosaba with participation of more than 50 farmers from nearby villages (Figure 8.14, right). There was participation of large number of women farmers.

Figure 8.14 Stakeholders workshop at CSSRI, Canning Town (left) and Farmers Field Day organized on 21 Feb 2019

7. TSRD is working with the community at the Gosaba sites (Figure 8.15). They organize field visits of farmers to our experiments/demonstration sites, awareness meeting, send farmers to the events and training organized by CSSRI and BCKV. The details are given in Annex Report 14. The key points are given below.
   - TSRD organized 21 awareness camps as well as knowledge sharing meetings in collaboration with respective research partners and a total number of 1,448 farmers attended the events, out of this 716 i.e. about 50% were women.
   - TSRD organized 54 farmers from Jatirampur and Sonaga villages to send to Canning for observing Farmers' Day conducted by CSSRI-Canning.
   - TSRD organized/facilitated the exposure visits/training at BCKV, Kalyani for 210 farmers (including 140 women) in batches for several times in the year 2018-19.

Figure 8.15 An orientation camp of Farmers Producer Organization (FPO) (left) and a discussion meeting at Jatirampur of Gosaba (right), both organized by TSRD

2016-2018

1. BRRI organized a Field Day on 31 July, 2017 at Amtali, Borguna in collaboration with DAE, Amtali for Aus rice cultivation in that location. The goal of the field day was to show farmers how to improve land productivity and income through crop intensification in coastal zones of Bangladesh. About 100 farmers (30 women) participated in the Field Day.
2. BRRI organized a field day on 07 October, 2017 Saturday at Khatail, Dacope on growing vegetables and rice under lowland conditions (Figure 8.16). About 200

farmers attended the field day. Director General of BRRI, Chairman of the local Upazilla Parishad, DAE officials, and scientists and officers of different organizations like, BRRI, BARI, Khulna University, and DAE attended the event and delivered speeches.

3. BARI has organized a focus group discussion to select the Rabi crops on 07 November 2017. Thirty farmers (8 women) participated in the workshop.
4. A Farmers Participatory Variety Selection Program was organized on 13 November 2017 at Amtali, Borguna by BRRI in collaboration with DAE, Amtali and BARI for T. Aman rice cultivation in that location. Twenty three male farmers, 13 female farmers, 3 DAE official and 6 scientists from BARI and BRRI participated in the event. A similar program was organized at Dacope on 12 November 2017. 45 farmers (30 male and 15 female), 3 DAE official and 7 scientists participated the event.
5. BARI organized a field day with a title ‘Rabi crops production in coastal saline soil’ on 26 February 2018 at Amtali for disseminating the BARI developed crop production technologies at the salt affected coastal areas of Bangladesh. Eighty local farmers (46 male and 34 female), local scientists and DAE officials attended the field day (Figure 8.17).

Figure 8.16 Farmers in the field day organized by BRRI on 07 October 2017

Figure 8.17 Farmers in the field day at Amtali (left), high level BARI officials visiting the field experiments (right)

6. BARI organized a field day with the title “Potato production in zero tillage method” at the Union Parishad Conference hall, Pankhali, Dacope, Khulna on 27 February 2018. Eighty farmers (25 women) participated in this event which was also attended by the local and district level DAE officials, local leaders (Union Parishad Chairman and members).
7. BRRI organized another field day on Boro rice cultivation on 26 April 2018 at Dacope, Khulna. Mr. Alhaj Sheikh Abul Hossain, Chairman, Upazilla Parishad, Dacope was present as a chief guest. Local Agricultural Officer from DAE Mr. Sheikh Abdul Kader, 3 members of Upazilla Parishad, Scientists and Officers from BRRI, BARI, and DAE

were present among others and expressed their opinions. About 170 farmers participated in the Field Day; 120 man and 50 women.

8. BRRI organized a Field Day on Boro rice cultivation on 01 May, 2018 at Amtali, Borguna. Director General of BRRI, Additional Director, DAE, Barishal, Deputy Director, DAE, Borguna, were present as Special Guests. Scientists and Officers from BRRI, BARI, and DAE were also present among others. About 170 farmers (50 women) participated in the Field Day.

9. TSRD organized 4 farmers meeting, 2 at the sites of BCKV and 2 at the sites of CSSRI. The details are given in the Annex Report 14. In addition, TSRD organized 15 awareness camps with respective research partners. In total 973 farmers attended the events, out of this 424 i.e. 43.6% were women.

Feature on project activities broadcasted in national TV and radio channel

2018-19

1. Channel I broadcasted a story on vegetables and fruit cultivation by integrated approach on the bank of pond and with T. Aman rice at Dacope, Khulna on 30 October 2019 at 5:00 pm.
2. Dr. S. K. Sarangi of CSSRI participated as an expert in Krishidarshan Live TV programme on “Use of solar drip Irrigation in Sundarbans agriculture” on 19.03.2019 at Doordarshan, Kolkata, the programme was repeat telecast on 21.03.2019 (Figure 8.18).
3. Channel I broadcasted a story on sunflower cultivation at Dacope, Khulna 23 May 2019 at 7:00 am.
4. Expert talk in the “Krishidarshan Live Programme” at DD7 Kolkata (DD Bangla) on 07.05.2019. Topic: Weather related services for coastal agriculture (emphasizing Sundarbans issues) by Prof. M. K Nanda and Dr. Sibani Choudhury.
5. Expert talk in the “Krishidarshan Live Programme” at DD7 Kolkata (DD Bangla – The Govt. of India Official TV Channel) on 18th December 2018. Topic: Winter Crops of Sundarbans: Prospects and Strategies by Prof. Koushik Brahmachari (Figure 8.18).

Figure 8.18 Dr S. K. Sarangi of CSSRI and Dr. K. Ray of BCKV team speaking to the TV program (left) and Prof. Koushik Brahmachari of BCKV speaking on the same channel (right)

5. Dr. S. K. Sarangi delivered Radio talk on 27.11.2018 in All India Radio – Akashbani Kolkata on zero tillage potato cultivation in salt-affected soils, aired in Aakashbani Moitri on 03.12.2018 & 10.12.2018.

6. At least 5 Expert talks in “All India Radio Programme” at the Akashbani Kolkata Centre on different project related issues on Sundarbans by Prof. Koushik Brahmachari.

2016-18

1. Dr S. K. Sarangi delivered Radio talk in All India Radio - Aakashbani Kolkata on ‘Labanakta Anchaler Dhan Chas’ (Rice Cultivation in Salt-affected Areas), aired in Aakashbani Moitri on 09.07.2017 and 19.07.2017 (Figure 8.19, left).
2. Dr S. K. Sarangi delivered Radio talk in All India Radio - Aakashbani Kolkata on ‘Labanakta Anchaler Jyonyo Dhaner Unnat Jaat’ (Improved Rice Varieties for Salt-affected Areas), aired in Aakashbani Kolkata on 11.07.2017.
3. K. K. Mahanta delivered Radio talk in All India Radio - Aakashbani Kolkata on “Krishi kathar asar: Upokulaborti anchale chasbas (Event for speaking on agriculture: cultivation in coastal area” aired in Aakashbani Moitri on 02.10.2017.
4. At least 5 Expert talks in “All India Radio Programme” at the Aakashbani Kolkata Centre on different project related issues on Sundarbans (West Bengal coastal zone) by Prof. Koushik Brahmachari.
5. BARI scientist Dr. Harun-ur-Rashid participated at a radio program related to farming at ‘Khulna Betar’, where he informed the audience about some of our project activities.

Figure 8.19 All India Radio personnel is speaking to a farmer at the project site (left photo) and the Exhibition both on the project at the Annual convention of the Indian Society of Soil Science (right photo).

News on project’s activities published in the newspapers

2019-20

1. Zero tillage potato cultivation is spreading in the coastal area. This news was published on 02 February 2020 in the national daily newspaper ‘Dainik Amadershomoy’. The title of the news is ‘**Zero tillage potato cultivation in Koyra**’.

2018-19

Project activities in the field (e.g. the crops project researchers and other farmers have grown in the Rabi season in an area formally in fallow until we started our work) have drawn widespread attention from the national print media. This media attention has allowed the outputs of the project to be nationally disseminated. All the newspaper articles are given in Appendix 1. These are:

1. News about cultivation of maize at Amtali published prominently in the national daily newspaper “The Daily Janakantha” on 20 April 2019 with the title “**Smile in the face of coastal farmers’.**
2. News published in the last page of Prothom-Alo, the most popular Bengali newspaper of the country, based on our work at Amtali, Borguna on 20 April 2019 with the title “***Splendour of green on the saline fallow lands***”.
3. News about the Field Day organized at Dacope, Khulna on 10 March 2019 published in the daily Khulna Times (left) with the title “**Field Day on suitability of innovated**

technologies at Dacope" and in the Parittran (right) with title "**Field Day observed at Dacope**".

4. News about the Field Day at Dacope published in the National Bengali newspaper "Jaijaidin" on 14 March 2019.
5. News story published on 15 May 2019 in the daily 'Prothomalo", the most popular national newspaper of the country, on the sunflower cultivation at Dacope Khulna. The title of the story is '**Wish success of Dacope spreads everywhere: sunflower cultivation in saline land**'
6. Another story published on 6 April 2019 in the national daily 'Janakantha' on the sunflower cultivation in Dacope. '**The title of the news is Sunflower cultivation in the coast: success of farmers'**
7. Kalerkantho, national newspaper, published a news on 10 April 2019 with title '**Success: sunflower in saline land**" based on sunflower cultivation in Dacope, Khulna.
8. News published in Daily Bengali newspapers about Boro rice and sunflower cultivation in Dacope during 2018-19. The caption of the left news items is 'Huge response to Boro rice and sunflower cultivation in Dacope' and the caption of the news at right is 'Interest of cultivation of Boro and sunflower is growing among farmers in Dacope".
9. Several newspapers published news on the bumper production of Aus rice at Dacope in 2018-19.
10. Anandabazar Patrika, the most widely circulated popular Bengali daily of India and abroad, published a report on the alternative crops cultivation in salt affected soil with the headline (in Bengali) 'Alternative cultivation in Salt Affected Soils of Ayla', on 14.01.2019.
11. Anandabazar Patrika, the most widely circulated popular Bengali daily of India and abroad, published a report on the low cost potato storage technology with the headline (in Bengali) '**Low Cost Household Potato Storage Structure'**, on 23.01.2019.
12. Anandabazar Patrika, published a report on the zero tillage potato cultivation technology with the headline (in Bengali) '**Cultivation of Zero tillage potato in rice fallow**', on 09.01.2019 with two big colour photographs based on potato grown in Gosaba, West Bengal.
13. Vhumiputra, a popular Bengali bi-monthly newspaper (farm journal) of West Bengal, published a report on the IPNI Scholar Award Programme with the headline (in Bengali) '**Two researches of the University have been awarded'**, on 21.01.2019.
14. Sabuj Sona, a popular Bengali bi-monthly newspaper (farm journal) of West Bengal, published a report on the IPNI Scholar Award Programme with the headline (in Bengali) '**Two researches of the University have been awarded with IPNI'**, on 1st February 2019.

2017-2018

1. Prothom-Alo, the most widely circulated and popular Bengali daily newspaper, published a story on the potato cultivation with the headline (in Bengali) '***Success in growing potato on saline land***' with big colour photo of the potato field, on 26 March 2018 based on potato grown in Dacope, Khulna.
2. Prothom-Alo published another story with a colour photo of the green crop field based on our work at Amtali, Borguna on 02 March 2018 with the title '***Many crops on saline land***".

1. The Daily Janakantha, another national popular daily newspaper Bengali newspaper of Bangladesh published a story with a photo of our tomato experiment based on our

activities at Amtali, Borguna on 03 March with the title '***Grandeur of green in the saline land: smile to farmers' face***".

2. The Daily Janakantha published another news based on our activities at Amtali on 27 February 2018 with a colour photo of a sunflower experiment titled '***Farmer are self-reliant after cultivating crops in the fallow saline land of the southern region***'.
3. The Daily Ittefaq, national daily newspaper' published a news about our field day at Amtali on 28 February 2018.
4. Sagorkonnya, a local newspaper of Borguna, published a story 26 February 2018 with a title ***"Field day about the use of saline land in the southern region'***.
5. The daily Amadershomoy, national newspaper, published a story with a big colour photo of our maize field at Amtali on 03 March 2018 with the title '***Smile on the farmers' face due to green crops on saline land***'.
6. The daily 'Bhorer Kagoj' published the news on 28th April 2018 of the Field Day organized by BRRI on Boro rice cultivation on 26 April 2018.
7. The daily 'Samakal' published the news on 27th April 2018 of the Field Day organized by BRRI on Boro rice cultivation on 26 April 2018.
8. Prothom-Alo published a long story in the last page with the title '***Vegetable cultivation with rice in saline water-logged land: raising new hope for coastal farmers'*** on 23 October 2017.
9. The daily Ittefaq published a long story with a colour photo of the field with title '***Huge response to grow vegetables with rice in Dacope***' on 20 October 2017.
10. News 71 online published a story on 07 October with colour photo of the field with title '***Farmers became successful growing vegetable with rice in water-logged land***'.
11. The Daily Khabarpatra, Daily Sangbad Protidin, Jai Din, Samakal, and The Ittefaq published the news of field day organized by BRRI at Dacope on 08 October 2017.

9 Conclusions and recommendations

At the end of Chapter 7 (Section 7.9), we comprehensively discussed the results of the major components of the project. That discussion provides a high level conclusion of the research activities carried out, their opportunities and risk for the cropping intensification in the coastal zones of Bangladesh and West Bengal, India.

In this section, we specifically draw the conclusions from the modelling and experiments results and the overall impacts of the projects. We also provide recommendation for future studies.

9.1 Conclusions

9.1.1 Land use, climate, and water resources

1. Land use analysis of the project sites at the commencement of the project indicated that most of the land remained fallow in the Rabi and Kharif-I season. The cropping intensity at Amtali, Dacope and Gosaba was around 110%.
2. The annual precipitation varies spatially across the Ganges delta, decreasing from more than 2,000 mm in the east (Amtali) to 1,800 mm in the west (Gosaba Island). About 82-83% of the average annual rainfall occurs in the wet season (May to October) and only 5% during the Rabi season (Dec-Feb). However, occurrences of sudden heavy rainfall increased in the Rabi season during the decade of 2008-2017.
3. There was statistically significant increase of annual average daily maximum temperature at all stations within the coastal zone in Bangladesh, with average rates of 0.028 °C year^{-1} to 0.01 °C year^{-1}. There was no change in temperature at Canning station representing Gosaba Island.
4. The salinity of the rivers surrounding the polders varies due to tidal condition and season. At Amtali, the salinity of Payra river stays always at the acceptable level for irrigation. Salinity of river water at Dacope and Gosaba remains very high (above 20 dS m^{-1}) in the dry season so not possible to use for irrigation.
5. There is a good canal network and ponds and they can be used to store water during the wet season for use in the dry season for irrigation. Some maintenance of sluice gates or re-excavation would be necessary. In Gosaba, salinity of pond water is about 1 dS m^{-1} but they are acidic with pH of 7.64.
6. Average groundwater level (below the surface) varies from 0.8 to 1.8 m at Amtali, 0.04–1.09 m at Dacope, and 0.05 to 1.93 m at Gasaba. Salinity of groundwater varies from 3.2 dS m^{-1} to 10.8 dS m^{-1}, 0.4–2.9 dS m^{-1}, and 7.4 dS m^{-1} to 13.3 dS m^{-1}, respectively.

9.1.2 Water, salinity and crop modelling

1. We developed a novel salt and water balance model for polders to investigate water and salt management strategies for crop production, including strategies to cope with climate change, flood inundation and sea level rise. The main impacts of climate change are through the indirect impacts on salt concentrations. Management practices to remove salt from polders are therefore likely to be effective in combatting the impacts of projected climate change. In the event of cyclone-induced inundation, the model simulations suggest that with sound maintenance of infrastructure and sound management, particularly of soil drainage, the polders and islands of the Ganges delta could recover fairly quickly from inundation events.
2. We developed two separate groundwater models for the two selected polders in Bangladesh to understand the surface water, groundwater and salinity interactions

and to simulate scenarios such as saline groundwater pumping for drainage, and impact of climate change. The results show that pumping of saline groundwater for drainage will reduce the groundwater level in the polders. However, saline water from the rivers will then flow inwards to the aquifer. Due to climate change, the existing water logging problem will further deteriorate in future due to the increase in groundwater level.

3. To maximise the flexibility in applying the APSIM model under saline soil conditions, we developed a novel technique for simulating surface-soil salt build-up and the associated Rabi crop response. This has positioned us well to simulate soil salinity dynamics (instead of given) and explore the performance of farmer management adaptations under both historical and future climate scenarios. This has been a major step forward for cropping systems modelling in saline zones in general – not just for the CSI4CZ project. We also developed new APSIM modules – APSIM-Grasspea and APSIM-Lentil.
4. We conducted a range of scenario simulations using the validated APSIM model to help understand crop responses to management change and environmental drivers in the CZ. The model has been particularly useful in understanding the risk, or variability in crop performance as driven by environmental constraints.
5. Electromagnetic soil survey was used to understand spatial variability of salinity up to a depth of 1.6 m and a procedure was developed using GIS to incorporate the apparent soil conductivity in covariance analysis to improve the efficiency of experiment testing treatments. A linear regression model was also developed to predict tuber yield from the ECa data which can be used to out-scale yield from a trial site to a surrounding area with ECa measurements.

9.1.3 Improving productivity of Kharif crops

1. We introduced and tested 11 high yielding, short duration varieties of Aman or Kharif-II rice in the two sites of Bangladesh. Results show that BRRI dhan87, BRRI dhan77, BRRI dhan76 gave higher grain yield (4.8 t ha^{-1} to 5.4 t ha^{-1}) than existing varieties (4.00 t ha^{-1} to 4.65 t ha^{-1}) and 50% to 60% higher net benefit in Amtali and Dacope. However, at Amtali farmers preferred one existing variety (BR23) with the introduced BRRI dhan76 and at Dacope the latest new variety (BRRI dhan87) over the existing varieties.
2. At Gosaba, we tested 15 Kharif-II varieties along with 8 local or existing varieties. Pratikshya, Santoshi and CR 1017 performed better with grain yields around 6.0 t ha^{-1} compared to the yield of existing varieties of 5 t ha^{-1}. By maturing at least by 15 days earlier, Pratikshya creates opportunities for cropping system intensification in the coastal zone by earlier establishment of Rabi season crops.
3. Alternative Kharif rice establishment methods such as dry direct seeded rice or non-puddled transplanted rice were found to be suitable for the submergence-prone lowlands of the coastal region of West Bengal. Soil acidity along with salinity prevails in many fields which can be amended using green manure (GM), lime (L), and rock phosphate (RP). Use of all (GM+L+RP) can increase yield by about 50% compared to the yield with no soil amendment.
4. We first introduced growing vegetables with Aman/kharif in bags over the highly water-logged rice fields in Bangladesh. While some farmers gained additional benefit some farmers also lost due to loss in rice yield and higher initial investment. However, in Gosaba it was observed that farmers/farm women can increase their income substantially to at least Rs.112,585 ha^{-1} by this technology from the existing level of Rs. 35,374 ha^{-1} from rice only cultivation.
5. Cultivation of Aus rice (BRRI dhan48) in the Kharif-I season was feasible and profitable in Bangladesh. The average yield was 4.1 to 4.6 t ha^{-1} with minimum net

benefit of Tk. 20,000 ha^{-1}. Production of Aus rice in the coastal area is an option for cropping intensification. The suitable sowing time for seedlings is 10-30 April which produced highest yield. The seedling raising period and the crop establishment period is the critical time due to water shortage.

9.1.4 Growing crops in the Rabi season

1. We introduced and found Boro rice varieties BINA dhan10 and BRRI dhan67 highly suitable and produced average yield of more than 6.0 t ha^{-1}. The net benefit gained was from Tk.41,155 ha^{-1} to Tk.46,675 ha^{-1}. The irrigation requirement was 560-990 mm depending on the time of transplanting and rainfall during the growing period. Alternating wetting and drying irrigation application would require 20-24% less water without any harmful effect of salinity on yield. Application of bio-organic fertilizer increased Boro rice yield by about 0.5 t ha^{-1} compared to use of full chemical fertilizer.
2. In West Bengal, we selected suitable salt-tolerant cultivars of Boro and their optimum time of sowing. Production of Boro rice in the coastal area is an option for cropping intensification in the comparatively low land areas where water levels recede slowly after T. Aman harvest and there is limited option for accelerated drainage.
3. We tested many new crops to find out their suitability for growing in the coastal saline soil in the Rabi season. In Bangladesh, we found several new crops such as foxtail millet, English spinach, barley are suitable for cultivation and they are profitable. For example, estimated gross return or net benefit from English spinach was Tk.108,440 ha^{-1}.
4. At Gosaba, we tested 19 Rabi crops (broccoli, onion, garlic, okra, French bean, Indian spinach, tomato, pumpkin, bitter gourd, snake gourd, cucumber, chilli, mung bean, mustard, cabbage, cauliflower, knol-khol, beetroot) with and without mulch for their suitability of cultivation in Gosaba. The economic benefit varies from year to year due to market price. A farmer's preference analysis reveals that broccoli, Indian spinach, mung bean, mustard, and other vegetables are favored by the farmers. The preference for sunflower, maize and capsicum was low and the other crops were not liked by the farmers.
5. We determined the optimum time of sowing for some of the suitable crops: wheat, sunflower, maize, mustard, English spinach and Indian spinach. Last week of November to 1st week of December is the optimum sowing period for wheat, sunflower, maize and mustard in Bangladesh. However, there are significant risk with early sowing in the Rabi season due to untimely heavy rainfall and further research needs to focus on risk alleviation strategies for the early-sown Rabi crops.
6. Sunflower and maize can be grown throughout the coastal zone of Bangladesh and local farmers are very much interested to cultivate them. Wheat is a risky crop due to its susceptibility to adverse climate, pest and diseases.
7. For sowing of maize we found that seed sown by Power Tiller operated Seeder (PTOS) was the best option for maize cultivation as it returns the highest. Transplanting of 14 days old seedings of maize under zero tillage condition also produced highest yield as it facilitates early establishment of the crop which enabled escape from soil salinity stress during the later cropping season.
8. Testing of sunflower transplanting against traditional practice showed that 14 days old seedlings with early transplanting realized the maximum seed yield. If farmers cultivate moderate or longer duration rice then they can even transplant 21-days-old seedlings without compromising the grain yield of sunflower. Transplanting of sunflower is possible and may be a better intervention of sunflower establishment in the coastal wet soil of Bangladesh.

9. Use of rice straw mulch significantly increased the yield of dibbled maize and sunflower by 22% and 4.3% compared to treatments of without residue or straw mulch. Furrow placement of basal fertilizers increases yield of sunflower.
10. Conjunctive use of fresh (low-saline: pond water) and saline water (medium saline: canal water) for growing sunflower, maize, wheat, barley and mustard in Bangladesh shows that use of fresh water (EC ≤ 1.2 dS m^{-1}) at early crop growth stages and saline water (EC ≥1.2 and EC ≤ 5 dS m^{-1}) at later growth stages of these crops could be an alternative irrigation method for increasing yield and water productivity with a little reduction in crop yield compared to only irrigating with fresh water. Furrow irrigation can reduce irrigation water use by 30% to 50% compared to flood irrigation method.
11. Waterlogging and poor surface drainage due to unexpected heavy rainfall are becoming a major constraint to the production of Rabi crops in the coastal region. Hence, Testing of the effect of surface drainage on crop growth of maize and sunflower indicates that drainage not only saves the crop it can also provide significantly higher yield.
12. Instead of straw mulch in between sunflower rows, farmers could get extra income from cover crops such as spinach. The results show that gross margin (Tk.106,550 ha^{-1}) of sunflower with spinach cover crop was 46% higher than sunflower with rice straw mulch.
13. Pumpkin cultivation in pit was profitable. Using rice straw as mulch at the bottom and above the pit of pumpkin produced better yield and increased net benefit.
14. Zero tillage (ZT)potato cultivation developed by CSSRI is the breakthrough technology of the project which has been taken up by the farmers in Gosaba rapidly. The net benefit of ZT cultivation in 2019-20 was $ 2,498 ha^{-1} against around US$500 ha^{-1} from conventional practice. Net benefit can be further enhanced by applying fertilizer as foliar application and by cultivating hybrid varieties. However, availability of seed potato is limited and farmers need to buy seed from distant places.
15. ZT potato was found successful at Dacope in Bangladesh as well. Salt tolerant varieties BARI Alu-72 and BARI Alu-73 with 7 to 10 t ha^{-1} straw mulch and 20% extra potassium produced the highest tuber yield (24.65 t ha^{-1} at Amtali and 11.67 t ha^{-1} at Dacope) and highest net economic benefit (Tk 92,582 ha^{-1} and Tk 160,252 ha^{-1}). Closer plant spacing (30 cm×25 cm) was suitable because with zero tillage no ridge formation is required and this leads to higher tuber yield and economic benefit.
16. Encouraged by the success of ZT potato, we carried out experiments to cultivate ZT garlic in both sites in Bangladesh. Economic analysis shows that farmers can gain net benefit of Tk 294,586 ha^{-1} by cultivating BARI Rasun-4. The local farmers previously had no idea about the cultivation of garlic under zero tillage along with straw much and were very impressed and interested to grow garlic.
17. In Gosaba, inclusion of pulses, as utera crop, is a potential option in rice-fallow areas with a dual advantage of crop diversification for sustainable production and area expansion of pulses for human nutrition. Foliar application of 2% di-ammonium phosphate (DAP) provide better yield and growth of utera lentil and lathyrus.
18. Use of mini pond in 3-6% of the total service area for storing water in the wet season and use them in the Rabi season for growing crops as part of integrated farming was suitable and highly profitable in Dacope.
19. Low-cost drip irrigation system is very promising and financially feasible with favorable economic return and payback period of 1.91 years in Gosaba. Drip irrigation at different frequency with tomato shows that drip irrigation at 80 % ETo with straw mulching provided significantly higher fruit yield (60 t ha^{-1}). Small-scale drip irrigation

using a plastic bottle beside plants such as okra, tomato, onion, knolkhol, beet and chilli in Gosaba were also profitable.

20. Several suitable and profitable cropping patterns have emerged based on our research over the last four years for the study areas. Some of the highly profitable cropping patterns for Bangladesh sites are sunflower-rice-rice, maize-rice-rice, pumpkin-rice-rice, etc. The current dominant cropping pattern is fallow-fallow-rice. For Gosaba, profitable cropping patterns are Kharif rice-ZT potato-green gram, Kharif rice-ZT potato, Kharif rice-maize, etc. There are several opportunities to achieve higher cropping intensities with substantially higher returns as compared to the existing practices.

9.1.5 Demonstration of successful technologies and adoption

1. The results of the demonstrations of sunflower, maize by PTOS and millet at Amtali show that farmers were highly satisfied maize with PTOS as it saves time and seed and reduces labour cost. However, PTOS should be available locally. Bird damage and untimely rainfall affected the yield of sunflower. Access to threshing machine and good market condition are necessary to promote sunflower to the farmers. Foxtail millet is a new crop in the region which looks promising.
2. For Boro rice cultivation, the number of farmers increased from 35 in 2017-18 to 86 in 2019-20 at Amtali and Dacope. Net benefit of Boro rice at average yield (5.4 - 5.7 t ha^{-1}) were between Tk. 55,030 ha^{-1} and 59,385 ha^{-1}. Farmers were satisfied and are willing to continue Boro rice cultivation as this is more resilient to extreme weather events compared to other non-rice crops It is likely that Boro rice area may increase in both locations in the future. However, strengthening policy supports for enhancing access to freshwater for irrigation and fair price of paddy rice are very important for sustainable intensification of Boro rice cultivation in the region.
3. For Aus rice in Bangladesh, the number of farmers increased from 12 to 59. The gross income or net benefit per hectare of Aus rice at average yield (4.1- 4.2 t ha^{-1}) were in the range between Tk.20,522 - 23,353 ha^{-1}. Famers are willing to cultivate Aus rice on a larger area subject to access to fair price of the paddy rice and freshwater for raising seedlings in the nursery.
4. In Gosaba, the main out-scaling activities was on the ZT potato cultivation. The number of farmers increased from 23 in 2016-17 to 208 in 2019-20. The main reason for its adoption is the ease of cultivation and economic profitability and it is expected that increasing numbers of farmers will continue to grow over the coming years.
5. We conducted baseline survey at each location at the start of the project. In Bangladesh, nearly one third of the households in the villages were landless labourers in the study areas. Most farm households were small (68-91% of total farm households) semi-subsistence and resource-poor, owner/tenant farmers. On average size of the small farms in the trial villages was less than 0.5 hectare.
6. In Gosaba, we conducted both baseline and endline survey and the farmer's response to adoption of these technological interventions. Most of the respondents (88.5%) rely on agriculture as their primary occupation followed by 11.5 % who rely on income other than agriculture. ZT potato is the most preferred intervention identified because of its low water requirements, better yield, and profit.

9.1.6 Impacts, communication and dissemination

1. The project made considerable scientific advances in understanding and modelling the crop systems and hydrology of the Ganges Delta. So far, 26 journal papers are published and 4 others are with journal for review. Several (at least 10) are under preparation. There were 30 conference presentations.

2. There was significant capacity building for the farmers and the local scientists. We organized formal and informal training for the farmers and the scientists every year throughout the project period.
3. The most significant capacity impact is the 16 students currently undertaking PhD's in collaboration with the project (4 in Australia as JA Fellows, 10 in Bangladesh and 2 are India). Nine of these students are women. In addition, 12 master students received support and completed their thesis works based on the project activities.
4. We organized and supported participation of 10 scientists (which includes 4 senior level officials) from the project team of KGF, BARI, BRRI, CSSRI and BCKV to attend the 'Third International Tropical Agriculture (TropAg) Conference organized during 11-13 November 2019 at the Brisbane Convention & Exhibition Centre in Australia.
5. There are evidences that farmers are adopting the technologies developed by the project and are getting economic benefit. The project was initiated during 2016-17 with 384 farmers (46 women), which increased to 511 farmers (36 women) in 2017-18, 934 farmers (118 women) in 2018-19 and 1,204 farmers (226 women) in 2019-20.
6. ZT potato is the breakthrough technology of the project. In Gosaba, the number of farmers growing ZT potato continues to increase every year. If we can achieve ZT potato on only 5% of the land (150 ha) in Gosaba, then the total benefit will be about AU$ 400,000 $year^{-1}$.
7. We managed to bring confidence among the farmers that higher productivity of Kharif rice and increasing cropping intensity by growing Rabi crops are possible if they adopt new agricultural technologies, and if the community works together to manage the water resources and sluice gate operations. In all sites, it is evident that the project team's intervention is having significant social impacts as many farmers have already adopted the demonstrated technologies.
8. There are a few positive environmental impacts mainly related to the storing of fresh water in the canals. Increase of GHG emission due to cropping intensification is the adverse direct environmental impact.
9. There is evidence that the Ministry of Agriculture in Bangladesh is using the information generated from the project. They allocated AU$425K to our partner BARI for a project on "Production, dissemination and postharvest technology development of sunflower for saline lands of coastal region" during July 2018 to June 2021) for promoting cropping intensification in the region.
10. Project activities were reported extensively with interview of local scientists in the national electronic and print media over the last 4 years. There were 5 TV programs (about 25 min each) fully based on the project activities in the national TV channel ATN Bangla and BTV.
11. In every season, several Farmers Field Day, community gatherings, and visits to the field sites were organized in collaboration with local leaders, extension officials and other stakeholders at each site to communicate and disseminate the project output to the farmers.
12. We organized two high level communication workshops with the policy makers in Dhaka and Kolkata. In Kolkata, the Agriculture Advisor to the Chief Minister attended the workshop.
13. Honourable Minister of Agriculture of the Government of Bangladesh visited the project activities in Dacope, Khulna on 12 March 2020 and commented that "*through these activities there will be agricultural revolution in the southwestern coastal area*'.

Through the intervention of the project, we have demonstrated that it is possible to intensify cropping in the coastal zone. There is evidence that the farmers can significantly raise their incomes by adopting improved water management and modern cropping technologies. It is evident that farmers are becoming confident in the cultivation of a range of crops in both Kharif II and Rabi season. In addition, farmers now believe that it is also possible to increase the production and profitability of the current wet season crops (Aman or Kharif rice).

9.2 Recommendations

A wide range of field crops and vegetable crops are feasible in the coastal zone, and profitable intensified cropping patterns have been identified. Within the coastal zone, the landscape is diverse in land type or elevation, proximity to rivers, salinity levels in the river water, soil types, density of canals and ponds. The profitable cropping intensification options will vary according to land type and hydrological characteristics. Classification of the landscape can be used to determine which cropping intensification opportunities developed in Amtali, Dacope and Gosaba can be applied in other parts of the coastal zone. Remote sensing technologies are recommended as an effective tool for classifying the landscape according to land use (Ghosh *et al.*, 2019).

Our findings provide evidence that cropping systems intensification is feasible and profitable. However, there is still much to be done to increase the resilience of this system by mitigating risks and increasing the productivity of crop using best management agronomic practices that optimise plant population, row spacing, seed depth and rate, time of sowing, fertilizer rate and placement for a range of promising crops. We need to identify packages of resilient technologies suitable for different parts of the region with different characteristics.

The main opportunity involves shifting the Rabi season with earlier planting so that crops use water stored from the monsoon season when the solute potential is low and reach harvest early enough to avoid crop stress from waterlogging, salinity/drought, heat and or storms. Early planting of Rabi season crops requires harvest of Kharif rice 15 to 30 days earlier in both West Bengal and Bangladesh. In both countries, several earlier maturing cultivars have been identified with yield gains of 0.5 to 1.0 t ha^{-1}. Early planting of Rabi season crops requires community action and possibly block planting to coordinate the drainage of excess water without causing conflict among water users.

One of the most profitable and promising new crops for the Rabi season is ZT potatoes (Sarangi *et al.*, 2018a; 2018b). The ZT potato is placed on wet soil and covered by a thick layer of rice straw mulch equivalent to 12 t ha^{-1} (Sarangi *et al.*, 2018a). Further experiments are underway to develop optimum agronomic practices for ZT potato including row spacing, plant density, cultivars and mulching materials and thickness. Development of the ZT potato production in the coastal zone will depend on developing a reliable supply chain for sale of seed potato and possibly for cold storage of surplus potato to reduce post-harvest losses and to enable farmers to capture better market prices.

From four years of investigations at three sites in the coastal zone it is clear that canal and pond water collected during the wet season remains mostly below 4 dS m^{-1} and hence is suitable for irrigation during the Rabi season. The main limitation is the small volume available of such water rather than its quality. Low cost drip irrigation was shown in both Bangladesh and West Bengal to be highly profitable and is a potential technology for value addition of the scarce water supplies.

In the coastal zone there is a high demand for increased rice production. Current Kharif season rice supplies are possibly not sufficient to meet food security needs. Promising new Kharif rice cultivars with higher yield could be promoted in the coastal zone of Bangladesh and West Bengal to alleviate this shortage. Where sufficient water is available, Boro rice is an option for lowlands, especially if it utilizes AWD technology to decrease water requirements. In addition, Aus rice was successfully grown at a number of locations and produced good yields (4 t ha^{-1}). Transplanting within the period 10-30 April is recommended, as is further work to develop a reliable methods for Aus seedling raising at the end of the dry season when soil salinity is highest and fresh water supplies limited.

Whilst early crop establishment with mechanised zero tillage and strip tillage were less successful than full tillage for Rabi crop yield, dibbling of seed by hand and transplanting of seedlings were very effective means of early establishment of Rabi season crops without tillage. Mulching is highly effective in increasing yield of Rabi season crops and is recommended as a standard practice. However, benefit-cost analysis is needed to confirm that mulching would be the most profitable use of the crop residue in the farming system.

Rabi season crop options need adequate drainage to minimize the risk of heavy rainfall events. Further research is needed to determine the most effective drainage arrangement and the form of drainage most acceptable to farmers.

Cropping systems intensification is technically feasible and profitable, but there are important social dimensions to ensure that benefits from technologies are accessed by farm communities. An important pre-requisite to adoption is that equitable arrangements are put in place to manage water in the coastal zone for socially inclusive outcomes.

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10.2 List of publications produced by project

Total journal paper: 29 (published– 24, under journal review – 5). Several others are in preparation (not included in this list). Conference paper: 30.

10.2.1 Journal papers

1. Ghosh, A., Nanda, M.K., Sarkar, D., Sarkar, S., Brahmachari, K., Ray, K., Mainuddin, M., (in journal review). Assessing the spatio-temporal changes in land use land cover using random forest classification of Landsat times series data: A case study in Indian Sundarbans. Environmental Monitoring and Assessment.
2. Mainuddin, M., and Kirby, M. (in journal review). Impact of flood inundation and water management on water and salt balance of the polders and islands in the Ganges delta. Ocean and Coastal Management.
3. Mainuddin, M., Karim, F. M., Gaydon, D.S., Kirby, M. (in journal review). Impact of climate change and management strategies on water and salt balance of the polders and islands in the Ganges delta. Scientific Reports.
4. Sarkar, S., Gaydon. D.S., Brahmachari, K., Perry, P.L., Chaki, A.K., Ray, K., Ghosh, A., Nanda, M.K., Mainuddin, M. (in journal review). Modelling crop production and soil dynamics (salinity and moisture) in a Rice-Grass Pea cropping system influenced by a shallow dynamic saline water-table in Coastal West Bengal, India. Environmental Modelling and Software.
5. Sarangi, S.K., Maji, B., Sharma, P.C., Digar, S., Mahanta, K.K., Burman, D., Mandal, U.K., Mandal, S., Mainuddin, M., (2020). Potato (Solanum tuberosum L.) cultivation by zero tillage and paddy straw mulching in the coastal zones of the Ganges delta. Potato Research, https://doi.org/10.1007/s11540-020-09478-6.
6. Samui, I., Skalicky, M., Sarkar, S., Brahmachari, K., Sau, S., Ray, K., Hossain, A., Ghosh, A., Nanda, M.K., Bell, R.W., Mainuddin, M., Brestic, M., Liu, L., Saneoka, H., Raza, M.A., Erman, M., Sabagh, A.E.L., (2020). Yield response, nutritional quality

and water productivity of tomato (Solanum lycopersicum L.) are influenced by drip irrigation and straw mulch in the coastal saline ecosystem of Ganges Delta, India. Sustainability, 12, 6779; doi:10.3390/su12176779.

7. Mainuddin, M., Maniruzzaman, M., Gaydon, D. S., Sarkar, S., Rahman, M. A., Sarangi, S. K., Sarker, K. K., Kirby, J. M. (2020). A water and salt balance model for the polders and islands in the Ganges delta. Journal of Hydrology 587, 125008; https://doi.org/10.1016/j.jhydrol.2020.125008
8. Paul, P.L.C., Bell, R.W., Barrett-Lennard, E.G. and Kabir, M.E. (2020a). Straw mulch and irrigation affect solute potential and sunflower yield in a heavy textured soil in the Ganges Delta. Agricultural Water Management 239, 106211; https://doi.org/10.1016/j.agwat.2020.106211
9. Paul, P.L.C., Bell, R.W., Barrett-Lennard, E.G. and Kabir, M.E. (2020b). Impacts of different tillage systems on the yield of sunflower (Helianthus annuus L.) in a salt-affected clayey soil of the Ganges Delta. Soil and Tillage Research 197, 104489; https://doi.org/10.1016/j.still.2019.104489
10. Mandal, S., Maji, B., Sarangi, S.K., Mahanta, K.K., Mandal, U.K., Burman, D., Digar, S., Mainuddin, M. Sharma, P.C. (2020) Economics of Cropping System Intensification for Small-holder Farmers in Coastal Salt-affected areas in West Bengal – Options, Challenges and Determinants. Decision. http://link.springer.com/article/10.1007/s40622-020-00236-8
11. Ray, K., Sen, P., Goswami, R., Sarkar, S., Brahmachari, K., Ghosh, A., Nanda, M.K., Mainuddin, M., (2020). Profitability, energetics and GHGs emission estimation from rice-based cropping systems in the coastal saline zone of West Bengal, India. PLoS ONE 15(5): e0233303. https://doi.org/10.1371/journal.pone.0233303.
12. Sarkar, S., Ghosh, A., Brahmachari, K., Ray, K., Nanda, M.K., Sarkar, S., 2020b. Weather relation of rice-grass pea crop sequence in Indian Sundarbans. Journal of Agrometeorology 22(2), 148-157.
13. Sarkar, S., Ghosh, A., Brahmachari, K., Ray, K., Nanda, M.K. (2020a) Assessing the yield response of Lentil (Lens culinaris Medikus) as influenced by different sowing dates and land situations in Indian Sundarbans. Legume Research, LR-4237, 1-8.
14. Mainuddin, M., Bell, R.W., Gaydon, D.S., Kirby, J.M., Barrett-Lennard, E.G., Glover, M., Akanda, M.A.R., Maji, B., Ali, M.A., Brahmachari, K., Maniruzzaman, M., Aziz, M.A., Burman, D., Biswas, J.C., Rahman, M.M., Sarangi, S.K. (2019a). An overview of the Ganges coastal zone: climate, hydrology, land use, and vulnerability. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 1-11.
15. Yu, Y., Mainuddin, M., Maniruzzaman, M., Mandal, U.K., Sarangi, S.K., (2019). Rainfall and temperature characteristics in the coastal zones of Bangladesh and West Bengal, India. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 12-23.
16. Hossain, M.B., Maniruzzaman, M., Yesmin, M.S., Mostafizur, A.B.M., Kundu, P.K., Kabir, M.J., Biswas, J.C., Mainuddin, M. (2019). Water and soil salinity dynamics and dry season crop cultivation in coastal region of Bangladesh. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 24-31.
17. Ghosh, A., Nanda, M.K., Sarkar, D., Sarkar, S., Brahmachari, K., Ray, K., (2019). Application of Multi-dated Sentinel-2 Imageries to Assess the Cropping System in Gosaba Island of Indian Sundarbans. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 32-44.
18. Mainuddin, M., Rahman, M.A., Maniruzzaman, M., Sarker, K.K., Mandal, U.K., Nanda, M.K., Gaydon, D.S., Sarangi, S.K., Sarker, S., Yu, Y., Islam, M.T., Kirby, J.M.

(2019b). The Water and salt balance of polders / islands in the Ganges Delta. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 45-50.

19. Kabir, E., Sarker, B.C., Ghosh, A.K., Mainuddin, M., Bell, R.W., (2019). Effect of sowing dates for wheat grown in excess water and salt affected soils in southwestern coastal soil. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 51-59.
20. Mahanta, K.K., Burman, D., Sarangi, S.K., Mandal, U.K., Maji, B., Mandal, S., Digar, S., Mainuddin, M. (2019). Drip irrigation for reducing soil salinity and increasing cropping intensity: case studies in Indian Sundarbans. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 64-71.
21. Saha, R.R., Rahman, M.A., Rahman, M.H., Mainuddin, M., Richard Bell, Gaydon, D.S. (2019). Cropping System Intensification under Rice Based Cropping System for Increasing Crop Productivity in Salt-Affected Coastal Zones of Bangladesh. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 72-81.
22. Sarker, K.K., Kamar, S.S.A., Hossain, A., Mainuddin, M., Bell, R., Barrett-Lennard, E.G., Gaydon, D., Glover, M., Saha, R., Ali, M.A., Khan, M. S. I., Maniruzaman, M., (2019). Cropping System Based Irrigation for Improved Crop and Water Productivity in the Coastal Zone of Bangladesh. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 82-97.
23. Sarkar, S., Samui, I., Brahmachari, K., Ray, K., Ghosh, A., Nanda, M.K., (2019). Management Practices for Utera Pulses in Rice-fallow System under Coastal Saline Zone of West Bengal. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 98-103.
24. Shahadat, M.K., Rashid, M.H., Ali, M.A., (2019). Performance of Garden Pea Varieties as Intercrop with Maize in the Coastal Area of Bangladesh. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 104-114.
25. Sarangi, S. K., Maji, B., Mahanta, K.K., Digar, S., Burman, D., Mandal, S., Mandal, U.K., Sharma, P.C., Mainuddin, M., Bell, R. (2019). Alternate kharif rice crop establishment methods and medium duration varieties to enable cropping system intensification in coastal saline region. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 115-122.
26. Maniruzzaman, M., Kabir, M.J., Hossain, M.B., Yesmin, M.S., Mostafizur, A.B.M., Biswas, J.C., Ali, M.A., Mainuddin, M., Bell, R.W., (2019). Adjustment in wet season rice planting for cropping intensification in coastal Bangladesh. Journal of the Indian Society of the Coastal Agricultural Research, 37 (2): 123-133.
27. Yesmin, M. S. Maniruzzaman, M., Hossain, M. B. Gaydon, D.S., Mostafizur, A. B. M., Kabir, M. J., Biswas, J. C., Mainuddin, M., Bell, R.W., (2019). Selection of suitable sowing window for Boro rice in coastal regions of Bangladesh. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 134-143.
28. Ray, K., Brahmachari, M., Goswami, R., Sarkar, S., Brahmachari, K., Ghosh, A., Nanda, M.K., (2019). Adoption of Improved Technologies for Cropping Intensification in the Coastal Zone of West Bengal, India: A Village Level Study for Impact Assessment. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 144-152.
29. Bell, R.W., Mainuddin, M., Barrett-Lennard, E. G., Sarangi, S. K., Maniruzzaman, M., Brahmachari, K., Sarker, K.K., Burman, D., Gaydon, D.S., Kirby, J.M., Glover, M., Rashid, M.H., Khan, M.S.I., Kabir, M.E., Rahman, M.A., Hossain, M.B., (2019). Cropping Systems Intensification in the Coastal Zone of the Ganges Delta: Opportunities and Risks. Journal of the Indian Society of the Coastal Agricultural Research, 37(2): 153-161.

30. Sarangi, S.K., Maji, B., Digar, S., Mahanta, K.K., Sharma, P.C. and Mainuddin, M., (2018). Zero-tillage potato cultivation - An innovative technology for coastal saline soils. Indian Farming, 68 (4): 23-26.

10.2.2 Conference papers

1. Mainuddin, M., Kirby, J.M., (2020). Impact of flood inundation and water management on water and salt balance of the polders and islands in the Ganges delta. International Conference on Earth and Environmental Sciences & Technology for Sustainable Development, 25-30 January 2020, Dhaka, Bangladesh.
2. Saha, R.R., Rahman, M.A., Rahman, M.H., Mainuddin, M., Richard Bell, Gaydon, D.S. (2019). Cropping system intensification for increasing crop productivity in salt-affected coastal zones of Bangladesh. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
3. M. Maniruzzaman, M. Mainuddin, R. Bell, J. C. Biswas, M. J. Kabir, M. B. Hossain, M. S. Yesmin1, A. B. M. Mostafizur and P. K. Kundu (2019). Rescheduling of wet season (T. Aman) rice planting for cropping intensification in coastal Bangladesh. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
4. M.J. Kabir, D.S. Gaydon, M. Mainuddin, and M. Maniruzzaman (2019). Understanding Farmers' Perceptions of and Livelihoods Adaptation to Climate Change: Insights from Coastal Bangladesh. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
5. Sarangi, S.K., Maji, B., Sharma, P.C., Digar, S., Mahanta, K.K., Burman, D., Mandal, U.K., Mandal, S., Mainuddin, M. (2019). Zero tilled-paddy straw mulched potato (Solanum tuberosum) cultivation in the coastal saline soils reduce soil salinity increase yield and profitability. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
6. Khokan Kumer Sarker, S.S.A. Kamar, A. Hossain, M. Mainuddin, R. Bell, E.G.Barrett-Lennard, D. Gaydon, M. Glover, Murad, M.H. Rashid, M.S.I. Khan, M. Maniruzaman, M.B. Hossain, B.C. Sarker (2019). Effect of Fresh and Saline Water Irrigation for Maize in the Salt-affected Coastal Zones of Bangladesh. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
7. K.K. Sarker, A. Hossain, E.G. Barrett-Lennard, R. Bell, M. Mainuddin, S.S.A. Kamar, D. Gaydon, M. Glover, P.C. Paul, M.H. Rashid, M.S.I. Khan, M. Maniruzzaman, B. Hossain, B.C. Sarker, 92019). Effect of straw mulch and irrigation on sunflower and maize cultivation in no tillage systems of coastal heavy soils. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
8. R.R. Saha, M.A.K. Mian, M.A. Rahman, S. Kundu and K.K. Sarker (2019). Performance of garlic (Allium Sativum) varieties under zero tillage mulch condition in southern coastal region of Bangladesh. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
9. Koushik Brahmachari, Sukamal Sarkar, Deepak Sahoo, Indranil Samui, MK Nanda, Argha Ghosh and Mohammed Mainuddin (2019). Foliar nutrient management on potato grown under zero tillage and mulching in Coastal Saline Soil of West Bengal, India. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
10. Koushik Brahmachari, Sukamal Sarkar, Donald S Gaydon, M.K. Nanda, Argha Ghosh and Mohammed Mainuddin (2019). Land situation and sowing date effects growth and yield of crops in the rice-pulse based cropping systems of coastal India. Poster

presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.

11. Sukanta K. Sarangi, B. Maji, P. C. Sharma, S. Digar, K. K. Mahanta, D. Burman, U. K. Mandal, S. Mandal and M. Mainuddin (2019). Zero tilled-paddy straw mulched potato (Solanum tuberosum) cultivation in the coastal saline soils reduce soil salinity, increase yield and profitability. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
12. Sukamal Sarkar, Donald S Gaydon, Koushik Brahmachari, M.K. Nanda, Argha Ghosh and Mohammed Mainuddin, (2019). Modelling grain yield and seasonal soil salinity dynamics in rice-grasspea cropping system for the coastal saline zone of West Bengal, India. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
13. M. Akkas Ali, M. K. Shahadat, Md. Harunur Rashid (2019). Performance of zero tillage potato cultivation with different mulch materials in the southwestern saline areas of Bangladesh. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
14. Mustafa Kamal Shahadat, M. H. Rashid, M. Akkas Ali, and M. Mainuddin (2019). Utilization of forgoing coastal rice fallow lands for Bangladesh with zero tillage potato cultivation using different rates of residues. Poster presented at the International Tropical Agriculture Conference 2019, 11-13 November, Brisbane, Australia.
15. Khokan Kumer Sarker, S.S.A. Kamar, A. Hossain, M. Mainuddin, R. Bell, E.G.Barrett-Lennard, D. Gaydon, M. Glover, K.F.I. Murad, R. R. Saha, M.H. Rashid, M.S.I. Khan, M.M.K. Shadat, M. Maniruzaman (2019). Effect of Fresh and Saline Water Irrigation for Sunflower in the Salt-affected Coastal Zones of Bangladesh. Saline Futures Conference, 10-13 September 2019, Leeuwarden, the Netherlands.
16. Kabir, E., Sarker, B.C., Mainuddin, M. and Bell, R.W. (2019). Constraint-level of soil moisture can be a resource for crop cultivation during winter in the southwestern coastal Bangladesh. Accepted for presentation. Saline Futures Conference, 10-13 September 2019, Leeuwarden, the Netherlands.
17. Sarangi, S.K., Maji, B., Mahanta, K.K., Mandal, U.K., Digar, S., Burman, D., Mandal, S., Sharma, P.C., Mainuddin, M. (2019). New cropping systems and management options to face the emerging challenges in the salt affected coastal zones. Central Soil Salinity Research Institute.
18. Ghosh A., Sarkar D., Sarkar S., Nanda M. K. and Brahmachari K. 2019. Assessing the seasonal pattern of land use and land cover in Gosaba island of Indian Sundarban using multi-dated Sentinnel-2 data. 6th "India Biodiversity Meet (International conference)", 14-16 February 2019. Indian Statistical Institute, Kolkata, India.
19. Ghosh A., Sarkar D., Sarkar S., Nanda M. K. and Brahmachari K. 2019. Analysis of cropping system in Gosaba island of Indian Sundarban using Sentinnel-2 data. International Symposium on “Advances in Agrometeorology for Managing Climatic Risks of Farmers” (INAGMET-2019). 11-13 February 2019. JNU, New Delhi, India.
20. Sarkar D., Ghosh A., Sarkar S., Nanda M. K. and Brahmachari K. 2019. Analysis of water resources in Gosaba island of Indian Sundarban using Remote sensing and GIS tool. International Symposium on “Advances in Agrometeorology for Managing Climatic Risks of Farmers” (INAGMET-2019). 11-13 February 2019, JNU, New Delhi, India.
21. Ghosh A., Sarkar S., Nanda M. K. and Brahmachari K. 2018. Assessing the performance of different rice cultivar as influenced by agroclimatic factors in coastal saline zone of West Bengal. International conference on "Livelihood Promotion,

Biodiversity Conservation and Social Security in Indian Sundarbans". 7-9 December, 2018.Jharkhali, Basanti, West Bengal.

22. Samui, I., Sarkar, S., Brahmachari, K., Sau, S. Ghosh, A and Nanda, M.K. 2018. Effect of different water saving options on tomato under coastal saline soil of Sundarbans, West Bengal International Conference on “Agriculture and allied sciences.......Ecology” 13-14th August 2018, BCKV, WEST BENGAL.
23. Ghosh A., Sarkar S., Nanda M. K., Brahmachari K. and Mainuddin, M. 2019. Climatological risk assessment from rainfall time series using Markov chain model for optimizing rice cropping window in Indian Sundarbans. International conference on “Sustainable Agricultural Development in Changing Global Scenario”, India. 11-13 October, 2019. BHU, UP, India.
24. Piyali Sen, Krishnendu Ray, Sukamal Sarkar, Rupak Goswami, Koushik Brahmachari, Argha Ghosh, Manoj Kr. Nanda and Mohammed Mainuddin. 2019. Profitability, energy and environmental assessment of cropping systems in the coastal zone of West Bengal, India. In: National Seminar on Agro-Chemical Inputs and Its Extension Approaches Towards Food-Security and Bio-Safety: Prospects & Challenges (AEFS-2019), organized by SAMETI-WB, and IRDM F/c. and SSKVK, RKMVERI, held during 15-16 November, 2019 at SAMETI-WB, Ramakrishna Mission Ashrama, Narendrapur, West Bengal, India.
25. Suman Mondal, Krishnendu Ray, Sukamal Sarkar, Rupak Goswami, Koushik Brahmachari, Md. Jahangir Kabir, Argha Ghosh, Manoj Kr. Nanda and Mohammed Mainuddin. 2019. Assessment of economic sustainability of cropping systems in salt-affected coastal zone of West Bengal. In: National Seminar on Agro-Chemical Inputs and Its Extension Approaches Towards Food-Security and Bio-Safety: Prospects & Challenges (AEFS-2019), organized by SAMETI-WB, and IRDM F/c. and SSKVK, RKMVERI, held during 15-16 November, 2019 at SAMETI-WB, Ramakrishna Mission Ashrama, Narendrapur, West Bengal, India.
26. Mainuddin, M. and Kirby, M. (2018). Salt and water balance model for the polders of the Ganges delta. Poster presented at the Fall Meeting of American Geophysical Union, 10-14 December 2018, Washington D.C., USA.
27. Sarangi, S. K., Maji, B., Digar, S., Mahanta, K.K., Mandal, U.K., Burman, D., Mandal, S., Sharma, P.C., Mainuddin, M. (2018). Zero tillage potato cultivation with paddy straw mulching increase yield, water productivity and income in the coastal saline soils. Indian Society of Agronomy.
28. Maji, B., Sarangi, S. K., Mandal, U. K., Mandal, S., Mahanta, K. K., Burman, D., Sharma, P. C. and Mainuddin Mohammed (2017). Challenges and options for sustainable intensification of cropping system in the salt affected coastal zone of Indian Sundarbans. Paper presented in the International Tropical Agriculture Conference on “High impact science to nourish the world” organized by TropAg2017 and held at Brisbane Convention & Exhibition Centre, Australia during November 20-22, 2017. Book of poster abstracts, p. 136.
29. Sukamal Sarkar, Koushik Brahmachari, Donald Gaydon, Debasis Mazumder and Manoj K Nanda. 2017. Dry matter accumulation, nutrient partitioning and yield of crops as influenced by date of sowing and land situation in rice-pulse based cropping systems of coastal West Bengal. National Seminar on “Nutrients and pollutants in soil-plant-animal-human continuum for sustaining soil, food and nutritional security – way forward” organized by Bidhan Chandra Krishi Viswavidyalaya, Mohanpur on 9th-10th June 2017.
30. Brahmachari, K., Sarkar, S. and Burman, D. 2017. Cropping System Intensification under salt affected Coastal Areas of West Bengal. In Proceedings: ISCAR Seminar on “Coastal Ecosystem of India – recent development and future strategies. pp. 57-60.

10.2.3 Leaflets/Folders

1. Sarangi, S. K., Maji, B., Digar, S. Burman, D., Mandal, U.K., Mahanta, K.K. and Mandal, S. (In press). Technologies for cropping system intensification in the salt-affected coastal zone of West Bengal, India. Technical Folder ICAR-CSSRI/Canning Town/Folder/2019/8.
2. Sarangi, S. K., Maji, B., Digar, S. Burman, D., Mandal, U.K., Mahanta, K.K. and Mandal, S. (In press). Acid saline soil management in coastal region. Technical Folder ICAR-CSSRI/Canning Town/Folder/2019/9.
3. Sarangi, S. K., Maji, B., Digar, S. Burman, D., Mandal, U.K., Mahanta, K.K. and Mandal, S. (In press). Drip irrigation and mulching for successful rabi crop cultivation in coastal saline soils. Technical Folder ICAR-CSSRI/Canning Town/Folder/2019/10.
4. Sarangi, S. K., Maji, B., Digar, S. Burman, D., Mandal, U.K., Mahanta, K.K. and Mandal, S. (In press). Package of practices for potato cultivation in coastal saline soils. Technical Folder ICAR-CSSRI/Canning Town/Folder/2019/11.
5. Sarangi, S. K., Maji, B., Digar, S. Burman, D., Mandal, U.K., Mahanta, K.K. and Mandal, S. (In press). Package of practices for rapeseed cultivation in coastal saline soils. Technical Folder ICAR-CSSRI/Canning Town/Folder/2019/12.
6. Sarangi, S. K., Maji, B., Digar, S. Burman, D., Mandal, U.K., Mahanta, K.K. and Mandal, S. (In press). Package of practices for maize cultivation in coastal saline soils. Technical Folder ICAR-CSSRI/Canning Town/Folder/2019/13.
7. Sarangi, S.K., Maji, B., Digar, S. Burman, D, Mahanta, K.K., Mandal, U.K. and Mandal, S. (2018). *Bharater Paschimbanger abom Bangladesher Labanau Upakulabarti Anchale Fasal Chaser Nibidata Badanor Prayas* (In Bangla). Leaflet published by ICAR-CSSRI, Karnal – 132001 (Haryana), India.
8. BCKV. Prepared a monograph in Bengali "সুন্দরবনের নোনামাটি এলাকার শস্য নিবিড়তা বাড়ানোর একটি প্রয়াস" (Cropping System Intensification in Coastal saline soil of Sundarbans). (DOI:10.13140/RG.2.2.14982.68161)

10.2.4 Master thesis

1. Islam, M.M., 2017. Evaluation of sowing Dates on Wheat Grown in a Medium Highland of Southwestern Bangladesh . Khulna University, Bangladesh.
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11 Appendixes

11.1 Appendix 1: Reports published in the newspapers on the project activities

2019-20

জমি চাষ না করেই আলুর আবাদ করেন কৃষক রবীন্দ্র ঢালী ● আমাদের সময়

কয়রায় বিনা চাষে আলু উৎপাদন

শেখ মনিরুজ্জামান কয়রা (খুলনা) ●
জমি চাষ না করেই আলু লাগানোয় কৃষক রবীন্দ্র ঢালীকে অনেকেই তুচ্ছ-তাচ্ছিল্য করত। বাড়ির পাশের স্বরাজ কুমার বলেই দিয়েছিলেন, 'কষ্ট করে লাভ নেই। বিনা চাষে আলু হয় না।' কথায় আছে, 'ষোল চাষে আলু'। কিন্তু মাত্র দেড় মাসের ব্যবধানে সেই উপহাসকারী প্রতিবেশী থেকে শুরু করে এলাকার মানুষ অবাক বিস্ময় নিয়ে তাকিয়ে থাকে রবীন্দ্রনাথ ঢালীর বিনা চাষের আলুর ক্ষেতের দিকে।

খুলনা শহর থেকে প্রায় ১০০ কিলোমিটার দূরের সুন্দরবনসংলগ্ন কয়রা উপজেলা সদর। সেখান থেকে আরও চার কিলোমিটার গেলে ৩ নম্বর কয়রা গ্রাম। ওই গ্রামের কৃষক রবীন্দ্রনাথ ঢালীর বসতবাড়ি লাগোয়া ১২ বিঘা জমির প্রায় পুরোটাই অনাবাদি। শুধু মাঝখানের ১০ শতক জমিতে সারি সারি দাঁড়িয়ে আছে গোলআলুর গাছ। বিনা চাষে রোপণ করা ওই গোলআলুর সবুজ গাছের সঙ্গে এলাকার কৃষকের বিস্ময় আর আগামীর স্বপ্নও যেন ফুটে উঠেছে।

সরেজমিন ঘুরে এবং স্থানীয়দের সঙ্গে কথা বলে জানা যায়, লোনায় আক্রান্ত কয়রা উপজেলায় মাত্র একটি ফসল হয়। সেটা বর্ষা মৌসুমে: আমন ধান। অনেকে অবশ্য লোনা পানিতে চিংড়ি চাষ করে। যারা চিংড়ি চাষ করে না, তাদের জমি বাকি সময় অনাবাদি থাকে। সেই অনাবাদি জমিতে এবারই প্রথম পরীক্ষামূলকভাবে 'বিনা চাষে' আলু রোপণ করেন রবীন্দ্র ঢালী। লবণাক্তসহিষ্ণু আলুর নতুন জাতের বীজ থেকে শুরু করে সার্বিক সহযোগিতা করেছে বাংলাদেশ কৃষি গবেষণা ইনস্টিটিউট (বিএআরআই) সরেজমিন গবেষণা বিভাগ।

ওই বিভাগের বৈজ্ঞানিক সহকারী জাহিদ হাসান বিনা চাষে আলু রোপণ করতে উদ্বুদ্ধ করেন রবীন্দ্র ঢালীকে। প্রথমে রাজি না হলেও পরে তিনি ঝুঁকি নেন। ১০ শতক জমিতে রোপণ করেন ৮০ কেজি আলুর বীজ। প্রথম দিকে অনিশ্চয়তা থাকলেও মাত্র দেড় মাস পর মুখে হাসি ফুটতে শুরু করে তার।

চাষের ধরন নিয়ে রবীন্দ্রনাথ ঢালী বলেন, ধান কাটার পর জমি পুরোপুরি শুকায়নি, জমিতে কাদা ছিল। সেই কাদামাটির ওপর দড়ি টানিয়ে সারি সোজা করে বীজ আলু বসিয়ে দিয়েছিলাম। এক সারি আলু থেকে আরেক সারির দূরত্ব ৬০ সেন্টিমিটার। প্রতি সারির একটি বীজ থেকে আরেকটির দূরত্ব ২৫ সেন্টিমিটার। আলুর ওপর গোবর ছড়িয়ে তার ওপর খড়কুটা দিয়ে ঢেকে রেখেছিলাম। একেই সোনা ফলেছে আলুর ক্ষেতে।

তবে বিনা চাষে আলুর ফলন ভালো হয় কিনা, এই দ্বিধা থেকে কিছু জমিতে চাষ করে আলু লাগিয়েছেন তিনি। হাতের ইশারায় সেই ক্ষেত দেখিয়ে বললেন, 'ওই ক্ষেতে তার ১৬ বার মাটির চাষ দেওয়া লেগেছে, মাটি একেবারেই ধুলার আকার নিলে সেখানে রোপণ করেছেন বীজ আলু। আর সেচ, সার, কীটনাশক মিলিয়ে অনেক খরচ হয়ে গেছে। তা ছাড়া আলুগাছের গোড়া বাঁধানো আর মজুরি খরচও অনেক। সেই তুলনায় বিনা চাষে একেবারে কম খরচে ফলন পেয়েছেন এই আলুর ক্ষেতে।' কৃষক রবীন্দ্র নাথের দেখাদেখি আরও অনেকেই আগ্রহ দেখাচ্ছেন চাষহীন পদ্ধতিতে আলু রোপণে।

বিনা চাষে আলু রোপণে সফলতা পেয়ে অনেক খুশি কৃষক রবীন্দ্রনাথ ও পরিবার। রবীন্দ্র নাথ বলেন, প্রথমে নিচু জমিতে বিলের মধ্যে চাষ না করে আলু লাগাতে আগ্রহী ছিলাম না। পরে কৃষি গবেষণা বিভাগের পরামর্শে আগ্রহী হয়ে উঠি। চাষাবাদের পর সুন্দর গাছ দেখে ও গাছের গোড়ায় আলু দেখে স্থানীয় আরও অনেক কৃষককে বিনা চাষে আলু আবাদের পরামর্শ দিয়েছি। এ পদ্ধতিতে খরচ কম আর আলুর ফলন ভালো হওয়ায় ভবিষ্যতে পুরো জমিতেই আলু রোপণ করবেন বলে জানান তিনি।

কৃষি গবেষণা কয়রার বৈজ্ঞানিক সহকারী জাহিদ হাসান বলেন, দক্ষিণাঞ্চলে আমন ধান কাটার পর মাটি শুকাতে অনেক বেশি সময় নেওয়ার কারণে সঠিক সময়ে আলু চাষ করা কঠিন হয়ে পড়ে। ধান কাটার পর জমি ফাঁকা হওয়ার সঙ্গে সঙ্গেই বিনা চাষে আলু আবাদের সুযোগ ঘটে। এ পদ্ধতিতে আলুর আবাদ করলে আলু বেশি সুস্বাদু হয় এবং এর আকারও অনেক বড় হয়।

কৃষি গবেষণা বিভাগ খুলনার প্রধান বৈজ্ঞানিক কর্মকর্তা ড. হারুন অর রশীদ বলেন, কয়রায় অনেক জমি আমন ধান কাটার পর পড়ে থাকে। ওই পড়ে থাকা জমিতে যদি এলাকার কৃষকরা বিনা চাষে আলু উৎপাদন কৌশল দেখে ও শিখে নিয়ে চর্চা করেন, তবে তারাও লাভবান হবেন। আর এভাবেই পরিবার ও দেশের খাদ্যনিরাপত্তায় তারাও অবদান রাখতে পারবেন বলে তিনি বিশ্বাস করেন।

Zero tillage potato cultivation is spreading in the coastal area. This news was published on 02 February 2020 in the national daily newspaper ‘Dainik Amadershomoy’. The title of the news is ‘**Zero tillage potato cultivation in Koyra**’.

2018-19


নীতির প্রশ্নে আপোসহীন দৈনিক জনকণ্ঠ
The Daily Janakantha

উপকূলীয় চাষীর মুখে হাসি

পতিত জমিতে লবণসহিষ্ণু জাতের ভুট্টার চাষ

News about cultivation of maize at Amtali published prominently in the national daily newspaper “The Daily Janakantha” on 20 April 2019 with the title “**Smile in the face of coastal farmers’**

শনিবার, ২০ এপ্রিল ২০১৯, ৭ বৈশাখ ১৪২৬

প্রথম আলো

লবণাক্ত পতিত জমিতে সবুজের সমারোহ

কৃষি গবেষণায় সাফল্য

চলতি বছর ৩ হেক্টর অতিমাত্রার লবণাক্ত জমিতে শস্য আবাদে ভালো ফল পাওয়া গেছে।

এম জসীম উদ্দীন, বরিশাল

[illegible]

এরপর পৃষ্ঠা ২ কলাম ১

প্রথম পৃষ্ঠার পর

[illegible]

লবণাক্ত জমিতে ভুট্টার আবাদ। বরগুনার আমতলী উপজেলার সোনাখালী গ্রামে। ছবি : প্রথম আলো

[illegible]

News published in the last page of Prothom-Alo, the most popular Bengali newspaper of the country, based on our work at Amtali, Borguna on 20 April 2019 with the title "***Splendour of green on the saline fallow lands***".

দাকোপে উদ্ভাবিত প্রযুক্তি উপযোগিতার মাঠ দিবস - Khulna Times

দাকোপে উদ্ভাবিত প্রযুক্তি উপযোগিতার মাঠ দিবস

মার্চ ১০, ২০১৯

প্রতিনিধি, দাকোপ :

খুলনার দাকোপ উপজেলায় বাংলাদেশ কৃষি গবেষণা ইনস্টিটিউট সরেজমিন গবেষণা বিভাগের আয়োজনে উপকূলীয় লবনাক্ত এলাকায় উদ্ভাবিত প্রযুক্তিসমূহের উপযোগিতা যাচাইয়ের ওপর মাঠ দিবস হয়।

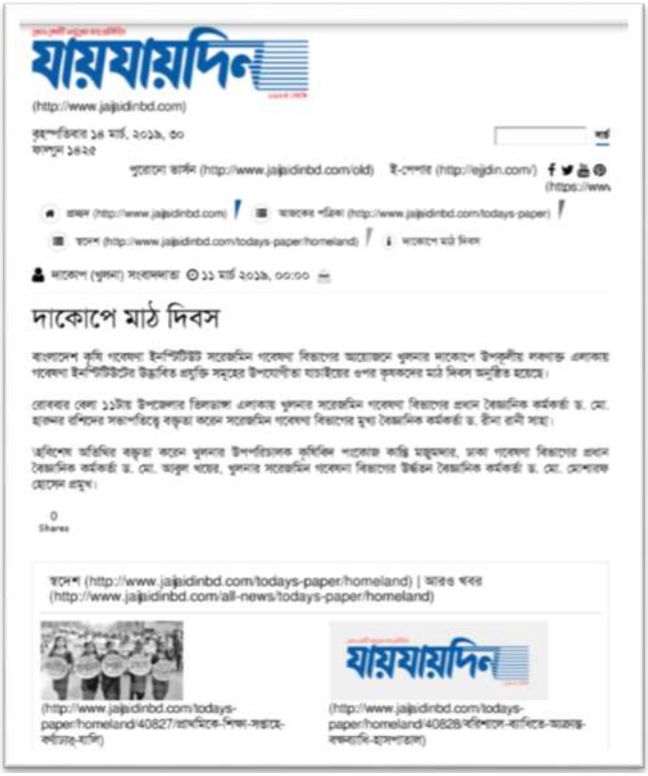
রোববার (১০ মার্চ) বেলা ১১টার দিকে উপজেলার তিলডাঙ্গা গ্রামে খুলনার সরেজমিন গবেষণা বিভাগের প্রধান বৈজ্ঞানিক কর্মকর্তা ড. মো. হারুনুর রশিদের সভাপতিত্বে কৃষক মাঠ দিবসে প্রধান অতিথি ছিলেন সরেজমিন গবেষণা বিভাগের মুখ্যবৈজ্ঞানিক কর্মকর্তা ড. রিনা রানী সাহা। বিশেষ অতিথি ছিলেন খুলনা কৃষি সম্প্রসারণ অধিদপ্তরের উপপরিচালক পঙ্কজ কান্তি মজুমদার, গবেষণা বিভাগের প্রধান বৈজ্ঞানিক কর্মকর্তা ড. মো. আবুল খয়ের, সরেজমিন গবেষণা বিভাগের উর্ধতন বৈজ্ঞানিক কর্মকর্তা ড. মো. মোশারফ হোসেন, উপজেলা কৃষি কর্মকর্তা মেহেদী হাসান খান, সেচ ও পানি ব্যবস্থাপনা বিভাগের বৈজ্ঞানিক কর্মকর্তা ড. খোকন কুমার সরকার। অন্যান্যের মধ্যে বক্তৃতা করেন প্রেসক্লাব সভাপতি শচীন্দ্রনাথ মন্ডল, কৃষক ভবেন্দ্রনাথ মন্ডল, দীলিপ কুমার হালদার, পাপিয়া সরকারসহ আরও অনেকে। এতে প্রায় ২০০ জন কৃষক অংশ নেন।

DALIT Voice

পরিত্রাণ PARITTRAN

দাকোপে মাঠ দিবস পালিত

News about the Field Day organized at Dacope, Khulna on 10 March 2019 published in the daily Khulna Times (left) with the title "**Field Day on suitability of innovated technologies at Dacope**" and in the Parittran (right) with title "**Field Day observed at Dacope**".


(http://www.jaijaidinbd.com)

বৃহস্পতিবার ১৪ মার্চ, ২০১৯, ৩০ ফাল্গুন ১৪২৫

(http://www.jaijaidinbd.com/old) (http://ejjdin.com/)

(http://www.jaijaidinbd.com) (http://www.jaijaidinbd.com/todays-paper)

(http://www.jaijaidinbd.com/todays-paper/homeland)

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(http://www.jaijaidinbd.com/all-news/todays-paper/homeland)

News about the Field Day at Dacope published in the National Bengali newspaper “Jaijaidin” on 14 March 2019

প্রথম আলো • মঙ্গলবার, ১৪ মে ২০১৯, ৩১ বৈশাখ ১৪২৬

৬ | খুলনা

স্যানিটেশন ব্যবস্থাপনা নিয়ে কর্মশালা

লবণাক্ত জমিতে সূর্যমুখী চাষ

খুলনার দাকোপ

সেখানে লাগাতে পারবেন সূর্যমুখী। সম্ভব হলে আউশ ধানও লাগাতে পারবেন তাঁরা।

নিজস্ব প্রতিবেদক, *খুলনা*

- লবণাক্ত জমিতে কীভাবে একাধিক ফসল ঘরে তোলা যায়, তা নিয়ে গবেষণা করছিলেন খুলনা বিশ্ববিদ্যালয়ের শিক্ষক মো. এনামুল কবীর ও বিধান চন্দ্র সরকার।
- এনামুল কবীর ও বিধান চন্দ্র সরকার প্রমাণ করেছেন, চাষিরা চাইলে আমন ধান কেটেই ওই কর্দমাক্ত জমিতে সূর্যমুখী চাষ করতে পারবেন।
- পতিত জমিতে সূর্যমুখী ও গম চাষ করে চাষিরা বিঘাপ্রতি ছয় থেকে আট হাজার টাকা লাভ করতে পারবেন।

জমির লবণাক্ততায় খুলনার দাকোপ উপজেলার হাজার হাজার বিঘা জমি অনাবাদি হয়ে পড়ে থাকে। ওই জমি থেকে বছরে মাত্র একটি ফসল ঘরে তোলার সুযোগ পান চাষিরা। আর সেটি হলো বর্ষা মৌসুমে আমন ধান।

তবে এবার আর ওই জমি পড়ে থাকবে না। বছরে অন্তত দুটি ফসল চাষ করতে পারবেন চাষিরা। আমন ধান কেটে জমি চাষ না করেই চাষিরা সেখানে লাগাতে পারবেন সূর্যমুখী। সম্ভব হলে আউশ ধানও লাগাতে পারবেন তাঁরা। খুলনা বিশ্ববিদ্যালয়ের শিক্ষকদের গবেষণায় ওই প্রমাণ মিলেছে। কয়েক বছর ধরে দাকোপের লবণাক্ত জমিতে কীভাবে একাধিক ফসল ঘরে তোলা যায়, তা নিয়ে গবেষণা করছিলেন বিশ্ববিদ্যালয়ের অ্যাগ্রোটেকনোলজি ডিসিপ্লিনের (বিভাগ) শিক্ষক মো. এনামুল কবীর ও বিধান চন্দ্র সরকার। তাঁরা প্রমাণ করে দেখিয়েছেন, চাষিরা চাইলে আমন ধান কেটেই ওই কর্দমাক্ত জমিতে সূর্যমুখী চাষ করতে পারবেন। এর জন্য নতুন করে জমি চাষ করার প্রয়োজন হবে না।

ওই গবেষণা কাজ করা হচ্ছে উপজেলার পানখালী ইউনিয়নের পানখালী গ্রামে। সম্প্রতি ওই গবেষণা প্লটে গিয়ে দেখা যায়, চারপাশে ফাঁকা জমি। আমন ধান কেটে নিলেও গাছের গোড়া রয়ে গেছে জমিতে। তবে ভিন্নচিত্র মধ্যের কয়েক একর জমিতে। সেখানে তৈরি হয়েছে সবুজ আর হলুদের মিশ্রণে এক অপূর্ব সৌন্দর্য। ফুটে আছে বড় বড় সূর্যমুখী ফুল।

সূর্যমুখী চাষ করা চাষিদের একজন শংকর প্রসাদ সরদার। বিশ্ববিদ্যালয়ের শিক্ষকদের সহায়তায় দুই বিঘা জমিতে সূর্যমুখী চাষ করেছেন তিনি। তিনি বলেন, জুন মাসের মাঝামাঝি সময়ে আমন ধান রোপণ করেন তিনি। ব্রি-২৩ জাতের ধান লাগানো হয়। নভেম্বরের মাঝামাঝি সময়ে সেই ধান কাটা হয়। এরপর ডিসেম্বরের শুরুতেই ওই জমিতে লাগান সূর্যমুখী। দুই বছর ধরে আমন ধান কাটার পরপরই সূর্যমুখীর চাষ করছেন তিনি।

পাশেই ৫০ শতক জমিতে সূর্যমুখী চাষ করেছেন সুকুমার সরদার। তিনি বলেন, সাধারণত আমন ধান কাটার সময় মাটি থাকে ভেজা। এতে সেখানে অন্য কোনো ফসল হয় না। জমি শুকিয়ে যেতে যেতেই মাটির লবণাক্ততার পরিমাণ বেড়ে যায়। এ কারণে তখনো কোনো ফসল করা সম্ভব হয় না। তবে দুই বছর ধরে সূর্যমুখীর চাষ তাঁদের নতুন করে আশার আলো দেখাচ্ছে।

যাঁরা চাষ করেছেন, তাঁরা তো আছেনই।; নতুন করে আশায় বুক বাঁধছেন ওই এলাকার অন্য চাষিরাও। এমনই একজন চাষি শ্যামল সরদার। তিনি বলেন, প্রথম বছর যখন আমন ধান কাটার পর ওই জমিতে সূর্যমুখী লাগানো হয়, তখন এলাকার চাষিরা তা বিশ্বাস করতে পারেননি। তবে প্রমাণিত হয়েছে যে ওই জমিতেও সূর্যমুখী চাষ করা সম্ভব। আগামী বছর থেকে তিনিও তাঁর তিন বিঘা জমিতে সূর্যমুখী লাগাবেন।

এলাকার কয়েকজন বাসিন্দার সঙ্গে কথা বলে জানা গেছে, দাকোপের ওই এলাকায় ২০০৭ সাল পর্যন্ত ছিল লবণপানির মাছের ঘের। ওই বছর তত্ত্বাবধায়ক সরকার ক্ষমতায় এলে এলাকাবাসীর সহযোগিতায় ঘের তুলে দেওয়া হয়। এরপর সেখানে লবণাক্ততায় কোনো ফসলই হতো না। তবে এখন লবণাক্ততা কমে গেছে।

গবেষণাকারী এনামুল কবীর বলেন, ওই এলাকার চাষাবাদ সাধারণত নির্ভর করে বৃষ্টির ওপর। বেশি বৃষ্টি হলে মাটির লবণের পরিমাণ কমে যায়। তখন চাষিরা আমন ধান রোপণ করতে পারেন। ধীরে ধীরে মাটি শুকিয়ে গেলে লবণের পরিমাণও বাড়তে থাকে। মাটি হয়ে যায় শক্ত পাথরের মতো। তাই ধান তুলে জমিতে লবণের পরিমাণ বাড়ার আগে অন্য কোনো ফসল ফলানো যায় কি না, তা দেখার চেষ্টা করা হয়। এমন পরিস্থিতিতে ওই জমিতে কীভাবে একাধিক ফসল উৎপাদন করা যায়, তা নিয়ে গবেষণা শুরু হয়। তিন বছর আগে ১০ বিঘা জমি নিয়ে শুরু করা গবেষণায় দেখা গেছে, ধান তুলেই ওই জমিতে সূর্যমুখী ও গম চাষ করা সম্ভব। এমন গবেষণা করা হচ্ছে ওই সূর্যমুখী ও গম চাষের সার ব্যবস্থাপনা নিয়ে। আশা করা যায়, আগামী দুই বছরের মধ্যে সেটাও ফলপ্রসূ হবে। পতিত জমিতে সূর্যমুখী ও গম চাষ করে চাষিরা বিঘাপ্রতি ছয় থেকে আট হাজার টাকা লাভ করতে পারবেন।

গবেষকেরা জানান, গবেষণার প্রথম প্রকল্পটির নাম ছিল 'ক্রপিং সিস্টেম ইনটেনসিফিকেশন ইন দ্য সল্ট-অ্যাফেক্টেড কোস্টাল জোন অব বাংলাদেশ অ্যান্ড ওয়েস্ট বেঙ্গল, ইন্ডিয়া (সিএসআইফোরসিজেড)'। ওই প্রকল্পের আওতায় একাধিক ফসল উৎপাদনের ব্যাপারে গুরুত্ব দেওয়া হয়। বর্তমানে দ্বিতীয় প্রকল্প চলছে। 'নিউট্রিয়েন্ট ম্যানেজমেন্ট অব ডাইভারসিফায়েড ক্রপিং ইন বাংলাদেশ (এনইউএমএএন)' প্রকল্পের আওতায় উৎপাদিত পণ্যের সার ব্যবস্থাপনা নিয়ে কাজ করা হচ্ছে। বিধান চন্দ্র বলেন, প্রথম প্রকল্পে নির্বাচন করার চেষ্টা করা হয়েছে যে লবণাক্ত জমিতে রবি মৌসুমে কোন ফসল চাষাবাদ করা সম্ভব। গম, ভুট্টা, সরিষা, মটরসহ অনেক ফসল নিয়ে কাজ করার পর সূর্যমুখী ও গম সফলভাবে চাষ করা সম্ভব হয়েছে।

খুলনা কৃষি সম্প্রসারণ অধিদপ্তরের উপপরিচালক পঙ্কজ কান্তি মজুমদার বলেন, লবণাক্ত জমিতে সূর্যমুখীর চাষ চাষিদের নতুন করে আশার আলো দেখাচ্ছে। সূর্যমুখী এমন একটি ফসল, যা ওই লবণাক্ত অঞ্চলে হচ্ছে, এর ফুল ধারণের ওপর দিনের দৈর্ঘ্যের কোনো প্রভাব নেই, মৌসুমের কোনো প্রভাব নেই, দেরিতে লাগালেও হচ্ছে।

News story published on 15 May 2019 in the daily 'Prothomalo", the most popular national newspaper of the country, on the sunflower cultivation at Dacope Khulna. The title of the story is '**Wish success of Dacope spreads everywhere: sunflower cultivation in saline land**'

উপকূলে সূর্যমুখী চাষ ॥ কৃষকদের সাফল্য

Another story published on 6 April 2019 in the national daily 'Janakantha' on the sunflower cultivation in Dacope. **The title of the news is Sunflower cultivation in the coast: success of farmers.**

Kalerkantho, national newspaper, published a news on 10 April 2019 with title '**Success: sunflower in saline land**" based on sunflower cultivation in Dacope, Khulna


দাকোপে বোরো ধান ও সূর্যমুখী চাষে ব্যাপক সাড়া


দাকোপে বোরো ও সূর্যমুখী চাষে আগ্রহ বাড়ছে কৃষকদের

News published in Daily Bengali News Papers about Boro rice and sunflower cultivation in Dacope during 2018-19. The caption of the left news items is '**Huge response to Boro rice and sunflower cultivation in Dacope'** and the caption of the news at right is '**Interest of cultivation of Boro and sunflower is growing among farmers in Dacope**"

News published in different daily Bengali newspaper on the bumper production of Aus rice at Dacope in 2018-19


৬ রাজ্য

আয়লায় লবণাক্ত জমিতে বিকল্প চাষ


খেতে-খামারে

বাড়িতেই অল্প খরচের হিমঘর


ধান জমিতে আলুর ফলন বিনাচাষে


পুরস্কৃত হলেন বিধানচন্দ্র কৃষি বিশ্ববিদ্যালয়ের দুই গবেষক

Top left: Anandabazar Patrika published a report on the alternative crops cultivation in salt affected soil with the headline (in Bengali) ‘**Alternative cultivation in Salt Affected Soils of Ayla’**, on 14.01.2019.

Top right: Anandabazar Patrika, published a report on the low cost potato storage technology with the headline (in Bengali) ‘***Low Cost Household Potato Storage Structure***’, on 23.01.2019.

Bottom left: Anandabazar Patrika, published a report on the zero tillage potato cultivation technology with the headline (in Bengali) ‘***Cultivation of Zero tillage potato in rice fallow***’, on 09.01.2019.

Bottom right: Vhumiputra, a popular Bengali bi-monthly newspaper (farm journal) of West Bengal, published a report on the IPNI Scholar Award Programme with the headline (in Bengali) '***Two researches of the University have been awarded***', on 21.01.2019.

কৃষি পাক্ষিক

সবুজ সোনা

SABUJ SONA

Ranaghat, 1st February, 2019 ১৭ই মাঘ, ১৪২৫ সবুজ সোনা

Regd No-32885/1977, P.R. No. W.B./ NSD/ Part/ 03 valid Dec,2021 পাক্ষিক কৃষি পত্রিকা। বার্ষিক গ্রাহক চাঁদা Maximum Retail Price Rs.1.50 Per Issue ৪২তম বর্ষ তৃতীয় সংখ্যা 3rd Issue

আই.পি.এন.আই. স্কলার পুরস্কারে ভূষিত

নিজস্ব : বিধান চন্দ্র কৃষি বিশ্ববিদ্যালয়ের শস্য বিজ্ঞান বিভাগের গবেষক শ্রী সুকমল সরকার ও মৃত্তিকা বিজ্ঞান বিভাগের গবেষিকা কুমারী মহাশ্বেতা চক্রবর্তী ভূষিত হলেন আন্তর্জাতিক উদ্ভিদ খাদ্য পুষ্টি সংস্থা (ইন্টারন্যাশনাল প্ল্যান্ট নিউট্রিশন ইন্সটিটিউট) -এর 'আই.পি.এন.আই. স্কলার' পুরস্কারে। আই.পি.এন.আই. সংস্থার পক্ষ থেকে এই পুরস্কার প্রদান অনুষ্ঠানের আয়োজন করা হয় গত ১২ই ডিসেম্বর, ২০১৮ তে - বিধান চন্দ্র কৃষি বিশ্ববিদ্যালয়ের কৃষি অনুষদের এক সভাকক্ষে। হাজির ছিলেন বিধান চন্দ্র কৃষি বিশ্ববিদ্যালয়ের উপাচার্য অধ্যাপক দরনীধর পাত্র, আই.পি.এন.আই. সংস্থার ভাইস প্রেসিডেন্ট (এশিয়া-আফ্রিকা-মধ্যপ্রাচ্য) ড. কৌশিক মজুমদার ও এই সংস্থার ডেপুটি ডাইরেক্টর (দক্ষিণ এশিয়া) ড. সুদর্শন দত্ত। পাশাপাশি উপস্থিত ছিলেন কৃষি অনুষদের অধ্যক্ষ অধ্যাপক শ্রীকান্ত দাস, শস্য বিজ্ঞান বিভাগের অধ্যাপক কৌশিক ব্রহ্মচারী, বিভিন্ন বিভাগের বিভাগীয় প্রধান, অধ্যাপক, অসংখ্য ছাত্র-ছাত্রী, গবেষক ও শিক্ষাকর্মীরা।

সুকমল গবেষণার কাজকর্ম করছেন ড. কৌশিক ব্রহ্মচারীর অধীনে - প্রত্যন্ত সুন্দরবনের নোনা এলাকার শস্য নিবিড়তা বাড়ানোর সাথে কৃষিজীবি পরিবারগুলোর উপার্জন বাড়ানোর লক্ষ্যে। এই এলাকায় শস্য নিবিড়তা বাড়ানোর লক্ষ্যে উদ্ভূত প্রযুক্তি গুলো যাতে দেশ তথা বিদেশের বিস্তীর্ন সমুদ্র উপকূলবর্তী নোনা এলাকাগুলোতেও কাজে আসে তার জন্য

(এরপর চারের পাতায়)

আই.পি.এন.আই. স্কলার

(তিনের পাতার পর)

সুকমল কাজ করছেন ক্রপ মডেলিং-এর ওপরে। এই প্রকল্পের সাথে যুক্ত আছে ভারতবর্ষের বিধান চন্দ্র কৃষি বিশ্ববিদ্যালয়, ক্যানিং-এর আই.সি.এ.আর সংস্থা (সেন্ট্রাল সয়েল স্যালিনিটি রিসার্চ ইন্সটিটিউট), গোসাবার টেগোর সোসাইটি ফর রুরাল ডেভেলপমেন্ট; বাংলাদেশের বাংলাদেশ কৃষি গবেষণা কেন্দ্র (বি.এ.আর.আই), বাংলাদেশ ধান্য গবেষণা সংস্থা (বি.আর.আর.আই), খুলনা বিশ্ববিদ্যালয়, আই.ডব্লিউ.এম; অস্ট্রেলিয়ার সি.এস.আই.আর.ও এবং মারডক ইউনিভার্সিটি। সমগ্র প্রকল্প রূপায়নের লক্ষ্যে আর্থিক সহযোগিতার হাত বাড়িয়েছে অস্ট্রেলিয়ান সেন্টার ফর ইন্টারন্যাশনাল এগ্রিকালচারাল রিসার্চ। মহাশ্বেতা কাজ করছেন মৃত্তিকা বিজ্ঞানী ড. বিশ্বপতি মণ্ডলের কাছে - বিষয় জিঙ্ক বায়ো ফর্টিফিকেশন-এর ওপরে। কিছুদিন আগে গবেষণার কাজ শেষ করে যোগ দিয়েছেন ভারতীয় কৃষি গবেষণা অনুসন্ধান পরিষদের বৈজ্ঞানিক পদে।

আই.পি.এন.আই. চলতি শতাব্দীর সাত সালের জানুয়ারি মাস থেকেই উদ্ভিদ খাদ্য মৌল সংক্রান্ত হরেক গবেষণারত। স্বাভাবিক কারণেই বিশ্বব্যাপী বিস্তৃত তাদের গবেষণাক্ষেত্র। বর্তমানে সংস্থাটি আফ্রিকা, অস্ট্রেলিয়া, নিউজিল্যান্ড, ব্রাজিল, চীন ইত্যাদি নানাদেশে ছাড়াও পশ্চিম ইউরোপ, এশিয়া ও আমেরিকার আরও অনেক দেশে খাদ্য সংকট তথা শস্য উৎপাদনের ভূমিকা নিয়ে বিভিন্ন কাজকর্ম করে আসছে। সারা বিশ্বের বিভিন্ন কাজকর্ম করে আসছে। সারা বিশ্বের বিভিন্ন বিশ্ববিদ্যালয় তথা গবেষণা সংস্থায় মৃত্তিকা বিজ্ঞান, শস্য বিজ্ঞান, উদ্যানবিদ্যা, উদ্ভিদ শারীর বিজ্ঞান ইত্যাদি নানান বিষয়ে স্নাতকোত্তর স্তরে (এম.এস.সি.ও পি.এইচ.ডি) গবেষণা বিশেষ সাফল্য অর্জন করেছে এমন সমস্ত ছাত্র-ছাত্রীদের কে আই.পি.এন.আই জনুয়ারি ২০০৭ সাল থেকেই নির্বাচিত করে আসছে এই পুরস্কার এর জন্য অবশ্যই নির্দিষ্ট প্রথা মেনে। এই বছর সারা বিশ্বে মোট ৩১ জন ছাত্র-ছাত্রীদের কে এই পুরস্কারটি দেওয়া হয়েছে। এদিনের সভায় মাননীয় উপাচার্যের বক্তব্যে বারবার উঠে আসে খাদ্য সংকট মোকাবিলার কথা অধিক উৎপাদনশীলতার লক্ষ্যে কৃষি বিজ্ঞানের বিভিন্ন বিভাগ সমন্বয়ে হাতে হাত না রেখে চলার সংকল্প গ্রহণের কথা। তিনি আরও বলেন, 'এই ধরনের পুরস্কার বিশ্ববিদ্যালয়ের গবেষক তথা ছাত্র-ছাত্রীদের আরো বেশি অনুপ্রাণিত করবে। উচ্চতর পড়াশোনা ও গবেষণার ক্ষেত্রে যা অতি গুরুত্বপূর্ণ।' ড. কৌশিক মজুমদার তাঁর সংস্থার কাজকর্ম বিশদভাবে আলোচনা করেন। ড. সুদর্শন দত্ত তাঁর বিশেষ বক্তব্যে আই.পি.এন.আই.-এর গবেষণা তথা গবেষণা পুরস্কারের বিষয়ে আলোচনা করেন। এদিনের অনুষ্ঠানে শ্রী সুকমল সরকার ও কুমারী মহাশ্বেতা চক্রবর্তীকে 'আই.পি.এন.আই. স্কলার সার্টিফিকেট ও পুরস্কার স্বরূপ দুই হাজার ডলারের চেক্ প্রদান করা হয়। স্বভাববিনয়ী সুকমল ও

(এরপর আটের পাতায়)

আই.পি.এন.আই. স্কলার

(সাতের পাতার পর)

মহাশ্বেতার চোখে মুখে আনন্দ ও গর্বের ছোঁয়া। অনুষ্ঠানের শেষে একান্ত আলাপ চারিতায় ভুলেন না তাঁরা বাবা, মা ও পরিবারের অন্যান্য সদস্যের পাশাপাশি বিশ্ববিদ্যালয়ের শিক্ষক-শিক্ষিকা, ছাত্র-ছাত্রী-বন্ধু-স্বজনদের ভূমিকা ও অনুপ্রেরণার কথা স্মরণ করতে। তাঁরা বিশেষভাবে সম্মান জানান তাঁদের পি.এইচ.ডি-র চেয়ারম্যান তথা শস্য বিজ্ঞান বিভাগের শিক্ষক অধ্যাপক কৌশিক ব্রহ্মচারী ও মৃত্তিকা বিজ্ঞান বিভাগের শিক্ষক অধ্যাপক বিশ্বপতি মণ্ডল কে।

Sabuj Sona, a popular Bengali bi-monthly newspaper (farm journal) of West Bengal, published a report on the IPNI Scholar Award Programme with the headline (in Bengali) '***Two researches of the University have been awarded with IPNI***', on 1st February 2019.

2017-18

প্রথম আলো

সোমবার

লবণাক্ত জমিতে ফলছে আলু। সম্প্রতি খুলনার দাকোপ উপজেলার পানখালী এলাকায়। ছবি: প্রথম আলো

লবণাক্ত জমিতে আলুচাষে সাফল্য

লবণাক্ত জমিতে আলুর চাষ দেখে অবাক এলাকাবাসীও। খুব সহজে এভাবে আলুর চাষ হতে পারে, তা যেন তাঁদের বিশ্বাসই হচ্ছে না।

Prothom-Alo, the most widely circulated and popular Bengali daily newspaper, published a story on the potato cultivation with the headline (in Bengali) '***Success in growing potato on saline land***' with big colour photo of the potato field, on 26 March 2018 based on potato grown in Dacope, Khulna. The caption of the photo is '*Potato grows in saline land: recently taken from Pankhali area of Dacope in Khulna*'.

News published in the last page of Prothom-Alo based on our work at Amtali, Borguna on 02 March 2018 with the title ‘***Many crops on saline land***: ***Bangladesh Agricultural Research Institute, Irrigation and Water Management Division and Agronomy Division’s joint research success***”. The caption of the picture in the newspaper is ‘*green crop fields on saline land. Once these were mono crop lands. Due to dissemination of agricultural technology now they are multi-crop area*. Photo taken in the Sekanderkhali village of Amtali Upazilla by Prothom-Alo.

জনকণ্ঠ

টেকনাফ থেকে তেঁতুলিয়া

লবণাক্ত জমিতে সবুজের সমারোহ

কৃষকের মুখে হাসি

The Daily Janakantha, another national popular daily newspaper Bengali newspaper of Bangladesh published a story with a photo of our tomato experiment based on our activities at Amtali, Borguna on 03 March 2018 with the title '***Grandeur of green in the saline land: smile to farmers' face***". The caption of the photo is "*use of polythene mulching to conserve soil moisture for growing tomato in the Sekandarkhali village of Amtali*".

দৈনিক জনকণ্ঠ
The Daily Janakantha

দক্ষিনাঞ্চলের লবনাক্ত পতিত জমিতে চাষ করে কৃষকরা স্বাবলম্বী

আমতলী (বরগুনা)ঃ আমতলীর সেকান্দারখালী গ্রামে সমন্বিত সার ব্যবস্থাপনায় বারি সূর্যমুখী-২ জাতের প্রদর্শনী।

নিজস্ব সংবাদদাতা, আমতলী, বরগুনা । দক্ষিণাঞ্চলের লবনাক্ত পতিত জমিতে সবুজের সমারোহ। কৃষকের মুখে হাসি। এক সময় যে জমিতে লবনের আবরন জেগে উঠতো সেই জমি এখন সবুজে ঘেরা। চারি দিকে শুধু সবুজ আর সবুজ। বিএআরআই সরেজমিন গবেষনা বিভাগ, সেচ ও পানি ব্যবস্থাপনা বিভাগ ও কৃষিতত্ত্ব বিভাগ যৌথ উদ্যোগে এ সফলতা পেয়েছে।

আমতলী কৃষি অফিস সূত্রে জানাগেছে, উপজেলায় ২ হাজার হেক্টর জমি লবনাক্ততার কারনে পতিত অবস্থায় পরে আছে। এক ফসলি হিসেবে শুধু আমনের চাষ করে কৃষকরা। রবি মৌসুমে লবনাক্ততার কারণে কোন রবি শস্য উৎপাদন হয় না। ফাল্গুন-চৈত্র মাসে জমিতে লবনের আবরন জেগে উঠে । লবনাক্ততার কারনে ফসল পুড়ে যেত বিধায় কৃষক ওই জমি চাষাবাদ করছে না । ডিসেম্বর থেকে এপ্রিল মাস পর্যন্ত এ জমির লবনাক্ততার মাত্রা ২-১০ ডিএস-মিটার বলে জানান সরেজমিন গবেষনা বিভাগ। ২০১৪ সালে বিএআরআই (বাংলাদেশ কৃষি গবেষনা ইনস্টিটিউট) পটুয়াখালী গবেষনা বিভাগ, সেচ ও পানি ব্যবস্থাপনা বিভাগ ও কৃষিতত্ত্ব বিভাগ দক্ষিনাঞ্চলে লবনাক্ত পতিত জমিতে বারি উদ্ভাবিত প্রযুক্তি ব্যবহারের মাধ্যমে শস্যের নিবিরতা বৃদ্ধির প্রকল্প হাতে নেয়।

উপজেলার বান্দ্রা বাজার সংলগ্ন সেকান্দারখালী গ্রামে ৩০ জন কৃষক নিয়ে একটি দল গঠন করে। ওই কৃষকদের উৎসাহিত করে চাষাবাদ শুরু করে সরেজমিন বিভাগ। বারি উদ্ভাবিত প্রযুক্তি ব্যবহার করে প্রথমে গবেষনামূলক ৫০ শতক জমি নিয়ে কাজ শুরু করে। তেমন সফলতা না পেলেও হাল ছাড়েনি। পরবর্তী বছরে ২০১৫ সালে .৭ হেক্টর, ২০১৬ সালে ১ হেক্টর, ২০১৭ সালে ১.৫ হেক্টর ও এ বছর ৩ হেক্টর জমিতে চাষাবাদ করেছে। দিন দিন এ প্রযুক্তির প্রসারতা বৃদ্ধি পাচ্ছে। কৃষকরা এ প্রযুক্তি ব্যবহার করে সফলতা পেয়েছে। কৃষকদের বীজ,সার, আগাছা নিরানো, সেচ, কীটনাশক ও জমি চাষাবাদে সকল প্রযুক্তিগত সহায়তা দিচ্ছে এ প্রকল্প।

এ বছর ওই তিন হেক্টর জমিতে পিটিওএস (বীজ বপন যন্ত্র) প্রযুক্তি ব্যবহার করে বারি গম-২৫, বারি মুগ -৬, বারি ফেলন -১, বারি ভুট্টা-৯, লবনাক্ত ও তাপ সহিষ্ণু আলুর জাত বারি আলু-৭২,অল্প পানি ব্যবহারের জন্য (ড্রিপ পদ্ধতিতে) বারি টমেটো -১৪ , আমন ধানের সাথে সাথি ফসল হিসেবে বারি ফেলন-১,সমন্বিত সার ব্যবস্থাপনায় বারি সূর্যমুখী-২ ও বারি সরিষা-১৪ জাতের বীজ বপন করেছে। এছাড়াও জমির আদ্রতা ধরে রাখার জন্য পলিথিন মালচিং পদ্ধতি ব্যবহার করে টমেটো চাষ ও পুকুরের মিঠা পানির সাথে লবন পানি মিশ্রন করে সূর্যমূখী ও ভুট্টা চাষ করেছে এ সরেজমিন গবেষনা বিভাগ।

বৈজ্ঞানিক কর্মকর্তা গাজী নাজমুল হাসান বলেন, লবনাক্ত পতিত জমিতে বারি উদ্ভাবিত প্রযুক্তি ব্যবহারের মাধ্যমে কৃষকরা সফলতা পেয়েছে। আশা করি দিন দিন এ সফলতা বৃদ্ধি পাবে।

উর্দ্ধতন বৈজ্ঞানিক কর্মকর্তা ড. মোঃ আলিমুর রহমান বলেন, ডিসেম্বর থেকে এপ্রিল মাস পর্যন্ত এ জমির লবনাক্ততার মাত্রা ২-১০ ডিএস-মিটার। এ মাত্রার লবনাক্ত জমিতে রবি মৌসুমে কোন ফসল ফলানো সম্বব নয়। প্রযুক্তি ব্যবহারের ফলে ওই লবনাক্ত পতিত জমিতে রবি শস্য উৎপাদন হচ্ছে।

গাজীপুর সেচ ও সরবরাহ বিভাগের পরিচালক ড. মোঃ আমজাদ হোসেন বলেন, লবনাক্ত জমিতে প্রযুক্তি ব্যবহার করে কৃষকরা আয়ের পথ বৃদ্ধি করছে। এ প্রসারতা আরো দিন দিন বৃদ্ধি পাবে। তিনি আরও বলেন, এক সময় ওই এলাকার কৃষকরা এক ফসলের উপর নির্ভর করতো। এখন রবি শস্য উৎপাদন করে কৃষকরা স্বাবলম্বী হবে।

The Daily Janakantha published another news based on our activities at Amtali on 27 February 2018 with a colour photo of a sunflower experiment titled ‘***Farmer are self-reliant after cultivating crops in the fallow saline land of the southern region***’.

দৈনিক ইত্তেফাক // বুধবার, ১৬ ফাল্গুন ১৪২৪/২৮ ফেব্রুয়ারি ২০১৮

সংবাদ সংক্ষেপ

আমতলীতে কৃষক মাঠ দিবস

আমতলী (বরগুনা) সংবাদদাতা॥ দক্ষিণাঞ্চলে লবণাক্ত পতিত জমিতে বারি উদ্ভাবিত প্রযুক্তি ব্যবহারের মাধ্যমে শস্যের নিবিড়তা বৃদ্ধির উপর সরেজমিন মাঠ গবেষণা নিয়ে আমতলীর বান্দরা গ্রামে সোমবার কৃষক মাঠ দিবস অনুষ্ঠিত হয়। বিএআরআই-এর পটুয়াখালী প্রধান বৈজ্ঞানিক কর্মকর্তা ড. মো. সহিদুল ইসলামের সভাপতিত্বে অনুষ্ঠিত মাঠ দিবসে প্রধান অতিথির বক্তব্য রাখেন বিএআরআই জয়দেবপুর গাজীপুর এর পরিচালক ড. মো. আমজাদ হোসেন। সভায় বিশেষ অতিথির বক্তব্য রাখেন বরিশালের মুখ্য বৈজ্ঞানিক কর্মকর্তা ড. মো. আ. ওহাব, কৃষি অধিদপ্তর বরগুনার উপ-পরিচালক শাহনুর আলম খান, আমতলী উপজেলা কৃষি কর্মকর্তা এসএম বদরুল আলম, আমতলী প্রেসক্লাবের সভাপতি মো. জাকির হোসেন প্রমুখ।

হোমনায় ইউনিয়ন স্বাস্থ্য কেন্দ্রে স্বাভাবিক প্রসবসেবা কর্মশালা

হোমনা (কুমিল্লা) সংবাদদাতা॥ মঙ্গলবার হোমনায় ইউনিয়ন স্বাস্থ্য ও পরিবার কল্যাণ কেন্দ্রে সার্বক্ষণিক স্বাভাবিক প্রসবসেবা জোরদারকরণ বিষয়ক অবহিতকরণ কর্মশালা অনুষ্ঠিত হয়েছে। উপজেলা পরিষদ মিলনায়তনে এতে প্রধান অতিথি ছিলেন পরিবার পরিকল্পনা বিভাগ চট্টগ্রাম বিভাগের পরিচালক মোহাম্মদ নুরুল আমিন। উপজেলা চেয়ারম্যান অ্যাড. মো. আজিজুর রহমান মোল্লার সভাপতিত্বে বিশেষ অতিথি ছিলেন পরিবার পরিকল্পনা অধিদপ্তরের লাইন ডাইরেক্টর ডা. মোহাম্মদ শরীফ, উপজেলা ভাইস চেয়ারম্যান শেফালী বেগম। বক্তব্য দেন পরিবার পরিকল্পনা অধিদপ্তরের এমসিএইচ সার্ভিসেস ইউনিটের প্রোগ্রাম ম্যানেজার ডা. এবিএম সামসুদ্দিন আহমেদ, উপজেলা স্বাস্থ্য ও পরিবার পরিকল্পনা কর্মকর্তা ডা. মো. সরফরাজ হোসেন খান, গাইনি কনসালটেন্ট ডা. সায়মা আহমেদ ও ডা. নমাইয়া হাবিব প্রমুখ।

The Daily Ittefaq, national daily newspaper' published a news about our field day at Amtali on 28 February 2018.

দক্ষিণাঞ্চলে লবনাক্ত জমির ব্যবহার সম্পর্কিত মাঠ দিবস পালন (http://www.sagorkonnya.com/99370)

হোমপেজ » বাংলা জেলা » দক্ষিণাঞ্চলে লবনাক্ত জমির ব্যবহার সম্পর্কিত মাঠ দিবস পালন

সোমবার, ২৬ ফেব্রুয়ারি ২০১৮

(mailto:?subject=দক্ষিণাঞ্চলে লবনাক্ত জমির ব্যবহার সম্পর্কিত মাঠ দিবস পালন&body= আমতলী সাগরকন্যা প্রতিনিধি ॥ দক্ষিনাঞ্চলে লবনাক্ত পতিত জমিতে বারি উদ্ভাবিত প্রযুক্তি ব্যবহারের মাধ্যমে শস্যের নিবিরতা বৃদ্ধির উপর আমতলীতে মাঠ দিবস পালিত... বিস্তারিত পড়তে ভিজিট করুন: http://www.sagorkonnya.com/99370) (?q=print)

লবনাক্ত জমির ব্যবহার সম্পর্কিত মাঠ দিবস পালন

আমতলী সাগরকন্যা প্রতিনিধি ॥

দক্ষিনাঞ্চলে লবনাক্ত পতিত জমিতে বারি উদ্ভাবিত প্রযুক্তি ব্যবহারের মাধ্যমে শস্যের নিবিরতা বৃদ্ধির উপর আমতলীতে মাঠ দিবস পালিত হয়েছে। সোমবার বিকেলে উপজেলার বান্দ্রা বাজার সংলগ্ন সেকান্দারখালী গ্রামে সরেজমিন গবেষণা বিভাগ, সেচ ও পানি ব্যবস্থাপনা বিভাগ ও কৃষিতত্ত্ব বিভাগ বিএআরআই বরিশাল যৌথভাবেএ মাঠ দিবসের আয়োজন করেছে।

সরেজমিন গবেষণা বিভাগ বিএআরআই পটুয়াখালী প্রধান বৈজ্ঞানিক কর্মকর্তা ড. মোঃ শহিদুল ইসলামের সভাপতিত্বে প্রধান অতিথি হিসেবে উপস্থিত ছিলেন, সেবা ও সরবরাহ বিএআরআই, গাজীপুর পরিচালক ড. মোঃ আমজাদ হোসেন।

বক্তব্য রাখেন মূখ্য বৈজ্ঞানিক কর্মকর্তা ড.মোঃ আবদুল ওহাব, উপ-পরিচালক মোঃ শাহনুর আজম খাঁন, প্রধান বৈজ্ঞানিক কর্মকর্তা ড. মোঃ মাইন উদ্দিন, উর্ধতন বৈজ্ঞানিক কর্মকর্তা ড. মোঃ আমিনুর রহমান, বৈজ্ঞানিক কর্মকর্তা গাজী নাজমুল হাসান, এসএম বদরুল আলম, কৃষক নাসির উদ্দিন, আলাউদ্দিন ও নাজমা আকতার। পরে প্রধান অতিথি ও বৈজ্ঞানিক কর্মকর্তারা লবনাক্ত পতিত জমিতে উদ্ভাবিত ফসল সরেজমিনে ঘুরে দেখেন।

Sagorkonnya, a local newspaper of Borguna, published a story 26 February 2018 with a title ***"Field day about the use of saline land in the southern region'***.

লবনাক্ত জমিতে সবুজের সমারোহে কৃষকের মুখে হাসি!

আমাদের সময়.কম
প্রকাশের সময় : 03/03/2018 -14:44
আপডেট সময় : 03/03/ 2018-14:45

আমতলী (বরগুনা)ঃ আমতলীর সেকান্দারখালী গ্রামে পিটিও
করে বারি ভুট্টা-৯ চাষের প্রর্দশনী।

The daily Amadershomoy, national newspaper, published a story with a big colour photo of our maize field at Amtali on 03 March 2018 with the title '***Smile on the farmers' face due to green crops on saline land***'.

মুক্ত প্রাণের প্রতিধ্বনি

ভোরের কাগজ

www.bhorerkagoj.net

/bhorerkagoj.online

দাকোপে কৃষক মাঠ দিবস পালিত

The daily ‘Bhorer Kagoj’ published the news on 28th April 2018 of the Field Day organized by BRRI on Boro rice cultivation on 26 April 2018

সমকাল

The daily ‘Samakal’ published the news on 27th April 2018 of the Field Day organized by BRRI on Boro rice cultivation on 26 April 2018

Prothom-Alo published a long story in the last page with the title '***Vegetable cultivation with rice in saline water-logged land: raising new hope for coastal farmers'*** on 23 October 2017.


দৈনিক ইত্তেফাক

দাকোপে ধানের সঙ্গে সবজি চাষে ব্যাপক সাড়া

The daily Ittefaq published a long story with a colour photo of the field with title ‘***Huge response to grow vegetables with rice in Dacope***’ on 20 October 2017. The caption of the photo is ‘*farmer is taking care of the vegetable garden with rice in Dacope*’.

নিউজ রুম এডিটর, নিউজ৭১অনলাইন

জলাবদ্ধ জমিতে ধানের সাথে সবজি চাষে সফল হয়েছেন কৃষকরা

দাকোপ(খুলনা) পানখালী ইউনিয়নের খাটাইল গ্রামের ইমরান শেখের ধানের সাথে সবজি ক্ষেত থেকে ফসল তুলছেন কৃষকরা

দীপক রায়,দাকোপ(খুলনা)থেকেঃ জলাবদ্ধ জমিতে ধানের সাথে সবজি চাষ করে সফল হয়েছেন দাকোপের একাধিক কৃষক। ৭ অক্টোবর সকাল ১১টায় দাকোপের খাটাইল গ্রামে ধান গবেষনা ইনস্টিটিউট,গাজীপুর এর উদ্যোগে আয়োজিত এক মাঠ দিবস অনুষ্ঠিত হয়। মাঠদিবসে খুলনা ও বরিশালালের উপকুলীয় এলাকার জলাবদ্ধ জমিতে ধানের সাথে সবজি চাষের মাধ্যমে দরিদ্র জনগোষ্টির নিজস্ব সবজির চাহিদা পুরণ এবং জমির উৎপাদনশীলতা বৃদ্ধি করা সম্ভব এ তথ্য জানানো হয়েছে। খাটাইল গ্রামের কৃষক ইমরান শেখের সবজি চাষের কৃষি মাঠ পরিদর্শন শেষে"জলাবদ্ধ জমিতে ধানের সাথে সবজি চাষ" শীর্ষক মাঠ দিবসের আলোচনায় সভাপতিত্ব করেন দাকোপের উপজেলা নির্বাহী কর্মকর্তা মোঃমারুফুল আলম। প্রধান অতিথি হিসাবে উপস্থিত ছিলেন ব্রি'র মহাপরিচালক ড. মোঃ শাহজাহান কবীর। বিশেষ অতিথি হিসাবে উপস্থিত ছিলেন উপজেলা পরিষদের চেয়ারম্যান আলহাজ্ব শেখ আবুল হোসেন ও উপ-পরিচালক ডিএই খুলনার আব্দুর লতিফ। অন্যদের মধ্যে উপস্থিত ছিলেন উপজেলা কৃষি কর্মকর্তা মোঃমোছাদ্দেক হোসেন, উপজেলা পরিষদের ভাইস চেয়ারম্যান এ্যাড.সুভদ্রা সরকার,পানখালীর ইউপি চেয়ারম্যান শেখ আব্দুল কাদের। সভাতে বক্তারা বলেন, জলাবদ্ধ জমিতে ধানের সাথে সবজি চাষ লাভজনক এটা পরিক্ষামুলকভাবে দাকোপে চাষ করে কৃষকরা সফল হয়েছেন। এখন থেকে এ প্রযুক্তি কাজে লাগিয়ে আরোও অধিক সবজি ফলানো সম্ভব হবে। মাঠ দিবসে এলাকার কৃষক,সরকারী ও বেসরকারী প্রতিষ্ঠানের প্রতিনিধি এবং সর্বস্তরের জনগন অংশগ্রহন করেন।

07.10.2017 | 05:56 PM | সর্বমোট ৪০৪ বার পঠিত

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News 71 online published a story on 07 October with colour photo of the field with title '***Farmers became successful growing vegetable with rice in water-logged land***'. The caption of the photo is '*Imran Sheikh of Khatail village of Pankhali Union harvesting vegetables grown with rice*.


খবরপত্র

সময় ও নিরপেক্ষতায় অগ্রণী

THE DAILY KHABARPATRA

দাকোপে কৃষি মাঠ দিবস

News on the Field Day published in the Daily Khabarpatra on 08 October 2017


প্রান্তজনের দৈনিক

সংবাদ প্রতিদিন

Daily Sangbad Protidin

sangbadprotidin.com

আজ রবিবার

দাকোপে কৃষি মাঠ দিবস অনুষ্ঠিত

News on the Feld Day published in the Daily Sangbad Protidin on 08 October 2017

যায়যায়দিন

মাঠ দিবস

দাকোপ (খুলনা) সংবাদদাতা

বাংলাদেশ ধান গবেষণা ইনস্টিটিউটের উদ্যোগে খুলনার দাকোপে জলাবদ্ধ জমিতে ধানের সঙ্গে সবজি চাষ শীর্ষক মাঠ দিবস অনুষ্ঠিত হয়েছে। শনিবার [illegible] কালি মন্দির প্রাঙ্গণে উপজেলা নির্বাহী অফিসার মো. মারুফুল আলমের সভাপতিত্বে অনুষ্ঠিত মাঠ দিবসে প্রধান অতিথি ছিলেন ব্রি'র মহাপরিচালক মো. শাহজাহান কবীর। স্বাগত বক্তব্য করেন প্রকল্পের প্রধান গবেষক ড. মো. মনিরুজ্জামান। বিশেষ অতিথি ছিলেন উপজেলা চেয়ারম্যান শেখ আবুল হোসেন, জেলা ডিএই উপ-পরিচালক মো. আব্দুল লতিফ, ভাইস চেয়ারম্যান শুভ্রা সরকার, ইউপি চেয়ারম্যান শেখ আব্দুল কাদের, উপজেলা সিনিয়র কৃষি অফিসার মো. [illegible] হোসেন।

News on the Feld Day published in the Daily Jai Din on 08 October 2017

অসংকোচ প্রকাশের দুরন্ত সাহস

সমকাল

প্রথম সংস্করণ www.samakal.com

রোববার ৮ অক্টোবর ২০১৭

মাঠ দিবস

■ দাকোপ (খুলনা) প্রতিনিধি

উপকূলীয় এলাকার জলাবদ্ধ জমিতে ধানের সঙ্গে সবজি চাষের মাধ্যমে দরিদ্র জনগোষ্ঠীর নিজস্ব সবজির চাহিদা পূরণ এবং লাভজনক চাষাবাদের লক্ষ্যে দাকোপে মাঠ দিবস অনুষ্ঠিত হয়েছে। এ লক্ষ্যে শনিবার উপজেলার খাটাইল গ্রামে বাংলাদেশ ধান গবেষণা ইনস্টিটিউট-ব্রি গাজীপুরের সহায়তায় এ মাঠ দিবস অনুষ্ঠিত হয়। উপজেলা নির্বাহী কর্মকর্তা মো. মারুফুল আলমের সভাপতিত্বে অনুষ্ঠিত মাঠ দিবসের আলোচনা সভায় প্রধান অতিথি ছিলেন ব্রির মহাপরিচালক ড. মো. শাহজাহান কবীর। বিশেষ অতিথি ছিলেন উপজেলা পরিষদ চেয়ারম্যান শেখ আবুল হোসেন, খুলনা বিশ্ববিদ্যালয়ের ধান ও কৃষি বিষয়ের বিজ্ঞানীরাসহ বিভিন্ন দপ্তরের কর্মকর্তারা। অনুষ্ঠানে মূল বিষয় উপস্থাপন করেন প্রকল্পের গবেষক ব্রির প্রধান বৈজ্ঞানিক কর্মকর্তা ড. মো. মনিরুজ্জামান।

News on the Feld Day published in the Daily Samakal on 08 October 2017

দৈনিক ইত্তেফাক

Date: 08.10.2017 Page:

ধানের সঙ্গে সবজি চাষ শীর্ষক মাঠ দিবস

দাকোপ (খুলনা) সংবাদদাতা॥ বাংলাদেশ ধান গবেষণা ইনস্টিটিউটের উদ্যোগে শনিবার দাকোপে জলাবদ্ধ জমিতে ধানের সঙ্গে সবজি চাষ শীর্ষক মাঠ দিবস অনুষ্ঠিত হয়েছে।

আনন্দনগর মাঝানের মোড়ে কালি মন্দির প্রাঙ্গণে উপজেলা নির্বাহী অফিসার মো. মারুফুল আলমের সভাপতিত্বে মাঠ দিবসে প্রধান অতিথির বক্তব্য রাখেন ইনস্টিটিউটের মহাপরিচালক মো. শাহজাহান কবীর। স্বাগত বক্তব্য রাখেন ব্রি প্রকল্পের প্রধান গবেষক ড. মো. মনিরুজ্জামান। বিশেষ অতিথি ছিলেন উপজেলা পরিষদ চেয়ারম্যান আলহাজ্ব শেখ আবুল হোসেন, জেলা ডিএই উপ-পরিচালক মো. আব্দুল লতিফ, ভাইস চেয়ারম্যান অ্যাডভোকেট শুভদ্রা সরকার, ইউপি চেয়ারম্যান শেখ আব্দুল কাদের প্রমুখ।

The Ittefaq published the news of field day organized by BRRI at Dacope on 08 October 2017.

12 Acronyms

ACIAR	Australian Centre for International Agricultural Research
ANCOVA	Analysis of Co-Variation
ANOVA	Analysis of Variation
APSIM	Agricultural Production Systems Simulator
AWD	Alternate Wetting and Drying
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agriculture Research Institute
BCKV	Bidhan Chandra Krishi Viswavidyalaya
BCR	Benefit Cost Ratio
BEY	Broccoli Equivalent Yield
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
CEGIS	Centre for Environment and Geographic Information Services
CIM	Crop Improvement and Management (ACIAR Program)
CIMMYT	International Maize and Wheat Improvement Center
CSI4CZ	Project acronym: Cropping systems intensification in the salt-affected coastal zones of Bangladesh and West Bengal, India
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSSRI	Central Soil Salinity Research Institute
DAE	[Bangladesh] Department of Agricultural Extension
DAP	Di Ammonium Phosphate
DFAT	[Australian Federal] Department for Foreign Affairs and Trade
DoA	Department of Agriculture, West Bengal
DS	Dry Season
DSR	Direct Seeded Rice
EM	Electromagnetic
EWS	Early Wet Season
FACC	Farmers' Academy and Convention Centre (at BCKV)
FGD	Focus group discussions
GHG	Greenhouse Gas Emission
GM	Green Manuring
GoB	Government of Bangladesh
GW	Groundwater
HYV	High Yielding Varieties
ICAR	Indian Council for Agricultural Research
IRRI	International Rice Research Institute
ISCAR	Indian Society of Coastal Agricultural Research
IWM	Institute for Water Modelling
IWM	Irrigation and Water Management
JAF	John Allwright Fellowship
KGF	Krishi Gobeshona Foundation
KU	Khulna University
LCDIS	Low-cost Drip Irrigation System
LSD	Least Significant Difference
MoA	Ministry of Agriculture, Bangladesh
MU	Murdoch University
NGO	Non-government Organisation
NUMAN	Nutrient Management (acronym of the ACIAR project' Nutrient management for diversified cropping in Bangladesh)
OFRD	On-Farm Research Division
PSM	Paddy Straw Mulching
PTOS	Power Tiller Operated Seeder
PTR	Puddled Transplanting
R4D	Research for Development

RCBD	Randomized Control Block Design
REY	Rice Equivalent Yield
RMVERI	Ramakrishna Mission Vivekananda Educational and Research Institute
RP	Rock Phosphate
Rs	Indian Rupees (currency), 1 AU$ = ~45 Rupee
SAMETI	State Agricultural Management and Extension Training Institute
SIAGI	Social Inclusion in Agricultural Intensification (ACIAR sister project)
SPDIS	Solar Powered Drip Irrigation System
SRDI	Soil Resources Development Institute
SW	Surface Water
Taka	Bangladeshi currency, 1 AU$ = ~62 Taka
TSRD	Tagore Society for Rural Development
UNO	Upazilla Nirbahi Officer (Bangladesh)
UNPTR	Unpuddled Transplanting
UP	Union Parishad (Bangladesh)
WS	Wet Season
WSMC	Water and Silt Management Committee
ZT	Zero Tillage