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Mitigating Risk and Scaling-Out Profitable Cropping System Intensification Practices in the Salt-Affected Coastal Zone of the Ganges Delta

MOHAMMED MAINUDDIN[1*], RICHARD W. BELL[2], SUKANTA K. SARANGI[3#*], MD. MANIRUZZAMAN[4], JORGE L. PENA-ARANCIBIA[1], DONALD S. GAYDON[5], FAZLUL KARIM[1], MARTA MONJARDINO[5], MARK GLOVER[5], KOUSHIK BRAHMACHARI[6], RUPAK GOSWAMI[7], MD. MAZHARUL ANWAR[8], EDWARD G. BARRETT-LENNARD[2] and YINGYING YU[1]

[1]CSIRO Environment, Australia
[2]Centre for Sustainable Farming Systems, Food Futures Institute, Murdoch University, Murdoch, WA - 6150, Australia
[3]ICAR-Central Soil Salinity Research Institute, RRS, Canning Town - 743 329, West Bengal, India
[4]Bangladesh Rice Research Institute (BRRI), Gazipur - 1701, Bangladesh
[5]CSIRO Agriculture and Food, Australia
[6]Bidhan Chandra Krishi Viswavidyalaya, Mohanpur - 741 252, West Bengal, India
[7]Faculty of Agriculture and Rural Development, Ramakrishna Mission Vivekananda Educational and Research Institute Narendrapur - 700 103, West Bengal, India
[8]Bangladesh Agricultural Research Institute (BARI), Gazipur - 1701, Bangladesh

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The polders and islands in the salt-affected coastal zone of the Ganges Delta, home to approximately 15 million people in Bangladesh and 5 million in West Bengal, face challenges such as poverty, food insecurity, environmental vulnerability, and limited livelihood opportunities. Historically, agricultural production in these areas was mainly confined to the wet/*Kharif* season, with much of the land remaining fallow during the dry/*Rabi* season due to waterlogging, soil salinity, and perceived lack of irrigation water. Since 2015, researchers and NGOs from Australia, Bangladesh, and India collaborated on the project "Cropping system intensification in the salt-affected coastal zones of Bangladesh and West Bengal, India" to sustainably increase cropping intensity and productivity in this area. During 2015-2021, the project has made significant achievements and has demonstrated strategies that are likely to increase productivity, cropping intensity, and livelihoods of the people. However, to maintain these gains and address risks like climate change impacts, untimely rainfall, and market fluctuations, further research was deemed necessary. Thus, ACIAR funded Phase 2 of the project for 2021-2025 which aims to sustain and enhance the achievements. This special issue presents some research findings on projected climate change, agronomic experiments, irrigation and drainage management, and social and economic issues conducted under the project Phase 2 in Bangladesh and West Bengal, India.

(***Key words:*** *ACIAR, Climate change, Crop model, Fallow, Livelihood, Socio-economics*)

The Ganges Delta (Fig. 1) includes a unique coastal zone of great significance for food security, biodiversity conservation, and fisheries production (Mainuddin *et al.,* 2019a; Tuong *et al.,* 2014). Within this low-lying deltaic region, large areas of agriculturally productive land known as 'polders' (http://en.wikipedia.org/wiki/Polder) have been enclosed and protected from flooding by the surrounding tidal rivers by constructed earth embankments. The dense networks of canals (former river distributaries) within the polders are connected to the surrounding rivers by a series of sluice gates in the embankments, providing the opportunity to bring water in at high tide, or to drain water from the polders at low tide, as needed. Thus, it creates opportunities for crop production especially in wet season by managing the tidal and rainwater within the polder. However, water management in the polders is poor, and infrastructure is inadequate, which makes the drainage of rainwater accumulated in the polders difficult (Ghosh and Mistri, 2020; Mainuddin *et al.,* 2019a; Mondal *et al.,* 2015; Yadav *et al.,* 2020). Due to this difficult drainage situation and the ~2000 mm of annual rainfall concentrated mostly in the monsoon season; polders are prone to flooding in the wet/*Kharif* season. As the dry/*Rabi* advances, the polder

**Correspondence authors:* E-mail: Mohammed.Mainuddin@csiro.au; sksarangicanning@gmail.com
[#]Present Address: ICAR-Central Institute for Women in Agriculture (CIWA), Bhubaneswar - 751 003, Odisha, India

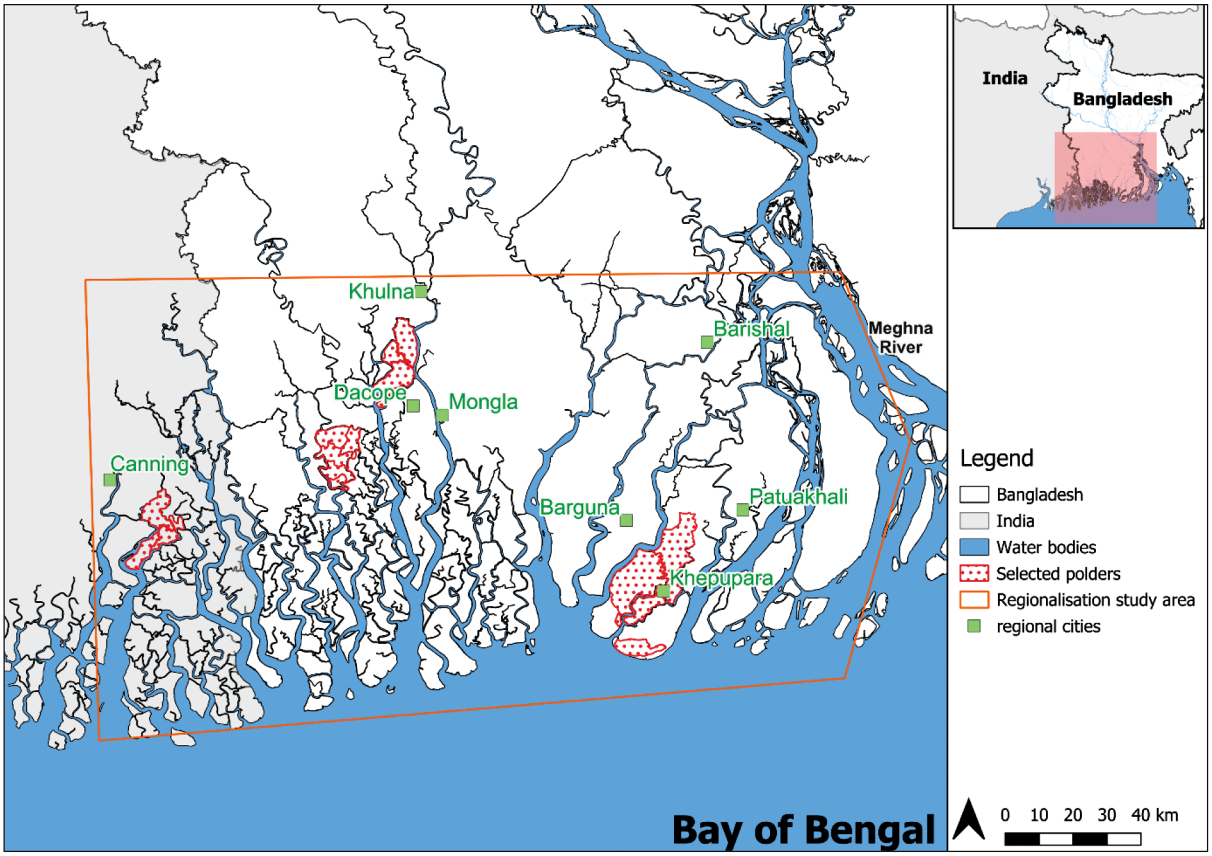

Fig. 1. *Map of the Ganges Delta with location of experiment sites within polders (hatched red), main regional cities (green squares) and regional study area (orange boundary)*

lands become salinised, because of the shallow saline water table and the increasing salinity of the rivers as freshwater that flows down the rivers diminish and the sea water moves inland.

The population of the salt-affected south-western coastal zone of the Ganges Delta in Bangladesh is about 14.12 million (Barisal Division and Khulna, Bagerhat and Satkhira districts of Khulna Division, 2011 Census, BBS, 2018). In West Bengal, the population of the salt-affected coastal zone called Sundarbans is 4.43 million (Census of India, 2011). These areas are disadvantaged by poverty, food insecurity, environmental vulnerability, and limited livelihood opportunities (MoA and FAO, 2013; Sánchez-Triana *et al.,* 2014; Tuong *et al.,* 2014).

Traditionally, farms grow low-yielding local *Aman* rice varieties under rainfed conditions in the wet/*Kharif* season (Maniruzzaman *et al.,* 2019; Mandal *et al.,* 2020; Sarangi *et al.,* 2014; Sarangi *et al.,* 2015a; Yadav *et al.,* 2020). In the dry/*Rabi* season, most agricultural land remains fallow due to: (i) late *Aman* rice harvest and prolonged waterlogging (which delays the planting of *Rabi* crops exposing the late planted crops to high soil salinity and untimely rains during the later part of the season), and (ii) the lack (or perceived lack) of good quality irrigation water for *Rabi* season irrigation (Mainuddin *et al.,* 2013; Mainuddin *et al.,* 2019a; Mandal *et al.,* 2020; Yadav *et al.,* 2020). There is potential to grow more dry season crops provided the above constraints can be alleviated or managed. The development of appropriate technologies is expected to improve socio-economic and livelihood conditions of the farming communities of the Ganges Delta, including marginalised and disadvantaged groups and sectors.

Phase 1 Project

In 2015, the Australian Centre for International Agricultural Research (ACIAR), Government of Australia funded a project on 'Cropping system intensification in the salt-affected coastal zones of Bangladesh and West Bengal, India (CSI4CZ). The project aims to sustainably increase cropping intensity and productivity in the coastal zone of Bangladesh and West Bengal particularly in the dry/*Rabi* season through integrated soil, water and crop management. During 2015–2021, CSI4CZ Phase 1 has demonstrated significant achievements from the experimental plots to regional scales, these are:

- Assessment of rainfall and temperature characteristics and assessment of agroclimatic potential (Ghosh *et al.,* 2021; Maniruzzaman *et al.,* 2024a; Sarkar *et al.,* 2020a; Yu *et al.,* 2019).
- Understanding of salt and water dynamics and balance in the polders and their impacts (Hossain *et al.,* 2019; Mainuddin *et al.,* 2019b, 2020, 2021; Mainuddin and Kirby, 2021; Mila *et al.,* 2021).
- Understanding of surface water, groundwater, and salinity interactions (IWM, 2020; Remesan *et al.,* 2021).
- Assessment of cropping systems in West Bengal coastal zone (Ghosh *et al.,* 2019; Ghosh *et al.,* 2023a, b; Nanda *et al.,* 2023).
- Understanding of soil, plant, waterlogging and salinity interactions (Islam *et al.,* 2022a, b; Mila *et al.,* 2023; Paul *et al.,* 2021c; Sarangi *et al.,* 2022)
- Selection of suitable and early maturing *Aman* rice varieties (Maniruzzaman *et al.,* 2019; Sarangi *et al.,* 2019).
- Identification of high-yielding *Aus* and *Boro* rice varieties and their suitable transplanting time (Saha *et al.,* 2019; Sarangi *et al.,* 2021a; Yesmin *et al.,* 2019).
- Early establishment of different *Rabi* season crops using different techniques such as zero tillage, relay cropping, dibbling, mulching, etc. (Kabir *et al.,* 2019; Maniruzzaman *et al.,* 2024b; Paul *et al.,* 2020a, 2020b, 2021a, 2021b; Sarangi *et al.,* 2018, 2021b; Sarkar *et al.,* 2019, 2020b).
- Development of technology for, and optimum use of, irrigation (Mahanta *et al.,* 2019; Samui *et al.,* 2020; Sarker *et al.,* 2019, 2024).
- Crop production modelling in a complex saline coastal environment (Sarkar *et al.,* 2022).
- Selection of suitable cropping pattern and their socio-economic impacts (Goswami *et al.,* 2021, 2024; Mandal *et al.,* 2020, 2022; Ray *et al.,* 2019, 2020, 2023; Saha *et al.,* 2019).

These achievements and underpinning model assessments have demonstrated strategies that are likely to increase productivity, cropping intensity and profitability. Several suitable and profitable cropping patterns for increasing cropping intensification have emerged from our research (Mandal *et al.,* 2020; Ray *et al.,* 2020; Saha *et al.,* 2019). There is clear evidence that both crop productivity and cropping intensity are 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; 2023).

The Need for a Phase 2 Project

However, there is still much to be done to increase the resilience of this system by mitigating risks and increasing the productivity of crops. This can be achieved by researching best agronomic management practices that specify optimal plant population, row spacing, seed depth and rate, time of sowing, fertilizer rate and placement (Bell *et al.,* 2019). Monitoring to date indicates that water stored in ponds and canals remains relatively fresh throughout the dry season, 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 cropland converted to ponds for surface water storage (*e.g.*, Ambast and Sen, 1998; Sen and Ambast, 2011) and the area of land and crop types that could be irrigated from existing storage. During our work in the 1st Phase (2015-2021), we encountered untimely heavy rainfall during the *Rabi* season. Rainfall trend analysis suggests these events are increasing in frequency (Yu *et al.,* 2019). 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. *Boro* rice has the obvious advantage over *Rabi* crops in tolerating heavy rainfall events.

Within the coastal zone, the landscape is diverse, particularly in land type (soil salinity during the dry season, soil properties, proximity to canals for irrigation or drainage or to other forms of water storage, etc.) or elevation (Bell *et al.,* 2019). The cropping intensification options will vary according to land type. Remote sensing technologies can be used to classify the landscape according to land use (Ghosh *et al.,* 2019). Satellite Remote Sensing (RS) data from the petabyte Landsat reflectance archive available via Google Earth Engine (Gorelick *et al.,* 2017), or Open Data Cube (https://www.opendatacube.org/) coupled with advances in geospatial techniques to filter clouds and fill gaps in the RS imagery (Cao *et al.,* 2018; Zhou *et al.,* 2015) plus the now ubiquitous techniques of data mining and pattern recognition via machine and deep learning used for landscape mapping (Li *et al.,* 2019; Xu *et al.,* 2020), provide an opportunity to look back to the 1980s and capture the dynamics of land cover changes month-by-month and at 30 m spatial resolution. The Open Data Cube is a response to the challenge in terms of the acquisition, processing, analysis, and integration of rapidly increasing large, robust critical satellite datasets. We can use the high-resolution remote sensing images through Open Data Cube to dynamically characterize the region and identify the suitable areas for intensification.

Climate change is a critical issue for the coastal zone of Bangladesh and West Bengal - for example, the projected large economic impact due to expected greater coastal inundation in Bangladesh (Dasgupta *et al.,* 2014; Mainuddin and Kirby, 2021). Earlier work shows that climate variability is likely to dominate climate change in the region at least up to 2050 (CSIRO *et al.,* 2014; Jeuland *et al.,* 2013; Mainuddin *et al.,* 2021; Moors *et al.,* 2011). CSIRO *et al.* (2014) point out that Bangladesh is coping well with climate variability (*i.e.,* coping with the extreme floods, storm surges and droughts already experienced) which is likely to prepare the country for the impacts of climate change. Concurrently, the population of Bangladesh and West Bengal is expected to grow at least up to 2050. The growing population and economic development will increase demand and competition for water resources, exacerbating an already difficult position (Kirby and Mainuddin, 2022).

So, the logical next steps after CSI4CZ Phase 1 were to identify packages of resilient technologies suitable for different parts of the region with context-specific 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 table depths, soil 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 research methods of long-term risk evaluation.

Phase 2 Project

Thus, to reap the full benefits of investment in Phase 1 in this complex and challenging region, it was essential to strengthen the outputs of Phase 1 and to develop risk mitigation strategies and management practices, such as drainage, to address untimely rainfall and other challenges at the field level. We needed to continue our engagement with the farmers to strengthen their confidence in terms of practice adoption and risk mitigation. Accordingly, ACIAR funded the Phase 2 of the project for the period of 2021 - 2024, which aims to sustainably mitigate risk and scale-out profitable cropping system intensification practices achieved through integrated soil, water, and crop management in the salt-affected coastal zone of the Ganges Delta.

The main outputs include:

(i) Models (such as the crop model APSIM), tools (Data Cube and Google Earth Engine) and strategies which in combination provide an improved, multi-scale understanding including series of maps, management guidelines to mitigate the risk of untimely and unexpected events (untimely rainfall, extreme climate events, market failure, etc.) for improving crop productivity and increasing cropping intensity.

(ii) A suite of tested, farm-level crop (including recommended varieties), nutrient and water management options and tools that are suitable for current and future salinity conditions through demonstration in the farmers' field.

In 2019, we published some of the outputs of Phase I in a special issue on 'Cropping system intensification in the salt-affected coastal zone of the Ganges Delta' of the Journal of the Indian Society of Coastal Agricultural

Research (Vol. 37, No. 2). This special issue showcases some of the outputs of Phase 2 in the following papers.

List of papers

1. Mainuddin, M., Bell, R.W., Sarangi, S.K., Maniruzzaman, M., Pena-Arancibia, J.L., Gaydon, D.S., Karim, F., Monjardino, M., Glover, M., Brahmachari, K., Goswami, R., Anwar, M.M., Barrett-Lennard, E.G. and Yu, Y. (2024). Mitigating risk and scaling-out profitable cropping system intensification practices in the salt-affected coastal zone of the Ganges Delta. *Journal of the Indian Society of the Coastal Agricultural Research* **41**(2): 1-13. https://doi.org/10.54894/JISCAR.42.1.2024.148094.

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16. Saha, A., Ray, K., Goswami, R., Roy, K., Sarkar, S., Brahmachari, K., Ghosh, A., Nanda, M.K. and Mainuddin, M. (2024). Qualitative Evaluation of the impact of cropping system intensification in coastal saline zone of West Bengal, India. *Journal of the Indian Society of the Coastal Agricultural Research* **42**(1): 189-201. https://doi.org/10.54894/JISCAR.42.1.2024.147831.
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The key research questions for sustainable intensification of the cropping system in the Ganges Delta include:

1. How can we characterize the coastal zone and sub-divide the area to demonstrate and recommend suitable cropping technologies for intensification? These questions are addressed partly by Pena-Arancibia and Yu (2024).
2. What are the risks (climate, water, salinity, etc.) to increasing productivity of the *Aman*/*Kharif* rice and cropping in the *Rabi* season? What are the risks to adoption and expansion of the field-tested profitable cropping practices? How can these risks be mitigated? These questions are addressed by Akther *et al.* (2024), Islam *et al.* (2024), Karim *et al.* (2024), Khatun *et al.* (2024), Kundu *et al.* (2024), Mahmud *et al.* (2024), Naher *et al.* (2024), Paul *et al.* (2024), Sarangi *et al.* (2024a), Sarkar *et al.* (2024) and Zahan *et al.* (2024). Additional output can be found in Begum *et al.* (2023, 2024).
3. What are the best options for using available fresh water to increase production of dry season crops under current and changed future climatic conditions? How profitable and sustainable are these options? How do different cropping options affect the livelihood of the landless and poor farmers depending on livestock grazing in the dry season? These questions are addressed in Sarangi *et al.* (2024b, c). Additional output can be found also in Sarker *et al.* (2024).
4. 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? Bell *et al.* (2024) and Saha *et al.* (2024). Goswami *et al.* (2024) provides additional important information.

We have developed a web-based functioning frame work (https://biggsj.shinyapps.io/CSI4CZ/) which illustrates gridded APSIM simulations for 'rice - wheat' and 'rice - rice' simulations, as a function of sowing date, residue retention (with/without) and drainage (yes/no). This is a prototype version with considerable functionality to be added, such as other *Rabi* crops, different varieties, different climates, etc., and additional mapped variables (gross margins, irrigation water use, etc.). Also, the current results will be fine tuned. This is an integration platform which takes input from the land use characterization, future climate change from risk modelling, soil salinity maps from the land characterization, and profitability from the socio-economic component. Experimental and demonstration results are used in calibrating and validating the APSIM model, ground-truthing of the land use characterizations using remote sensing and developing the functional relationship of apparent soil conductivity acquired by EM survey with the yield of the crop.

Extensive surveys of farmers involved with project experiments and demonstrations underpin various socio-economic assessments, including partial budget analysis, whole-farm simulation, risk analysis, and adoption prediction (e.g., using ADOPT (https://adopt.csiro.au/) and Value-Ag (Monjardino *et al.,* 2020)). Guided by farm typology classification in the project region, we quantify the relative advantage and impact of our technologies in terms of profitability, adoptability, environmental sustainability, diversity, food security, gender equity, marketability, and resilience to future risks including climate change.

The project has a strong gender component and strives towards gender equitable outcomes. The project has increased women farmers' access to new agricultural technologies and associated advisory services to help offset the predominantly male-dominated extension services. Growing new rice varieties in the *Kharif* season, growing vegetables with rice in lowland rice fields, homestead cultivation of different vegetables, growing many crops in the dry *Rabi* season (ZT potato and garlic, watermelon, dry season *Boro* rice, etc.) increased women's knowledge, skill, confidence, and ability to make farm management decisions. During the COVID pandemic, women farmers who adopted these new technologies, were immensely benefited and provided strong livelihood support to their family. Women are expected to fully control the cash benefit from some of these crops in the absence of their partners, particularly in West Bengal. Group participation has increased the social capital of women, thus leading to capacity building and access to/awareness of other technologies, institutions, services, and markets. Increased confidence and collective decision-making have enhanced receptiveness to new ideas, along with other fringe benefits enjoyed by women farmers.

Our engagement through CSI4CZ Phase 2 was essential to ensure farmers develop full confidence in our interventions and practices. Across all our project areas, about 9,000 farmers (24% female) are reporting significant economic benefits from growing high-yielding varieties of *Kharif* rice (*Aus* and *Aman*), as well as *Boro* rice and different non-rice crops in the *Rabi* season. The project team's intervention is having significant community impacts. For example, in Bangladesh, large areas of fallow land and free-grazing cattle have given way to widespread farmer adoption of project technologies and a significant increase in cropped area coverage in all project sites. Farmers are willingly organizing themselves to construct temporary bunds to store fresh water for irrigation, livestock shelters are being built, and employment opportunities are attracting local farmers/labourers. Male farmers who moved to nearby districts earlier to work as farm labourer returned to work on their own land. Continuing our engagement consolidated our findings and strengthened the confidence of the farmers to a level where farmers are fully independent of project support. It is expected that this will have a long-lasting impact on the socio-economy and livelihood of the farmers including women and girls in the region.

CONCLUSION

Whilst there has been wide adoption of these practices throughout the region, there is however a real possibility that some practices will be disadopted, and gains will potentially be lost, once project support is withdrawn, along with reliable production inputs and information. To secure the gains made already, it is necessary to strengthen the resilience and sustainability of these emerging agrifood systems from a holistic net benefit perspective by integrating the climate resilient novel farming systems frame work, adoption of water-smart irrigation methods, shift adoption pathways towards assessing the relative advantage of suitable adaptation, development of operational tools and apps for farming system decision making, and capacity building.

CONFLICTS OF INTEREST

The authors declare no conflicts of interests.

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