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Cropping system intensification for smallholder farmers in coastal zone of West Bengal, India: A socio-economic evaluation

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Introduction: It is estimated that five out of six farms in the world are operating less than two hectares of land, called smallholder farmers, and they are producing over one third of the global food. Cropping system intensification research and interventions at farmers' fields could be one of the ways to improve the prevailing cropping systems. Understanding socio-economic issues are important for the successful implementation of improved or new cropping systems and for increasing farmers' income in the coastal zone of the Ganges delta. A socio-economic evaluation study was carried out to understand how far the suggested cropping options were feasible to smallholder farmers in the coastal zone; quantify the benefits due to the adoption of new cropping systems; how far those options were socio-economically suitable for the targeted smallholder farmers; and to identify the key factors that might be affecting the out-scaling of the evolved options to a larger group of farmers.

Methods: Baseline and endline surveys were conducted with 90 farmers before and after the demonstration of various cropping systems at farmers' fields. Techno-economic suitability of new crops and management options were evaluated through accounting benefits of adoption and identifying various constraints in adoption. Behavioral analysis was carried out to identify factors affecting large-scale adoption of the new/improved cropping systems evolved.

Results and discussion: The socio-economic survey quantified the increase in cropping intensity higher than the baseline level (123–142%) and reduced the *rabi* (winter/dry) season fallow area by 30–35%. The study identified farmers' preferred interventions were low-cost drip irrigation and mulching, zero-tillage (ZT) potato with straw mulching, improving soil quality with lime and green manuring, and vegetable-based cropping systems interventions. Although the economics of the evolved cropping systems were favorable, however, availability of freshwater stored in ponds/canals, and income from on and off-farm were the most important factors determining the adoption of new systems on a larger scale.

KEYWORDS

cropping systems, coastal zone, agricultural income, socio-economic impact, technology adoption

Introduction

Globally, around 40% of the world's population lives within 100 km of coastline (Small and Nicholls, 2003; Kummu et al., 2016) and most of the largest urban concentrations are on the coast. The current coastal urban population of 220 million is projected to almost double in the next 20–30 years (FAO., 1998). Indian agriculture comprises 263.1 million farmers, 138 million operational holdings, farming on 160 million ha, with an average holding size of 1.15 ha (Govt. of India, 2020). Coastal Zone in India covers 7,516 km of coastline (SAC (Space Applications Centre), 1992), spread over 9 States, 2 Union Territories, 2 Island Territories; 77 districts (69 on the mainland and others in the Island system), housing 171 million population (14.2 percent of India). The geographical area of the Ganges delta which is shared with neighboring Bangladesh is one of the most important parts of the coastal zone in India, and has great significance for food security, biodiversity conservation, and fisheries production (Mainuddin et al., 2019; Mandal et al., 2020). The region is endowed with rich and diverse natural resources. Agriculture, horticulture, aquaculture, animal husbandry, etc. are the primary livelihoods of the people living in the coastal zones of India but the productivity of all these sectors is much below the national average because of various constraints related to soil, water, and climate (Bandyopadhyay et al., 2011; Mandal et al., 2013; Burman et al., 2015). The socio-economic status of the population dwelling in coastal areas is also much below as compared to the national level. The Coastal region is likely to face severe challenges in the future due to the rise in sea levels following global warming (Mandal et al., 2019a,b; Mainuddin and Kirby, 2021; Mainuddin et al., 2021a). The management of the natural resources and sustenance of ecology in the coastal region are some of the vital issues in this Ganges delta. Major challenges to achieving the self-reliance goal for the region could be, managing the natural resources of the smallholder farmers with gainful engagement, uses of critical resources (land and water) sustainably, reducing the farmers' distress by scientific input management or compensating through direct benefit transfer schemes, managing environmental risk, enhancing marketable surplus through grassroots level institutional innovations (like farmers organization) and linking farmers to markets. The Human Development Report (Govt. of West Bengal, 2009) highlighted that the agriculture in the coastal district is turning out to be gradually un-remunerative, and observed a declining trend in the agricultural workforce and often leading to poverty due to high dependence on the primary sector. Despite having many constraints, farming in coastal regions has good potential to enhance farmers' income through the scientific intervention of soil and water resources (Mandal et al., 2015a, 2018b).

One of the ways to improve the agriculture-dependent livelihoods conditions of farmers can be achieved through the promotion of viable cropping systems suitable for the smallholder farmers in the region (Mandal et al., 2017; Ray et al., 2018, 2020; Bell et al., 2019; Remesan et al., 2021). Agricultural production systems evolved around the principles of sustainable intensification to increase agricultural productivity with minimum environmental and social trade-offs. System intensification is now widely recognized as an important pathway to food security in developing countries (Garnett et al., 2013). Farmers' decision of choosing the cropping system in the coastal region is influenced by several biotic and abiotic factors including waterlogging, salinity, lack of good quality irrigation water, capital inadequacy, agricultural risk, and uncertainties in production systems (Kabir et al., 2017a, 2018; Krupnik et al., 2017; Aravindakshan et al., 2018; Hasan and Kumar, 2020). Often, despite having the available options, farmers sacrifice the expected higher return through an intensive cropping system due to these prevailing multiple stressors as the resource-poor farmers prefer to remain safe than sorry in an unforeseen situation (Mandal et al., 2019a,b). Several suitable cropping system options for coastal Bangladesh were identified, but their adoption was challenged by factors such as limited access to stress-tolerant varieties, extension services, and affordable agricultural credit, combined with high production costs, variability in crop yields, and output prices (Kabir et al., 2017b; Mandal et al., 2018a). Agricultural development policies in the coastal region have been emphasized mainly on two strategies, developing salt-tolerant crop varieties and utilizing rainwater harvested in canal systems or creation of on-farm reservoirs (Sharma et al., 2016; Mandal et al., 2017; Kumar and Sharma, 2020). *Kahrif* (rainy/wet) season is extensively cultivated but most of the land in *rabi* (winter/dry) season remained fallow due to a shortage of good quality irrigation water and therefore targeted by the policy planners to achieve higher cropping system intensification (Aravindakshan et al., 2018; Mainuddin et al., 2019; Yadav et al., 2020). Therefore, enhancing crop production, particularly by growing a crop in the typically-fallow dry season is a key strategy that has a direct positive impact on alleviating poverty in the Ganges delta region (Mainuddin et al., 2021b), and productivity in the coastal zone can be increased by several folds (Bhattacharya et al., 2015; Ritu et al., 2015; Saha et al., 2015).

Key challenges for achieving higher cropping intensifications are: excess water in *kharif* season causing a waterlogged situation; availability of less water (good quality) during *rabi* season (dry) resulting in salinity building up on the soil surface that limits the number of choices of crops (Mandal et al., 2011a; Humphreys et al., 2015); the trade-off between off-farm and on-farm income often becomes unfavorable to agriculture due to low return; in coastal saline conditions, particularly in *rabi* season cropping becomes more risky and uncertain that leads to large areas under fallow land. Historical records indicated that in the Delta region on average, 4.29 cyclones originated annually in the Bay of Bengal, constituting only 5–6% of the global total and these are very severe among all cyclones (Paul, 2009; Alam and Dominey-Howes, 2014; Paul and Rashid, 2017). Climate fluctuations are likely to alter the profitability and suitability of cropping choices and patterns across the Delta region (Yu et al., 2010) which are major challenges to farming communities. Also, the climate change projections indicated future spatio-temporal challenges for yield stability over time, especially for less diversified agricultural systems (Berzsenyi et al., 2000; Lin et al., 2011; Urruty et al., 2016), hence stressed the importance of cropping system research and adoption by the smallholder farmers in the region. All these also influence large-scale seasonal migration for alternative livelihoods; and poor road infrastructure and market linkages lead to higher income instability (Tur-Cardona et al., 2018; Bell et al., 2019; Mandal et al., 2019a). Research recommendations on cropping system intensification in coastal zones are often drawn from the improved yields and return of the crops, based on researchers' managed experimental findings (Dillon and Hardaker, 1993; Childs and Kiawu, 2009; Neumann et al., 2010; Fisher, 2015), ignoring the socio-economic suitability of the evolved options. Often recommended new cropping systems require higher investment to turn the options into practice or return to scale may not be as attractive or easy to adopt, as it is perceived to be, becomes a key determinant factor to affect smallholder farmers' decisions. Thus, analyzing farmers' preferences and desires are the pre-requisite for consideration in policy decision for its success (Dolinska, 2017; Aravindakshan et al., 2018). Farmers' preferences for alternate cropping options are studied by quantitative ranking procedures (Soltanmohammadi et al., 2010) or qualitative focus groups (Mekoya et al., 2008). The extent to fulfill the household goals depends on managerial skills and also considerable luck with the weather and other uncertain environmental factors without any control of the households (Anderson and Dillon, 1992). While recommending the strategies, the cumulative interaction of the biophysical and socio-economic elements over time needs to be considered (Norman et al., 1981; Pingali et al., 1987; Walker and Ryan, 1990). Socio-economic studies can highlight the enabling strategies required for the out-scaling of such recommended package of practices in the targeted areas. Therefore, along with the experimental findings, it is imperative to study the socio-economic suitability of the new cropping systems that are suggested. In view of these issues, on-farm research on cropping system intensification in the salt-affected coastal zones of West Bengal, India was implemented with the objective of evolving new cropping systems or improving the existing cropping system suitable for the smallholder farmers in the region. This socio-economic impact analysis was carried out with the objectives of (1) understanding the existing cropping practices and comparing those to the proposed change that was evolved/ improved through the cropping system intensification research project; (2) identifying various socio-economic factors that determine the adoption of new/evolved cropping system options; (3) understanding various knowledge gained by the farmers through demonstration of cropping systems at farmers' fields and their potential use; and (4) how far such options were financially feasible to out-scale to a large number of farmers in the coastal saline zone through public investment.

Materials and methods

Study area and site description

The study area is located on Gosaba island of South 24 Parganas district in the Ganges delta. The coastal zone of the Ganges Delta in India, known as *Sundarbans,* is comprised of a geographical area of 9,630 km^2 spread over 102 islands, and among these 54 islands have human settlements. The area under human inhabitation is 4,444 km^2, falling under two coastal districts of West Bengal, South and North 24 Parganas. The Indian *Sundarban* region (Indian part of the Ganges delta) accounts for 33% (0.44 million ha) of the total area (1.33 million ha) of these two coastal districts. Out of the total population of the *Sundarban* region (4.43 million), almost 74% are from South 24 Parganas and the rest (26%) are from North 24 Parganas district (Census of India, 2011). Among the total workers (1.67 million) in *Sundarbans*, around one-fifth (20%) are agricultural laborers and 12% are cultivators, directly thriving on agriculture. The economy of coastal areas of West Bengal is mainly dependent on agriculture and allied activities, comprising crop cultivation, fisheries, animals, and forestry, which influences the livelihoods

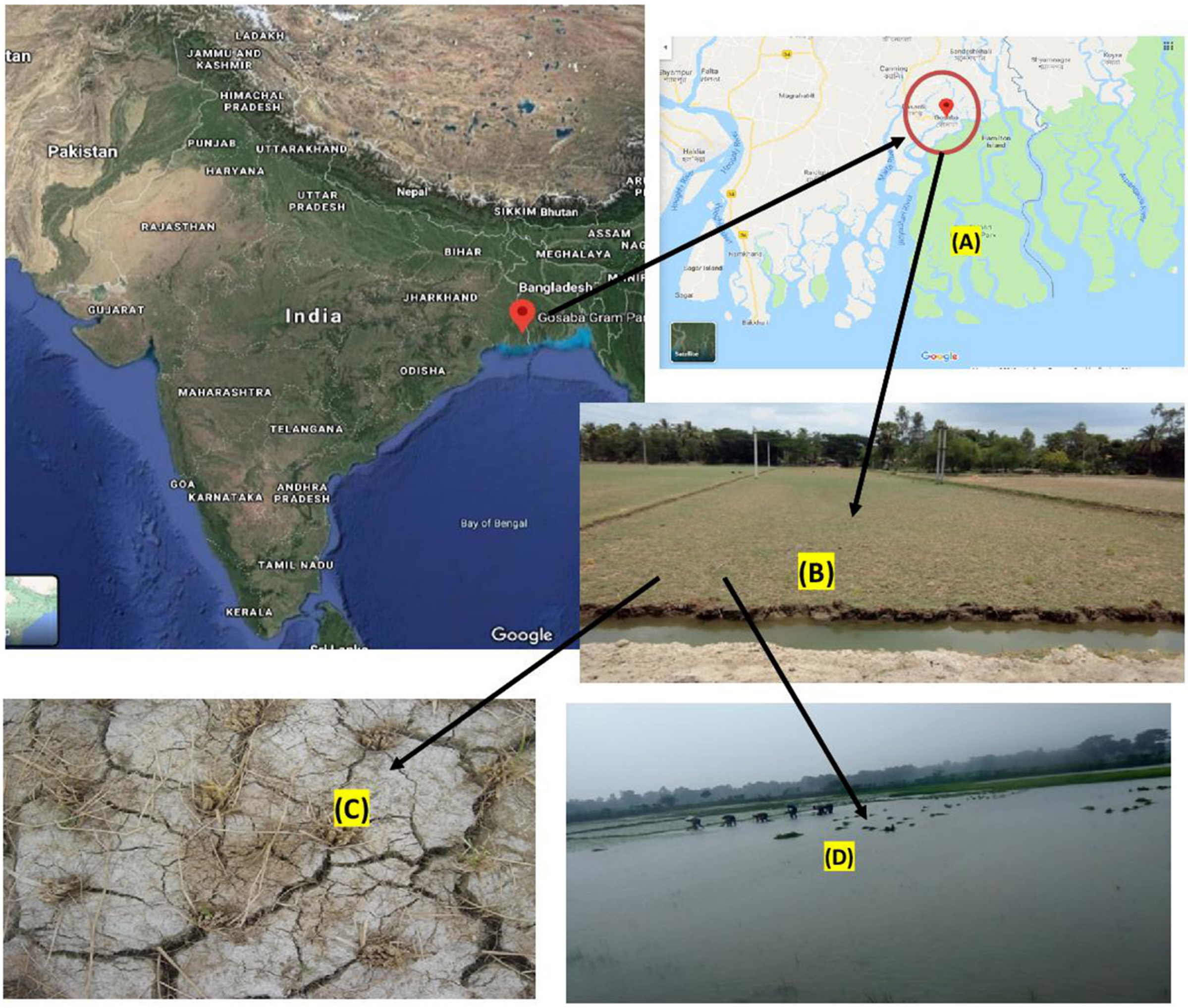

FIGURE 1
Location of the study area **(A)** and the physiography **(B)** of the coastal zone during *rabi (dry/winter)* **(C)** and *kharif (wet/rainy)* season **(D)**.

of millions of rural households in the region. The cropping system in coastal West Bengal is dominated by *kharif* rice (86%) followed by *rabi* rice, and vegetables in main fields and in homestead lands. Homestead production system is an integral part of daily household activities and produces food (fruits, vegetables, fish, and livestock) for household consumption and contributes significantly toward meeting daily food and nutrition requirements and generates cash income when surplus is produced on a limited scale (Mandal et al., 2015b; Goswami et al., 2021). Drainage congestion leads to prolonged waterlogging is one of the major issues for coastal agriculture in the coastal area (Ghosh and Mistri, 2020). Agricultural operation on the island is primarily rain-fed as the availability of groundwater in the coastal zone is extremely limited and often withdrawal becomes uneconomical for use in agricultural production. Supplementary irrigation depends on the collection of rainwater from the monsoon season in ponds and canals. The rainwater harvested and stored in ponds or canals is normally used for irrigation during the *rabi* season. A multidisciplinary research project on improving cropping system intensification was carried out in this coastal saline zone of West Bengal, India from 2016 to 2020 (Figure 1). A number of field experiments (8) were undertaken at the farmers' field under the supervision of a team of agro-scientists covering experts from agronomy, soil science, soil and water conservation specialist, agricultural engineers and economist (ACIAR, 2020). Keeping in view of resource availability of smallholder farmers and the actual challenges of managing soil and water, different cropping system experiments were conducted. This ensured the creation of several options for the farmers so that they can choose the best combination of crops as per their needs and suitable to their resource base.

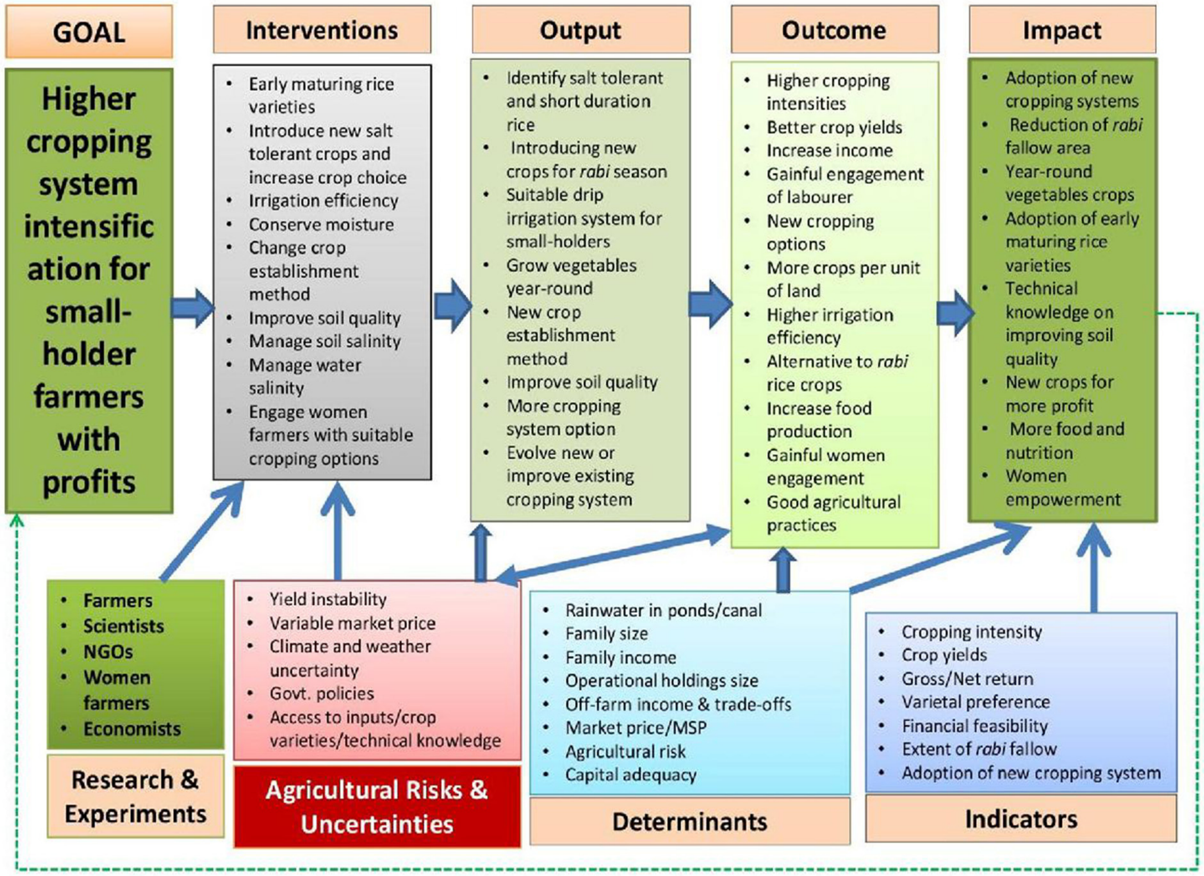

FIGURE 2
Framework for cropping system intensification interventions and outcomes.

Framework for cropping system intensification interventions and outcome

Smallholder farmers with an operational area below two hectares of land are the most dominant category of farmers in the coastal zone of West Bengal, India (Supplementary Figure A1 in Annexure I) and they manage their land with limited available resources (land, good quality water, and finance). Keeping in view the limited availability of freshwater water resources and the coastal stressed environment (salt-affected soil), various field experiments were carried out to improve the cropping system intensification with the goal to enhance agricultural income. Research experiments were initiated with active consultation of the farmers to prioritize the problems and to find a need-based solution to facilitate the easy adoption of new or improved cropping systems generated through these interventions. Possible agricultural risks and uncertainty like salinity and instability of crop yield due to climatic factors were kept in mind to design these cropping intensification experiments. Key strategic research interventions promoted were, introducing early maturing rice varieties aligning with farmers' preferences, introducing salt-tolerant crop varieties (rice and non-rice), increasing irrigation water use efficiencies through drip irrigation systems, water conservation, and utilizing the field water for crop production, improving soil and water quality through applying amendments and green manuring and finally keeping in view of the activities and role of women farmers in managing the cropping systems. The outcomes of the experiments were expected to be affected by several determinants (bio-physical and socio-economic) during the experimental period and post-project period. Socio-economic factors were identified and considered while conducting the socio-economic impact study. All these factors affecting the adoption of the cropping systems were analyzed. The conceptual framework of the study is given in Figure 2.

Data source, baseline, and end-line surveys

A baseline survey was conducted to collect primary data during 2017–2018 from 90 farmers in the study village, *Sonagaon* under the Gosaba community development block of South 24 Parganas district, West Bengal. Almost all farmers in the area was belonging to smallholder categories, and random sampling was followed for the selection of the farmers. The list of households dwelling in the village was obtained from the local government office (called *gram panchayat*) and the sample farmers were drawn randomly. Data were collected through a personal interview, interviewing key informants, and conducting focus group discussion (FGD) with the farmers by using a pre-structured and tested survey schedule. Responses of farmers were recorded to understand their experiences/opinions on cropping intensification interventions while they managed farmlands under scientists' supervision and also by themselves ICAR-CSSRI CSI4CZ (2020). Detailed information on farm size, educational status, occupation, cropping systems practiced, cropping pattern, income sources, costs and returns of crops grown, production and marketable surplus of crops, selling of crops, agricultural risks, and constraints in farming were collected. Baseline information on socio-economic characteristics and economics of cropping practices of the farmers was analyzed by employing farm budgeting analysis.

During and after 4 years, the project interventions were spread over a large number of farmers but the end-line survey was conducted during 2020–2021 from the same 90 farmers to understand the impact of interventions. To understand the farmers' response/perception, feedback surveys of the farmers on all different interventions made through the project period was also conducted. The primary survey was conducted through a personal interview based on a pre-structured tested survey schedule. Also, some qualitative information was collected through different ways such as FGDs (15–20 farmers in each group) and telephonic interviews with the key informants. The baseline and end-line survey data were compared (before and after the project) to analyze the socio-economic impact of the various interventions made during the project. Changes in cropping area at the farm households level were recorded due to the adoption of the cropping systems as compared to the baseline situation. The socio-economic impact assessment also included identifying new knowledge/experience gained by the farmers during the active demonstration of the experiments and possible changes that they might be adopting in their existing cultivation practices. The study also recorded key knowledge gained that could be helpful for addressing the critical constraints and have implications for larger policy perspectives, relevant to the coastal zone as a whole. Besides, women folk also plays a very active role in almost all the farming operation in the coastal zone in West Bengal, India, therefore separate FGDs (4 number) were conducted with the women farmers. During each FGDs 8–10 woman farmers were invited to discuss their role and activities in the farming operation in the existing practices, likely changes in the workload while adopting the new cropping systems, and their opinion regarding the adoption of new interventions/options suggested.

Economics of cropping systems

The economics of the crops has been analyzed through farm budget analysis, following the norms of cost of cultivation methods of Commission for Agricultural Costs and Prices (Govt. of India, 2008). Costs components included, input costs incurred on seed, fertilizers, irrigation, human labor (hired and own) required for all activities (land preparation, sowing, applying irrigation/pesticides/fertilizers, intercultural operation, harvesting, etc), machine labor (mainly power tiller), fertilizers, organic manure/compost, irrigation charges, pesticides (insecticides/fungicides/herbicides), interest rate on working capital as the opportunity cost of capital expenditure (maximum 6 months for annual crops), depreciation charges, and miscellaneous (like watch and ward, unforeseen expenditures, etc) expenses. Cost of labor has been calculated based on open market prices of labor hiring charges and the cost of family labor has been imputed with same rate. Gross return has been calculated based on the gross value of output (production multiplied by farm-gate prices) plus the value of by-product. Net return has been calculated by deducting the total cost of cultivation from the gross value of output.

Preference analysis of kharif rice varieties

Rice in both *kharif* and *rabi* seasons is the main crop in the coastal areas. One of the key strategies to achieve higher cropping system intensification was to promote suitable short-duration *kharif* rice varieties so that fields will be ready early, facilitating intensive *rabi* season cultivation, then alternate to *rabi* rice. Thus, ranking analysis for varietal preference and adoption behavior of farmers was carried out for *kharif* rice only. Varietal preferences were largely dependent on several criteria, varietal attributes, and the expectations of farmers (Burman et al., 2018). Farmers' choice of a particular rice variety was influenced by several attributes like salinity tolerance, the capacity to withstand waterlogging (plant height), tolerance to pests and diseases, grain and straw quality, tolerance to lodging, and duration of the crop. To rank various preference criteria, the rank-based quotient (RBQ) analysis was employed (Burman et al., 2018). The criteria used by farmers for their selection of the most preferred variety were listed first, and then they were asked to rank those criteria according to their individual priority on a scale of 1–5. The most preferred criteria were ranked as 1, and the least preferred as 5. The analysis allowed the ranking of farmers' preferences based on RBQ values. The RBQ is a problem identification technique, mathematically presented as follows:

$$RBQ = \sum\nolimits_{j=1}^{n} \frac{fi\,(n+1-i)*100}{N*n}$$

where N = total number of farmers, n = total number of ranks (there are five ranks, n = 5), i = the rank for which the RBQ is calculated (for a problem), and f = number of farmers reporting the rank *i* (for the problem). This analysis was carried out to prioritize the rice varieties to be grown as per the farmers' preferences.

Identification of constraints

Agricultural production systems for smallholder farmers are affected by different social and economic factors which determine the adoption behavior of new technologies (Mandal et al., 2019b). A detailed discussion was held with the farmers to identify the critical constraints experienced by the farmers. These factors were of different types such as environmental constraints (soil and water salinity, water availability); institutional (input availability in time and quality, access to technical know-how,); and economic constraints (input cost, access to markets, capital adequacy, agricultural production, and marketing risks). Farmers were asked to respond to a list of all these constraints and the percentage of farmers who responded to each of these constraints was recorded. Likely solutions or options to address these constraints were also discussed and different new knowledge gained from the project interventions might be useful to mitigate those problems, was highlighted.

Statistical analysis for mean differences

A paired '*t*' test was applied to compare the changes in cropping area, cost, and return for the cropping systems before and after the interventions made through this project. The hypothesis was:

H_0 = area under crops, cost, or return structures was remaining the same before and after the interventions.

H_1 = area under crops, cost or return structures were different before and after the interventions.

The value of '*t*' was calculated as below:

$$t = \frac{\overline{d}}{SE(\overline{d})}$$

and

$$SE\left(\overline{d}\right) = \frac{s_d}{\sqrt{n}}$$

where, $\overline{d}$ = Mean difference in area, cost or return before and after interventions $SE(\overline{d})$ = Standard error of mean area, cost, or return before and after the interventions.

s_d = Standard deviation of mean area, cost, or return before and after the interventions,

n = number of observations on area, cost, or return before and after the interventions.

Factors affecting adoption of new/improved cropping systems

Adoption behavior and decision-making of farmers to adopt new/improved cropping systems depends on several socio-economic factors. Various socio-economic factors that may determine the adoption of new/improved interventions were analyzed through behavioral analysis. The expected sign and justification for the inclusion of these variables area explained in Supplementary Table A1 in Annexure II. The cropping intensity of individual farm households' level was estimated during baseline and endline surveys along with different key socio-economic parameters that were likely to affect farmers' decision-making. Achieving higher cropping intensity as compared to the estimated baseline level of cropping intensity (up to 142%) by the individual farm households, after the project intervention, was desirable. The cropping system experiments were conducted in the fields of a few farmers in a small part of their lands and based on the performance of crops, different cropping systems were promoted to other farmers and subsequently many of them adopted the new cropping systems, for which their cropping intensities increased. Therefore, farmers' who practiced the new cropping systems and achieved the cropping intensities (including the farmers who had provided part of their land for experiments) above the baseline level (142%) were assigned 1 in the binary dependent variable (*Zi*), and 0, otherwise. The behavioral analysis was done using a binary logistic regression model to identify the different key determinants of the adoption of new cropping systems toward achieving higher cropping intensity in the coastal zone.

The framework for binary logistic regression is specified as:

$$\mathrm{Yi} = \mathrm{g}\ (\mathrm{Z_i}) \tag{1}$$

Here Z_i is an index variable (or vector of X_{ki} independent attributes) and formally can be written as:

$$\mathrm{Z_i} = \ln\left(\frac{\mathrm{P_i}}{1-\mathrm{P_i}}\right) = \alpha + \beta_{\mathrm{k}}\mathrm{X_{Ki}} \tag{2}$$

$$P_i = F(Z_i) = F(X_i) = \frac{1}{1+e^{-z_i}} \tag{3}$$

Once this equation is estimated, *P* can be calculated as:

$$= \frac{1}{1+e^{-(\alpha+\beta_k X_{ki})}} \tag{4}$$

where,

Y_i = Status of farmers (Y = 1 for farmer who has achieved higher cropping intensity than baseline average and 0 otherwise);

Z_i = An underlying and unobserved response for the ith farmer. When Z exceeds threshold Z^*, the farmer takes the decision to adopt, otherwise not.

X_{ki} = kth explanatory variable for the ith farmer;

$i = 1,2,3, \ldots, N$, where N is the number of farmers;

$K = 1,2,3,\ldots, M$, where M is the total number of explanatory variables;

α = constant;

β = unknown parameters, and e denotes the base of natural logarithim with a value ∼2.718.

The variables included in the model, were:

Zi—a binary variable, 1 = farmer achieved higher cropping intensity as compared to baseline value (142%), 0 otherwise,

X_1–Operational holding size (average in ha household^{-1}, excluding homestead area),

X_2–Homestead area (average in ha household^{-1}),

X_3–Income from agriculture (in ₹ year^{-1} household^{-1}),

X_4–Off-farm income (in ₹ year^{-1} household^{-1}),

X_5–Number of adult male (Number household^{-1}),

X_6–Number of adult female (Number household^{-1}),

X_7–Number of perennial ponds (Number of ponds household^{-1} available having water for 9 or more months),

X_8–Primary occupation (If agriculture = 1, 0 otherwise),

X_9–Age of respondents (Years in number),

X_{10}–Status of education (Number of years of schooling), and

X_{11}–Distance of nearest market fields (in km),

All these variables were expected to influence, either positively or negatively, farmers' decision to adopt new/improved cropping systems for enhancing their level of cropping intensification and farm income.

Results and discussion

Socio-economic status of farmers and economics of cropping system practices

Most farmers (98%) in the study area belonged to the marginal categories and operated less than a hectare of land (average of 0.48 ha). The livelihood pattern of the farmers was dominated by agriculture as the primary occupation (44% of the farmers), but the agricultural income was meager (around ₹21,000 hh^{-1} year^{-1}), not sufficient for the families, therefore migration (32%) to other places for the search of alternative livelihoods was quite common. The cropping pattern was dominated by *kharif* rice (86% of gross cropped area) followed by *rabi* rice and a number of vegetables in small plots (mostly as mixed cropped plots). The Homestead production system was (average of 0.07 ha) an integral part of their production system, having a good contribution in terms of providing household food security to the farmers. The baseline cropping intensity was estimated to be 123 and 142% in the study area, with and without the inclusion of homestead area, respectively (Supplementary Table A2 in Annexure II).

Crop selection is a key management decision to improve yield stability over time in the coastal region of Bangladesh to improve the livelihoods condition of smallholder farmers, also ascertained by Carcedo et al. (2022). The interventions on cropping system intensification successfully evolved new or improved the existing cropping systems. A number of cropping system options were found feasible to increase the farmer's income from agriculture as compared to the existing cropping system. Dominant cropping systems were *kharif* rice-fallow, *kharif* rice-*rabi* rice, *kharif* rice-mixed vegetables, *kharif*-rice-potato (ridge) and homestead production system. Based on the experiments, cropping systems such as *kharif* rice-green gram, *kharif* rice-ZT (zero-tillage) potato, *kharif* rice-ZT potato-green gram, *kharif* rice-ridge potato, *kharif* rice-maize, and *kharif* rice-vegetables were suggested. Besides, the vegetable–vegetable–vegetable cropping system was also evolved by using solar-powered drip irrigation systems (Table 1, also Supplementary Tables A3, A4 in Annexure II). The most profitable cropping system was *kharif* rice-ZT-potato (output–input ratio 2.33), followed by *kharif* rice-vegetables (2.31), *kharif* rice-ZT potato-green gram (2.28), *kharif* rice-green gram (1.82), *kharif* rice-maize (1.71), *kharif* rice-ridge potato (1.61) and *kharif* rice-fallow (1.36). In terms of net return, *kharif*-rice-ZT potato-green gram cropping system provided the highest profitability (₹2,05,079 ha^{-1}), followed by *kharif* rice-ZT potato (₹1,62,290) and vegetables–vegetables under solar drip system (₹20,059 for 1,000 m^2 area). All the evolved cropping systems provided higher profitability as compared to the existing cropping systems (Mandal et al., 2020). Besides, the proposed cropping system intensification has the potential to increase the cropping intensity to 200–300% in the study area as compared to the existing 123–142%. Alam et al. (2021) also concluded in a study in coastal Bangladesh that the crop diversification in the existing rice-based (boro) cropping system with the introduction of the high-yielding potato, cucumber, and *T.* Aus rice, improved the system productivity, profitability, and sustainability in terms of higher gross margin (by 74%), net return (double) and benefit-cost ratio (BCR) (1.69 vs. 1.44). The improved cropping system increased the gross return by 2,666 US$ ha^{-1} (49%) and net return by 1,616 US$ ha^{-1} (double) as well as higher BCR (1.69) as compared to the existing system.

Preference analysis of kharif rice varieties

The preference analysis was done after *kharif* rice harvest to understand the key attributes of rice preferred by the farmers. This ranking analysis was carried out with 20 farmers who participated in the rice varietal trials. Ranking analysis through RBQ score indicated yield was the major factor to choose a rice (*kharif* season) variety followed by resistance to lodging, duration of crops, capacity to withstand waterlogged (even submergence sometimes) situation or plant height, pest and disease resistance, quality of

TABLE 1 Cropping system intensifications and profitability in coastal zone of West Bengal, India.

Cropping system	Total cost (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	Output-input ratio
Existing (farmers practices)				
Kharif rice-fallow	38,393	52,350	13,957	1.36
Kharif rice-*rabi* rice	93,110	1,39,294	46,184	1.50
kharif rice-ridge potato	1,71,905	2,25,150	53,245	1.31
Evolved/improved (experimental plot)				
Kharif rice-fallow*	38,046	80,835	42,789	2.12
Kharif rice-green gram	63,384	1,15,635	52,251	1.82
kharif rice-ridge potato	1,59,824	2,57,415	97,591	1.61
Kharif rice-ZT potato	1,22,125	2,84,415	1,62,290	2.33
Kharif rice-ZT potato-green gram	1,60,171	3,65,250	2,05,079	2.28
Kharif rice-maize	95,031	1,62,278	67,247	1.71
Vegetable-vegetable-vegetable through Solar drip irrigation system (for 1,000 m^{-1})#	15,360	35,419	20,059	2.31

**kharif* rice -fallow system was improved over the farmers' practices in terms of soil management (e.g., lime/rock phosphate application for acid sulfate soil management along with green manuring) and introducing early maturing/submergence/waterlogged tolerant rice variety.

#Average area under experimental mixed vegetables crop plot was 725 m^2 and the calculation is on the basis of 1,000 m^2, @ Rabi rice was not under experiments. Source: primary survey by authors (2017–2018 and 2018–2019). Adapted from Mandal et al. (2020). 1 USD = INR or ₹70 (approximately) as on January 2021.

straw, grain quality and tolerance to salinity (Table 2). Different motivation factors that influence farmers' decision or willingness to choose their varieties indicated that the farmers' decision to change a rice variety remained unchanged when the incremental yield was obtained to the extent of 15% (Mandal et al., 2016). Under a saline environment, the instability of yield was quite high and the farmers have a rational expectation, therefore, farmers' willingness to change a variety remained indifferent up to incremental yield by 15%. Keeping in mind these attributes preferred by the farmers, the rice varietal selections for the experiments were made, subsequently (for example, the *Amal-Mana* rice variety was replaced by CR-1017 or CR1018 after the first year of interventions). The preference analysis indicated that yield was the most dominant factor to choose a rice variety by the farmers followed by resistance to lodging and duration of crop. Early-maturity rice variety was more preferred because it created the possibility of taking additional crop in subsequent seasons.

Socio-economic impact of cropping system intensification

Adoption of new/improved cropping systems

As the cropping systems experiments progressed more and more farmers participated and became active participants in the project. The project interventions also included leased-in/share cropper farmers enabling a higher level of community participation which increased the enthusiasm among the farmers and their participation was very active. The activities were initiated during 2016–2017 with 61 collaborative farmers, which increased to 111 farmers in 2017–2018, 188 farmers in 2018–2019, and 338 farmers in 2019–2020. Besides these collaborative farmers, the project activities were also extended to 214 farmers (other) either through input or technical support during 2016–2017 covering 42 ha, increased to 304 farmers (45 ha) in 2017–2018, by 2019–2020, the project activities covered over 700 numbers of farmers/farm women toward increasing the cropping intensity and agricultural livelihoods. The technical/input support was extended to a large number of farmers as per their willingness to adopt the new cropping systems. New crop varieties for potato, rice varieties (short duration or submergence tolerant), maize or rock phosphate as soil ameliorants for acid saline soil were made available to the farmers through the project interventions. Farmers continued to practice the new cropping systems and different socio-economic benefits were accrued (Ray et al., 2019; ICAR-CSSRI CSI4CZ, 2020). Besides, training on improved cropping management practices and varieties was imparted to about 685 farmers (470 male and 215 female) in 25 numbers of events. The endline survey indicated that all collaborative farmers and over 65% of other farmers adopted new/improved cropping systems in the study area.

TABLE 2 Ranking of farmers criteria for preferring rice varieties.

Preference criteria	Ranks (*kharif* rice)					RBQ score	Rank
	1	2	3	4	5		
Yield	6	6	3	3	1	46.67	1
Tolerant to salinity	1	0	1	3	3	11.33	8
Capacity to withstand waterlogging/plant height	2	2	2	4	3	23.33	4
Pest and disease resistant	2	1	2	2	3	18.00	5
Quality of straw for thatching/fodder/fuel	1	3	2	2	3	20.00	6
Resistance to lodging	4	4	3	2	2	34.00	2
Grain quality for better market price	1	1	3	2	3	16.67	7
Duration of crop	3	3	4	2	2	30.00	3
No of observations (N)	20	20	20	20	20		

Impact of interventions on prevailing cropping practices

Changes in the cultivation practices of farmers were analyzed for both *kharif* and *rabi* seasons. The project was primarily targeted to increase cropping systems intensification during *rabi* season, however, also involved some activities in improving *kharif* season rice, such as the selection of early maturing rice varieties, establishment methods, amelioration of acid saline soils through lime/rock phosphate application along with green manuring and technology on vegetable cultivation in sacks (bags filled with soil) along with *kharif* rice. A comparison of farm-level cropping area before and after the project, indicated that 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 rice fields, higher net return was realized (Table 3). Additionally, an average net return of ₹20,206 was obtained from 1,153 m^2 cultivated area due to rice-plus-vegetable cultivation in sacks (bags) as compared to ₹1,195 from conventional rice cultivation alone in the same area. The impact of the project interventions was more visible in *rabi* season cultivation. A significant change in area and production was observed for potato, green gram, lathyrus, and vegetables. All these expansions in areas successfully reduced the extent of *rabi* season fallow area (30–35%) in the study area. Additional crops were taken during *rabi* season with higher cropping intensification, and resulted into higher production and income. Overall, the interventions were successful to increase the cropping intensity to around 202% from 123 to 142%. An increase in cropping system intensification was recorded even higher (300%) for the vegetable-vegetable-vegetable cropping system under a solar-powered drip irrigation system (Mandal et al., 2020). 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. It indicated, with a 19% increase in expenditures, the average gross return from the cultivation (households^{-1}) increased by 46%. Out of this total increase, a higher return was obtained from *rabi* season cultivation (88% increase) as compared to *kharif* season cultivation (42%). In both seasons, expenditures and returns were increased but the incremental return was higher in *rabi* season as compared to *kharif* season, and also indicated that interventions in the project were successful.

Farmers' perception on different interventions for cropping system intensification

During the project period, several interventions were attempted and demonstrated with the active participation of the farmers. Farmers' perception of these interventions was recorded on the basis of (a) percentage of farmers who liked the intervention and were willing to adopt, (b) they liked the interventions but were not sure to adopt due to some specific reasons like suitable land availability or capital inadequacy, and (c) farmers who were undecided whether to adopt the specific interventions (may need more experiments to gain confidence). Also, the reasons for their responses (yes or no) were recorded for each of these interventions. The most preferred interventions reported by the farmers were, ZT potato (Sarangi et al., 2018, 2020), vegetables in sacks with *kharif* rice, straw mulching, green manuring, lime applications, and growing new crops like broccoli, green gram, mustard, sunflower, maize and other vegetables (Table 4). The low-cost drip irrigation method, direct seeded rice, and drum seeded rice method was also preferred by the farmers but they were not quite sure whether to adopt on a large scale, primarily due to erratic rainfall pattern and operating very small area of land. Overall, it was realized that farmers prefer interventions that require less water and resources but give higher production (laborer and fertilizers), conserved moisture, improved soil quality, and provided

TABLE 3 Cultivation practices before and after the project interventions.

Cultivation practices	**Major varieties/crops**	**Average area (ha households^{-1})**		**'*t*' value**	**Implications**
		Before	**After**		
***Kharif* season**					
Kharif Rice	*CR 1017, CR1018, CR1075,Prateeksha, Swarna*	0.43	0.43	0.53319^{NS}	No change except few varieties and additional return from vegetables in rice fields
Mixed crop/homestead plot (non-rice)	*Bittergourd, snake gourd, basella, okhra, colocasia, brinjal, cucumber*	0.05	0.07	0.47055^{NS}	No area change, increased production by better seeds
Vegetables with *kharif* rice	*Bittergourd, snake gourd, cucumber, bottlegourd*	0.00	0.11	–	Additional cropping intensifications with rice in *kharif* season
***Rabi* season**					
Rabi rice	*Lal minikit (WGL 20471), Sada minikit (IET 4786)*	0.21	0.24	0.33385^{NS}	3% additional farmers (from 19 to 22%) grew *rabi* rice as compared to baseline
Potato	*Kufri Pukhraj, Kufri Jyoti*	0.02	0.06	3.59765***	Increased area and production significantly
Moong/Lathyrus#	*Sonamoong, Chaiti moong*	0.02	0.07	2.9014**	Increased area and production significantly, decreased *rabi* fallow
Vegetables, mixed vegetables plot (non-rice)	*Brinjal, tomato, chili, cucumber, Cabbage, Cauliflower*	0.01	0.05	2.6290**	Number of crops introduced, more options, increase production and return

NS indicates not significant, ** and *** indicates significant at 10 and 5% level of significance. #Scientific names of moong and lathyrus are Vigna radiata and Lathyrus sativa, respectively. Vegetables with *kharif* rice was first time introduced cropping systems in the study area, hence 't' test was not required.

vegetables throughout the year. Key reasons for not being able to adopt the new interventions despite they liked was a lack of suitable land area and uncertainty of availability of quality inputs.

New technical knowledge and likely implications on cropping practices

The project activities in the study area helped farmers to acquire new knowledge of cultivation practices and cropping systems. Based on these experiences, farmers also reported adopting some changes in their future cultivation practices. Results of the ZT potato cultivation with rice straw mulching helped to understand that the success of this technology depends on the optimum depth of straw mulching, proper nutrient application, use of water-soluble fertilizers, use of organic manure, and maintaining recommended spacing (Table 5). The low-cost drip irrigation system was good in terms of growing more crop with less water and the number of vegetables it was feasible to grow throughout the year. The solar-powered drip irrigation system can be adopted if the subsidy (80%) is provided by the government. Growing vegetables in sacks along with the rice was easy, and early sowing of crop varieties helped to grow additional crops, which otherwise remained fallow during post-*kharif* season. Following good agricultural practices like green manuring (mainly *Sesbania* sp.), recommended doses of fertilizer, and lime application in acid sulfate soil can reduce the cost of cultivation while providing better production and return. Options for several new crops (maize, capsicum, sunflower, broccoli, onion, garlic) were successfully demonstrated in farmers' fields and they were confident to choose among those alternatives. Besides, all the knowledge was also shared among the farmers through farmers-farmers interaction. They reported that around 47% of the collaborator farmers discussed their knowledge with 11–20 fellow farmers; 32% discussed with 1–10 fellow farmers and 11% of the farmers discussed with 21 and above other farmers. Overall, on average each farmer discussed their activities with around 15 other farmers and many of them were willing to adopt some of the interventions on their own in other areas of the coastal zone.

Constraints, issues, and possible ways forward toward adoption of new practices

The constraints of the coastal zone were kept in mind while formulating and implementing the cropping system intensification strategies (Bandyopadhyay et al., 2011; Mandal et al., 2011b; Burman et al., 2015). Successful demonstration of the interventions was able to increase the cropping system intensifications through different alternative crop choices, crop establishment methods, and improve soil and water management method. However, several constraints still remained critical for decision-making by the farmers. Some

TABLE 4 Farmers perceptions on interventions and improved practices of agriculture.

Interventions	% respondents liked and willing to adopt	Reasons	% respondents liked but not sure to adopt	Reasons	Can't say/undecided
Zero tillage potato	99.00	Less water, low cost, less labor	1.00	Lack of suitable land	0.00
Solar powered drip irrigation system	77.00	Less water, year round cultivation	12.00	Costly, difficult to mange	11.00
Low cost drip irrigation system	86.00	Less water, year round crops, more production	8.00	Difficult to manage, maintenance cost	6.00
Vegetables in sack with rice	98.00	Easy method, additional return	2.00	Very tiny land available	0.00
Sunflower	64.00	Oil for home consumption	30.00	Input not available, bird damage	6.00
Maize	58.00	Multipurpose use—food and feed	23.00	Good but can't sell or process	19.00
Direct seeded rice	61.00	Can be sown early, easy method	22.00	Weed, heavy rain may damage crop	17.00
Drum seeded rice	53.00	Easy method, less labor, less time to sow	19.00	Not sure about uniformity of spacing	28.00
Plastic mulch	61.00	More production, less water, less weed	31.00	Not available, additional cost, not good for environment	8.00
Straw mulch	94.00	More production, conserve water, less water, less weed	6.00	Straw not available at home, more labor	0.00
Capsicum	42.00	May give good return	11.00	Not suitable to grow	44.00
Broccoli	69.00	Profitable, grow well	11.00	Seed availability, price uncertainty	19.00
Mustard	88.00	Oil for home consumption, oil cake	8.00	Doesn't grow well, chances of crop failure	3.00
Green gram	97.00	Low cost, good production, additional crop, home consumption	3.00	Land not available, Low land	0.00
Sesbania sp. as green manure	100.00	Good for soil, less fertilizer required, fertility improves	0.00	–	0.00
Lime application	94.00	Soil quality improves, more production	2.00	Not available locally, costly	1.00
Other vegetables	81.00	Additional income, more option	19.00	Suitable land area not available	0.00

of these critical constraints might be mitigated through the knowledge gained from experiences of the action research and some needed policy attention for the out-scaling of such practices in the coastal zone. 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 (Table 6). Uncertainty of input costs, productivity, and profitability are serious concerns for sustaining dry-season crop production (Mainuddin et al., 2021a,b). Prevailing agricultural risks (production, marketing, and environmental) impede farmers' decision-making on the adoption of newer interventions, despite having favorable economics. Agricultural risks and coping strategies both at the farm-level and on the regional scale needed special attention, especially managing the environmental risks (Ali and Kapoor, 2018; Mandal et al., 2018b; Mainuddin et al., 2019, 2020). The cropping system research interventions revealed that alternate crop establishment methods (e.g., direct seeded rice, drum seeding rice), early sowing of crops through choosing early maturing crop varieties (for *kharif* rice), improved irrigation methods (drip irrigation system), moisture conservation through mulching (straw/plastic),

TABLE 5 New technical knowledge acquired and likely change over the existing agricultural practices.

Technology/ interventions	Knowledge acquired	Likely change to adopt
Zero Tillage Potato	• Depth of straw mulching to be more • Foliar/liquid application of fertilizer • Organic manure during planting	• Will follow the improved methods of fertilizer applications and mulching depth • Spacing and organic manure application
Low cost drip irrigation method	• More crop with less water • Vegetables cultivation year-round • More production from same land	• Suitable for highland area • Management of drip pipes be made easy • Willing to adopt with overhead tank, pump and less number of pipes
Solar powered drip irrigation method	• More crop with less water • Vegetables cultivation year-round • More production from same land • Easy irrigation method	• Farmers willing to adopt, if subsidy are provided • Needs to be made low cost/affordable • Straw mulch preferred over plastic mulch
Vegetable in sack with *kharif* rice	• New and easy method of growing vegetables in rice • Additional return from same land • Women friendly	• Willingness to adopt by many farmers • Will follow the new methods for growing vegetables in *kharif* and even in post-*kharif* seasn
Early sowing rice varieties	• Short duration rice varieties to be preferred • Early harvest (15-20 days) is good for sowing next crop • Utilization of field moisture and opportunities for many *rabi* crops	• Preference will be given for early maturing rice varieties • Higher cropping system intensification with additional crops • *Rabi* fallow land can be reduced by 30-35%
Reducing cost of cultivation through better nutrient management	• Following recommended fertilizer dose, adding green manure, moisture conservation through straw mulching and using quality seeds	• Good agricultural practices learned will be followed • More organic manure to be used as far as possible
Lime application for managing acid sulfate soil	• Improves fertility of acid sulfate soil • Increases crop yields significantly • Crop losses reduced	• Lime application will be followed, subject to availability of lime in local market
New crops (maize, capsicum, sunflower, broccoli, onion, garlic)	• Several new crops were introduced and crop establishments were successful • New cropping options realized • Maize is a potential crop	• Farmers will continue growing selected crops like broccoli, garlic, onion • Maize can be taken up, but need value addition toward like conversation to animal feed

choosing alternative crops from several options in *rabi* season, establishing institutional linkages (research organization, state government agencies, non-governmental organizations, social networking) for dissemination of technical know-how and input delivery by using information technologies was helpful to mitigate these critical constraints (Mandal et al., 2011a,b; Kabir et al., 2017c; Mishra et al., 2017; Mahanta et al., 2019).

The participation of women in agricultural operation

The participation of women in agricultural activities was an integral part of all kinds of farming systems. During 2019–2020, project activities were implemented in about 335 farmers including 201 male and 137 female farmers covering about 20 crops to increase cropping intensity through the introduction of improved management practices, new crops, and varieties. Women folk in the farm families performed routine daily work starting from 4.30 am up to sleep at 10 pm. The various activities performed by them are, cleaning house, cleaning cattle shed area, feeding animals, poultry, duck, goat; fetching water, managing homestead garden, kitchen work; helping at field activities, cultivation, and entertainment. Very often role and contribution of women in agriculture remained unnoticed or under-appreciated. Increasing income for women farmers or women engaged in agriculture needed special attention. It was noted that the livestock components within the farming system provided additional income (10–20%) opportunities, particularly to women farmers with a marginal increase (1–2 h daily) in their existing workload (Supplementary Table A5, Annexure II). Cropping system intensification created opportunities to increase overall households' income (2–5 times) and simultaneously also increased workload (2–3 h daily) of women to varying extents. The participation of women in some of the agricultural activities continued throughout the year and some others were seasonal. Active participation in homestead gardening, vegetable harvesting, weeding/intercultural operations were normally practiced by

TABLE 6 Framers perception on constraints and possible mitigation options to take forward the successful interventions.

Critical constraints	% farmers reported	Likely solution/options	Key knowledge gained from research interventions
Environmental			
More water in *kharif* (waterlogged/prolonged inundation)	95	Embankments, drainage, canal renovation and excavation	Crop establish method like direct seeded rice
Less water (good quality/non-saline) in *rabi*	100	Conserve freshwater, rainwater harvesting, canal renovation and excavation	Early sowing of crops/varieties from many alternative crops demonstrated increased choice. Drip irrigation method
Soil salinity	100	Efficient water management, mulching, early sowing of crops, salt tolerant crops, use of field water as much as possible	Improved irrigation method using solar powered and low cost drip system can manage soil salinity
Water salinity	90	Use of pond/canal water, salt tolerant crop/variety adoption	Efficient irrigation method with straw and adoption of plastic mulching
Institutional			
Unavailability of quality inputs	86	Formation of farmers group like producer's organization	Quality inputs are available and can be delivered the villages. Need support from service providers through institutional linkages
Input unavailability in time	90	Formation of farmers group like producer's organization	Establishing linkages with formal institutions/organization
High input cost	90	Bulk purchase through formation of farmers group like producer's organization	Reducing chemical fertilizer use by supplementing green manure, organic manure like FYM, bulk purchase
Limited access to technical know-how	85	Continuous linkages with local extension officers (ADAs, govt. of West Bengal), non-governmental organizations or Scientists through social media or using information technologies	Establishing linkages with resource persons of formal organization like ICAR-CSSRI, KVKs, State University, ADAs and continuing discussion through using social media platform
Economic			
Marketing of produce with remunerative price	82	Direct selling to city market through bulk selling as farmers group	Selection of crops having market demand, new crops and early sowing
Risk in agriculture (production and marketing)	95	Institutional linkages for bulk purchase and direct selling of produce in wholesale markets/consumer. Access to compensation during disasters or participation in crop insurance schemes	Contingency planning like keeping ready seeds/planting material in case of damage/calamities. Early sowing, choosing high value crops and growing multiple crops
Insufficient capital	90	Access to Govt. scheme (*Krishak Bandhu*), choosing profitable crops based on market demand	Increasing marketable surplus through multiple cropping and saving from additional return

ADA, assistant director of agriculture; ICAR-CSSRI, ICAR central soil salinity research institute; KVV, krishi vigyan kendra.

the women folk throughout the year and typically they spent 2–3 h daily on these activities. Women also actively participated in seasonal activities like transplanting of rice (almost 30–35% are women laborers), intercultural operations, weeding in rice fields, harvesting of rice and vegetables/maize, and carrying the harvested crops. Seasonal work participation of women varied from 2 to 3 h to full-time laborers (8 h a day). Women folk reported that their participation has increased (40–45%) in agricultural activities particularly after the cyclone *Aila* in 2009 (seawater intruded and a large area remained inundated for several weeks making the land less/unproductive for the subsequent 3 years), due to which large scale male migrated for the search of alternative livelihoods. The women farmers opined that the higher cropping system intensification will increase their work load marginally but they were happy to participate in the activities so long it was profitable. Women folk actively participated in decision-making such as rice variety selection and homestead gardening. However, the decision on fertilizer and pesticide application was taken by male farmers only. Keeping in view the interest of women farmers and to increase their participation in agricultural activities, 3 groups (5 women in each group) were provided small irrigation pumps to be utilized on sharing basis. With the help of pumps, these women farmers could grow additional crops (such as ZT-potato) in the fields and generate additional income, managed by themselves. The creation of more such interest groups among women farmers can be gainful engagement in the region to increase agricultural production and income.

Factors affecting adoption of new/improved cropping systems

The field trials successfully evolved or improved several cropping systems that could be suitable for smallholder farmers in the coastal zone of West Bengal, India. These new options have the potential to increase the farmers' income substantially. Binary dependent variables were constructed as 1 for farmers whose cropping intensity was higher than the baseline level of intensification (142%) or 0 otherwise. The extent of homestead area managed by individual farm households, income from agriculture, income from off-farm activities, and the number of perennial ponds available for irrigation water, significantly influenced the adoption of higher cropping intensification positively (Table 7). Homestead areas are small production units that are suitable to manage even with limited resources and are managed by the farmers throughout the year. Both incomes from agriculture, as well as off-farm sources, induced the higher adoption of new/evolved cropping systems. Smallholder farmers are constrained with insufficient capital to invest in agriculture and the off-farm income increased their capacity to invest in the new cropping systems in expectation of a better income. The Coastal zone of West Bengal has very limited irrigation water resources and the rainwater stored in ponds/canals is mostly used for cultivation during *rabi* season. Therefore, the number of perennial ponds available for farm households was a very important factor to facilitate the adoption of higher cropping intensification. It was interesting to note that the operational holdings were not influencing (significantly) the adoption of higher cropping intensification. The probable reason is that the availability of a sufficient quantity of good quality irrigation water (non-saline) in the *rabi* season affected the large-scale adoption of new cropping systems, despite having the potential for higher profitability. Other factors that remained non-significant in changing the adoption of new cropping systems were, the number of male or female adults in the family, whether the primary occupation was agriculture or non-agriculture, age of the respondent farmers, education status, and the distance from the nearest markets.

Conclusion

The cropping systems practiced by smallholder farmers play a vital role in agri-food production systems and help to reduce hunger, improve nutrition, and provide livelihoods to millions across developing countries. The number of smallholder farmers are rapidly increasing in both developing and underdeveloped countries, however, they are increasingly facing challenges to running profitably. Cropping system intensification (CSI) can be one of the ways to make such production systems more remunerative for these farmers. The agricultural cropping options are highly restricted with more water during the wet (*kharif)* season (waterlogged), scarcity of good quality irrigation water, and soil salinity during the dry (*rabi)* season in the Ganges delta. Farmers sacrifice the expected higher return through intensive cropping system attributed to different socio-economic factors, often remaining unnoticed. Therefore, the socio-economic suitability of new crops and management options were evaluated by accounting the benefits of adoption and identifying various constraints in adoption. Baseline and end-line surveys were conducted to quantify the impact of interventions. Behavioral analysis was carried out to identify factors affecting large-scale adoption of the new/improved cropping systems evolved. The socio-economic impact study revealed that the field trials and subsequent adoption of evolved cropping systems successfully increased the cropping intensity in the study area. Cropping system intensification was quite successful and there were several opportunities to achieve higher cropping intensities (from baseline 123–142% to over 202–300%) with substantially higher returns (2–5 times) as compared to the existing practices. The experiments showed there were a number of feasible cropping options that could be promoted (*kharif* rice-ZT potato-green gram, *kharif* rice-ZT potato, *kharif* rice-maize, vegetables-vegetables). Besides, some existing cropping options (*kharif* rice, *kharif* rice-ridge potato, mixed cropping system) were improved through suitable soil and water management as demonstrated at farmers' fields. These interventions increased the smallholder farmers' income substantially by reducing the yield gap in the coastal zone. The cropping system intensification was also found to be encouraging for the women farmers that could empower them financially. Promotion of new cropping systems may be complemented with farm-level risk mitigation measures like quality input supply to the region, regular weather advisory services, and disease or pest attack forecasting, because weather aberrations are more critical factors than climate change as far as sustaining the farm-level production management are concerned. Farmers' perception of cropping system intensification indicated that the project interventions helped them to acquire new knowledge on cultivation practices and adopted better cropping systems. For example, the ZT potato cultivation with rice straw mulching helped them to realize better yields that can be obtained through using optimum depth of straw mulching, proper nutrient application, use of water-soluble fertilizers, use of organic manure, and maintaining recommended spacing. The low-cost drip irrigation system facilitated the growing of more crops with less water and a number of vegetables were feasible to grow throughout the year. Interventions for cropping system intensification interventions

TABLE 7 Factors affecting adoption of higher cropping system intensification.

Factors	Name	Co-efficient	SE
A	Constant	−4.582**	2.262
X_1	Operational holding size (average in ha household^{-1}, excluding homestead area)	−4.869***	1.516
X_2	Homestead area (average in ha household^{-1})	0.790	13.193
X_3	Income from agriculture (in ₹year^{-1} household^{-1})	0.053***	0.020
X_4	Off-farm income (in ₹year^{-1} household^{-1})	0.086***	0.032
X_5	Number of adult male (Number household^{-1})	0.085	0.266
X_6	Number of adult female (Number household^{-1})	−0.556	0.446
X_7	Number of perennial ponds (Number of ponds household^{-1} available having water for 9 or more months)	1.003***	0.388
X_8	Primary occupation (If agriculture = 1, 0 otherwise)	0.498	0.652
X_9	Age of respondents (Years in number)	0.040	0.031
X_{10}	Education status (Number of years of schooling)	0.058	0.215
X_{11}	Distance of nearest market fields (in km)	−0.257	0.242
	−2 Log likelihood		79.592
	Correct prediction (%)		75.60
	No of observation		90

***, **, and * indicated level of significances at 1, 5, and 10% level, respectively.
Authors' estimation based on primary survey baseline (2018–2019) and end line (2020–2021).

were found to be profitable, employment generating, suitable for smallholder farmers, and profitable for the region. The amount of homestead land possessed, income from agriculture, off-farm income, and the number of perennial ponds as irrigation water sources were the most important factors in the adoption of new cropping systems in the coastal zone. However, the size of the operational holding was neutral to the adoption of higher cropping intensification in the study area. The socio-economic impact study identified the interventions that are preferred by the smallholder farmers in the coastal zone and those can be out-scaled in the larger part of the Ganges delta for increased income, better livelihoods, and higher social benefit.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SM, SKS, and MM contributed equally to research experiment design, data collection, analysis, and manuscript writing. KM, UM, and DB contributed in setting experiments and data collection. SD helped in data collection. PS and BM contributed in manuscript writings. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.1001367/full#supplementary-material

References

ACIAR (2020). *Cropping Systems Intensification in the Salt Affected Coastal Zones of Bangladesh and West Bengal, India (CSI4CZ).* Final report, ISBN 978-1-922345-79-0, p. 121. Available online at: https://www.aciar.gov.au/publication/cropping-system-intensification-salt-affected-coastal-zones-bangladesh-and-west-bengal (accessed April 15, 2022).

Alam, E., and Dominey-Howes, D. (2014). A new catalogue of tropical cyclones of the Northern Bay of Bengal and the distribution and effects of selected land falling events in Bangladesh. *Int. J. Climatol.* 35, 801–835. doi: 10.1002/joc.4035

Alam, M. J., Al-Mahmud, A., Islam, M. A., Hossain, M. F., Ali, M. A., Dessoky, E. S., et al. (2021). Crop diversification in rice—based cropping systems improves the system productivity, profitability and sustainability. *Sustainability* 13, 6288. doi: 10.3390/su13116288

Ali, J., and Kapoor, S. (2018). Farmers' perception on risks in fruits and vegetables production: an empirical study of Uttar Pradesh. *Agric. Econ. Res. Rev.* 21, 317–326. doi: 10.22004/ag.econ.47881

Anderson, J. R., and Dillon, J. L. (1992). "Risk analysis in dryland farming systems," in *Farm Systems Management Series No. 2* (Rome: FAO), 117.

Aravindakshan, S., Rossi, F., Amjath-Babu, T. S., Veettil, P. C., and Krupnik, T. J. (2018). Application of a bias-corrected meta-frontier approach and an endogenous switching regression to analyze the technical efficiency of conservation tillage for wheat in South Asia. *J. Prod. Anal.* 49, 153–171. doi: 10.1007/s11123-018-0525-y

Bandyopadhyay, B. K., Burman, D., and Mandal, S. (2011). Improving agricultural productivity in degraded coastal land of India: experiences gained and lessons learned. *J. Indian Soc. Coast. Agric. Res.* 29, 1–9. Available online at: https://www.iscar.org.in/_files/ugd/c3cacb_7d758f73929b409fa1de1f303b228ab8.pdf?index=true

Bell, R. W., Mainuddin, M., Barrett-Lennard, E. G., Sarangi, S. K., Maniruzzaman, M., Brahmachari, K., et al. (2019). Cropping systems intensification in the coastal zone of the Ganges Delta: opportunities and risks. *J. Indian Soc. Coast. Agric. Res.* 37, 153–161.

Berzsenyi, Z., Gyorffy, B., and Lap, D. (2000). Effect of crop rotation and fertilisation on maize and wheat yields and yield stability in a long-term experiment. *Eur. J. Agron.* 13, 225–244. doi: 10.1016/S1161-0301(00)00076-9

Bhattacharya, J., Mondal, M. K., Humphreys, E., Saha, N. K., Rashid, M. H., Paul, P. C., et al. (2015). "Rice-rice-rabi cropping systems for increasing the productivity of low salinity regions of the coastal zone of Bangladesh," in *Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices. Conference Proceedings, CGIAR Challenge Program on Water and Food (CPWF)*, Sri Lanka (Colombo), eds E. Humphreys, T. P. Tuong, M. C. Buisson, I. Pukinskis, and M. Phillips, 436–448.

Burman, D., Maji, B., Singh, S., Mandal, S., Sarangi, S. K., Bandyopadhyay, B. K., et al. (2018). Participatory evaluation guides the development and selection of farmers' preferred rice varieties for salt- and flood-affected coastal deltas of South and Southeast Asia. *Field Crops Res.* 220, 67–77. doi: 10.1016/j.fcr.2017.03.009

Burman, D., Mandal, S., Bandyopadhyay, B. K., Maji, B., Sharma, D. K., Mahanta, K. K., et al. (2015). Unlocking production potential of degraded coastal land through innovative land management practices: a synthesis. *J. Soil Salinity Water Qual.* 7, 12–18. Available online at: http://issswq.in/download/2015-volume-7-issue-1-june/

Carcedo, A. J. P., Bastos, L. M., Yadav, S., Mondal, M. K., Jagadish, S. V. K., Kamal, F. A., et al. (2022). Assessing impact of salinity and climate scenarios on dry season field crops in the coastal region of Bangladesh. *Agricul. Syst.* 200, 103428. doi: 10.1016/j.agsy.2022.103428

Census of India (2011). *District Census Handbook: South 24 Parganas, Village and Town Wise Primary Census Abstract, Series 20, Part XII-B, Directorate of Census Operation, Govt. of West Bengal.* New Delhi: Census of India. Available online at: www.censusindia.gov.in (accessed May 20, 2020).

Childs, N., and Kiawu, J. (2009). *Factors Behind the Rise in Global Rice Prices in 2008. A Report from the Economic Research Service.* Washington, DC: United States Department of Agriculture. Available online at: https://www.ers.usda.gov/webdocs/publications/38489/13518_rcs09d01_1_.pdf?v=41056 (accessed February 10, 2021).

Dillon, J. L., and Hardaker, B. (1993). *Farm Management Research for Small Farmer Development, Vol. 6.* Rome: Food and Agriculture Organization of the United Nations (FAO).

Dolinska, A. (2017). Bringing farmers into the game. Strengthening farmers' role in the innovation process through a simulation game, a case from Tunisia. *Agric. Syst.* 157, 129–139. doi: 10.1016/j.agsy.2017.07.002

FAO. (1998). "Issues, perspectives, policy and planning processes for integrated coastal area management," in *Integrated Coastal Area Management and Agriculture, Forestry and Fisheries. FAO Guidelines, Environment and Natural Resources Service*, ed. N. Scialabba (Rome: FAO), 256. Available online at: https://www.fao.org/3/W8440e/W8440e02.htm#TopOfPage (accessed May 21, 2021).

Fisher, R. A. (2015). Definitions and determination of crop yield, yield gaps, and of rates of change. *Field Crops Res.* 182: 9–18. doi: 10.1016/j.fcr.2014.12.006

Garnett, T., Appleby, M. C., Balmford, A., Bateman, I. J., Benton, T. G., Bloomer, P., et al. (2013). Sustainable intensification in agriculture: premises and policies. *Science* 341, 33–34. doi: 10.1126/science.1234485

Ghosh, S., and Mistri, B. (2020). Drainage induced waterlogging problem and its impact on farming systems: a study in Gosaba island, Sundarban, India. *Spatial Inform. Res.* 28, 709–721. doi: 10.1007/s41324-020-00328-8

Goswami, R., Roy, K., Dutta, S., Sarkar, S., Brahamachari, K., Nanda, M. K., et al. (2021). Multifaceted impact and outcome of COVID-19 on small holder agricultural systems: integrating qualitative research and fuzzy cognitive mapping to explore resilient strategies. *Agricul. Syst.* 189, 103051. doi: 10.1016/j.agsy.2021.103051

Govt. of India (2020). *Agricultural Statistics at a Glance (2019).* New Delhi: Govt. of India. Available online at: https://eands.dacnet.nic.in/PDF/At%20a%20Glance%202019%20Eng.pdf (accessed May 5, 2021).

Govt. of West Bengal (2009). *District Human Development Report: South 24 Parganas, Chapter 9, Sundarbans and Remote Islanders.* West Bengal: Govt. of West Bengal. Available online at: http://www.wbplan.gov.in (accessed April 5, 2018).

Hasan, M. K., and Kumar, L. (2020). Perceived farm-level climatic impacts on coastal agricultural productivity in Bangladesh. *Clim. Change* 161:617–636. doi: 10.1007/s10584-020-02708-3

Humphreys, E., Tuong, T. P., Buisson, M. C., Pukinskis, I., and Phillips, M. (2015). "Revitalizing the ganges coastal zone: turning science into policy and practices," in *Conference Proceedings, Colombo, Sri Lanka, CGIAR Challenge Program on Water and Food (CPWF)*, Sri Lanka (Colombo), 652.

ICAR-CSSRI CSI4CZ (2020). "Final report of ACIAR, Australia funded project on: cropping systems intensification in the salt affected coastal zones of Bangladesh and West Bengal, India (CSI4CZ)," in *Indian Council of Agricultural Research (ICAR)-Central Soil Salinity Research Institute, Regional Research Station, (CSSRI, RRS)*, ed S. K. Sarangi (Canning Town: ICAR-CSSRI CSI4CZ), 94.

Kabir, J. M., Rob, C., Donald, S. G., and Roth, C. H. (2017a). Bio-economic evaluation of cropping systems for saline coastal Bangladesh: II. Economic viability in historic and future environments. *Agric. Syst.* 155, 103–115. doi: 10.1016/j.agsy.2017.05.002

Kabir, J. M., Rob, C., Donald, S. G., and Roth, C. H. (2018). Bio-economic evaluation of cropping systems for saline coastal Bangladesh: III. Benefits of adaptations in current and future environments. *Agric. Syst.* 161, 28–41. doi: 10.1016/j.agsy.2017.12.006

Kabir, M. J., Alauddin, M., and Crimp, S. (2017b). Farm-level adaptation to climate change in Western Bangladesh: an analysis of adaptation dynamics, profitability and risks. *Land Use Policy* 64, 212–224. doi: 10.1016/j.landusepol.2017.02.026

Kabir, M. J., Cramb, R., Gaydon, D. S., and Roth, C. H. (2017c). Bio-economic evaluation of systems for saline coastal Bangladesh: II. Economic viability in historical and future environments. *Agric. Syst.* 155, 103–115.

Krupnik, T. J., Schulthess, U., Ahmed, Z. U., and McDonald, A. J. (2017). Sustainable crop intensification through surface water irrigation in Bangladesh? A geospatial assessment of landscape-scale production potential. *Land Use Policy.* 60, 206–222. doi: 10.1016/j.landusepol.2016.10.001

Kumar, P., and Sharma, P. K. (2020). Soil salinity and food security in India. *Front. Sustain Food Syst.* 4, 533781. doi: 10.3389/fsufs.2020.533781

Kummu, M., Moel, H. D., Salvucci, G., Viviroli, D., Ward, P. J., and Varis, O. (2016). Over the hills and further away from coast: global geospatial patterns of human and environment over the 20th−21st centuries. *Environ. Res. Lett.* 11, 1. doi: 10.1088/1748-9326/11/3/034010

Lin, X., Zhu, D., and Lin, X. (2011). Effects of water management and organic fertilization with SRI crop practices on hybrid rice performance and rhizosphere dynamics. *Paddy Water Environ.* 9, 33–39. doi: 10.1007/s10333-010-0238-y

Mahanta, K. K., Burman, D., Sarangi, S. K., Mandal, U. K., Maji, B., Mandal, S., et al. (2019). Drip irrigation for reducing soil salinity and increased cropping intensity: case studies in Indian Sundarbans. *J. Indian Soc. Coast. Agric. Res.* 37, 64–71.

Mainuddin, M., Alam, M. M., Maniruzzaman, M., Kabir, M. J., Mojid, M. A., Hasan, M. M., et al. (2021a). Yield, profitability, and prospects of irrigated Boro rice cultivation in the North-West region of Bangladesh. *PLoS ONE* 16, e0250897. doi: 10.1371/journal.pone.0250897

Mainuddin, M., Bell, R. W., Gaydon, D. S., Kirby, J. M., Barrett-Lennard, E. G., Razzaque Akanda, M. A., et al. (2019). An overview of the Ganges coastal zone: climate, hydrology, land use, and vulnerability. *J. Indian Soc. Coast. Agric. Res.* 37, 1–11.

Mainuddin, M., Karim, F., Gaydon, D. S., and Kirby, J. M. (2021b). Impact of climate change and management strategies on water and salt balance of the polders and islands in the Ganges delta. *Sci. Rep.* 11, 7041. doi: 10.1038/s41598-021-86206-1

Mainuddin, M., and Kirby, J. M. (2021). Impact of flood inundation and water management on water and salt balance of the polders and islands in the Ganges delta. *Ocean Coast. Manag.* 210, 105740. doi: 10.1016/j.ocecoaman.2021.105740

Mainuddin, M., Maniruzzaman, M., Gaydon, D. S., Sarkar, S., Rahman, M. A., Sarangi, S. K., et al. (2020). Water and salt balance model for the polders and islands in the Ganges delta. *J. Hydrol.* 587, 125008. doi: 10.1016/j.jhydrol.2020.125008

Mandal, S., Bandyopadhyay, B. K., Burman, D., Sarangi, S. K., and Mahanta, K. K. (2011a). *Baseline Report of the NAIP Project on Strategies for Sustainable Management of Degraded Coastal Land and Water for Enhancing Livelihood Security of Farming Communities*. Canning Town: Central Soil Salinity Research Institute, Regional Research Station, 74.

Mandal, S., Burman, D., Bandyopadhyay, B. K., Mandal, U. K., Sarangi, S. K., Mahanta, K. K., et al. (2015a). Crop-fish integration through land shaping models for enhancing farm income under eastern coastal region of India. *Agric. Econ. Res. Rev.* 28, 47–54. doi: 10.5958/0974-0279.2015.00021.X

Mandal, S., Burman, D., Mandal, U. K., Lama, T. D., Maji, B., and Sharma, P. C. (2017). Challenges, options and strategies for doubling farmers' income in West Bengal: reflections from coastal region. Agric. Econ. Res. *Rev.* 30, 89–100. doi: 10.5958/0974-0279.2017.00024.6

Mandal, S., Burman, D., Sarangi, S. K., Bandyopadhyay, B. K., and Maji, B. (2015b). *"Homestead production systems in Sundarbans region of West Bengal, India: current status and opportunities," in Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices, Conference Proceedings, CGIAR Challenge Program on Water and Food (CPWF)*, Sri Lanka (Colombo), eds E. Humphreys, T. P. Tuong, M. C. Buisson, et al., 241–250.

Mandal, S., Maji, B., Sarangi, S. K., Mahanta, K. K., Mandal, U. K., Burman, D., et al. (2020). Economics of cropping system intensification for small-holder farmers in coastal salt-affected areas in West Bengal: opt ions, challenges and determinants. *Decision* 47, 19–33. doi: 10.1007/s40622-020-00236-8

Mandal, S., Mandal, U. K., Lama, T. D., Burman, D., and Sharma, P. C. (2019b). Economic analysis of farm-level agricultural risks in coastal region of West Bengal in India. *Indian J. Soil Salinity Water Qual.* 11, 269–279. Available online at: http://issswq.in/download/jsswqvol7issue12015/

Mandal, S., Raju, R., Kumar, A., Kumar, P., and Sharma, P. C. (2018a). Current status of research, technology response and policy needs of salt-affected soils in India: a review. *J. Indian Soc. Coast. Agric. Res.* 36, 40–53. Available online at: https://epubs.icar.org.in/index.php/JISCAR/article/view/89004

Mandal, S., Sah, K. D., Das, K., Sahoo, A. K., Reza, S. K., Nayak, D. C., et al. (2018b). Increasing small-holder farmers' income through alternate land-use options in coastal salt-affected areas of West Bengal. *J. Soil Salinity Water Qual.* 10, 268–278. Available online at: http://issswq.in/download/jsswqvol6issue22014/

Mandal, S., Sarangi, S. K., Burman, D., Bandyopadhyay, B. K., Maji, B., Mandal, U. K., et al. (2013). Land shaping models for enhancing agricultural productivity in salt affected coastal areas of West Bengal -An economic analysis. *Indian J. Agri. Econom.* 68, 389–401. doi: 10.22004/ag.econ.206342

Mandal, S., Sarangi, S. K., Burman, D., Bandyopadhyay, B. K., Maji, B., Singh, S. B., et al. (2011b). Agricultural marketing efficiency of major vegetables crops in coastal districts of west Bengal: current status and way forward. *J. Indian Soc. Coast. Agric. Res.* 29, 93–98. Available online at: https://www.iscar.org.in/_files/ugd/c3cacb_7d758f73929b409fa1de1f303b228ab8.pdf?index=true

Mandal, S., Sarangi,. S. K., Burman, D., Mandal, U. K., Maji, B., and Sharma, D. K. (2016). Impact of improved salt tolerant rice varieties on farmers' economy under coastal salt affected areas of Sundarbans. *Paper presented during 11 National Symposium on Innovations in Coastal Agriculture: Current Status under Changing Environment, Indian Society of Coastal Agricultural Research, 14-17 January, 2016, held at ICAR-Indian Institute of Water Management*, (Bhubaneswar: Indian Society of Coastal Agricultural Research).

Mandal, U. K., Nayak, D. B., Mullick, S., Samui, A., Kumar, A., Mahanta, K. K., et al. (2019a). Trend analysis of weather parameters over Indian Sundarbans. *J. Agrometeorol.* 21, 307–315. doi: 10.54386/jam.v21i3.253

Mekoya, A., Oosting, S. J., Fernandez-Rivera, S., and Van der Zijpp, A. J. (2008). Multipurpose fodder trees in the Ethiopian highlands: farmers' preference and relationship of indigenous knowledge of feed value with laboratory indicators. *Agric. Syst.* 96, 184–194. doi: 10.1016/j.agsy.2007.08.001

Mishra, S., Goswami, R., Mondal, T., and Jana, R. (2017). Social networks in the context of community response to disaster: study of a cyclone affected community in Coastal west Bengal, India. *Int. J. Disaster Risk Reduct.* 22, 281–296. doi: 10.1016/j.ijdrr.2017.02.017

Neumann, K., Verburg, P. H., and Stehfest E, Muller, C. (2010). The yield gap of global grain production: a spatial analysis. *Agric. Syst.* 103, 316–326. doi: 10.1016/j.agsy.2010.02.004

Norman, D. W., Newman, M. D., and Ouedraogo. (1981). *Farm and Village Production Systems in the Semi-Arid Tropics of West Africa: An Interpretive Review of Research*. Patancheru: International Crops Research Institute for the Semi-Arid Tropics. p. 94.

Paul, B. K. (2009). Why relatively fewer people died? The case of Bangladesh's cyclone Sidr. *Nat Hazards* 50, 289–304. doi: 10.1007/s11069-008-9340-5

Paul, B. K., and Rashid, H. (2017). *Climatic Hazards in Coastal Bangladesh: Non-Structural and Structural Solutions*. New York, NY: Elsevier. doi: 10.1016/B978-0-12-805276-1.00008-9

Pingali, P., Bigot, Y., and Binswanger, H. P. (1987). *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa*. Baltimore: John Hopkins University Press, 216.

Ray, K., Brahmachari, M., Goswami, R., Sarkar, S., Brahmachari, K., Ghosh, A., et al. (2019). Adoption of improved technologies for cropping intensification in the coastal zone of West Bengal, India: a village level study for impact assessment. *J. Indian Soc. Coast. Agric. Res.* 37, 144–152. Available online at: https://www.jstor.org/stable/4299200

Ray, K., Hasan, S. S., and Goswami, R. (2018). Techno-economic and environmental assessment of different rice-based cropping systems in an inceptisol of West Bengal, India. *J. Clean. Prod.* 205, 350–363. doi: 10.1016/j.jclepro.2018.09.037

Ray, K., Sen, P., Goswami, R., Sarkar, S., Brahmachari, K., and Ghosh, A. (2020). Profitability, energetics and GHGs emission estimation from rice-based cropping systems in the coastal saline zone of West Bengal, India. *PLoS ONE* 5, e0233303. doi: 10.1371/journal.pone.0233303

Remesan, R., Arjun, P., Sangma, M. N., Janardhanan, S., Mainuddin, M., Sarangi, S. K., et al. (2021). Modelling and management option analysis for salty/saline groundwater drainage in a Deltaic Island. *Sustainability* 13, 6784. doi: 10.3390/su13126784

Ritu, S. P., Mondal, M. K., Tuong, T. P., Talukdar, S. U., and Humphreys, E. (2015). "An aus-aman system for increasing productivity of a moderately saline region of the coastal zone of Bangladesh," in *Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices. Conference Proceedings, CGIAR Challenge Program on Water and Food (CPWF), Colombo, Sri Lanka*, eds E. Humphreys, T. P. Tuong, M. C. Buisson, I. Pukinskis, and M. Phillips, 361–388.

SAC (Space Applications Centre) (1992). *Coastal Environment, SAC Report No RSAM/SAC/COM/SN/11/92. DEPARTMENT of Space GOI*. Satellite: SAC (Space Applications Centre), 114.

Saha, N. K., Mondal, M. K., Humphreys, E., Bhattacharya, J., Rashid, M. H., Paul, P. C., et al. (2015). "Triple rice in a year: is it a feasible option for the low salinity areas of the coastal zone of Bangladesh?," in *Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices. Conference Proceedings, CGIAR Challenge Program on Water and Food (CPWF), Colombo, Sri Lanka*, eds E. Humphreys, T. P. Tuong, M. C. Buisson, I. Pukinskis, and M. Phillips, 421–435.

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 Farm*. 04, 23–26.

Sarangi, S. K., Maji, B., Sharma, P. C., Digar, S., Mahanta, K. K., Burman, D., et al. (2020). Potato (*Solanum tuberosum* L.) cultivation by zero tillage and paddy straw mulching in the saline soils of the Ganges Delta. *Potato Res*. 64, 277–305. doi: 10.1007/s11540-020-09478-6

Sharma, D. K., Singh, A., and Sharma, P. C. (2016). "Role of ICAR-CSSRI in sustainable management of salt-affected soils: achievements, current trends and future perspectives," in *Proceedings of 4th International Agronomy Congress (November 22–26)* (New Delhi: Indian Society of Agronomy), 91–103. doi: 10.13140/RG.2.2.34451.78888

Small, C., and Nicholls, R. J. (2003). A global analysis of human settlement in coastal zones. *J. Coast. Res*. 19, 584–599.

Soltanmohammadi, H., Osanloo, M., and Bazzazi, A. A. (2010). An analytical approach with a reliable logic and a ranking policy for post-mining land-use determination. *Land Use Policy* 27, 364–372. doi: 10.1016/j.landusepol.2009.05.001

Tur-Cardona, J., Bonnichsen, O., Speelman, S., Verspecht, A., Carpentier, L., Debruyne, L., et al. (2018). Farmers' reasons to accept bio-based fertilizers: a choice experiment in seven different European countries. *J. Clean. Prod*. 197, 406–416. doi: 10.1016/j.jclepro.2018.06.172

Urruty, N., Tailliez-Lefebvre, D., and Huyghe, C. (2016). Stability, robustness, vulnerability and resilience of agricultural systems. A review. *Agron. Sustain. Dev*. 36, 15. doi: 10.1007/s13593-015-0347-5

Walker, T. S., and Ryan, J. G. (1990). *Village and Household Economies in India's Semi-arid Tropics*. Baltimore: John Hopkins University Press, 394

Yadav, S., Mondal, M. K., Shew, A., Jagadish, S. V. K., Khan, Z. H., Sutradhar, A., et al. (2020). Community water management to intensify agricultural productivity in the polders of the coastal zone of Bangladesh. *Paddy Water Environ.* 18, 331–343. doi: 10.1007/s10333-019-00785-4

Yu, W. H., Alam, M., Hassan, A., Khan, A. S., Ruane, A. C., Rosenzweig, C., et al. (2010). *Climate Change Risks and Food Security in Bangladesh*. Washington, DC: Earthscan. doi: 10.4324/9781849776387