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Overcoming Risks Associated with Cropping Systems Intensification in the Coastal Zone of the Ganges Delta

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Along with other Asian Mega Deltas, the Ganges Delta, and its coastal zone, are attracting increased attention due to the threats posed by climate change and the extent of rural poverty, juxtaposed against the potential for systems intensification and improved livelihoods. While it is a salt-affected zone, the constraints to systems intensification are many and they often interact (drought-salinity, waterlogging-salinity, heat stress). Moreover, the expression and intensity of these constraints can change throughout the year, particularly during the dry/*Rabi* season, from year to year, and from location to location. Improved rice varieties that mature 10 to 15 days earlier and increase yield by 0.5-1 t ha^{-1} are a foundational change that enables cropping systems intensification in the coastal zone in the dry season. Sowing *Rabi* season crops earlier (before mid-December) increases their yield potential and decreases the risk associated with many constraints which intensify towards the end of the dry season (low solute potential, waterlogging and salinity, heat stress, storms). However, early sowing of *Rabi* season crops increases the risk of early waterlogging and that needs to be managed by drainage. Scarcity of freshwater continues to be a major constraint to dry season cropping. Short duration crops (*e.g.,* vegetables, watermelon), water-saving technologies (*e.g.* mulch, drip irrigation) and restricted planting of dry-season *Boro* rice (to areas with adequate fresh water) are needed for resilience of the cropping systems intensification. Community-based management of water resources for both drainage and equitable allocation of freshwater needs to be part of intensification plans. Within the coastal zone, there is considerable diversity of land type, fresh water resource availability, and farm type which need to be recognized in scale-out programs. Disaster preparedness needs to be embedded in any scale-out plans for systems intensification since the risk of land and water salinization from storm surges is real and enduring.

(***Key words:*** *Drainage, Dry season, Early sowing, Heat stress, Mulch, Salinity, Storms, Waterlogging*)

The coastal zone of the Ganges Delta across southern Bangladesh and West Bengal, India is generally described as a salt-affected region, since 65% of it is affected by salinity of varying levels (Mainuddin *et al.,* 2019). Its proximity to the Bay of Bengal and exposure to repeated storm surges, the low land elevation, and diminishing water flows from the major river systems that pass through the coastal zone are all significant driving factors causing land and water salinity (Mainuddin *et al.,* 2024). Groundwater is already saline in significant areas (Mila *et al.,* 2021). Also, during the dry/*Rabi* season, the salinity (EC_w) of river water commonly rises to over 15 dS m^{-1}, while water storages on land within the coastal zone increase in EC with the progress of the dry season from February to May before declining as the monsoon rain dilutes, and flushes salt (Mila *et al.,* 2021). However, defining the coastal zone only by its salinity is misleading because it diminishes other significant constraints, risk factors, and threats to crop production and cropping systems intensification.

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Water logging, alone or in combination with salinity, are significant risk factors for dry season cropping (Islam *et al.,* 2022a,b). Drought exacerbating low solute potential in the soil solution is an additional risk factor for crops (Paul *et al.,* 2020a,b). Heat stress during March-May and cyclones and storms during April-May add to the risks associated with dry season crop production (Bell *et al.,* 2019; Paul *et al.,* 2021b).

Risks to dry season crops are not the same everywhere: they vary with land type (elevation, presence or absence of acid sulfate layers), proximity to rivers, canals and sluice gates, and the potential for draining excess water away from cropping land. Finally, crop choice can mitigate risk, particularly if there is scope to grow *Boro* or *Aus* rice crops where waterlogging is no longer a risk factor (Maniruzzaman *et al.,* 2024b). Hence, programmes to scale out technologies associated with cropping systems intensification need to classify coastal land according to the risks and profitability of alternative technologies and land uses that determine their overall suitability. Blanket recommendations of technologies or crop choices are not likely to be uniformly successful.

In this paper, we review a body of recent research, as outlined by Mainuddin *et al.* (2024), which has examined the range of constraints and explored the possibilities of a significant change in the cropping seasons to allow system intensification in this region. We also examine the diversity of landscapes and crop suitability within the region, as well as the risks associated with cropping systems intensification, particularly for non-rice crops grown in the dry season.

Risk due to climate variability and the seasonal dynamics of crop stress

The traditional crop production system favours a single long-duration rice crop; this minimizes the risks of failure for the staple crop on which food security in the coastal zone is based. Growing crops at other times of the year has not until now been a major part of cropping systems, presumably because farmers perceived an unacceptable level of risk and insufficient reward for the effort required to reduce it. Hence, the development of new technologies and options for cropping systems intensification needs to carefully consider when and where risks exist, the causes of those risks, the likelihood of crop failure or substantial loss in yield or profitability, and the potential for mitigation of risks.

Climate variability is the major driving factor behind risk for dry season crops. That variability adds to the known risks for crop production due to processes occurring during the dry season: rises in soil and water salinity, increasing soil dryness, heat stress and storms that cause crop lodging and inundation. While these processes can be predicted to occur during known periods of the dry season, the probability and severity of those events occurring or coinciding with one another varies from year to year (Maniruzzaman *et al.,* 2024b; Yu *et al.,* 2019).

The monsoon season rains generally end in October, but in November and December, there remain significant risks of heavy or very heavy rainfall, defined as greater than 10 or 20 mm day^{-1} events, respectively (Maniruzzaman *et al.,* 2024b). From February, there is a progressive increase in the probability of heavy to very heavy rainfall events. Such events can cause severe and widespread waterlogging and crop damage because the present drainage systems are not designed to quickly remove large volumes of excess water.

The low rainfall during the dry season, coupled with reduced river flows, decreases the availability of soil water, particularly from February onwards (Paul *et al.,* 2020a,b), and decreases the volume of stored freshwater (Mila *et al.,* 2021). Coupled with the decline in fresh stored water, increasing soil salinity limits crop growth from February onwards.

Temperatures vary during the dry season. Cold temperatures are rarely a limitation for crops in the coastal zone. However, daytime temperatures exceeding 30-35°C can cause heat stress for crops, particularly when high temperature events coincide with the flowering of crops (Bita and Gerats, 2013).

Cyclones and storms become more frequent between March and May, causing crop lodging due to strong winds and heavy rain. Additionally, intense rainfall during this period can damage crops due toflooding.

By contrast with other *Rabi* crops, *Boro* rice has very little yield variability from year to year and site to site across the coastal zone due to its ability to tolerate waterlogging, and the fact that standing water in paddy fields diminishes root zone salinities (Maniruzzaman *et al.,* 2024b). However, in the coastal zone only low and very low land or land close to rivers with fresh flowing water throughout the year are likely to have sufficient fresh water available to enable *Boro* rice crops to be irrigated. This contrasts with highland, medium-highland and medium-lowland, which occupy about 80 percent of land in southern Bangladesh (Poulton, 2011), characterized by insufficient fresh, stored water to meet the requirements of *Boro* rice.

Constraints and mitigating technologies for *Rabi* crops

Given the seasonal pattern of risk for non-rice *Rabi* crops in the coastal zone, mitigating technologies are needed to give confidence to farmers that crop loss or damage will not occur or occur at manageable levels. Research has identified several promising technologies, namely- cultivation of early maturing, high yield *Aman* rice cultivars; the early sowing of *Rabi* crops, the use of shallow soil drainage and surface soil mulches, and the growth of short-duration, high-value crops such as vegetables. The foundational change in the cropping system to allow intensification is switching to earlier maturing cultivars of monsoon rice.

Early-maturing high-yield rice cultivars

Despite shorter growth duration than traditional varieties, several rice cultivars have demonstrated increased yield of the monsoon rice crop by 0.5-1.0 t ha^{-1} (Maniruzzaman *et al.,* 2019). In practice, 10-15 days earlier maturity compared to the current varieties grown by farmers is sufficient to allow for the early sowing of *Rabi* season crops. Like the current varieties, the early maturing cultivars need to be tall in stature to cope with high flood water levels in the Coastal zone, especially in the tidal floodwater zone. Farmers have identified BRRIdhan 76, BRRIdhan 77 and BRRIdhan 87 as improved cultivars that are favoured for home consumption.

To minimize the risk of bird and rat damage to the early maturing rice cultivars in farmer's fields, community-based block planting is recommended and has been successful in coastal zone settings in Khulna and Barguna districts in Bangladesh and South 24 Parganas in West Bengal. An added benefit of the early maturing cultivars is the provision of straw for livestock feeding earlier than it is available from traditional varieties. The demand for this straw increases its market price, and this has been an added incentive for farmers to replace their traditional varieties. Using a novel system of intercropping vegetables within the paddy field by planting them in bags of soil, it is possible to supplement household income and/or diets with fresh vegetables during the rice season (Maniruzzaman *et al.,* 2024a).

Understanding the risks from multiple constraints in *Rabi* crops

Developing productive dry season non-rice crops for the coastal zone requires more than just salinity management. Salinity levels are dynamic during the dry season: they vary with depth in the root zone, and the impact on crop production varies with soil dryness, waterlogging and heat stress. Rainfall events and the timing and EC of irrigation water also influence root zone salinity and its impacts. The sensitivity of crop species to salinity also varies with the stage of growth; for example, for sunflower, flowering was the most sensitive phase of growth (Mila *et al.,* 2023).

Interactions between soil water, waterlogging and salinity have been examined in a range of recent studies (Islam *et al.,* 2022a,b; Mila *et al.,* 2023; Paul *et al.,* 2021c; Sarker *et al.,* 2023). For *Rabi* crop management and risk mitigation, the new insights that the recent studies provide is that multiple constraints often exist and the main constraint to crop growth can change during the growing season. While either salinity or waterlogging can hamper crops in the coastal zone, the combination of salinity and waterlogging is more common. Crop tolerance to waterlogging is decreased by salinity even at salinity levels lower than generally considered to be limiting (Barrett-Lennard and Shabala, 2013). While EC levels in soils are generally low at the end of the monsoon season, waterlogging risk is high and crop damage was attributable to the waterlogging-salinity interaction (Islam *et al.,* 2022a,b). From February onwards, the rising risk of heavy rainfall overlaps with increasing soils salinity. Hence salt-waterlogging interactions can be particularly damaging to crops at this time, especially if such events coincide with the sensitive flowering phase of crop phenology (Mila *et al.,* 2023). From February onwards, *Rabi* crop growth can be depressed by low solute potential in the soil solution (Islam *et al.,* 2022a,b; Paul *et al.,* 2020b), which is the caused by the interaction of root zone soil water content with its solute concentration. Hence, either rising soil salinity levels or increasing soil dryness, or both, can lower solute potential of soil water and restrict root uptake of water.

Mitigation of multiple constraints

Drainage

Rabi season crops are very vulnerable to heavy or very heavy rainfall in the coastal zone. Most soils have a high clay content witha predominance of swelling clays, which coupled with shallow water table, low elevation and slope and earthen bunds around the polders means that waterlogging of the root zone and inundation is highly likely from heavy or very heavy rainfall events. Even very short periods of waterlogging, particularly when coupled with even moderate salinity levels in the root zone, can cause very severe and rapid crop death, or severe inhibition of growth. In sunflower, more than 24 hours was sufficient to cause severe damage to seedlings (Paul *et al.,* 2021b). However, the maximum period that other crops can tolerate waterlogging has not been well defined. The SEW30 index is a useful indicator of the severity of waterlogging events (Islam *et al.,* 2022a,b). It assesses not only the proportion of the root zone in 0 to 30 cm depth that is waterlogged but also the duration of waterlogging in the root zone.

Encouragingly, the drainage required to improve crop growth in landscapes at risk may not necessarily be difficult. Islam *et al.* (2022a) concluded that shallow surface drains, 10 cm deep with 1.8 m between drains, were sufficient to alleviate the waterlogging. Subsoil drains at 30 cm depth combined with shallow surface drains were additionally effective, but the installation and maintenance of subsoil drains is perceived as too expensive for smaller farmers at this stage.

While drainage of a waterlogged field is clearly necessary and highly beneficial for *Rabi* season crops,the question arises as to where the drainage water can be released. Release into nearby canals and ponds is possible, but such storage capacity is limited and may not be available if these are already full, or the heavy rainfall that causedthe waterlogging filled those storages before field drainage could take place. Just as community-based planting of early maturing rice varieties enables the early sowing technology to be implemented, so too will community-based drainage networks enable *Rabi* season crops to take advantage of early sowing. Programmes are needed to test this hypothesis and to work out the mechanisms by which block-scale drainage could be implemented and coordinated to ensure equitable benefits to those that plant *Rabi* crops without causing damage outside of the block from the discharge of excess water. The Samoloy programme, initiated in Bangladesh by the Department of Agricultural Extension to facilitate collective action by farmers, may be such an enabling approach for cropping system intensification in the coastal zone. Farmer Producer Organisations in West Bengal may be able to provide similar community-based coordination of crop choice, crop planting time and drainage for excess water.

Early sowing of *Rabi* season crops

Amongst the stresses that restrict crop yield in the coastal zone, most occur late in the dry season, that is from mid-February onwards. In addition to drought and low solute potential, which occurs from February onwards when there is little rainfall in the dry season, salt-waterlogging interactions can also cause devastating effects on crops when heavy rainfall occurs in March-April coinciding with rising soil salinity levels. Heat stress during this period exacerbates the effect of the salinity, low solute potential, drought and waterlogging-salinity interactions. Finally, strong winds associated with cyclones and storms that occur from mid-March onwards can cause severe crop lodging.

The early sowing of *Rabi* season crops enables them to complete flowering and seed set, which are very sensitive phases to abiotic stresses and mature before these stresses increase in prevalence and severity. Not only that, but early sown crops can take advantage of the full profile storage of non-saline water to accumulate vegetative biomass and achieve high yield potential before these crop stresses become acute. For wheat, maize, sunflower and potato in Bangladesh and for lentil in West Bengal, there is clear evidence of the higher yield potential from early sowing (Akhter *et al.,* 2024; Kabir *et al.,* 2019; Kundu *et al.,* 2022; Paul *et al.,* 2021c; Sarkar *et al.,* 2020). However, early sowing does increase the risk of waterlogging and the possibility of waterlogging-salinity interactions damaging seedling establishment and early vegetative growth (Paul *et al.,* 2021c). Since the soil profile is close to saturated at the end of the rice growing season, even small amounts of rainfall, falling before the rice harvest, or soon after the early sowing of the *Rabi* crop can cause severe waterlogging, which either delays sowing, prevents germination and emergence of crops or damages their early growth. For example, even two days of continuous waterlogging was sufficient to severely depress the growth and yield of sunflower (Paul *et al.,* 2021c). In order to take advantage of the high yield potential from early sowing it is therefore necessary to either install drainage before sowing (*e.g.,* Islam *et al.,* 2022a,b) or have a contingency plan to install drains rapidly ahead of predicted rainfall from tropical depressions that originate in the Bay of Bengal.

With sunflower, the early sowing increases yield through several potential benefits. The stresses alleviated by early sowing vary from year to year and from site to site. Alleviation of waterlogging and waterlogging-salinity interactions were the factors responsible for improved sunflower growth with drainage (Islam *et al.,* 2022a,b). In other studies, early sowing ensured that solute potential was less negative later in the season, so the plants suffered less severe water stress. The early sowing also decreased crop exposure to high temperatures and that can increase yield if crops avoid exposure to temperatures over 35°C. The early sowing of sunflower also extended the pre-flowering growth duration, which increases overall biomass production and that in turn can help boost the number of seeds per head and seed size (Paul *et al.,* 2021b).

The optimum time for early sowing appears to be late November to mid December for sunflower, maize, wheat and lentil. Further evaluation of the optimum sowing window for other crops would benefit from additional time of sowing experiments across the coastal zone. Insight gained from simulation modelling *e.g.,* APSIM would also help to refine the optimum sowing window and how they might vary across the coastal zone.

Early establishment of different *Rabi* season crops can be achieved 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.,* 2021, 2024c; Sarkar *et al.,* 2020).

Mulch (using rice straw) placed on the surface of the soil is another strategy that reduces the accumulation of salt in the root zone and helps maintain soil moisture, thereby increasing solute potential. In the coastal zone, the groundwater is relatively shallow and moderately saline. At the end of the wet season, the water table is close to the surface within 30 cm and relatively fresh. As the water table declines during the dry season due to evaporation, capillary rise of pore water brings salt to the surface. Irrigation and dry rainfall may reverse the salinisation of the upper 20-30 cm of the rootzone, which appears to be the most crucial part of the roots for *Rabi* season crop growth. Mulch also retains more moisture at the surface and reduces the extent of vertical cracks in the clay rich soils of coastal zone (Paul *et al.,* 2021a). With mulch there is an increased root density in the surface soil layer, and overall yields are boosted by 15 to 20% (Paul *et al.,* 2020a).

Previously in the coastal zone when cropping intensity was low there was abundant rice straw available for use as mulch applied at 5 to 10 t ha^{-1}. For sunflower, 5 t ha^{-1} of rice straw provided similar benefits to 10 t ha^{-1} of rice straw (Paul *et al.,* 2020a). For drip irrigated tomato, 4 t ha^{-1} of rice straw improved yield and water use efficiency (Samui *et al.,* 2020). However, 12-15 t ha^{-1} of rice straw was more favourable than 9 t ha^{-1} of rice straw for zero-tillage (ZT) potato cultivation in the coastal zone (Sarangi *et al.,* 2021).

Competition for the use of rice straw for livestock feeding or other purposes may impact on availability of mulch and therefore the feasibility of the technology. However, as long as the area of ZT potato or mulched *Rabi* season crops does not cover the whole of the cropping area, there should be sufficient straw available for mulching crops (Goswami *et al.,* 2024). In the absence of sufficient rice straw, plastic mulches can be effective for some high value crops such as tomato. However, disposal of plastic mulch requires further consideration. The availability of bio-plastics that are bio-degradable may make such mulches more acceptable.

High-value, short-duration crops

Short duration crops are likely to avoid salt stress, low osmotic potential, salt-waterlogging interactions, and heat stress. A range of high value vegetables, some of which are harvested within 60 days from planting will fit comfortably in the period from mid to late December to the end of February and hence avoid most of those stresses. In Bangladesh, watermelon has recently become popular at Dacope in Khulna district for *Rabi* season cropping. Watermelon harvested outside of the peak supply period in the Dhaka market attracts very high prices and can result in a very profitable *Rabi* season crop for farmers. However, once supply to the market increases, prices drop sharply and farmers are likely to lose money from growing late-sown watermelon. In addition, failure to design watermelon fields with provision for drainage has resulted in crop failure from waterlogging in the Dacope region (M.B. Das, personal communication).

Boro and Aus rice

On low and very low land, or on lands close to freshwater rivers, *Boro* and *Aus* rice could be the most suitable options to intensify the cropping system (Maniruzzaman *et al.,* 2024b). Not only are the rice crops able to tolerate heavy and very heavy rainfall events without the need for drainage, but market demand for rice is strong at those times. In the case of *Aus* rice, so long as there is enough fresh water to raise seedlings for transplanting, the post-transplanting growth of the crop can benefit from high rainfall from April onwards. High-yielding *Aus* and *Boro* rice varieties and their suitable transplanting times have been identified (Saha *et al.,* 2019; Sarangi *et al.,* 2019; Yesmin *et al.,* 2019). Initial attempts at wet direct seeding of *Boro* rice resulted in decreased yield compared to transplanting (Paul *et al.,* 2024). However, in medium-lowland and medium-highland and highland fields, where alternative crops such as sunflower and watermelon can be grown, higher profits can be generated by using fresh water to irrigate higher value crops, and more farmers can benefit from *Rabi* crops with the limited fresh water resource.

Livestock and fodder production

Cattle, sheep and goats are a traditional component of farming systems in the coastal zone. However, their productivity and health are poor due to inadequate and low nutritive value feed, especially during the dry season when rice straw is the main feed available. Increased livestock productivity could improve farm efficiencies, diversify income streams and spread risk, and generate additional income for farmers (Sarangi *et al.,* 2024a). Well-managed and irrigated fodder production plots around farm dwellings can produce enough high-quality feed for goats and cattle without sacrificing land for other crops.

Water use efficient irrigation

Fresh water is a scarce resource in the dry season in the coastal zone. Increases in water storage capacity by renovating ponds and canals can play a role in increasing the potential for *Rabi* season cropping. However, water-efficient irrigation, water-saving technologies and reserving fresh water for high value crops can all play a part in cropping systems intensification.

Drip irrigation technology has been effective for vegetable crops and potato in the coastal zone (Mahanta *et al.,* 2019; Samui *et al.,* 2020). However, the uptake of drip irrigation by farmers is still limited, suggesting that either more effective training of farmers in its use or systems with lower investment costs are needed. Simple drip irrigation from pitcher pots combined with rice straw mulch is suitable for producing high value vegetables in home gardens and small fields and requires low investment costs (Sarangi *et al.,* 2024b).

The conjunctive use of moderately saline water together with freshwater can decrease the overall demand for scarce freshwater. Numerous studies suggest that one or two of the scheduled irrigation events for *Rabi* crops can be with moderately saline water without loss of yield (*e.g.,* Sarker *et al.,* 2023). Reserving freshwater for irrigation during flowering is advisable since this is the period of greatest sensitivity by crops to salinity (Mila *et al.,* 2023). Saving of freshwater by relying on moderately saline water for irrigation opens up the opportunity for strategic use of that freshwater for high value crops such as vegetables, turmeric, ginger and watermelon, in either home gardens or crop fields (Mila *et al.,* 2021). Risks of the long-term accumulation of salt in soil profiles from such strategies may be low because the areas where this would be implemented still receive ~1800 mm of annual rainfall, mostly in the monsoon. Community-managed irrigation, or water sharing mechanisms are important to ensure that water is managed and shared equitably in communities (Bell *et al.,* 2019).

Scaling out cropping system intensification

Numerous studies have been conducted in the Ganges coastal zone to evaluate and select suitable cropping patterns based on their socio-economic impacts (Goswami *et al.,* 2021; Islam *et al.,* 2024; Mandal *et al.,* 2020, 2022; Ray *et al.,* 2019, 2023; Saha *et al.,* 2019; Sarangi *et al.,* 2024c). Other studies have determined improved fertilizer strategies for intensified cropping systems (Zahan *et al.,* 2024). There are still opportunities for optimizing the agronomic management of *Rabi* crops in the coastal zone. For example, Kundu *et al.* (2024) found that increasing plant density from 72,272 to 266,667 plants m^{-2} increased ZT potato yield by 7.5 t ha^{-1}. Mahmud *et al.* (2024) reported that a ridge and furrow planting arrangement and close spacing improved yield of sunflower while decreasing soil salinity.

However, these studies are still restricted to a few sites and a few years. The variability of outcomes over longer time frames could be explored by simulating crop performance with models like APSIM (Sarkar *et al.,* 2022, 2024). Modelling could also be used to predict the effects of future climate change scenarios on crop performance. Future increases in rainfall intensity in the dry season are predicted by global climate models for the coastal zone (Karim *et al.,* 2024).

Scaling out of technologies needs a more detailed assessment of where to promote particular options to suit the constraints of each location. Mapping of cropping systems in West Bengal coastal zone indicates the degree of landscape diversity (Ghosh *et al.,* 2019, 2023a, 2023b; Nanda *et al.,* 2023). Demonstrations of technologies and *Rabi* season crops need to be completed more comprehensively across the coastal zone. Such demonstrations can then be used to calibrate crop models so that the variability of crop yield across landscapes and over time can be used to calculate gross margins and other values for farmers. In addition to landscape diversity, there is diversity of farm type and that will determine the magnitude of benefits that can be accessed by farm families (Goswami *et al.,* 2021). Whole-farm economic models (*e.g.* Value-Ag-Monjardino *et al.,* 2020a,b; 2021) can account for this heterogeneity and hence help to identify niches where particular technologies could be targeted for greatest adoption and impact.

The expansion of production areas for new crops in the coastal zone can be expected to increase the prevalence of diseases and insect pests. Hence for potato, sunflower, maize, watermelon and vegetables that are being grown on expanding areas, monitoring of farmers' crops needs to be carried out by research institutes to identify emerging pests and diseases and to develop control measure before they spread widely and damage the confidence of farmers in these crops. The work of Khatun *et al.* (2024) on Fall armyworm in maize is a good example of this approach and showed that, even though this pest was a recent introduction to the coastal zone of Bangladesh, farmers were already aware of it and applying chemical control measures.

Supply chain and market barriers

The development of new crops and out scaling of them in the coastal zone faces many of the usual challenges. Firstly, enough farmers need to develop confidence in growing the new crops and realizing their benefits for adoption to reach a critical mass that can support supply chains for a reliable and cheap supply of inputs. For example, ZT potato has attracted much interest from farmers, and extension officers as a profitable new cropping option for the *Rabi* season, but so far projects have supplied seed potato to farmers. An independent potato sector in the coastal zone needs to be supported by a reliable supply of seed potato. Secondly, supplying potatoes to city markets requires reliable transport infrastructure and sufficient volume of supply to attract traders. For periods when there is a glut in the market supply, cold storage facilities would enable farmers in the coastal zone to delay sales until market prices become more favourable. Storage would also help to ensure timely seed potato supply for the critical planting times. Emerging Farmer Producer Organizations may be the vehicle for driving these supply changes in a manner that empowers farmers to be the prime beneficiaries of a potato production and supply sector (Goswami *et al.,* 2024).

Sunflower and maize are also promising field crop options for the *Rabi* season, but both of them need market development, and or crushing and processing facilities in the coastal zone to add value to the products produced. High value production of vegetables needs to be linked to reliable and fast transport to markets in order to maintain product quality so that farmers gain maximum value from their produce.

Sustaining intensification

The physical proximity of the coastal zone to the Bay of Bengal and to major rivers in the Ganges Delta means that cyclone and storm surge damage is almost inevitable from time to time. To mitigate effects on human safety, governments in both West Bengal and Bangladesh have constructed secure cyclone-safe shelters where significant numbers of people can take refuge. Facilities for keeping animals safe are less well developed, though. However, land which is inundated by saline water will be damaged for some years. Modelling of water and salt balances in the polders (Mainuddin *et al.,* 2020, 2021; Mainuddin and Kirby, 2021) suggests that in well-drained polders with functioning sluice gates and well-maintained canals, the salt load accumulated from inundation storm surges can be leached out within 2 to 3 years. However, *Rabi* season crops during that period are likely to suffer yield loss. A storm recovery programme could involve options for saline agriculture that can be quickly deployed. These might include quick-growing forages to ensure that surviving livestock are adequately fed in the months after storm surges (Sarangi *et al.,* 2024a). Maintaining a store of seed of salt-tolerant *Aman* rice varieties would enable the first *Aman* season crop after storms to restore food security. Seed of short duration salt-tolerant vegetable crops (*e.g.,* Naher *et al.,* 2024) might also be storedand distributed in the period after floodwaters recede.

Preparation for storms can be improved by better mass communication of storm warnings in the coastal zone. Storm warnings 7-10 days ahead of these eventswould give farmers sufficient time to implement surface drainage, harvest crops (where appropriate) and find secure places for the refuge of animals.

With continuing climate change in the Ganges Delta (Ghosh *et al.,* 2021; Karim *et al.,* 2024), farming systems will approach critical tipping points: land will become increasing salinized, waterlogged, and prone to storm surges; heat stress and seasonal droughts will become more important as limiting factors. This will necessitate the evolution of farming systems. The production of rice can be expected to give way to aqua culture in some areas. Rice may also have to give way to the growth of more water efficient crops. Farmers are often reluctant to change from traditional farming systems. This creates an inertia that limits the adoption of new technologies but there is evidence of adaptation by farmers in the coastal zone to climate changes that they already perceive to be occurring (Begum *et al.,* 2023a,b). The barriers to change are far greater where farms are hydrologically interconnected, bound within polders with common water ingress and egress points through sluice gates: here communities have to transition together. Research needs to be conducted to define where and when the transitions should occur, and what kinds of support communities need to make the necessary changes. New capabilities for mapping land use change, vegetation health, water balance and crop zones in the coastal zone using blended MODIS images will improve the ability to define where research and transitions should be targeted (Pena-Arancibia and Yu, 2024).

Another issue is that farmers and their advisors need better tools for determining land capability, leading to better targeting of plants (based on their tolerances) and land management options to land of differing capabilities. It remains true that in landscapes affected by salinity, land and water capability is presently assessed primarily in terms in salinity. This must change because: (a) waterlogging and drought are major features of coastal landscapes, (b) when combined with salinity, waterlogging profoundly affects plant ion relations, growth and yield, and (c) crops have differing tolerances to salinity and water availability (drought to waterlogging). As we look forward, there are new opportunities to improve crop-livestock integration in farming systems to achieve better synergy between agricultural production, food security, and environmental sustainability. We also envisage that extension packages will be developed that better assess the risks to terrestrial agriculture in coastal landscapes, and there will be better tools to train extension workers to think more creatively about helping farmers make better choices in this multi-dimensional risk-prone environment.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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