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Cropping Systems Intensification in the Coastal Zone of the Ganges Delta: Opportunities and Risks

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The coastal zone of the Ganges delta has many constraints and threats that have hampered development. However, recent research indicates that there are numerous viable options for cropping systems intensification that have yet to be fully exploited. The main opportunity involves changing the cropping season to use stored water with a low solute potential in the *rabi* season and to harvest crops early to avoid crop stress from waterlogging, salinity/drought, heat and or storms. Early planting of *rabi* season crops requires harvest of *kharif* rice 15 to 30 days earlier. Several earlier maturing cultivars have been identified with yield gains of 0.5 to 1 t ha^{-1}. The early harvest of *kharif* rice opens up opportunities for promising new crops for the *rabi* season such as zero tillage potatoes. Moreover, for a range of other *rabi* crops (e.g. wheat) early sowing results in higher yield potential. Realising the higher yield potential depends on early drainage of excess floodwater, and a drainage system to mitigate the risk of heavy rainfall events in the *rabi* season. Canal and pond water remains mostly below 4 dS m^{-1} and hence is suitable for irrigation during the *rabi* season but the volume available is limited. Low cost drip irrigation was shown to be highly profitable and is a potential technology for value addition of the scarce water supplies. In the coastal zone, current *kharif* season rice supplies are not sufficient to meet food security needs. *Aus* rice was successfully grown at a number of locations and produced good yields (4.0-4.5 t ha^{-1}). A diverse range of new crops were successfully grown especially vegetables for which local markets exist. However, dry season cropping in the coastal zone involves risks, particularly from heavy rainfall either at the end of the monsoon season or from February onwards and climate analysis suggests the frequency of these heavy rainfall events has increased in the last 40 years. The technologies developed and the risk management strategies required will need to be adapted to the variation in rainfall and river water salinity across the coastal zone of the Ganges delta.

(**Key words:** *Aus rice, Crop establishment, Crop stress, Drought, Kharif rice, Salinity, Time of sowing, Waterlogging, Zero-till potato)*

The Ganges delta, one of the world's mega-deltas, has been relatively neglected in terms of agricultural development even though it is the home to over 50 million people (Mainuddin *et al*., 2019a). Compared to adjacent regions of Bangladesh and West Bengal, the cropping intensity is much lower as is the yield of the monsoon-season rice (referred to as *kharif* rice), which is the main crop grown. The livelihood of over 50 million people is in the balance in the Ganges delta due to current low agricultural productivity, the threat of rising seawater and to climate change. Currently, a range of constraints are perceived to limit the options for cropping intensification by growing additional crops in the dry season (*rabi*) and early wet season. The major constraints are perceived to be soil salinity and the apparent lack of fresh surface water for *rabi* season crop production (Humphreys *et al*., 2015). However, the collective work reported in this special issue and related papers (Humphreys *et al*., 2015) seek to challenge those perceptions and present the evidence for realistic and profitable cropping systems intensification opportunities.

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Understanding the coastal zone environment and hydrology

1. *Climate and trends*

Across the Ganges delta, climate varies significantly (Yu *et al*., 2019). Hence, some variation in profitability and suitability of cropping choices and patterns is expected across the region. Rainfall declines in a gradient from east to west and north to south. In Patuakhali, Bangladesh, annual rainfall is 2,000 mm but only 1,800 mm in Canning Town. The total rainfall is relatively high, suggesting that the region should be able to take advantage of the available water for crop production. However, the rainfall is mostly compressed into 3-4 months. The decrease in rainfall from east to west was associated with a decline in rainy days from 123 to 100.

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

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

2. *Polder scale hydrology*

Agricultural land within the coastal zone of the Ganges delta is generally enclosed by earthen embankments called polders (Bangladesh) or islands (West Bengal). Polders are surrounded by river water that can vary from continually fresh (especially to the north of the coastal zone) to continually saline (especially closer to the Bay of Bengal) (Mainuddin *et al*., 2019b). Most previous research in this region has focused on experimental plots within polders: Mainuddin *et al*. (2019b) developed a polder scale water and salt conceptual model to provide greater clarity about the distinctive water and salt dynamics at polder scale. The low-lying land within polders is only 1-2 m above sea level and has a shallow, moderately saline water table [2.3-3.5 dS m^{-1} at Dacope; 3.12 to 11.7 dS m^{-1} at Amtali (Sarker *et al*., 2019)] that is rarely deeper than 2.5 m (Hossain *et al*., 2019; Schulthess *et al*., 2019). Annual rainfall in the coastal zone ranges from 1,800-2,000 mm and the recharge of this rainfall in the monsoon season creates a fresh water lens on top of the saline groundwater. The fresh water lens is a resource for crops to use, but during the course of the dry season, it becomes contaminated by capillary rise of salts from the groundwater and from the dominant clay loam soils, which also act as temporary salt stores. Capillary rise of salts from these sources also increases surface soil salinity during the *rabi* season.

The excess of rainfall over evaporation in the coastal zone is 500-1300 mm annually, so that there is ample opportunity for leaching and dilution of salt, provided the drainage system allows flushing of the salt. Without removal of salts, the polder model suggests that salts recycle from the groundwater to the upper soil layer and then back to the groundwater (Mainuddin *et al*., 2019b). In addition, through the irrigation of crops with water in canals and ponds, salt re-circulates to the soil and groundwater. Episodic storm surges that breach the embankments surrounding polders can cause catastrophic input of salt into the soil and groundwater system in the polder. Under the existing drainage infrastructure, the natural rate of flushing of salts by wet-season rains means that these events can take viable land out of production for many years.

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

Opportunities

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

- surface drainage of excess water at the end of the wet season,
- better understanding and use of the limited fresh groundwater (after investigating potential acid sulphate soil problems),
- increased surface water storage capacity, and better maintenance, management and use of the existing limited storage,
- separation of lands of higher and lower elevation taking advantage of existing infrastructure (e.g. roads) and strategic construction of small levees,
- planting of earlier maturity and shorter duration rice varieties during the monsoon season to provide better timeliness of *rabi* crops in relation to water availability,
- increased use of salt tolerant *rabi* cultivars, and
- optimising areas of cropping in relation to areas devoted to surface storage.
- pumping to lower saline water tables during *rabi* season, and reduce salt build-up in surface soil.
- use of mulches to reduce *rabi* season soil evaporation and hence reduce salinity build-up in surface soil.

Investigations into a number of these opportunities are reported in this special issue and discussed below.

1. *Early kharif harvest*

Traditional *kharif* rice varieties for the coastal zone are relatively low yielding but well adapted to the wet season water regimes. They have been selected for tall stature to cope with deep standing water level and mature in December when flood water recedes. In both Bangladesh and West Bengal, recently released cultivars with tall stature that mature 15-30 days earlier than traditional varieties have 0.5-1.0 t ha^{-1} higher yield than existing cultivars (Maniruzzaman *et al*., 2019; Sarangi *et al*., 2019a). Direct seeding was also advantageous for early harvesting and crop tolerance to deep flooding. In West Bengal, cv. Pratikshya was the most promising rice variety with 20 days earlier maturity, tall stature and lodging resistance. In Bangladesh, three promising cultivars with increased yield and 30 days earlier maturity were selected by farmers (Maniruzzaman *et al*., 2019). The traits preferred by farmers were high yield potential, taller plants, strong stem, more tillers per hills, increased panicle length and longer grain size. Hence there do appear to be win-win solutions for *kharif* rice varieties with earlier harvest by 15-40 days, depending on location and variety, and 0.5-1.0 t ha^{-1} yield increases. However, to capture the benefits of early maturity and early sowing of the *rabi* season crops, coordinated planting of the improved cultivars is needed over a sizable area of land. Otherwise there will be increased bird attack on the ripening grain of the early variety, and conflict between the interests of farmers wanting to retain deep flood water for long duration varieties versus the need for rapid drainage of excess standing water to prepare land for *rabi* season crops.

2. *Early sowing of rabi season crops*

Provided early maturing rice varieties are grown and rapid drainage of excess water can be effectively managed, early sown *rabi* season wheat crops out yield those sown after the natural recession of the flood waters (Kabir *et al*., 2019). Wheat produced a maximum yield of 4.2-4.4 t ha^{-1} when sown between 25 November and 1 December (Kabir *et al*., 2019). Delay in sowing decreased wheat yield. Similar benefits with early planting (late November to mid December) are being found in experiments for yield of maize, sunflower (P.L.C. Paul, personal communication), lentil and grass pea (K. Brahmachari, BCKV through personal communication). For crops like wheat, early sowing delays flowering which lengthens the vegetative growth period: the longer vegetative growth together with higher level of soil water and lower soil salinity appear to explain why the early sown crops have higher yield potential in the coastal zone. Schulthess *et al*. (2019) reported that due to the shallow water table and clay-textured soils, that maize and wheat crops could produce satisfactory yields in the coastal zone of the Ganges delta without irrigation except in the driest of winters when supplementary irrigation during early growth was sufficient. In their studies, wheat was sown in the later half of December and maize on around 1 January after the recession of flood waters.

3. *Boro and aus rice*

Despite the range of *rabi* season cropping options found to be profitable in the coastal zone (see below), farmers still have a strong preference to grow more rice. This suggests that current *kharif* season rice supplies are not sufficient to meet food security needs. When fresh water is available, farmers in Dacope, Khulna and Amtali, Barguna have preferred *boro* rice even though it has very high water requirements. The optimal period for establishing seedling nurseries for *boro* rice was mid-November to mid-December. The salt-tolerant cultivars, BRRI dhan67 and BINA dhan10, produced the highest yield (about 6 t ha^{-1}) in Bangladesh (Yesmin *et al*., 2019). For the low lying areas in the coastal zone where adequate water is available, *boro* rice is an option. Further evaluation of the reliability of *boro* rice over the long term in the coastal zone is being carried out using APSIM modelling (Don Gaydon, personal communication). In addition, water-saving options for growing *boro* rice such as alternate-wetting and drying should be examined.

As an alternative to *boro* rice where water is more limiting, *aus* rice is an option since it needs less irrigation water. Transplanting in April-May ensures that some of the *aus* rice crop's water requirements are from early monsoon rainfall. *Aus* rice in Amtali, Barguna averaged 3.8-4.0 t ha^{-1} (Saha *et al*., 2019; Sarker *et al*., 2019). Lack of water to establish the rice seedling nursery may hamper *aus* rice in some years. Further evaluation of the reliability of *aus* rice over the long term in the coastal zone and optimum sowing time can be assessed using APSIM modelling.

4. *Soil management*

Early establishment of the *rabi* season crops will inevitably involve sowing into wet soils. Mechanised seeding could facilitate rapid crop establishment after rice harvest, but experiments at Dacope indicate that high levels of soil disturbance are more effective for crop yield in this environment than minimum soil disturbance (Paul *et al*., 2019). Full rotary tillage and planting on shallow beds resulted in highest yield of sunflower, even though emergence of plants was delayed relative to strip planting and zero tillage. The high level of soil disturbance decreased the accumulation of salt in the upper soil layer and maintained higher soil water levels, both of which ensured higher solute potential in the upper root zone.

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

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

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

5. *Tolerance of salinity*

For *rabi* season cropping, increased salt tolerance seems an obvious solution to the salinity constraint but this opportunity is not examined in any of the papers in this special issue. Indeed, caution should be exercised before focusing on salt tolerance alone. The *rabi* season in the coastal zone involves several crop stresses, not just salinity. In addition to rising salinity, drought, heat stress, waterlogging and the waterlogging - salinity interaction need to be considered. Solute potential is a useful concept to link the combined stresses of salinity and drought or soil dryness. Salt concentrations in the soil solution rise as the soil dries, and the resulting increase in soil solution salt concentration (i.e. decrease in solute potential) limits crop water uptake at higher levels of soil water and lower levels of salinity than are normally considered a risk. Paul *et al*. (2019), Sarker *et al*. (2019) and Kabir *et al*. (2019) have all shown that solute potential is more closely related to crop response than either electrical conductivity or soil water content.

A further challenge for screening for salt tolerance and assessing crop response to treatments in the field is the variability of salinity levels (Rawson *et al*., 2013). Intensive soil sampling and laboratory analysis of EC could quantify the variability of salinity when used as a co-variate in statistical analysis. A less tedious approach is to use EM sensing with the Dual EM (E. G. Barrett-Lennard and M. Glover, personal communication) and preliminary results suggest that this is an effective, rapid method of quantifying salinity variation across experiments.

6. *Increase surface water storage*

The most obvious opportunity for cropping system intensification is to create more surface water storage capacity to enhance the supply of irrigation water for the *rabi* season. Monitoring to date indicates that water stored in ponds and canals remains relatively fresh throughout the dry season, but the volume available is limited and insufficient for major expansion of irrigated *rabi* season cropping. Economic analysis is needed to determine the optimum proportion of farms for surface water storage. Due to the high investment cost of digging water storage ponds and canals, co-investment of government agencies is likely to be essential to accelerate the increase of water storage capacity.

7. *Drainage*

More effective surface drainage is essential to decrease the risk of crop failures or delayed sowing due to heavy rainfall events in the early *rabi* season. Rainfall trend analysis suggests these events are increasing in frequency. Kabir *et al*. (2019) describe the steps that they took with surface drains to remove excess water in paddy fields after harvest of the *kharif* season. Further research is needed to design and evaluate the most effective forms of drainage, including the possibility of sub-soil drainage.

8. *Drip irrigation*

Considering the shortage of fresh water storage in the coastal zone, water-saving irrigation by drip technology should be an attractive option. Mahanta *et al*. (2019) demonstrated that drip irrigation even by low cost technology was highly profitable for high value vegetables such as chilli, knol-khol, okra and bitter gourd in the *rabi* season and cucumber, bitter gourd and okra in the *kharif* season. Benefit-cost ratios (BCR) ranged from 1.26 to 6.4. Drip irrigation also decreased the electrical conductivity (EC) in the upper part of the root zone compared to non-irrigated soil.

Risks

1. Early maturing kharif rice

Individual farmers growing early maturing rice cultivars will experience a number of risks (Kabir *et al*., 2019). Firstly, bird and rat damage may be severe unless precautions are taken. Secondly, rapid drainage of excess flood water after rice harvest can be hampered by the need of neighbouring farmers to retain that water as long as possible, highlighting the need for an equitable water management strategy.

2. Late monsoon rain

As noted above, heavy rainfall events in November are relatively common (Yu *et al*., 2019). This will delay the sowing of *rabi* season crops unless effective surface drainage systems are set up. Flooding in fields or waterlogging can only be tolerated by the *rabi* season crops like sunflower for 1-2 days. Hence rapid responses are needed to heavy rainfall events or else crop failure is likely. The likelihood of heavy rainfall events declines in December (Yu *et al*., 2019). Further research is needed on the relative tolerance of *rabi* season crops to waterlogging and flooding during the crop establishment phase. *Boro* rice has the obvious advantage over *rabi* crops in tolerating heavy rainfall events.

3. Mid-season rain

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

4. Kharif rain and storms

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

5. Heat stress

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

New cropping systems that manage risk and opportunity

A wide range of field crops and vegetable crops are feasible in the coastal zone, and profitable intensified cropping patterns have been identified (Saha *et al*., 2019). Among the cropping patterns that increased BCR in Amtali, Barguna compared to the farmer's practice (a single *kharif* rice crop) are: T. *aman* - Potato - Mungbean - T. *aus*; T. *aman* - Mustard - Mungbean - T. *aus*; T. *aman* - Garden pea – Mungbean - T. *aus*; T. *aman* - Spinach - Mungbean - T. *aus*. At Dacope, a second crop of mustard, garden pea, spinach and potato increased BCR compared to a single *kharif* rice crop. By contrast, Sarker *et al*. (2019) did not achieve increase in BCR from 3-crop patterns because the *kharif* rice cultivars chosen were not the optimal cultivar for early maturity (Maniruzzaman *et al*., 2019).

One of the most promising new crops introduced was zero-tillage (ZT) potato (Sarangi *et al*., 2018a&b). The ZT potato is placed on wet soil and covered by a thick layer of rice straw mulch equivalent to 12 t ha^{-1} (Sarangi *et al*., 2018a). Further experiments are underway to develop optimum agronomic practices for ZT potato including plant density and cultivars.

Within the coastal zone, the landscape is diverse, particularly in land type or elevation. The cropping intensification options will vary according to land type. Remote sensing technologies can be used to classify the landscape according to land use (Ghosh *et al*., 2019).

The studies reported in the special issue provide evidence that cropping systems intensification is feasible and profitable. However, there is still much to be done to increase the resilience of this system by mitigating risks and increasing the productivity of crops by best management agronomic practices that specify optimal plant population, row spacing, seed depth and rate, time of sowing, fertilizer rate and placement.

Research continues to demonstrate that there are numerous viable options for cropping systems intensification in the coastal zone. The main opportunity involves changing the cropping season to use stored water from the monsoon season in the *rabi* season when the solute potential is low and to harvest crops early enough to avoid crop stress from waterlogging, salinity/drought, heat and or storms. Early planting of *rabi* season crops requires harvest of *kharif* rice 15 to 30 days earlier in both West Bengal and Bangladesh. In both countries, several earlier maturing cultivars have been identified with yield gains of 0.5 to 1.0 t ha^{-1}. One of the most profitable and promising new crops for the *rabi* season is ZT potatoes. Experiments continue to demonstrate improved yields with up to 20 cm of rice straw mulch equivalent to 12 t ha^{-1} (Sarangi *et al*., 2018a&b).

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

In the coastal zone there is a high demand for increased rice production. Current *kharif* season rice supplies are possibly not sufficient to meet food security needs. Where sufficient water is available, *boro* rice is an option for lowlands. In addition, *aus* rice was successfully grown at a number of locations and produced good yields (4 t ha^{-1}).

Whilst early crop establishment, mechanised zero tillage and strip tillage were less successful than full tillage for crop yield, dibbling of seed by hand and transplanting of seedlings were very effective means of early establishment of *rabi* season crops without tillage. Mulching is highly effective in increasing yield of *rabi* season crops.

There are important social dimensions to cropping systems intensification, to ensure that access to and benefits from technologies are socially inclusive, and secondly to ensure that equitable arrangements are put in place to manage water in the coastal zone.

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