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Rice-based Cropping System Intensification in the Coastal Saline area of Bangladesh: Problems and Prospects

P L C Paul[1*], D Roy[1], M N H Mahmud[1], M B Hossain[1], M S Yesmin[1], P K Kundu[2] and M T Islam[3]

ABSTRACT

The coastal zone environment of Bangladesh is characterised geographically by river deltas and estuaries, where tidal and riverine flooding and varying salinity levels affect agriculture and livelihoods. In this area, the land and agricultural productivity is very low because of several constraints, particularly waterlogging, high salinity of soil and water, freshwater scarcity for crop irrigation and natural disaster. In this review, the objectives are to focus on the limiting factors for crop intensifying and highlighting the opportunities to increase coastal agriculture while enhancing farmer's livelihoods. Some recent studies demonstrated many opportunities for increasing cropping systems that have not yet been exploited extensively. Rainwater or low saline river water storing in the internal canal can fulfil the water requirement for dry season rice and non-rice crops, thereby increasing growth and yield. Early establishment of "Rabi" crops (non-rice) can utilize maximum low-saline soil water and escape high salinity/drought or heat/storms at later period of the growing stages, but this early sown Rabi crops needs early harvest of Aman rice around 15-30 days earlier than farmer practices. Moreover, early sowing by zero tilled dibbling (such as sunflower, maize, wheat, and potato) in wet soils results in higher yield potential. Using rice straw mulch ~5 t ha^{-1} has been shown to be highly beneficial for ameliorating soil constraints. A recent study revealed that straw mulch application on soil surface increased soil water and soil solute potential in the upper root zone, reduced soil salinity, soil strength, and cracking which attributed to higher yield. Considering the successful dry season crop establishment and yield potential requires early drainage to remove excess soil water and a drainage system that mitigates waterlogging from heavy rainfall events during the growing season. We expect this review will facilitate the future research planning and execution in this vulnerable coastal environment.

Key words: Waterlogging, salinity, drainage, tillage, mulching, rabi crop establishment

INTRODUCTION

Bangladesh coastal area is in the lower floodplain of the Ganges delta. This area is extremely vulnerable to increasing sea level as the elevation of the area is ~2-3 metres above mean sea level (Paul *et al.,* 2020b). Besides sea level rise, this area is most prone to cyclones, storm surges, and flooding (Paul *et al.,* 2016). The coastal zone comprises ~32 % of the net cultivable land of Bangladesh and is home to over 30 million people (BBS, 2018). Around 1.1 million hectare of coastal land is impacted by various salinity level (Paul, 2020). In this area, cropping intensity is low less than 150% as farmers only grow low-yielding traditional rice ('Aman') in the monsoon season, and huge area stand uncultivated during the dry season (Paul, 2020). Since 2007, this area has been faced by several super cyclones such as "Sidr" in 2007, "Aila," in 2009, "Mahasen" in 2013, and "Amphan" in 2020. These environmental vulnerabilities limit agricultural production, food security, and livelihood improvement in this area. Over the last 10-15 years, several research projects have been implemented especially for cropping system intensification through adoption of high yielding rice and non-rice cultivars, escaping salinity and waterlogging risk, improving soil physicochemical properties, practicing a range of tillage operation, conjunctive use of fresh

[1]Senior Scientific Officer; [2]Scientific Officer; [3]Chief Scientific Officer; Irrigation and Water Management Division, Bangladesh Rice Research Institute, Gazipur 1701.
[*]Corresponding author's Email: plcpauliwm@yahoo.com (P L C Paul)

and saline water and assessment of salt and water balance (Kabir *et al.,* 2019; Mainuddin *et al.,* 2020; Mondal *et al.,* 2015b; *Paul et al.,* 2021a; Sarangi *et al.,* 2020; Yesmin *et al.,* 2019).

Even though there were some improved technologies for crop establishment, growth, and yield, some negative findings were also recorded from these studies. For example, Paul *et al.* (2021b) demonstrated that early establishment of sunflower has the risk for waterlogging from sudden heavy rainfall while late sowing of sunflower suffers salinity and heat stress later stage of the growing season. On the other hand, mechanized zero tillage in clay-textured soil creates soil smearing, compaction, and cracking, thereby depressing crop growth and development (Paul *et al.,* 2020a).

Furthermore, the land shape and topography and lack of available agricultural tools limit the crop intensification in this area (Mandal *et al.,* 2019). Moreover, a new global pandemic of novel coronavirus (COVID-19) has started to disrupt agricultural farming and could affect food availability in the future. So, it would be challenging to continue the food supply to the entire nation. There is a scope to use underutilized or fallow land during the dry season estimated around 800,000 ha land in the coastal zone, contributing to adding the nation's food basket (Mainuddin *et al.,* 2013). However, a range of constraints needs to be addressed to explore the coastal area for increasing the cropping intensity and productivity.

COASTAL ZONE HYDROLOGY

Land topography

Hydrologically, Bangladesh's coastal zone is influenced by three river basins: the Ganges, Brahmaputra, and Meghna (GBM), which landmass holds 19 districts (Fig. 1). Agricultural land in the coastal area is generally protected by earthen embankments called polders. In the 1960s, 139 polders were constructed to protect agricultural land and livelihoods from tidal inundation and seawater intrusion (Paul, 2020). Figure 2 shows a typical polder view in the coastal zone of Bangladesh. Polders are generally surrounded by river water, which may vary from fresh water in the upper zone (Northern coastal zone) to saline water in a lower zone (close to the Bay of Bengal).

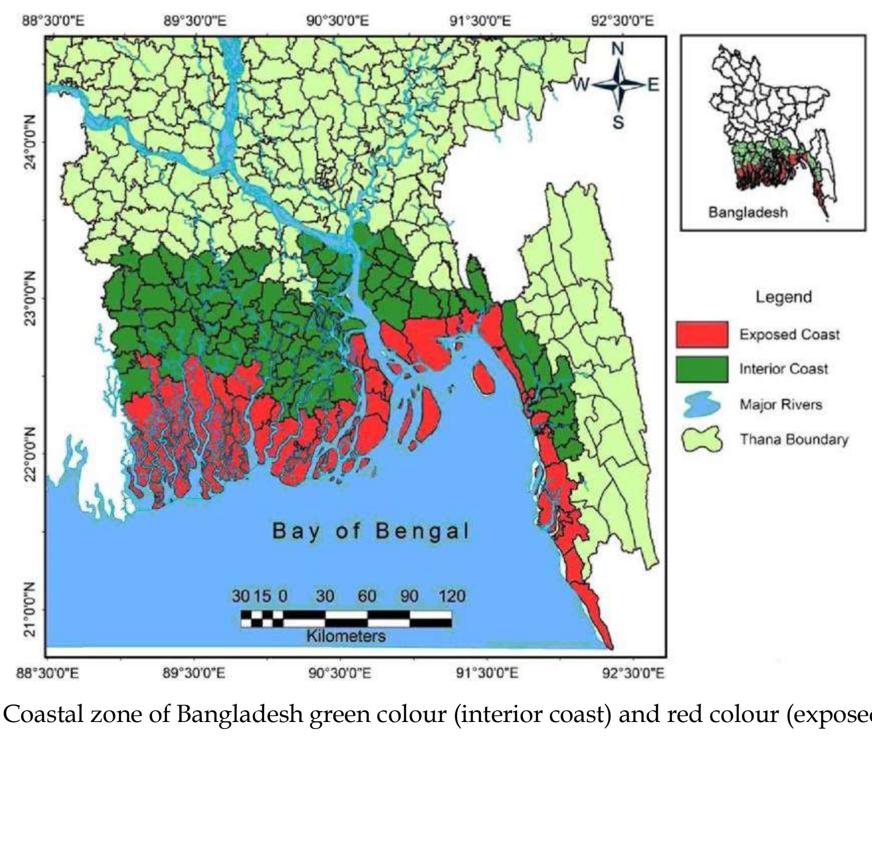

Fig. 1. Coastal zone of Bangladesh green colour (interior coast) and red colour (exposed coast)

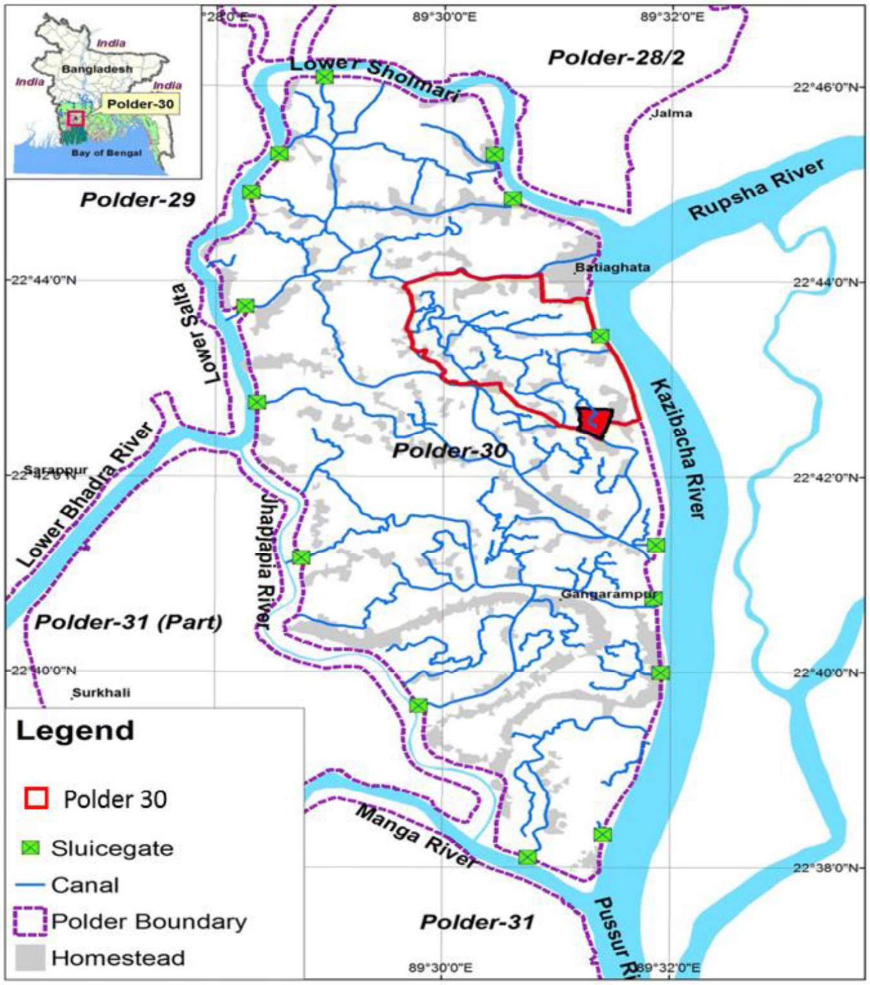

Fig. 2. Plan view of a typical polder in the coastal zone of Khulna district (Yadav *et al.*, 2011)

Variation of water salinity

The water and soil salinity within low-lying polders show both seasonal and spatial variation. Salinity remains low during the monsoon season (July-November) and high in the dry season (December-June). Fig. 3 shows the variation in the EC_w (electrical conductivity of water) of river water at a specific location in the area of Khulna district over five years (2016-17 to 2020-21) and its average. As in the figure, the surface water salinity is very low < 1 dS m^{-1} during August to November, but it exceeds 4 dS m^{-1} in January, reaching a maximum of about 20-30 dS m^{-1} in April-May (ACIAR annual report, 2021). Another report has sown the increasing trend of river water salinity in the coastal area which was 26 dS m^{-1} during April in 2017 and 30 dS m^{-1} during May in 2028 (Belal *et al.,* 2019). The water salinity from different sources during the growing season in 2016-17 is shown in Figure 4. River water salinity increased from mid-December and peaked at 25 dS m^{-1} in April and May (Fig. 4). River water salinity during low tide was slightly lower than high tide. Canal water salinity varied 1 to 3.5 dS m^{-1} entire the season. The pond water salinity was lower than the canal, however, water salinity was almost similar in the two sources in May. Groundwater salinity in this area varies with aquifer depth. The shallow aquifer (~30-50 m deep) has EC_w values ranging from 2.5 to 3.5 dS m^{-1} in March to May, while the deeper aquifer (~150 m deep) has EC_w values greater than 4 dS m^{-1} (Bell et al., 2019).

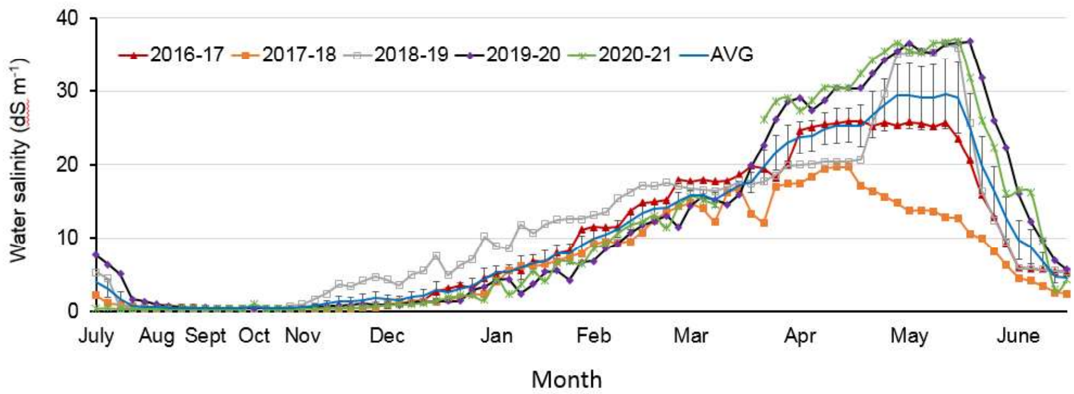

Fig. 3. River water salinity throughout the year in Khulna, Bangladesh.

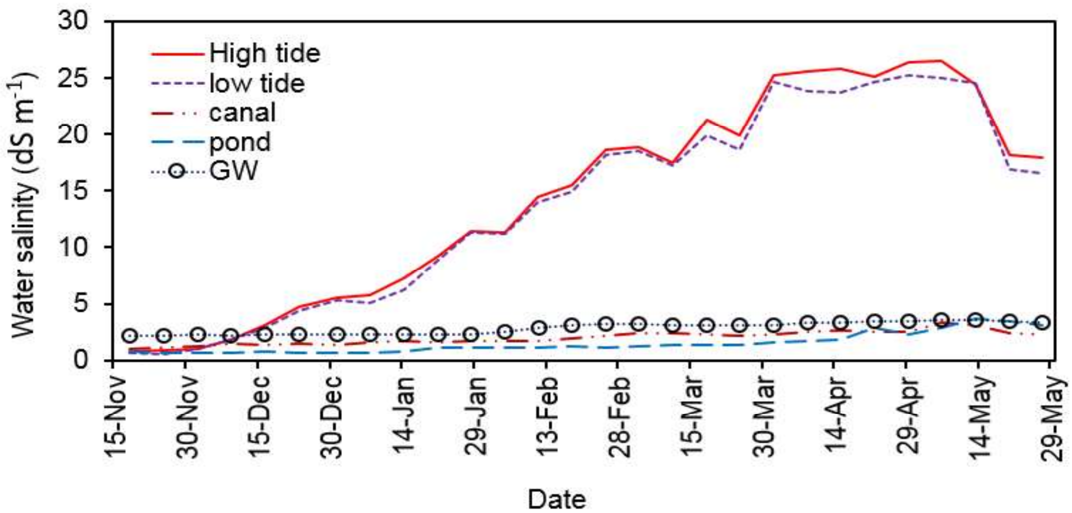

Fig. 4. Variation of water salinity from different sources during the dry season in 2016-17 in Dacope upazila under Khulna district.

Climate and seasonal risk

This area has a subtropical monsoonal climate. The annual rainfall is ~1,800 mm, and ~ 80 % of this occurs in the monsoon season (July to October). Although conditions are generally more humid with higher temperatures in the summer (March-June) and drier with cooler temperatures in the winter (December-February), long-term weather data also show significant variation across the coastal zone (Yu et al., 2019). The temperature in the coastal zone has shown an increasing trend (0.04 ^{0}C year^{-1}) over the last 40 years (Yu *et al.*, 2019), although the west region tends to be warmer than the east (Mondal *et al.*, 2015a). Long-term temperature data showed that the maximum and minimum temperature in the west region (e.g., Khulna) varied from 25 and 35 ^{0}C, and 12 and 26 ^{0}C, respectively, and in the east area (e.g., Patuakhali) varied from 25 and 33 ^{0}C and 13 and 26 ^{0}C, respectively. A recent study has shown that increased temperature was negatively correlated with sunflower yield, and the temperature was the most dominating factor in the variation of sunflower yield than soil salinity (Paul, 2020).

There is a decreasing trend in rainfall from the eastern region to the western region, and from north side to south side. More than 200 mm rainfall (monthly average) occurred in May to October, and the amount was always higher in the east (e.g., Patuakhali) than that in the west (e.g., Khulna) (Bell *et al.,* 2019). Since the 1960s, maximum rainfall over a 5-day period has increased (Yu *et al.,* 2019). This rainfall is beneficial for overall crop production (Bell *et al.*, 2019) as heavy rainfall in the monsoon season dilutes and washes out the available salt in the soil, decreases water salinity (below 1.0 dS m^{-1}), and improves the favorability of the wet season for rice cultivation. In the dry season, increased rainfall is useful to crop production by mitigating salt and drought stress. However, recent studies have shown that a few heavy events of rain often occur in the dry season (November to April), which can interfere with early crop establishment or cause crop damage (Bell *et al.,* 2019). In the same report, they also reported that in November, there could be greater than 20 mm rainfall events in fifty percent of years and greater than 50 mm in 25 % of years, but in December and January, rainfall > 20 mm is unlikely. Similarly, the probability of heavy rain may increase by 25-65 % and 5-30 % for > 20 mm and > 50 mm events, respectively from February to April. These heavy rainfall events in the dry season can create waterlogging, which interacts with salinity in the root-zone to jeopardise crop growth and survival (Barrett-Lennard, 2003). Another study conducted by Paul *et al.* (2020c) found that post-monsoon rain in December damaged sunflower seedlings and decreased yield by about 50% (Fig. 5).

Fig. 5. Sunflower seedling waterlogged by post-monsoon rain in Dacope, Khulna in 2018

ABIOTIC CONSTRAINTS FOR DRY SEASON CROP ESTABLISHMENT

Waterlogging

Large land areas in the coastal zones are seasonally flooded due to the combined effects of monsoon rainfall and tidal influence. These effects usually lead to prolonged waterlogging (saturation of the soil) and water stagnation because of siltation in the river, low infiltration rate, shallow water tables, and poorly structured soils (Ghassemi *et al*., 1995; Ismail and Tuong, 2009). About one million ha of land are annually affected by waterlogging in the coastal zone (Ismail and Tuong, 2009). Waterlogging of soils is crucial abiotic stress that affects plant growth and development (Jackson and Colmer, 2005). Waterlogged soils develop hypoxia (low concentration of oxygen) due to the lower oxygen solubility in water (0.28 mol m-3 at 20 0C) (Qureshi and Barrett-Lennard, 1998), lower rates of oxygen diffusivity in water-filled soil pores (Grable, 1966), and a quick depletion of dissolved oxygen by the respiration of soil bacteria and plant roots (Armstrong and Drew, 2002).

Many winter crops such as vegetables, pulses, and oilseed species cannot tolerate prolonged waterlogging and consequently suffer from plant cell injury over this period because oxygen deficiency strongly restricts ion uptake by roots and ion transport to the shoot. Wilting, chlorosis, and leaf senescence are common plant symptoms in flooded soils (Drew, 1990).

Studies showed that waterlogging under saline conditions can have more damaging impacts on crop growth and yield than waterlogging alone (Singh, 2015). Barrett-Lennard (2003) reviewed the waterlogging and salinity interaction in relation to ion movement and transport, and plant survival status. He showed that plant growth is hindered by the combined effect of waterlogging and salinity because of higher concentration of Na+ and Cl- in the shoot. An experiment conducted by

Paul et al. (2021c) in the south-west coastal region of Bangladesh demonstrated that short term waterlogging more than 24 hours diminished early growth of sunflower.

Soil salinity

The salinity of agricultural land is a severe issue for crop production globally as well as in the coastal zone of Bangladesh. Most tropical coastal zone soils are identified as saline and sodic soils. The main causes of salt build-up in soils are the intrusion of seawater or brackish water flow, irrigation with saline water, salt accumulation on the soil surface through capillary rise from shallow groundwater, poor drainage, and changing climate (Michael, 1978). Fig. 6 shows the process of salinization through seawater intrusion.

Saline soil is defined when the electrical conductivity of soil saturated paste extract (ECe) is > 4 dS m^{-1} at 25 ^{0}C, and exchangeable sodium percentage (ESP) <15 and sodium adsorption ratio (SAR) <13-15 (Richards, 1954). Most plant species are adversely affected when EC_e is higher than 4 dS m^{-1} (George *et al.*, 2012). However, many factors including soil texture, soil moisture, formation of salts, climatic conditions and groundwater table can influence soil salinization.

Salinity problems affect plant growth and deteriorate soil physicochemical properties, resulting in soil degradation and lower crop production. In salt problematic soils, crop growth is mainly impeded by three main reasons. These are water deficit (because of the lower osmotic potential of soil water), ion toxicity due to excess salt availability (Na^+, Cl^- and SO_4^{2-}), and nutrient imbalance in the internal mechanism of plants (George et al., 2012). In saline soils, the main cations are Na^+, K^+, Ca^+, and Mg^+ and the most anions are Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-} and $NO^{3,}$ which are highly variable concentrations and proportions (Tanji, 2002).

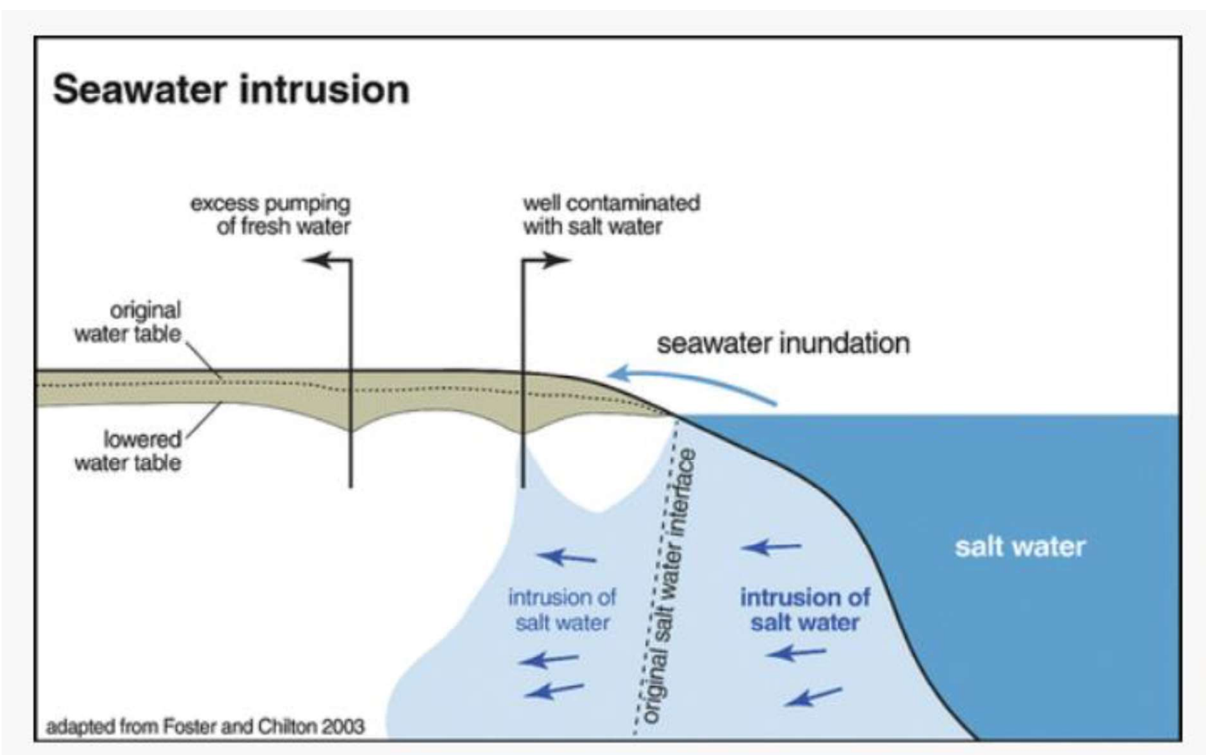

Fig. 6. Salinization of coastal soil and aquifers due to saltwater intrusion from the sea (Greene *et al.*, 2016)

Sodicity is another barrier to crop and soil management. Sodicity problems occur in soil when dissolved salts are leached out into the soil, but exchangeable sodium (Na^+) is retained on soil cation exchange sites (Rengasamy, 2002). An excessive proportion of Na^+ in soil relative to calcium and magnesium may cause soil structural collapse (George *et al.,* 2012; Horneck *et al.,* 2007).

Effects of salts on soil properties

Irrigation water can improve or damage soil properties as a certain amount of soluble salts are presented in irrigation water. However, the effects depend on the salts type and quantity of salts and their management, soil texture, and hydrology (Warrence *et al.,* 2002). Both concentrations of soluble salts and exchangeable cations of soils can affect soil properties simultaneously. For example, an excess of exchangeable Na^+ affects the soil physical properties more than the chemical properties (Mondal, 1997). The increased ESP often caused soil swelling and dispersion, resulting in soil clogging, reduction of soil permeability and hydraulic conductivity, and surface crusting (Frenkel *et al.,* 1978; Pearson and Bauder, 2006). Occasionally, increased salt concentration in the soil solution can have a flocculating effect on soil, which enhances clay particle aggregation (Warrence *et al.,* 2002). The benefits of soil aggregation are more permeability, higher infiltration, better soil aeration, root penetration, and growth (Hanson *et al.,* 1999; McNeal, 1968).

Constraints for Non-Rice Crop Establishment

The use of late-maturing traditional rice varieties and the lack of timely drainage together result in the late establishment of traditional rabi crops such as sesame and mungbean because the soil is too wet to cultivate until February. Late rabi crop establishment, in turn, results in crop damage or complete failure because of high soil and water salinity and soil inundation from pre-monsoon rain prior to harvest. Practicing minimum tillage such as zero and strip tillage can facilitate the early sowing of non-rice crops into the wet soil juts after the rice harvest. However, a recent study has demonstrated that mechanized minimum tillage in clay-wet soil created soil smearing and compaction, resulted in poor sunflower root growth and development and yield (Paul *et al.,* 2020a). Moreover, minimum tillage increased soil surface dryness and salt accumulation on the soil surface hence decreased soil solute potential. The same study also pointed out that increased soil surface disturbance (reduced tillage like single pass and bed planting) increased soil water storage and decreased soil salinity, thereby increased yield. Another study conducted by Paul *et al.* (2021a) for the same area has reported that no-tillage in clay textured soil increased soil resistance and surface cracking, which reduced root biomass and plant growth, hence decreased yield.

SCOPE OF CROPPING SYSTEM INTENSIFICATION

Storing of non-saline/low-saline surface water

Irrigation water availability is a prerequisite for crop intensifying in the coastal area. There is an opportunity to store surface water in the surface water bodies (canals or ponds) for enhancing the supply of irrigation water during the rabi season (Fig. 7). After the rainy season, river water remains non-saline until mid-December. Therefore, before river water become saline and unsuitable for irrigation, water stored in the internal canals and ponds can be used throughout the dry season. However, the volume of fresh water is limited and not enough for irrigated rice and expansion of Rabi crop cultivation (Mila *et al.,* 2021). Re-excavation of existing canals can increase the volume of irrigation water, hence increasing Boro/Rabi crop cultivation.

Fig. 7. Water storage in the internal canal in Dacope Upazilla under Khulna district for Rabi crop cultivation.

Surface drainage to mitigate waterlogging

For the timely establishment of rabi crops, drainage is essential to remove excess water from the field as well as from the surface soil (Fig. 8). Moreover, drainage is effective to cope up the risk of crop failures from the heavy rainfall events throughout the crop season. Paul *et al.* (2020a) have conducted an experiment on the early establishment of sunflower and showed that a surface drainage (15-20 cm deep and 20-25 cm wide) after crop harvesting of wet season rice is effective for mechanized Rabi crop establishment while escaping salinity and heat stresses at later stages of crop. Another study showed that surface drainage saved early sowing crop failure from waterlogging (Paul *et al.*, 2021a and Islam *et al.*, 2022)

Fig. 8. Pictorial view of a surface drainage system to remove excess soil water from the field in Khulna district.

Early establishment of rabi season crops

Growing medium duration of high yielding Aman rice at 15-20 days earlier than farmer's practices and rapid drainage of excess soil surface water can facilitate early sowing of rabi crops. Wheat planting between 25 November and 1 December had a yield of 4.2 -4.4 t ha^{-1} and delayed in sowing decreased yield (Kabir *et al.*, 2019). Similarly, no-tilled sunflower dibbling in wet soil between 20 November and 15 December produced a maximum yield of 3.5 - 4 t ha^{-1} (Paul *et al.*, 2021b). The early establishment of sunflower (23 November 2016) by dibbling in the wet soil in Dacope, Khulna, is shown in Figure 9. The benefit of early sowing is the maximum utilization of residual soil moisture and lower salinity, resulting in higher soil solute potential and grain yield.

Fig. 9. Early sowing of sunflower by no-tilled dibbled in the wet soil in Dacope, Khulna in 2016-17.

Soil water and salinity management by novel tillage and mulching practices

Early rabi crop establishment in the low-lying area of the coastal area is challenging due to excess wetness of soils. Some studies have found that rabi crops such as sunflower, maize, and potato can be dibbled into the wet soil and produced satisfactory yield (Paul *et al.*, 2021b; Kabir *et al.*, 2019, Paul *et al.*, 2022). However, for the delayed establishment, no-tilled dibbled and the mechanized minimum soil disturbance (zero and strip tillage) is less effective in clay-textured soil than intensive soil disturbance (Paul *et al.,* 2020a). Mechanized minimum tillage was related to increased soil bulk density, soil compaction, increased soil surface dryness and salinity, hence decreased yield. While more soil disturbance (bed planting and single pass) reduced the salt deposition on the upper soil and increased soil moisture storage, which maintained higher solute potential in the upper root zone, thereby improving yield. Figure 10 shows the soil condition after the operation of minimum tillage (zero tillage) and reduced tillage (bed planting).

In the coastal saline area, the rapid loss of surface soil moisture in clay-textured soil increased soil strength and crack formation in the dry season, which was related to the reduction of yield loss. The application of rice straw mulch on the soil surface significantly increases crop yield during the rabi season (Sarangi *et al*., 2018, Paul *et al*., 2020b). There is plenty of straw mulch in the coastal area, during the dry season despite it competes with cattle feeding. Paul *et al.* (2020b) have shown that using straw mulch on soil surface at 5 t ha^{-1} enhanced sunflower yield by 16-26% which was related to improved soil water content, reduced soil salinity, and increased solute potential of soil solutions in the 0-15 cm soil layer. Also, rice straw mulch ~ 5 t ha^{-1} is effective in lowering the soil resistance and surface cracking (Fig. 11) (Paul *et al.,* 2021a). The benefits of soil surface mulch on sunflower yield, soil water content, soil salinity, soil resistance and cracking in the coastal saline area of Bangladesh in 2019 are presented in Table 1.

Fig. 10. The surface condition of soil under zero tillage (left) and bed planting (right) in Dacope, Khulna.

Table 1. Effects of different mulch treatments on sunflower yield, soil water content, soil salinity, soil resistance and soil cracking in Dacope, Khulna in 2019 (Paul *et al*., 2020b and Paul *et al*., 2021a)

Mulch treatments	Sunflower yield (t/ha)	Soil water content (%, w/w)	Soil Salinity (EC1:5)	Soil resistance (MPa)	Soil cracking (m^3/m^2)
No-Mulch	2.6	32	0.79	1.7	0.025
Rice straw (5 t/ha)	3.1	35	0.65	0.4	0.005
Rice straw (10 t/ha)	3.2	36	0.60	0.4	0.003
Rice residue	2.2	-	-	-	-

Fig. 11. Soil and crop condition under no-mulch (left) and rice straw mulch (right) in Dacope, Khulna

Cultivation of Boro and Aus rice for cropping system intensification

Though available freshwater is limited during the dry season in the coastal saline area, farmers still have a strong choice to grow Boro rice. Although Boro rice needs a high-water requirement, it can be grown if freshwater is abundant for irrigation. A recent study showed that in the medium saline area like Dacope upazila in Khulna district, some salt-tolerant cultivars such as BRRI dhan67 and BINA dhan10 were grown by using stored non-saline water in the existing canal. The optimal time for preparing seedling nurseries for Boro rice was the second week of November to the second week of December, which produced average 6 t ha^{-1} of yield. Figure 12 shows the Boro cultivation (BRRI dhan67) using stored less saline water. Therefore, where fresh irrigation water is available in the low-lying coastal area, Boro rice can be grown on a smaller scale because the volume of fresh water is not enough to grow rice in wider scale.

On the other hand, if freshwater is scarce, Aus rice is an alternative option to grow in this area as it needs less irrigation water. Some studies demonstrated that transplanting Aus rice in April-May can save irrigation water because of pre-monsoon rainfall (Bell *et al.,* 2019). Using freshwater from a pond or canal for rice seedling nursery and rainfall water for the later part of the season can produce a 3.5-4 t ha^{-1} yield.

Fig. 10. Boro rice cultivation using stored canal water in Dacope, Khulna in 2018.

Strategies for Water management

In the coastal region, freshwater availability during the dry season is limited because of the high river and groundwater salinity. Therefore, some strategies are necessary to diminish the salinity stress on crop growth. Saline water irrigation can increase plant root zone salt concentration, which results in lower crop yield than the non-saline condition. Moreover, irrigation water containing high in carbonates and bi-carbonates (alkali water) accounts for precipitation of Ca and Mg and thereby influence to increase soil pH and sodium concentration (Minhas et al., 1998; Sharma and Minhas, 2005). One strategy to control root zone salinity is the combined utilization of saline and freshwater (Murad *et al.,* 2018). The blending and cyclic modes are commonly used for different quality of irrigation water in many areas (Gawad *et al.*, 2005; Oster, 1994; Qadir and Oster, 2004). The blending method can be used by mixing two different sources of water to obtain a certain level of salinity for a specific crop. However, the effectiveness of this method depends on crop species, degree of salinity, soil texture, and the volumes of the two water supplies (Grattan *et al.*, 2009; Minhas *et al.*, 2020; Sharma and Minhas, 2005). Some studies have suggested that using cyclic modes (fresh and saline water) provided better crop and soil management for higher yield (Minhas *et al.*, 1998). In the cyclic method, low saline irrigation water (<1.0 dS m^{-1}) can be applied at the early period (germination to seedling stage) because most crops are sensitive at these stages, and water with high salinity can be used at later growth stages when crops usually tolerate higher salinity (Naresh *et al.*, 1993; Rhoades, 1992). Chauhan *et al.* (2007) advocated that the practical way to alleviate the effect of saline water irrigation is cyclic use. For example, if two water sources are available, the preferred option is to use fresh water at the early and sensitive stage and the using of saline water should be applied at the later stages of growth when the plants are often more tolerance to salt.

CONCLUSION

The salt-affected coastal region of Bangladesh is highly vulnerable to salinity, waterlogging and natural disasters. However, recent studies conducted in the coastal region of Bangladesh have demonstrated many opportunities for cropping systems intensification. The main scope involves: (i) storing the surface water in the internal canal from the monsoon season to use for the dry season crops when solute potential is low, and (ii) early establishment of rabi crops to use maximum soil residual moisture and avoid crop stress from increasing salinity and drought, heat stress and storms at latter part of the growing season. One of the most effective ways to establish rabi crop early on wet soil is zero tilled sunflowers, potato, maize, and wheat. Straw mulch is highly beneficial for increasing soil water storage, reducing salinity, and reducing soil compaction and cracking. Boro rice can be grown if enough water is available for irrigation, whereas pond water can be used to prepare Aus seedling and the available rainfall at the rest of the growing season. To achieve the sustainable coastal agricultural development, it is essential to ensure that access to the benefits of available technologies is socially inclusive.

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