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Realizing the Potential of Coastal Flood-Prone Areas for Rice Production in West Bengal: Prospects and Challenges

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Abstract

Rice is the major food staple for millions of people in coastal flood-prone areas of South and Southeast Asia. In India, these areas are distributed over nine states (Andhra Pradesh, Goa, Gujarat, Karnataka, Kerala, Maharashtra, Odisha, Tamil Nadu, and West Bengal) and four union territories (Andaman and Nicobar, Daman and Diu, Lakshadweep, and Puducherry). The state of West Bengal (WB) has the highest area under coastal saline lands (0.82 million hectares) and also one of the most flood-prone states in India. The coastal stretch of this state is part of the alluvial and deltaic plains, confined to East Midnapore, Howrah, North 24 Parganas, and South 24 Parganas districts.

As a consequence of climate change, rice production in recent years becomes highly variable due to an increased likelihood of flood and/or drought, besides widespread occurrence of saline soils with variable salinity levels. High monsoon rainfall, poor soil and water quality, and natural weather adversities like

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coastal storms and cyclones make agriculture in these areas highly non-remunerative, more complex, and risky. Monocropping of traditional rice varieties, unstable productivity, and high poverty among farming communities are common. Since multiple abiotic stresses are common, stress-intolerant varieties do not survive well in flood-prone coastal areas. Farmers are often compelled to implement suboptimal crop management as they do not have much access to newer varieties and improved technologies, besides being risk avert. These areas are relatively underexploited, though they hold enormous potential for more food production and act as natural laboratories for advancing rice research and for the validation of modern technologies to improve farmers' livelihood and ensure household food and nutritional security. Here we review the outcomes of research conducted at the Rice Research Station, Chinsurah, Hooghly, and Salt and Flood Resistant Paddy Research Station, Gosaba, South 24 Parganas over the past decades, involving on-farm validations of improved varieties and technologies. The review also touches bases on the research conducted by the International Rice Research Institute (IRRI), Philippines, and the Institutes of the Indian Council of Agricultural Research (ICAR). We discussed the development and deployment of stress-tolerant rice varieties (STRVs), like Gosaba 5 (Chinsurah Nona 1) and Gosaba 6 (Chinsurah Nona 2), as an effective and affordable strategy for enhancing rice production and productivity, widening the opportunities for improving the system productivity when combined with appropriate technological interventions and best management practices. Addressing multiple abiotic stresses under the fragile rainfed ecosystems could enhance the resilience and sustainability of the rice-based cropping systems, consequently increasing and stabilizing farmers' income in salt- and flood-affected tropical deltas of WB and coastal zones as a whole.

Keywords
Coastal soils · Flood-prone areas · Management practices · Salinity · Stress-tolerant rice varieties · Submergence

28.1 Introduction

Rice is the staple food for about half of the world's population, and about 90% of the world's rice is produced and consumed in Asia (Mackill et al. 2012). Several climatic adversities including abiotic stresses like soil and water salinity during both wet (*kharif*) and dry (*boro*) seasons and waterlogging or flash floods, coastal storms, and cyclones during the wet season often affect its productivity, especially in the coastal areas (Burman et al. 2013, 2018; Islam and Gregorio 2013; Ismail and Tuong 2009; Ismail et al. 2010; Sarangi et al. 2015b; Singh et al. 2010a, b).

Agriculture continues to be a gamble in coastal flood-prone areas. In coastal rainfed lowlands, rice is the predominant crop in the wet season because growing other crops becomes difficult due to excessive wetting and waterlogging of low-lying fields (Sarangi et al. 2015b, 2016). In fact, rainfall and river flow help to flush out some of the salt, making rice cropping possible during the wet season (Ismail 2009) although the yields remain low and unstable because of ecosystem complexity and limited access to new technologies (Szuster et al. 2010). Rice is also grown during the dry season from November to April. Still the dry season rice is confined to a limited area (10–20%), and majority of the land remains fallow due to either scarcity of good-quality irrigation water or a combination of factors like prevalence of moderate to high soil salinity owing to seawater intrusion and shallow saline water table along with a number of other soil and climatic constraints in coastal areas (Yadav et al. 1979; Bandyopadhyay et al. 2003; Sarangi et al. 2014, 2015b). Farmers in these areas are mostly resource-poor and marginal (<1 ha landholding) and smallholder (1–2 ha landholding) with highly fragmented land holdings; the rest are landless. Low food production and high poverty are common.

Globally, about 230 million hectares (m ha) of coastal areas are saline (Li et al. 2014), of which about 27 m ha is in coastal zones of South and Southeast Asia (Ismail et al. 2010). The coastal delta of the Ganges river system, encompassing large parts of Bangladesh and the Indian state of West Bengal (WB), is one of the most populated regions of the world (Kabir et al. 2015). Approximately 22 m ha of rice lands in South and Southeast Asia are also flood-prone, and more than 100 million people primarily depend on these ecosystems for their livelihood (Hossain and Abedin 2004). The flood-prone ecosystems are characterized by a wide diversity of conditions, particularly timing, duration, and intensity of rainfall and floods, ranging from a short duration (1–2 week) of flash floods to more than 6 months of deep stagnant waterlogging. Soil types, topography, and prevailing biotic and abiotic stresses also vary considerably (Ram et al. 2009).

India, by far, has the largest area under rainfed lowland and flood-prone ecosystems in South and Southeast Asia (Sarangi et al. 2015b). Out of the total geographical area of 328.73 m ha, about 49.81 m ha is flood-prone, and on average, 10–12 m ha is affected every year (NRAA 2012). Most of the floods occur during monsoon period mainly due to heavy rainfall, inadequate capacity of rivers to carry the high flood discharge from upper catchments, and inadequate drainage, typhoons, and/or cyclones. About 13 m ha of rice lands are prone to floods in eastern India, causing partial to complete submergence every year. Rice is commonly affected by either too little or too much water during early stages depending on the onset of rainfall and the time of sowing. At later stages, mostly a couple of inundations occur due to rainfall in August and September (Ram et al. 2009). In recent years, there has been an increased incidence of floods, caused by extreme weather events, commonly attributed to climate change (Schiermeier 2011; Mirza 2011). Additional constraints to rice production in flood-prone areas include the widespread existence of problem soils with either excess or deficiency in certain elements (Sarkar et al. 2009).

The coastal zone in India stretches from western to eastern coast, with a total coastal area of about 10.78 m ha (Velayutham et al. 1999; Pal and Lama 2016), of which 3.09 m ha is reported to be saline (Yadav et al. 1983; Bandyopadhyay et al. 2003; Saha et al. 2009). Based on the estimates of the Indian Council of Agricultural Research-Central Soil Salinity Research Institute (ICAR-CSSRI), Karnal, Haryana (India), the area under salt-affected soils in India has been reported to be 6.74 m ha, including 1.24 m ha under coastal saline, 1.71 m ha under saline, and 3.79 m ha under alkali soils, of which WB occupies 0.44 m ha under coastal saline soils (CSSRI 2010; Mandal et al. 2010). The coastal agro-ecosystem in the country plays a significant role in maintaining the overall ecological balance and in meeting the livelihood requirements of the largely agriculture-based dense populations living in these areas.

West Bengal is the thirteenth largest state in India, covering 2.70% of the country's geographical area, and the fourth largest populous state supporting about 7.54% of the country's population, based on the census of 2011 (SOE 2017). Agriculture is the livelihood for 65% of the state's population living in villages, with 95.4% of them being small and marginal farmers, who, besides supporting their own families, are also feeding the remaining 35% of the state population (SOE 2017). It is also one of the most flood-prone states in the country with 3.76 m ha affected by floods, spreading over 111 community development (CD) blocks in the state (AFR 2016; Basu et al. 2017). About 42.34% of the total geographical area of the state and 69% of its area under farming has been identified as flood-prone (AFR 2016; WBSDMP 2016). WB has a total coastline length of 158 km, constituting the high saline area (0.82 m ha) in the districts of South 24 Parganas, East Midnapore, North 24 Parganas, and Howrah (Sharma 1998; Bandyopadhyay et al. 2003; CGWB 2014; Sarangi et al. 2015b).

The coastal stretch of WB is highly vulnerable to cyclones and submergence. The single largest problem during the wet season is waterlogging or submergence of varying depth and duration (CGWB 2014). Due to water stagnation, the average yield of the wet season crop in the coastal zone of WB (<2.0 t ha^{-1}) is below both the national average (2.4 t ha^{-1}) and the state average (2.6 t ha^{-1}). Crop sensitivity to salt stress in the presence of high soil and water salinity is another reason for such low productivity in coastal areas (Sinha et al. 1982). These problems are further compounded by occasional natural disasters such as cyclones, seawater intrusion, drought, and flood in the changing climatic situation that greatly influences the rainfed rice production system. The grave concern is that unpredictable rainfall pattern, rising temperatures, and changes in weather pattern are directly impacting cropping seasons. These constraints are causing a significant strain on rice production and productivity, making it a highly challenging and risky venture (Sheinkman et al. 2015).

The coastal zone of WB faces considerable challenges but also holds some opportunities (Saha et al. 2009; Mondal et al. 2015; Maji and Lama 2016). Since the traditionally cultivated areas are under constant pressure and already over-utilized, the under-utilized areas, as in the coastal zone, should get utmost importance to achieve higher agricultural production. There are tremendous opportunities for increasing productivity, diversity, and resilience of rice-based production systems to improving food security and livelihoods in coastal flood-prone areas (Saha et al.

2008). Rice production and productivity can be increased through the use of improved germplasm along with appropriate management options, technological interventions including improvement of soil condition, and adapting new rice varieties with matching cropping systems. Use of reclamation technology and continuous cultivation of stress-tolerant rice varieties (STRVs) in these areas constitute the primary approach for bringing lands into production within a period of 3–4 years (Singh et al. 2017). Not much attention has yet been paid for developing and disseminating suitable rice varieties and good management options that can enhance and sustain the productivity of coastal flood-prone ecosystem to exploit their considerable potentials to enhance food supply.

We discuss the ways to enhance productivity of rice-based cropping systems in coastal flood-prone areas by integrating improved varieties with appropriate crop and natural resource management practices, validated through farmers' participatory research carried out under the aegis of Rice Research Station (RRS), Chinsurah, Hooghly; and Salt and Flood Resistant Paddy Research Station (SFRPRS; erstwhile Sir Daniel Hamilton's Farm), Gosaba, South 24 Parganas, WB, India. Certain important research accomplishments under the Indian Council of Agricultural Research-Central Soil Salinity Research Institute-Regional Research Station (ICAR-CSSRI-RRS), Canning Town, South 24 Parganas, WB along with those in other states have also been reviewed in this chapter.

28.2 Characterization of Coastal Flood-Prone Lowlands in West Bengal

West Bengal is broadly divided into three regions viz. (1) Eastern Himalayas (in the north), (2) Eastern or Chota Nagpur Plateau, and (3) Alluvial and Deltaic Plains. These three broad regions are further stratified into six agro-climatic zones based on climate and soil. These include (1) hill zone, (2) terai zone, (3) old alluvial zone, (4) new alluvial zone, (5) red and laterite zone, and (6) coastal saline zone (SOE 2017). The coastal zone as a whole belongs to the broad geographic unit of alluvial and deltaic plains in WB. Geomorphic subunits such as lower alluvial plain, deltaic flood plains, marshy/inundated area, coastal sand dunes, and coastal plains predominate in the zone (Bandyopadhyay et al. 2003). Research studies were conducted on farm at different locations together with RRS, Chinsurah (22°52′N latitude, 88°24′E longitude, and altitude of 8.62 m above mean sea level) and SFRPRS, Gosaba (22°10′N latitude, 88°49′E longitude, and altitude of 7.00 m above mean sea level).

28.2.1 Nature and Extent of Distribution of Salt-Affected Soils

Distributed over the southern part of South 24 Parganas, the southern part of North 24 Parganas, the southern part of Howrah, and south-eastern part of East Midnapore

Table 28.1 Distribution of salt-affected soils in four coastal districts of West Bengal

District	Total geographical area (m ha)	Coastal saline area (m ha)	Coastal blocks
East Midnapore	0.47	0.26	Tamluk-I, Tamluk-II, Chandipur (Nandigram-III), Mahishadal-I, Mahishadal-II, Nandigram-I, Sutahata-I, Sutahata-II, Bhagawanpur-I, Bhagawanpur-II, Egra-I, Egra-II, Contai-I, Contai-II (Deshapran), Contai-III, Khejuri-I, Khejuri-II, Ramnagar-I, Ramnagar-II
Howrah	0.15	0.06	Bagnan-I, Bagnan-II, Uluberia-I, Uluberia-II, Shyampur-I, Shyampur-II
North 24 Parganas	0.41	0.15	Sandeshkhali-I, Sandeshkhali-II, Hingalganj, Haroa, Minakhan, Hasnabad, Swarupnagar, Basirhat-II
South 24 Parganas	0.99	0.35	Jaynagar-I, Jaynagar-II, Kultali, Basanti, Canning-I, Canning-II, Gosaba, Diamond Harbour-I, Diamond Harbour-II, Falta, Kulpi, Magrahat-I, Magrahat-II, Mandirbazar, Mathurapur-I, Mathurapur-II, Kakdwip, Namkhana, Patharpratima, Sagar

Source: Bandyopadhyay et al. (1988, 2003), GoWB (2016)

(Table 28.1), WB comprises the largest area under coastal saline lands in India. The coastal zone of WB lies between 87°25′ E and 89° E latitude, and 21°30′ N and 23°15′ N longitude along the Bay of Bengal coast, covering an extensive area of about 1.46 m ha (GoWB 2016), representing about 16.77% of total geographical area in the state (SOE 2017). Starting from a narrow strip of land from its southwest corner at the WB–Odisha border near Digha, the coastal area gradually becomes wider towards the east and ultimately meets the eastern boundary bordering Bangladesh (Bandyopadhyay et al. 2003). Three main rivers in the northern part of WB flow as the tributaries of the Brahmaputra, and these are Teesta, Torsa, and Jaldhak. Other two important rivers passing through the state are Ganga and Hooghly. The Ganga drains into the Bay of Bengal forming the famous delta of Indian Sundarbans (covering the districts of South 24 Parganas and North 24 Parganas in WB). Since the coefficient of variation of annual rainfall is less than 25% in WB, the state is prone to floods, being manifested by various modes (WBAPCC 2012; WBSDMP 2016).

Coastal saline areas differ from inland salt-affected areas in that the latter are affected by secondary salinization through high water table conditions caused by the excessive irrigation in arid and semi-arid areas, whereas salinity in coastal soils is caused by periodical inundation with tidal water, and, in case of lowlands having proximity to the sea, due to the high water table with high concentration of salts (Sen 1998). In WB, about 4.26% area is affected by salinity and requires soil management involving the removal of soluble salts from the root zone. However, the vast majority (95.74%) of soils in the state contain low soluble salts (SOE 2017).

28.2.2 Soil

The soils in the coastal zone of WB are variable, depending on the physiographic and climatic conditions. Coastal soils in the state are mostly heavy textured (silty clay to clay loam) with high soluble salts, comprising chlorides and sulfates of sodium (with almost no carbonates and trace amount of bicarbonates), magnesium (Mg), calcium (Ca), and potassium (K) in decreasing order of preponderance, besides organic matter at different stages of decomposition (Biswas et al. 1982; Sen 1998; Bandyopadhyay et al. 2003). Chloride is the predominant anion (Sen 1998). These soils crack when dry and are whitish on the surface due to the presence of salts, accumulating through capillary movement of saline water from the shallow ground aquifer and evaporation. Because of heavy texture, these soils have very low hydraulic conductivity, one of the limitations for reclaiming these soils (Bandyopadhyay and Bandyopadhyay 1984). Coastal soils with pH of 6.5–7.5 and electrical conductivity of saturated soil extract (ECe) in the range of 3.0–18.0 dS m^{-1} are not in a good state of physical conditions due to destructive, transportive, and constructive activities of waves, tides, currents, rivers, and winds acting throughout the year. Highly acidic soils ($pH < 4.5$) are found only in the Sundarbans region. The acid soils are very rich in available iron (Fe) but poor in available zinc (Zn) and copper (Cu). Soils having free calcium carbonate also show low phosphorus (P) availability, particularly in the surface horizon. Soils of other pH groups are medium to high in available P. All the soils are generally deficient in nitrogen (N). Available K is high, mainly due to illitic clay minerals and the K-containing salts like KCl and K_2SO_4 (Bandyopadhyay et al. 2003).

The soils of Sundarbans areas are generally rich in Ca, Mg, sulfur (S), and micronutrients, except Zn (Bandyopadhyay et al. 2003). According to Bandyopadhyay and Maji (1995), the acid soils of Sundarbans could not be described as true acid sulfate soils. Dent (1986) broadly termed some of these soils as acid sulfate soils in higher categories. Common nutritional disorders of rice in acid sulfate soils are Fe toxicity when waterlogged and aluminum (Al) toxicity when dry (Sen 1998).

Except for some soils in Contai, Digha, and Ramnagar, most of the coastal soils in East Midnapore district are only marginally saline. Besides, there are small areas of beach sand dune in the district along the coast of the Bay of Bengal. These sand dunes are rich in salts. Most of the soils in coastal Howrah have marginal or no salinity, but the water table exists at a very shallow depth leading to drainage congestion. Soil pH varies from 5.4 to 8.2, increasing with depth. High pH in some of the lower horizons may be due to deposition of lime concretions along with the alluvium. The soils are low to medium in organic carbon content. Soils have high base saturation (74–92%) with more Mg followed by Ca, Na, and K. The ECe increases with depth ranging from 0.6 to 6.3 dS m^{-1}. The preponderance of chlorides and sulfates of Na, Mg, and Ca with a lesser amount of bicarbonates is the main feature of the soluble salts (Bandyopadhyay et al. 2003).

28.2.3 Climate

The climate in the coastal zone of WB is hot and humid with three distinct seasons viz. winter (*boro*), summer (pre-*kharif* or *aus*), and monsoon (*kharif* or *aman*). Winter starts in the later part of November and lasts up to the middle of February when heavy dew at night can be marked. January is the coldest month of the year. Summer starts from the middle of March and continues up to June with occasional pre-monsoon rains in the later part of the season. Monsoon continues from July to September. The rainfall trend of the last 10 years showed an average annual rainfall of about 1500 mm or more in the coastal zone. The rainfall is received mostly from the South-West monsoon, contributing more than 80% of total annual rainfall from July to mid-September (Fig. 28.1). The rain ceases around the middle of October, with light showers in other months. Rainfall pattern is erratic in both time and space, leading to incidences of drought in summer and flood during monsoon. Even the onset of monsoon is being delayed in recent years. The average minimum and maximum temperatures in the zone during winter, summer, and monsoon seasons are 13.6 and 31.6, 18.6 and 38.3, and 23.5 and 34.1 °C, respectively. In the context of climate change, however, there is an overall warming trend with minimum temperatures increasing faster than maximum temperatures (WBAPCC 2012). The mean summer and winter soil temperatures are about 29 °C and 20 °C, respectively. Since the difference between mean summer and winter temperature is more than 5 °C, the soil temperature is classified under hyperthermic regime. The relative humidity is quite high throughout the year, even in the months of March to May and more in other months. The prevailing wind directions are from South to Southwest

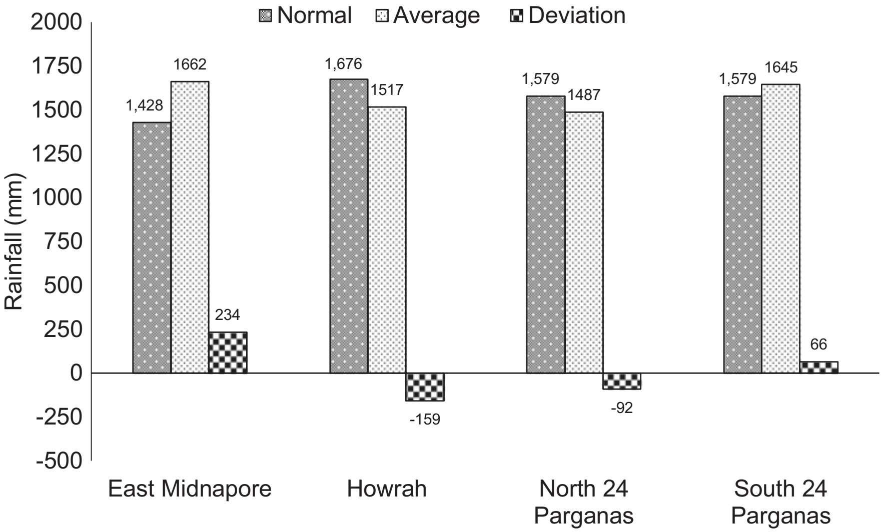

Fig. 28.1 Rainfall pattern in four coastal districts of West Bengal over the last 10 years. [Source: GoWB (2015) and IMD (2013–2017)]

during summer and from North to Northeast during winter, whereas the wind blows normally from the Southwest direction during monsoon. Due to the proximity to the sea, the coastal area is exposed to nor'wester and cyclonic storms during April to October; the largest and fiercest cyclones may normally occur in September (end phase) or October. The cyclones at times bring in the high tidal bore, causing massive devastation (Bandyopadhyay et al. 2003). The frequency of severe cyclonic storms is increasing over the Bay of Bengal, and the sea level is rising globally. However, the level of rising is higher across the coastline of WB, mostly due to subsidence of the land mass near the coast and also possibly due to developmental activities, leading to submergence of islands in the eastern region of the coast.

28.2.4 Nature and Types of Flooding

Most of the coastal areas are prone to frequent cyclonic storms, waterlogging, as well as floods. Different types of floods in coastal areas include flash floods, stagnant floods, river floods, and coastal floods. Flash flooding may last for several days or several weeks. In some cases, it repeatedly occurs during the season and growth stages of rice crop—from directly after sowing to flowering stage. Stagnant flooding may occur after a flash flooding event or alone (Collard et al. 2013). In the case of stagnant flooding, water does not recede, and it remains in the field at a depth of 50–60 cm for up to several months (Mallik et al. 1995). Both flash flooding and stagnant flooding are highly unpredictable. River floods are caused by precipitation over large catchment areas. These floods normally build up slowly or seasonally and may continue for days or weeks. Coastal floods are associated with cyclonic activities like hurricanes, tropical cyclones, etc. Rice fields in the coastal zones are classified as medium-low and low lands, subjected to waterlogging and inundation by flood and rainwater with poor drainage.

Vast areas of East Midnapore district often come under severe floods due to high rainfall with uneven distribution, accompanied by breaching of embankments of rivers traversing through the coastal zone of the state. The southern-most areas of the state in the districts of South 24 Parganas, East Midnapore, and southern Howrah are low-lying and level part of the deltas of the river system of the Ganga on the northern coast of the Bay of Bengal.

28.3 Coastal Flood-Prone Areas in West Bengal

The state of WB as part of Bengal Delta has a long history of floods. While the floods in the northern part of the state generally occur early during the wet season and tend to be intense and of short duration, the floods in the southern part come later in the season (Basu et al. 2017). In South Bengal, there are certain distinctive features of drainage condition that lead to flooding. This feature is again adversely affected by the tidal condition as is generally noticed in September, the likely month of occurrence of the flood (AFR 2016). Coastal areas are confined to the southern part of the state, facing severe floods in most years. A major portion of coastal zone falls within the boundary of the districts of South 24 Parganas and North 24 Parganas (Bandyopadhyay et al. 2003).

East Midnapore district is part of the lower Indo-Gangetic Plain (IGP) and eastern coastal plains. Topographically, the district has coastal plains on the south. The vast expanse of land is formed of alluvium and is composed of younger and coastal alluvial deposits. Flood-prone CD blocks in the district include Tamluk, Panskura-I, Moyna, Kolaghat, Sahid Matangini, Patashpur-I, Egra-I, and Bhagwanpur-I, while five coastal CD blocks viz. Khejuri-II, Contai-II (Deshapran), Contai-I, Ramnagar-I, and Ramnagar-II are occasionally affected by cyclones and tornadoes (Table 28.1). Tidal floods are quite regular in these blocks.

In Howrah district, mainly four CD blocks viz. Udaynarayanpur, Amta-I, Amta-II, and Bagnan-II are flood-prone. Floods generally occur in the district in two phases: (1) early flood during the end of July to the middle of August and (2) late flood during the middle of September to the middle of October. Both types of flood never happened so far within the same year. Floods occur due to excessive rainfall, causing waterlogging of farmlands. Major coastal blocks of the district are Shyampur-I, Shyampur-II, Bagnan-I, and Bagnan-II (Table 28.1). Though Shyampur does not directly face the Bay of Bengal, tidal influence is predominant in the river Rupnarayan.

The coastal zone under the districts of South 24 Parganas and North 24 Parganas is commonly known as Sundarbans region, covering about 60% of the coastal area of WB (Morgan and Mcintire 1959; Chakrabarty 1991, 1995). The Sundarbans region with the geographical area of 0.96 m ha includes 102 deltaic islands, of which 54 islands are under habitation (0.45 m ha), spreading across 19 CD blocks of the two south most districts of the state (6 in North 24 Parganas, and 13 in South 24 Parganas), while other 48 islands are under wetland mangrove forest (0.42 m ha), and the rest of the area (about 0.09 m ha) is occupied by rivers (Bandyopadhyay et al. 2003).

In North 24 Parganas, six CD blocks surrounded by tidal rivers are Sandeshkhali-I, Sandeshkhali-II, Hingalganj, Haroa, Minakhan, and Hasnabad (Table 28.1), while the major flood-prone blocks include Hingalganj, Hasnabad, Sandeshkhali-I, Sandeshkhali-II, Minakhan, Horoa, Baduria, Swarupnagar, Bagdah, Bongaon, Gaighata, Deganga, Habra-I, and Habra-II.

In the district of South 24 Parganas, the Sundarbans areas, with either saline or degraded alkaline soils, are distributed over a total of 13 CD blocks viz. Sagar, Namkhana, Kakdwip, Pathar Pratima, Kultali, Mathurapur-I, Mathurapur-II, Jaynagar-I, Jaynagar-II, Canning-I, Canning-II, Basanti, and Gosaba (Table 28.1). However, a major part of the district is affected by waterlogging in the “basin-like islands” of degraded or saline soils, coupled with poor irrigation facilities that permit only monocropping of rice. The most vulnerable blocks of the district are Gosaba, Basanti, Canning-I (Canning Sub-division); Kakdwip, Sagar, Namkhana, Patharpratima (Kakdwip Sub-division); Jaynagar-II, Kultali (Baruipur

Sub-division); and Mathurapur-II (Diamond Harbour Sub-division), which are most affected by several natural calamities.

28.4 Constraints of Coastal Flood-Prone Environments

Although the coastal areas hold tremendous scope for the production of many high-value commodities, these are beset with many production constraints, including (1) high soil salinity; (2) shallow depth of saline underground water table; (3) heavy texture and poor filtration rate in many areas; (4) periodic inundation of soil surface by the tidal water *vis-à-vis* climatic disaster and their influence on soil properties; (5) low-lying land; (6) poor surface and sub-surface drainage conditions; (7) lack of good-quality irrigation water during summer and winter seasons; (8) short winter and prolonged monsoon; (9) heavy and intensive rains during monsoon, resulting in deep waterlogging of cultivated rice fields; (10) eutrophication, hypoxia, anoxia, and nutrient imbalance; and (11) frequent cyclonic storms along with heavy rains, causing crop damage.

Of different constraints in coastal areas, salinity is more dynamic and varies with the season, being very high during the dry season with the peak around April to May, as a result of high evaporative demand with the consequent high concentration of salts at soil surface due to the capillary movement of saline underground water. Salinity in the soil and water then decreases progressively with the onset of the monsoon rains between June and September in the wet season, reaching levels close to normal conditions later in the season (Bandyopadhyay and Bandyopadhyay 1984; Biswas et al. 1990; Bandyopadhyay et al. 2003; Ismail et al. 2007; Ismail and Tuong 2009; Radanielson et al. 2018). Secondary salinization of coastal soils also takes place with the mismanagement of water for irrigation and drainage (Sen 1998; Ismail et al. 2007). The monsoon situation becomes more complicated with the events of waterlogging, flood, and/or cyclones. Because of excess water due to drainage congestion and high rainfall coupled with high humidity, most of the coastal areas are under rice monocropping during the monsoon season (Bandyopadhyay et al. 2003; Ismail and Tuong 2009; Das 2014).

About 80% of cultivated land remains submerged at varying depths and durations during the crop growth period, resulting in a significant reduction in rice yield. Apart from salinity and waterlogging, saline water inundation sometimes poses a problem and contributes to low productivity (Sinha et al. 1982). In fact, stress-intolerant high-yielding varieties (HYVs) do not withstand these adversities. Local rice varieties have certain level of tolerance of these conditions, including water stagnation and short-term complete inundation, but their productivity is very low due to crop damage (e.g., high seedling mortality, low tiller production), varying from slight (when flooded during seedling and ripening, the most tolerant stages) to severe (if the flood coincides with flowering) during the wet season (Sinha et al. 1982; Bandyopadhyay and Abrol 1986). During the rest of the year, the area mostly remains fallow due to high soil and water salinity and lack of good-quality irrigation water, high saline water table, and relatively high evaporative demand (Ismail and Tuong 2009).

28.5 Management Options for Rice Production in Coastal Flood-Prone Environments

Rice production systems have to cope with direct or indirect effects of unfavorable climatic conditions such as submergence, waterlogging, salinity, drought, and mineral toxicities. Management practices for rice cultivation in coastal salt-affected areas are different from those in normal soil areas and also for a short-duration variety than medium to long-duration varieties (Singh et al. 2016, 2017). Available STRVs have been reported to produce significantly higher grain yield than their recurrent parents with and without stress condition under rainfed ecosystem. These STRVs, developed by the International Rice Research Institute (IRRI) through conventional and molecular breeding with the help of NARES (National Agricultural Research and Extension Systems) partners, are being disseminated in South Asia and Africa through STRASA (Stress-tolerant Rice for Africa and South Asia) and other projects. Use of conforming agronomic management practices can further add 1.0–1.5 t ha^{-1} yield benefit to these STRVs and even exhibit no yield penalty during the normal year (Sheinkman et al. 2015; Srivastava et al. 2016).

28.5.1 Crop Management

28.5.1.1 Identification of Salt- and Flood-Tolerant Rice Varieties

The development and evaluation of climate-resilient crop varieties, with enhanced tolerance to flooding and salinity stresses in coastal areas, are essential to sustain and improve crop yields to cope with the challenges of climate change (Maheswari et al. 2015).

Farmers in coastal areas commonly grow naturally selected tall *indica*, traditional, photoperiod-sensitive rice varieties with some level of salt tolerance during the wet season. Rice is salt sensitive, and none of the modern varieties developed for intensive systems can satisfactorily withstand high salinity throughout the growth cycle (Moormann and van Breemen 1978). Salt tolerance of rice varies throughout its growing cycle (Pearson and Ayres 1960). The plant becomes relatively tolerant to salinity stress during germination, active tillering, and towards maturity. Damage to rice roots at transplanting increases its sensitivity to salinity at early stages. An increase in salt tolerance occurs during the tillering phase, but the plant again becomes sensitive at flowering. Sensitivity again diminishes during the maturation period (Moormann and van Breemen 1978; Anandan et al. 2018). Reproductive-stage salinity significantly reduces spikelet number, effective tiller number, pollen fertility, panicle length, and number of primary branches in a panicle. During active growth, it reduces plant growth rate, cellular and leaf expansion, number of tillers, and photosynthesis and causes premature senescence of older leaves. Soil

ECe of 3.5 dS m^{-1} can reduce rice yield by about 10%, and this reduction can reach up to 50% at ECe of 7.2 dS m^{-1}, while plants eventually die at ECe of 10 dS m^{-1} depending on the evaporative demands, and duration of exposure, besides other factors. The survival and loss in yield may vary with the tolerance ability of rice genotypes (Anandan et al. 2018).

A large number of rice genotypes have been screened for salt tolerance at SFRPRS (Gosaba) and ICAR-CSSRI-RRS (Canning Town), WB. Damodar (CSR 1), Dasal (CSR 2), Getu (CSR 3), Nonabokra, and Nonasail Selection (CSR 6) were identified as salt-tolerant cultivars (Sinha et al. 1982; Sinha and Bandyopadhyay 1984). Of these landraces, Damodar, Dasal, and Getu were traditional, tall, weakly photosensitive cultivars, and suitable for growing in the dry season, whereas Nonabokra and Nonasail (Sel.) were photosensitive, tall *indica* cultivars, suitable only for the wet season (Ravindra Babu et al. 2016). Two promising cultures viz. Mut 1 (CSR 4: Mohan) and Mut 2 were developed through mutation breeding, selected for salt tolerance and high yield. Both genotypes were dwarf and matured in 95–105 days in the wet season (Sinha et al. 1982). Talmugur (IC No. 594003), Dudheswar (IC No. 593998), and Nonabokra (IC No. 594027) were identified as salt tolerance donors for breeding salt-tolerant varieties under lowland conditions. Another two potential cultivars viz. Matla (selection from Benisail) and Hamilton (selection from Nonabokra), developed at SFRPRS (Gosaba), a sub-station of RRS, Chinsurah, were earlier under cultivation in saline soil (Datta and Banerji 1980; Sinha and Bandyopadhyay 1984), but no longer being used by farmers (Pani et al. 2012).

Traditional rice cultivars predominate because they have acquired moderate tolerance to flooding, but they are inherently low yielding (Singh et al. 2014a). Few of these landraces can withstand flooding by developing a "quiescent strategy" under flash flooding and an "escape strategy" for stagnant and deepwater flooding that persist for most of the season (Hattori et al. 2011). According to Biswas et al. (1982) and Bandyopadhyay and Bandyopadhyay (1984), Nonasail (Sel.), SR 26B, BKN, Sadamota, and Kalamota Selection were suitable for low (15–25 cm water depth) to medium (25–50 cm or above water depth) land situation, whereas Damodar, Dasal, Getu, Jaya, Matla, and Hamilton were well suited for high (up to 15 cm water depth) to medium land, and Mohan, Ratna, Cauvery, and Palman 579 for high land situation during wet season. Biswas et al. (1982) also reported salt tolerance and stable yield of cultivars like Damodar, Dasal, Getu, Mohan, Nonasail (Sel.), and SR 26B under conditions where salinity (ECe) reached up to 5.8 dS m^{-1}.

Since most of the lands in coastal areas are low-lying, the varieties that are generally tall, high-yielding, and stress-tolerant (flash floods, stagnant floods, lodging, diseases, and pests) with long slender grains and good cooking quality are preferred during the wet season. In a study conducted under ICAR-CSSRI-RRS (Canning Town), different entries (SR 26B, Sabita, Geetanjali, Amal-Mana, Patnai 23, NC 678, Swarna-Sub1, BRRI Dhan 47, and BINA Dhan 8) along with certain CSRC(D) lines were evaluated at different locations of South 24 Parganas district (Basanti, Gosaba, and Sandeshkhali) that experienced a range of water depths during wet season (Sarangi et al. 2015b). All of these varieties were moderately tolerant of salinity with long duration, tall or very tall and photoperiod sensitive (Sarangi et al. 2015b), except Swarna-Sub1 (IET 20266), which is submergence-tolerant (containing the *SUB1* gene) developed by IRRI (Mackill et al. 2012). The CSRC(D) series were promising lines (7-0-4, 13-16-9, 12-8-12, and 2-17-5), developed at ICAR-CSSRI-RRS (Canning Town) for low-lying coastal lands. BRRI Dhan 47 and BINA Dhan 8 are medium height, salt-tolerant, and photo-insensitive varieties from Bangladesh. The study revealed that improved varieties had higher yields of about 4.0 t ha^{-1}, which was 20% higher than the local cultivars (3.4 t ha^{-1}) across all water depths. Amal-Mana [CSRC(S) 7-1-4] was consistently the best performer (3.8–5.0 t ha^{-1}) across all water depths experienced. Other best-performing entries across all water depths were Swarna-Sub1, CSRC(D) 7-0-4, and CSRC(D) 12-8-12. The Bangladeshi varieties (BRRI Dhan 47 and BINA Dhan 8) performed well at the shallowest water depth (water depth increased gradually from 15 to 45 cm during the first 3 weeks of August) but performed poorly with deeper water (Sarangi et al. 2015b). The duration of the most wet season varieties was around 160–165 days, while that of Swarna-Sub1 (140 days), BRRI Dhan 47 (130 days), and BINA Dhan 8 (125 days) was much shorter, facilitating earlier harvest of *aman* crop and widening the possibilities for early establishment of subsequent dry season (*boro*) crop, reduced irrigation requirement for land preparation, early *boro* maturity, and comparatively less exposure to soil salinity (Sarangi et al. 2015a, b).

A participatory study of Burman et al. (2018) reported that the most preferred varieties and breeding lines were Geetanjali, Amal-Mana, CSRC(S) 21-2-5-1-1, and Sabita, which were preferred for their tall stature (140–170 cm), long duration (160–170 days), lodging resistance, and high yield in lowlands where water stagnates in the field (>30 cm water depth) for about 4 months (July–October). Uncontrolled waterlogging and poor drainage are the dominant risks that require taller varieties or varieties capable of elongation with rising water (Singh et al. 2011; Kato et al. 2014). Farmers prefer long-duration varieties (160–170 days) like CSRC(D) 12-8-12, Geetanjali, Amal-Mana, CSRC(D) 7-0-4, CSRC(D) 13-16-9, Sabita, SR 26B, and Patnai 23 for lowlands to avoid harvesting in standing water. They prefer certain other genotypes with medium height (100–115 cm) and medium duration (140–150 days) like Sumati, CSRC(S) 21-2-5-B-1-1, and Swarna-Sub1 for their suitability in medium lands having water depth of 20–30 cm for most of the wet season with no flooding problem (Burman et al. 2018).

According to Mandal et al. (1991), the criteria for breeding improved rice varieties suited to the diverse coastal ecosystems include (1) shallow water (up to 20 cm) with tolerance to moderate to high soil salinity (ECe > 8–10 dS m^{-1}), (2) semi-deep water (20–30 cm) with tolerance to moderate soil salinity (ECe 6–8 dS m^{-1}), and (3) deep water (30–50 cm or more) with tolerance to low soil salinity (ECe 4–6 dS m^{-1}). Current rice varieties suitable for flood-prone coastal areas of WB are presented in Table 28.2.

Recently two rice varieties viz. Chinsurah Nona 1 (Gosaba 5) and Chinsurah Nona 2 (Gosaba 6) have been developed by RRS, Chinsurah, and released by the

Table 28.2 Recently released stagnant flood-tolerant rice varieties for coastal flood-prone areas of West Bengal

Variety	Plant height (cm)	Duration (days)	Grain type	Grain yield (t ha^{-1})
Amal-Mana (IET 18250)	135–140	140–145	LS	4.0–4.5
Bhoothnath (IET 12855)	110–112	105–110	LS	3.5–4.0
Chinsurah Nona 1 (Gosaba 5) (IET 23403)	115–120	138–142	MB	4.5–4.8
Chinsurah Nona 2 (Gosaba 6) (IET 21943)	115–120	135–140	MS	4.8–5.2
CSR 23 (IET 13769)	115–120	130–135	LS	4.0–4.5
CSR 27 (IET 13765)	115–120	120–125	LS	4.0–4.5
CST 7-1 (IET 12490)	105–110	130–140	MB	2.5–3.0
Dudheswar	135–140	150–155	LS	3.5–4.0
Jarava (DRR Dhan 33) (IET 15420)	115–120	140–145	MB	4.5–5.0
Luna Sampad (CR Dhan 402) (IET 19470)	120–125	135–140	SB	3.5–4.0
Luna Suvarna (CR Dhan 403) (IET 18697)	130–135	145–150	MS	4.0–4.5
Luna Shankhi (CR Dhan 405) (IET 21237)	100–105	105–110	MS	4.4–4.8
Luna Barial (CR Dhan 406) (IET 19472)	125–130	150–155	SB	4.0–4.5
Lunishree (IET 10678)	130–135	145–150	LS	4.0–4.5
Mohan (CSR 4) (IET 12494)	95–100	115–120	MB	3.0–3.5
Sabita (IET 8970)	140–150	150–155	LS	4.5–5.0
Swarna Dhan (IET 5656)	120–130	145–150	SB	5.5–6.0

LS long slender, *MB* medium bold, *MS* medium slender, *SB* short bold

State Variety Release Committee (SVRC) of WB for coastal saline areas, with ECe of up to 6 dS m^{-1} (Table 28.2). Gosaba 5 (IR 55179-3B-11-3) showed about 7.8% yield improvement over the national check, CST 7-1 in coastal saline areas. Its yield advantages were 15, 28, and 46% compared to Jarava, CST 7-1, and a local Check (CSR 4), respectively, at SFRPRS, Gosaba (South 24 Parganas). This variety also proved to be suitable for semi-deep water situation (50–60 cm) in these areas. In on-farm trials of South 24 Parganas and Hooghly districts, the salt-tolerant variety "Gosaba 5" and the submergence-tolerant variety "Swarna-Sub1" exhibited 11.39 and 14.58% yield advantages over Dharitri (CR 1017) and Swarna (MTU 7029), respectively (Fig. 28.2). Another variety Gosaba 6 (RP 4919-50-13-CN 2079) was comparable with the HYVs like Swarna, Swarna Dhan, and Pratiksha, besides being suitable for growing in coastal saline soils with ECe of up to 6 dS m^{-1}, and also under rainfed shallow lowland situation (30–50 cm water depth) in the wet season. Table 28.3 shows the yield advantages of Gosaba 6, ranging between 8.1 and 54.0%, compared with different checks in an observational yield trial at SFRPRS, Gosaba during the wet seasons.

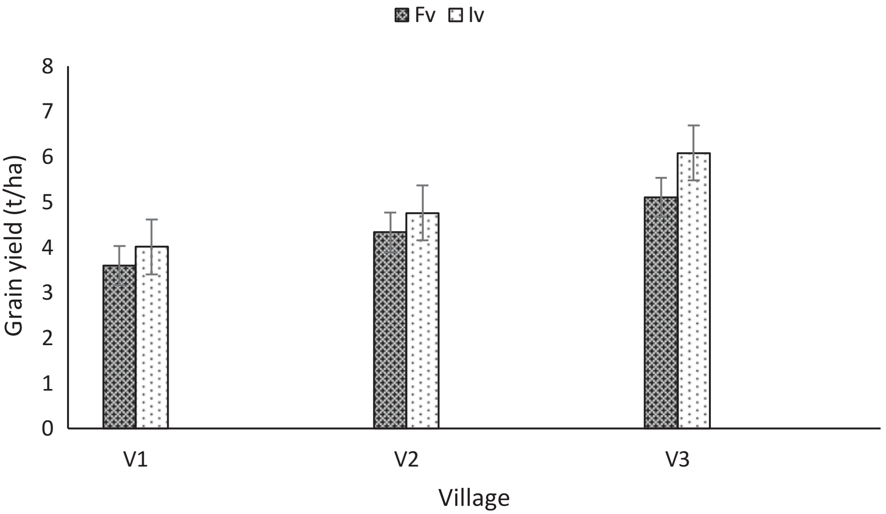

Fig. 28.2 Comparative yield of improved stress-tolerant varieties (Iv) and farmers' preferred varieties (Fv) in an on-farm experiment conducted during the wet season of 2016 in different lowland environments of South 24 Parganas and Hooghly districts of West Bengal. V1 represents the group of villages (Kalidaspur and Mollakhali) with a total of 16 farmers covering 2 ha of land under the coastal saline environment in Gosaba, South 24 Parganas (Fv and Iv are Dharitri and Gosaba 5, respectively). V2 represents the group of villages (Dahartironnai, Humjanpur, Inchura, Beleswar, Damorgacha, Majdia, Sarenda, and Tironnai) with a total of 20 farmers covering 2 ha of land under the rainfed shallow lowland environment in Balagarh, Hooghly (Fv and Iv are Swarna and Swarna-Sub1, respectively). V3 represents the village (Damra) with a total of three farmers covering 1.06 ha of land under the rainfed shallow lowland environment in Chinsurah-Mogra, Hooghly (Fv and Iv are Swarna and Swarna-Sub1, respectively)

Table 28.3 Yield of newly released stagnant flood-tolerant rice varieties at SFRPRS, Gosaba during the wet seasons of 2013–2015

	Grain yield (t ha^{-1})				
Variety	2013	2014	2015	Pooled	Yield advantage (%)
Gosaba 6 (improved variety)	5.07	5.80	5.80	5.56	–
Gosaba 5 (best check)	5.04	4.88	5.50	5.14	8.11
Jarava (latest released variety)	4.80	4.20	4.80	4.60	20.82
Mohan (local check)	3.59	3.71	3.53	3.61	54.00
CST 7-1 (national check, CSTVT)	4.56	4.05	4.53	4.38	26.95
$LSD_{0.05}$	0.05	0.07	0.05	0.05	–

CSTVT Coastal Saline Tolerant Variety Trial

Prominent salinity tolerant rice varieties were evaluated under the collaborative effort of RRS, Chinsurah with the Society for Socio-Economic and Ecological Development (SEED), Kolkata in farmers' fields located under Sagar Block (South

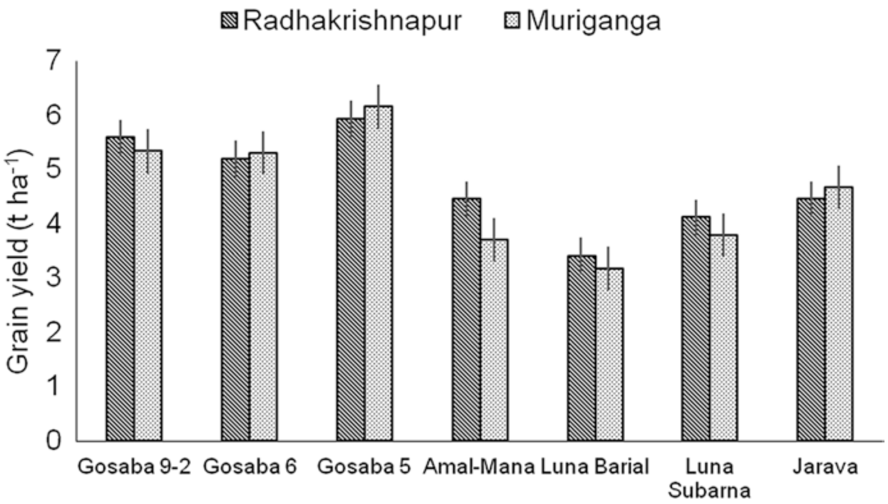

Fig. 28.3 Yield of improved stagnant flood-tolerant rice varieties in on-farm experiments at Sagar Block, South 24 Parganas district during the wet season of 2014. The trial was conducted at two sites: Radhakrishnapur (ECe 4.93–5.70 dS m^{-1} and pH 6.5) and Muriganga (ECe 4.03–4.18 dS m^{-1} and pH 6.8)

24 Parganas) during the wet season (Fig. 28.3). Of these, Gosaba 5 recorded the highest grain yield (6.04 t ha^{-1}), followed by Gosaba 9-2 (5.46 t ha^{-1}) and Gosaba 6 (5.25 t ha^{-1}).

Flooding, in combination with salinity, can cause partial to complete crop failure in rainfed coastal zones. Considerable progress in breeding submergence-tolerant rice varieties has been made over the last two decades after the identification of a major quantitative trait locus (QTL), named *SUB1* (Bailey-Serres et al. 2010; Mackill et al. 2012; Xu and Mackill 1996; Xu et al. 2006). Using marker-assisted backcrossing (MABC), this QTL was subsequently incorporated into many popular Asian mega-varieties with high precision and in a much shorter time compared to using conventional methods (Collard et al. 2013). Furthermore, these "upgraded" mega-varieties have been widely adopted by farmers in a relatively short time (Mackill et al. 2012; Singh et al. 2013; Ismail et al. 2013). For example, Swarna-Sub1 (BRRI Dhan 51 in Bangladesh), Samba-Sub1 (BINA Dhan 12), IR 64-Sub1, Ciherang-Sub1 (BINA Dhan 11 in India, Nepal and Bangladesh), and BR 11-Sub1 (BRRI Dhan 52 in Bangladesh) are few popular submergence-tolerant rice varieties available in South Asia for cultivation (Srivastava et al. 2016). *SUB1* generally confers tolerance to complete submergence for approximately 10–15 days but not for submergence during germination or stagnant flooding (Singh et al. 2011; Collard et al. 2013). Field trials have shown that rice varieties with *SUB1* have a yield advantage of 1–3 t ha^{-1} over their recurrent parents following 10–15 days flooding (Ismail et al. 2013; Singh et al. 2014a).

Identification of the major QTL *Saltol* for salinity tolerance on chromosome 1 (Bonilla et al. 2002) and its thorough characterization (Islam et al. 2011; Thomson et al. 2010) helped in widening breeding opportunities for salt-affected areas. Several QTLs and genes associated with salinity tolerance are being identified, and numerous varieties with notable tolerance of coastal inland salinity and alkalinity were released over the past decade (Ismail and Horie 2017). Combining submergence and salinity tolerance is of particular importance, especially for coastal flood-prone areas where salt stress is common at the beginning of the wet season, followed by submergence later in the season, and in some cases, floodwaters became saline as in tidal flood areas (Collard et al. 2013). Many new elite submergence-tolerant breeding lines have been developed by IRRI and its collaborators, by incorporating the *SUB1* gene. Few breeding lines combining both *SUB1* and *Saltol* have also been developed using marker-assisted backcrossing (MABC) for both loci (Collard et al. 2013). Incorporating two QTLs for salinity tolerance and submergence tolerance traits in one rice variety would be an effective strategy, because of the fact that *Saltol* confers tolerance to 0.4–0.7% salinity level in water while *SUB1* confers tolerance to submergence for up to 18 days (Ismail et al. 2013; Ham 2016).

Moreover, the combination of submergence, stagnant flooding, and salinity tolerance is anticipated to be of great importance in coastal or deltaic regions due to rising sea levels and also ingress of salinity in inlands, all of which are being aggravated by climate change. No elite breeding lines with tolerance to all the three types of abiotic stresses have yet been developed. Currently, there are only a few salinity-tolerant lines with submergence tolerance (Collard et al. 2013). More efforts are needed for the screening of elite breeding lines to improve tolerance of stagnant flooding in rice, in order to identify major QTLs for use in short breeding cycles to combine with other QTLs like *SUB1* and *Saltol*, using modern breeding tools.

28.5.1.2 Nursery Management

Proper nursery management can substantially improve rice productivity in flood-prone rainfed lowland areas (Ella and Ismail 2006; Bhowmick et al. 2013, 2014; Singh et al. 2013, 2016; Banayo et al. 2019). Farmers commonly use higher seed rates due to poor germination in saline areas. Even they hardly apply any fertilizers in the nursery. Suboptimal nursery management produces lanky and thin seedlings leading to poor crop establishment upon transplanting. Nutritional status of seedlings before transplanting is of immense importance, especially when plants are submerged during early growth stages (Ram et al. 2009; Ella et al. 2010). On-station experiments conducted at RRS, Chinsurah during the wet seasons of 2012–2013 revealed that healthier and sturdier seedlings (seedling growth expressed in terms of dry matter accumulation, root length, and shoot length at transplanting) could be raised through conjunctive application of organic manures and chemical fertilizers (100-50-50 kg $N\text{-}P_2O_5\text{-}K_2O$ ha^{-1}, supplementing 25 kg N through 5 t FYM ha^{-1}) in wet nursery (Table 28.4). Singh et al. (2016) also advocated integrated use of organic manures and inorganic fertilizers in the nursery to improve seedling growth, post-submergence crop survival, and productivity in the main field. Using appropriate seed rate (45, 50, and 55 kg ha^{-1} for fine, medium, and coarse grain, respectively) is another consideration for achieving strong and robust seedlings.

Table 28.4 Effect of seedling age and nursery nutrition on seedling growth of Swarna-Sub1 in an on-station experiment at RRS, Chinsurah during the wet seasons of 2012 and 2013

	Dry matter accumulation (g seedling^{-1})		Root length (cm)		Shoot length (cm)	
Treatment	2012	2013	2012	2013	2012	2013
Seedling age (days)						
30	1.06	1.35	16.43	16.58	22.60	22.80
35	1.23	1.45	16.66	16.85	22.98	23.07
40	1.38	1.51	16.78	17.40	23.04	23.27
$LSD_{0.05}$	ns[a]	0.09	ns	0.07	ns	0.04
Nutrient management (N-P_2O_5-K_2O *kg* ha^{-1})						
50-25-25	0.94	1.34	16.12	16.75	21.85	22.61
80-40-40	1.18	1.38	16.48	16.98	22.63	23.09
100-50-50	1.33	1.47	17.02	17.02	23.47	23.19
120-60-60	1.43	1.55	16.87	17.02	23.52	23.28
$LSD_{0.05}$	0.11	0.11	ns	0.08	1.04	0.05

Measurements were taken when seedlings were uprooted for transplanting

[a] *ns* not significant; Experimental design (nursery and main field): factorial RCB with three replications; Dates of sowing: July 9, July 3, and June 28 in 2012, and July 11, July 6, and July 1 in 2013, corresponding to the seedling age of 30, 35, and 40 days, respectively; Dates of transplanting: August 9 in both the years of study; Nutrient application in nursery (as per treatments): 25 kg N through 5 t FYM ha^{-1} and remaining N through urea, full doses of P_2O_5 (single superphosphate) and K_2O (muriate of potash) applied as basal

Application of sufficient organic matter in the nursery not only helps in raising healthy seedlings but also reduces the detrimental effect of salt infiltration. The wet nursery is more desirable for avoiding salinity hazards in coastal areas (Biswas et al. 1982; Bandyopadhyay and Bandyopadhyay 1984). Whenever the leaves of seedlings start rolling and burning from the tips, standing water in the nursery needs to be removed and replaced with fresh water to avert salinity injury (Datta 1986).

Establishing staggered community nursery at an interval of 2 weeks is a contingency measure for delayed planting, which can be explored as a local adaptation strategy to combat the situations under deficit or excess rainfall in lowlands. In anticipation of a 2-week delay in monsoon, the first nursery is taken up as a contingency by the middle of June with long-duration varieties (>140 days) to transplant 3- to 4-week-old seedlings by first fortnight of July. If the monsoon is delayed by 4 weeks, the second nursery is raised with medium-duration varieties (125–135 days) by the first week of July to supply 3- to 4-week-old seedlings for transplanting in the third or fourth week of July. In case further delays are anticipated or with poor rainfall, the third nursery is raised by mid-July with short-duration varieties (<110 days) for transplanting of 3- to 4-week-old seedlings in the first fortnight of August (Prasad et al. 2014).

28.5.1.3 Crop Establishment Methods

Poor crop establishment is one of the major factors contributing to low productivity in coastal flood-prone rice ecosystems. Farmers adopt different crop establishment methods like conventional transplanting, double transplanting, and very recently the System of Assured Rice Production (SARP), depending on the availability of resources, land situation, and prevailing climatic conditions.

Conventional Transplanting

Transplanting is a common method for crop establishment in coastal flood-prone areas. This is mainly due to erratic floods caused by early rains causing a delay in sowing, and negative or poor seed germination coupled with high seedling mortality when rice is directly seeded. During the initial part of the monsoon season, soil salinity usually remain high, causing high mortality of seedlings. Thus, the date of sowing plays a crucial role in optimizing crop production in the context of climate change (Radanielson et al. 2018). An on-station experiment conducted at SFRPRS, Gosaba during the wet season revealed that the highest grain yield could be obtained with sowing during the first week of July and transplanting in the first week of August (Table 28.5). Transplanting beyond the first week of August might expose the crop to excess standing water caused by heavy rainfall later in the season, reducing grain yield.

In order to ensure sufficient plant population, it is recommended to transplant 2–3 seedlings hill^{-1} at an optimum spacing of 20 cm × 15 cm for local landraces and tall varieties, and 15 cm × 15 cm for semi-dwarf and dwarf HYVs (Biswas et al. 1982; Bandyopadhyay and Bandyopadhyay 1984; Bandyopadhyay 1999). Wider spacing for early transplanting and closer spacing or using more seedlings hill^{-1} for late transplanting and high salinity are particularly beneficial (Biswas et al. 1982).

Seedling age is also directly related to survival upon submergence; older seedlings are more tolerant of complete submergence because of higher vigor and mature tissues, lower underwater shoot elongation, and high carbohydrate content than younger seedlings (Datta 1986; Chaturvedi et al. 1996; Singh et al. 2005, 2016; Parvin 2005; Bhowmick et al. 2014). In an on-station experiment at RRS, Chinsurah during the wet seasons of 2012 and 2013, it was found that transplanting older seedlings (35–40 days) had better survival after submergence than younger (30 days)

Table 28.5 Yield of stagnant flood-tolerant rice varieties as influenced by time of sowing and transplanting at SFRPRS, Gosaba during the wet seasons of 2014 and 2015

	Grain yield (t ha^{-1})							
	2014				2015			
Variety (V)/ planting time (P)	July 16 (June 17)	July 28 (June 27)	August 6 (July 4)	August 14 (July 15)	July 15 (June 15)	July 26 (June 25)	August 5 (July 5)	August 14 (July 15)
Gosaba 5	4.50	5.20	5.40	4.30	–	–	–	–
Gosaba 6	4.50	5.00	5.50	4.50	4.70	5.10	5.40	4.50
Gosaba 9-2	–	–	–	–	4.80	5.30	5.80	4.40
Jarava (ch.)	3.59	4.04	4.03	3.06	2.80	3.60	4.00	2.20
$LSD_{0.05}$ (V)	0.17				0.12			
$LSD_{0.05}$ (P)	0.04				0.03			

Figures within and without parentheses indicate sowing and transplanting dates, respectively

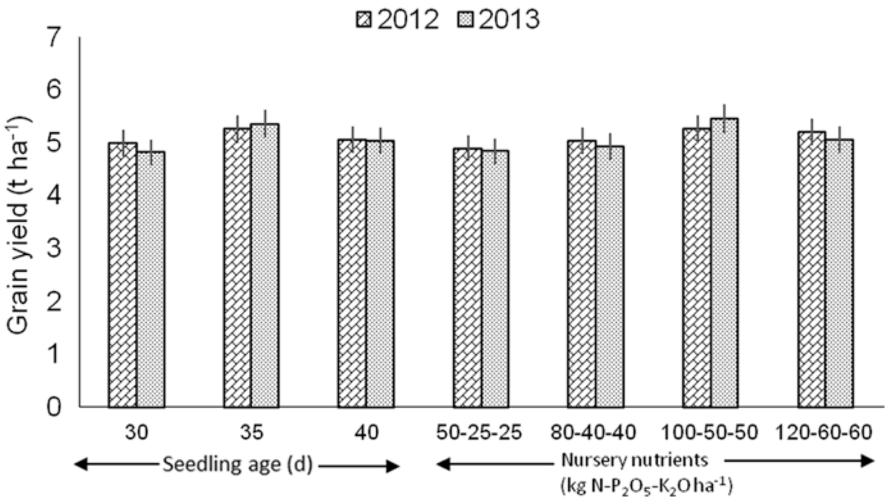

Fig. 28.4 Swarna-Sub1 grain yield as influenced by seedling age and nursery nutrients in an on-station experiment conducted at RRS, Chinsurah, West Bengal during the wet seasons of 2012 and 2013

seedlings and produced more grain yield (Fig. 28.4). An increasing trend in dry matter accumulation along with improved root and shoot length was recorded with the aging of nursery seedlings (Table 28.4).

System of Assured Rice Production

In recent years, and due to shortage of rainwater for timely transplanting, rice farmers are often compelled to use aged seedlings. The System of Assured Rice Production (SARP) is a new method involving scientific principles and simple indigenous practices for producing healthy seedlings, prolonging nursery duration if required, and shortening the main field duration of transplanted rice in the wet (*kharif*) season. This practice seems suitable for adapting to these harsh production conditions and for climate resilience (Patra et al. 2014; Patra 2019). The basic principles include the production of healthy seedlings using very low seeding density (15–20 g m^{-2}) and adequate addition of organic manure (1.0–2.0 kg m^{-2}) along with integrated nutrient management in the nursery; flexibility in seedling age for transplanting in the main field, based on weather conditions; and reduced use of seeds (Patra et al. 2013; Patra et al. 2015; Patra and Bhowmick 2020). Very low-density seeding in nursery provides sufficient space to keep the seedlings for a prolonged period (Bhowmick et al. 2014). In the nursery, N may be top-dressed at 2.5 g m^{-2} at 15-day interval up to transplanting, whereas phosphate is doubled (10.0 g m^{-2}) to supply more phosphate at the initial growth stages and to keep rice seedlings in the nursery for a prolonged period. The amount of potash is reduced (2.5 g m^{-2}) for its low requirement in the early growth stages, although it is sometimes further top-dressed (WMRS 2013). There was no or negligible yield reduction with the delayed transplanting of 55–60 days old seedlings raised by SARP during *kharif* season (WMRS 2014).

Double Transplanting

Double transplanting is a traditional practice of contingent planning, especially in flood-prone areas, where conventional transplanting sometimes results in complete crop failure if floods occur early in the season. In this practice, wet nursery is initiated during the first week of June with a normal seed rate (40–50 kg ha^{-1}) under upland situation; seedlings are then uprooted after 25–30 days after sowing (DAS) and transplanted densely (15 cm × 15 cm) with 12–14 seedlings $hill^{-1}$ in the first upland transplanted field. After another 30–35 days of first transplanting, the seedlings are uprooted, and the second transplanting is done at a spacing of 20 cm × 20 cm with 2–3 seedlings $hill^{-1}$ in the main field (Ram et al. 2009; Yadav et al. 2014).

28.5.1.4 Integrated Nutrient Management

Nutrient management in the main rice field before transplanting and also after the recession of flood water plays an important role in improving rice productivity in flood-prone ecosystems (Singh et al. 2014c).

Nitrogen Management

Most of the coastal soils are deficient in nitrogen (N) due to heavy loss through volatilization, leaching, and run-off (Sen and Bandyopadhyay 1987; Sen 1998). Application of 80–100 kg N ha^{-1} for HYVs and 40–50 kg N ha^{-1} for tall *indica* varieties under proper management is essential for high yield in coastal saline areas during the wet season (Biswas et al. 1982; Bandyopadhyay and Bandyopadhyay 1984; Bandyopadhyay et al. 1988).

Among different N sources, urea proved to be the most efficient although its efficiency is not more than 25–30% in wet season. N-use efficiency can further be improved by coating urea with suitable materials (Bandyopadhyay and Biswas 1982; Bandyopadhyay and Bandyopadhyay 1984; Bandyopadhyay et al. 1988). Under deepwater condition where there is no control over water for rice cultivation, slow-release nitrogenous (coated urea) fertilizers are found to be more efficient than the normal source of N. According to Bandyopadhyay et al. (1988), ranking of fertilizers in the order of volatilization loss is: ammonium sulfate (AS) > prilled urea (PU) > lac-coated urea (LCU) > sulfur-coated urea (SCU) > urea super granules placed as urea briquettes (UB) > urea placed in paper packet (UPP). Farmers can also easily prepare neem-coated urea (NCU) by adding 0.5 kg neem oil t^{-1} of urea (Pathak et al. 2012).

Different combinations of application time and method of NCU and foliar spray of PU were tested at ICAR-CSSRI-RRS, Canning Town during the wet season using stagnant-flood tolerant variety, Amal-Mana. By simply replacing the NCU application with PU, Amal-Mana produced 22.9% higher grain yield. Shifting basal N application to 1 week after transplanting and splitting last N application using PU foliar application produced significantly higher grain yield (Singh et al. 2017).

Table 28.6 Grain yield of rice varieties as affected by nitrogen management practices in an on-station experiment at SFRPRS, Gosaba during the wet seasons of 2013–2015

	Grain yield (t ha^{-1})		
Variety	2013	2014	2015
Gosaba 5	4.84	4.78	4.76
Gosaba 9-2	4.73	4.74	4.95
Jarava	3.75	4.81	3.50
$LSD_{0.05}$	0.12	ns[a]	0.14
Nitrogen management			
100% RDN (basal)	3.87	4.24	3.67
75% RDN (basal) + 2% urea spray (AT and PI)	4.58	4.79	4.35
50% RDN (basal) + 50% RDN (mud balls) (AT)	4.21	4.50	3.97
50% RDN (basal) + 25% RDN (AT) + 25% RDN (PI)	4.69	5.13	4.95
25% RDN (basal) + 50% RDN (AT) + 25% RDN (PI)	4.85	5.21	5.09
$LSD_{0.05}$	0.09	0.11	0.09

RDN recommended dose of nitrogen, *AT* active tillering, *PI* panicle initiation

[a] *ns* not significant; main field nutrient dose: 70-35-35 kg N-P_2O_5-K_2O ha^{-1}

In an on-station experiment at SFRPRS, Gosaba during the wet season (2013–2015), it was found that the application of N through foliar spray or mud balls showed hardly any advantages over the common practice of applying N in three splits (Table 28.6). Foliar application of N has only a bleak possibility due to frequent rainfall and cloudy weather or when rice plants are under complete submergence. The results confirmed the need for applying N fertilizer in splits, synchronizing the critical crop demand for N, because a portion of the N fertilizer applied in advance of crop demand gets lost or temporarily fixed in the soil even when there are no leaching and run-off losses. Scheduling N application in three splits is preferred to apply a basal dose of one third N at 7–10 days after transplanting (DAT), another one third N at maximum tillering, and the remaining one third N at the booting stage (15 days before flowering primordia initiation). Before applying N to the soil, there should have been a rain gap period to reduce the losses of N and ensuring higher efficiency (Bandyopadhyay and Bandyopadhyay 1984).

Phosphorus Management

Submergence- and/or salinity-induced membrane damage is one of the injuries that leads to plant death under stress. Membrane damage is caused by reactive oxygen species generated in the mitochondria when aerobic respiration is hindered (submergence) or in chloroplasts when photosynthesis is slow (salinity). Plants need energy for repair and maintenance processes under anaerobic stress caused by flooding in coastal areas. Supply of sufficient P might have positive impacts on the tolerance and survival of rice plants, presumably through the maintenance of a high level of energy (Ram et al. 2009). Moreover, P deficiency is a common phenomenon in coastal acid sulphate or acid saline soils (Dhanushkodi and Subrahmaniyan 2012; Ray et al. 2014; Maji and Lama 2016). Available P in these soils can be improved with the application of single superphosphate, rock phosphate (2 t ha^{-1}), and sometimes liming (3–4 t ha^{-1}). Application of rock phosphate does not produce any immediate benefit, but the beneficial effect is observed a few years after the application in flooded fields because of its slow release (Sen 1998; Bandyopadhyay 1999; Bandyopadhyay et al. 2003). Application of Ca-rich oyster shell (95% $CaCO_3$), which is available in plenty, in powdered form, was found to be a cost-effective soil-ameliorating agent in coastal saline soils (Sen 1998).

Potassium Management

Plants grown in coastal soils may show K deficiency due to the antagonistic effect of Na and K absorption and/or disturbed Na/K ratio. Though most of the salt-affected soils contain an adequate amount of available K, their high Na content may inhibit plant absorption of K. In highly saline condition, the absorption of Na increased, and that of K decreased (Dhanushkodi and Subrahmaniyan 2012). Hence, split application of K is beneficial (Bandyopadhyay and Bandyopadhyay 1984) and better when simultaneously applied with N, possibly due to the increased availability of ammonium N to the plants owing to preferential fixation of K in the illitic type of clay soils (Biswas et al. 1982).

Zinc Management

Zn is one of the essential micronutrients, which serves as a co-factor for more than 300 enzymes involved in the metabolism of carbohydrates, lipids, proteins, and nucleic acids necessary for normal growth and development of plants and animals (Mallikarjuna Swamy et al. 2016). There are reports of Zn deficiency in coastal soils (Maji and Lama 2016). Thus, a combination of good agronomic management practices and genetic approaches is essential to improve the soil health for enhancing the root uptake of Zn in coastal flood-prone areas. Application of zinc (5 kg ha^{-1} using 25 kg $ZnSO_4.7H_2O$ ha^{-1}) in combination with N-P_2O_5-K_2O can boost grain yield.

Use of Organic Manures

Organic matter in sufficient quantity should be applied to avoid the detrimental effect of salt infiltration in coastal areas. Organic manuring also reduces the loss of N through leaching and volatilization. Organic acids produced during decomposition of organic manure reduce the activity of polyvalent cations such as Fe, Al, and Ca through chelation, reduced P fixation, and the increasing availability of P in soil. Application of bio-compost, vermicompost, and composted coir pith can enhance the availability of K because compost itself adds an appreciable quantity of K to the soil. Also, due to rapid decomposition and mineralization, it releases a higher amount of NH_4^+ ion, leading to the increased availability of K in soil (Muthuraju et al. 2005). Addition of farmyard manure (FYM) to soil has also been found to be beneficial for raising the productivity of coastal soils (Bandyopadhyay and Bandyopadhyay 1984).

Integrated Use of Organic Manures and Chemical Fertilizers

Integrated application of chemical fertilizers along with organic manures will help in improving not only the soil nutrient status but also the soil quality through higher soil organic carbon to sustain crop production and reduce the vulnerability of farming systems (Maji and Mandal 1991). Addition of *Sesbania, Gliricidia*, compost, *Azolla,* and leaves of locally available trees along with inorganic N-fertilizer improves crop yield and soil health (Chaudhari 2013). Nitrogen fertilizer-use efficiency becomes better when combined sources of nutrients are applied.

Post-submergence Nutrient Management

Post-submergence nutrient management in flood-prone ecosystems has a strong bearing on regeneration growth after the flood water recedes and on grain yield of rice. Farmers in flood-prone areas mostly broadcast small amounts of urea without solid recommendations. Possibilities of recurrent submergence during the season are one of the reasons for avoiding nutrient application (Ram et al. 2009). It was reported that an additional N and K_2O dose of 20–20 kg ha^{-1} at 6–7 days after receding of flood water resulted in better crop survival, post-submergence recovery, regrowth, higher yield attributing characters, and better grain yield (Bhowmick et al. 2014; Singh et al. 2014b).

28.5.2 Water Management

Proper management of water is difficult in low-lying coastal areas. It needs well-planned large-scale drainage system with sluice gates and network of channels to effectively drain excess water, but this is beyond the abilities of resource-poor farmers living off these areas (Biswas et al. 1982). Construction of earthen embankment of suitable size will help control the ingress of seawater. Channelization of the catchment is necessary to directly route the excess rainwater from different areas to sluice gates (Yadav et al. 1981; Rao 1982; Bandyopadhyay and Bandyopadhyay 1984). Excess rainwater can be harvested and stored in farm ponds/channels, creating a source of irrigation, especially for the dry season. Appropriate land shaping technologies viz. farm ponds, deep furrows and high ridges, shallow furrows and medium ridges, broad beds and furrows, three-tier land configuration, paired bed techniques, paddy-cum-fish cultivation, and brackish water aquaculture ponds that suit different land situations, farm size, and farmers' requirements under coastal agro-ecosystem have been found very effective in reclaiming degraded coastal lands and enhancing their productivity (Chaudhari 2013; Burman et al. 2015).

28.5.3 Soil Management

Fields should be properly leveled to prevent the accumulation of water in low-lying coastal areas and to facilitate uniform drainage of excess water as well as uniform application of irrigation water at latter stages (Yadav et al. 1981; Bandyopadhyay 1999). Since the source of soil salinity is primarily the groundwater table enriched with salts and present at shallow depth, permanent reclamation of fields becomes difficult and expensive (Sen 1998). To bring the soil salinity to a minimum during the dry season, it is advisable to keep the soil under continuous crop cover instead of summer fallow (Bandyopadhyay 1999). More favorable effect is obtained if the crop is irrigated. When no cropping is possible, the soil surface needs to be covered with suitable mulches like paddy husk, straw, farm waste, etc. during winter and summer months (Biswas et al. 1982). Mulching with well-decomposed organic matter like vermicompost, compost, paddy husk/straw, or any organic waste material at 8–10 t ha^{-1} after harvest of wet season rice leads to improvement of the physical properties of soils and enhance leachability of soluble salts (Bandyopadhyay 1999). If suitable materials for mulching are not available, at least the field should be kept plowed where loose soil acts as surface mulch, thereby reducing the soil salinity and increasing the yield of successive wet season rice (Biswas et al. 1982; Bandyopadhyay 1999). Mixing of sand in the surface soil up to 15 cm at 30% by volume also leads to increased leachability of soluble salts, especially for clay and clay loam soils. Leaching of soluble salts by rainwater is also possible if it rains before planting (Bandyopadhyay et al. 1988). In Sundarbans, application of lime and a higher dose of phosphatic fertilizers and green manure is beneficial for the amelioration of acid sulfate soils (Burman et al. 2010). Green manures are more effective in areas where waterlogging occurs for longer duration and where chemical fertilizers cannot be used. *Sesbania* as an effective green manure and *Azolla* as a biofertilizer both offer considerable opportunities to enhance rice productivity in coastal areas.

The cropping system in coastal areas is predominantly rice as a monocrop. But the productivity is constrained by soil and climatic factors. There is a fair possibility of multiple cropping through efficient water use, adopting proper land management techniques and cultural practices with a view to minimize the salinity problem and to avert the risk of flood damage. Introduction of an integrated farming system combining crop production with horticulture, agroforestry, animal husbandry, and fisheries has considerable scope and potential for improving system productivity, farmers' income, and environmental sustainability in these areas (Bandyopadhyay et al. 2011). Such diversification of rice production system would provide opportunities for farmers to offset losses in the event of crop failures caused by aberrant climatic conditions (Maji and Lama 2016).

28.6 Conclusions

Despite having a complex array of climate-, soil-, and water-related problems, coastal flood-prone areas support the livelihood of millions in South and Southeast Asia. West Bengal occupies the highest area under coastal saline lands in India (0.82 million hectares), confined to the districts of East Midnapore, Howrah, North 24 Parganas, and South 24 Parganas. As a whole, coastal areas are highly fragile and extremely dynamic, being featured with varying soil characteristics, differential land uses, climatic adversities, and multiple abiotic stresses including waterlogging and/or submergence and salinity. Most of the farmers in these areas are small and marginal landholders and often face several risks and uncertainties of climate adversities, leading to low and unstable crop productivity, or even complete crop failures. Still, there exists an enormous potential for agricultural research and development to properly exploit these areas for food production. Most of these areas are underexploited and overpopulated with highly impoverished communities with limited access to new varieties and technologies. Monocropping of rice is a common practice because of the difficulties in growing other crops due to high humidity, excessive wetting, and waterlogging or submergence of varying depths and durations during the monsoon season. Excess water in the season causes long-term partial submergence (stagnant flooding) or short-term complete submergence (flash flooding), coupled with saline water intrusion and suboptimal management, leading to substantial yield losses. Advances in rice breeding for submergence and salinity tolerance offer huge prospects for enhancing and sustaining productivity of the rice-based rainfed lowland system in coastal flood-prone areas. Newly released STRVs like Gosaba 5 (Chinsurah Nona 1) and Gosaba 6 (Chinsurah Nona 2) are found to mitigate stress-induced yield losses and are gaining popularity to replace traditional and old varieties currently being used, but with limited yield potential in farmers' fields. Further interactions of these STRVs with matching technologies for crop and natural resource management can usher higher productivity and benefits to farmers. We conclude that combining recently developed STRVs for the coastal flood-prone environment with improved management options and opportunities to address multiple abiotic stresses can ensure higher and stable productivity, making rice-based cropping systems more resilient and attractive, thereby enhancing and stabilizing farmers' income in these vulnerable areas.

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