6 Coastal Water Resource Use for Higher Productivity: Participatory Research for Increasing Cropping Intensity in Bangladesh

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Abstract

In Bangladesh, about 1.0 million ha of coastal saline soils have been monocropped with low-yielding, traditional rice varieties during the monsoon season from June to December. Most of these lands remain fallow in the dry season because of high soil salinity and the lack of good-quality irrigation water. This research was conducted with farmers' participation to test the hypothesis that a combination of on-farm storage of surface water, to prolong freshwater availability beyond the end of the rainy season, together with the proper selection of rice varieties, can increase cropping intensity and productivity of the area. Selected farmers and local leaders were involved in the whole process, from designing the new cropping systems to managing, testing and evaluation. In the wet season, the traditional rice varieties were replaced by short-duration, high-yielding varieties (HYV), which can be harvested earlier, about 1.5 months before traditional varieties. This opened up opportunities for early establishment (in mid-November) of short-duration HYV of rice during the dry season. River water was directly used for irrigation of the dry-season crop up to mid-February. Beyond this time, river water became too saline for irrigation purposes. Before it became too saline, river water was taken in through sluices in the first week of February and conserved in on-farm canal networks. The stored water was used to irrigate rice from mid-February to the end of March. The new cropping system increased annual rice yield by two- to threefold and farmers' profits by 1.5- to twofold compared with the farmers' traditional system, and with no apparent negative effect on the environment. The technology was taken up at a fast pace, indicating that farmers preferred it to shrimp farming. Principles of the technology can be applied to other monsoon, deltaic coastal areas.

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Introduction

More than 30% of the cultivable land in Bangladesh is in the coastal area. About 1.0 million ha of arable lands are affected by varying degrees of salinity. Farmers grow mostly low-yielding, traditional rice varieties during the wet season. Most of the lands remain fallow in the dry season (January–May) because of soil salinity and the lack of good-quality irrigation water (Karim *et al.*, 1990; Mondal, 1997). Crop yields, cropping intensity, production levels and people's quality of livelihood are much lower in this region than in other parts of the country, which have enjoyed the fruits of modern agricultural technologies based on high-yielding varieties, improved fertilizer and water management and improved pest and disease control measures (BBS, 2001). At the same time, food demand in the area is increasing with the steady increase in human population.

During recent years, commercial shrimp farming became very attractive in the coastal region of the country. Small and medium farm-holders often lease out their agricultural lands to wealthy people, who have converted large tracts of traditional rice lands to shrimp farms. This conversion sometimes induced environmental degradation and social unrest, and it may not deliver sustainable benefits to small farm-holders (Majid and Gupta, 1997). Supplying farmers with alternative production systems with high land and water productivity is crucial for food security, enhancing farmers' livelihood and sustaining the environment of the coastal zone.

Experiences elsewhere proved that the use of short-duration, high-yielding rice varieties (HYV), the effective use of rainwater and proper crop scheduling that matches crop water requirements with the water supply and quality dynamics can increase the cropping intensity and productivity of rice lands in coastal areas (Tuong *et al.*, 1991; My *et al.*, 1995). Mondal (1997) successfully grew HYV in the wet season in the coastal zone areas of Bangladesh. Mondal (2001) also showed that river water in Khulna District remained suitable for irrigation far into the dry season until mid-February. We hypothesized that, if the river water could be taken into and stored in on-farm canal networks before it became too saline, freshwater availability could be prolonged adequately to irrigate an additional crop of HYV of rice grown after wet-season rice, thus increasing the cropping intensity of the coastal land and improving the socio-economic status of the resource-poor farmers in the coastal areas of Bangladesh. This chapter describes the processes and outcomes of farmer participatory research (2001–2004) to develop a new, rice-based cropping system at a typical site in the south-western coastal area of Bangladesh, which was carried out to test the above hypothesis. It also discusses possible refinements of the system and the implications of the findings for resource management for improving farmers' livelihood in coastal areas.

Methodology

Characteristics of the study site

The study was carried out at Kismat Fultola village under Batiaghata Upazila (subdistrict, the smallest administrative unit in Bangladesh), Khulna District (Fig. 6.1). The site has many typical characteristics of the agricultural land of the south-western coastal zone of the country. The area has two distinct seasons: a rainy season from June to October and a dry season from November to May (Fig. 6.2). Formerly, the soil was very saline because of the intrusion of seawater during the dry season. To increase agricultural production, in the 1960s the area was included in the government's Coastal Embankment Project (CEP), in which designated areas (polders) were surrounded by dykes or embankments, separating them hydrologically from the main river system and offering protection against tidal floods, salinity intrusion and sedimentation (Islam, 2005). Thanks to the CEP project, crops have been saved from salinity and flooding, and wet-season rice yields at some places increased by 200–300% (Nishat, 1988, as cited in Islam, 2005). Nevertheless, most rice soils in the area are still moderately saline (EC_e = 4–8 dS/m) to saline (EC_e = 8–16 dS/m).

The area of the present study lies on the banks of the Kazibachha River (Fig. 6.1). The river has a diurnal tidal regime. During flood tide (daily high tide), the water level could be 1–3 m higher than the land surface, thus offering opportunities for gravity irrigation in both the wet and dry seasons, provided the salinity level is not too high. Water of the river is fresh most of the time during the rainy season, with an average electrical conductivity mostly below 1.0 dS/m from July to December and below 4.0 dS/m from mid-January to mid-February (Fig. 6.3). However, the average monthly salinity of the river water can reach a maximum of about 20 dS/m at the end of the dry season, and this high salinity level makes the river water unsuitable for irrigation during March to June.

The farmers' common practice is to grow rainfed, low-yielding and long-duration local rice varieties in the wet season (transplanted in July and harvested in December, Fig. 6.4), with an annual average yield of only 2.0–2.5 t/ha. Inadequate rainfall (Fig. 6.2) and the lack of good-quality irrigation water restrict crop cultivation during the dry season, but about 40% of the farmers grow sesame during March to May on residual soil moisture. However, the crop is often damaged by unpredictable high rainfall that may occur in May (Fig. 6.2) at the reproductive stage. The farmers reported that, out of 30 years of sesame cultivation, they were

Fig. 6.1. Location map of the study site (Kismat Fultola village, Khulna District).

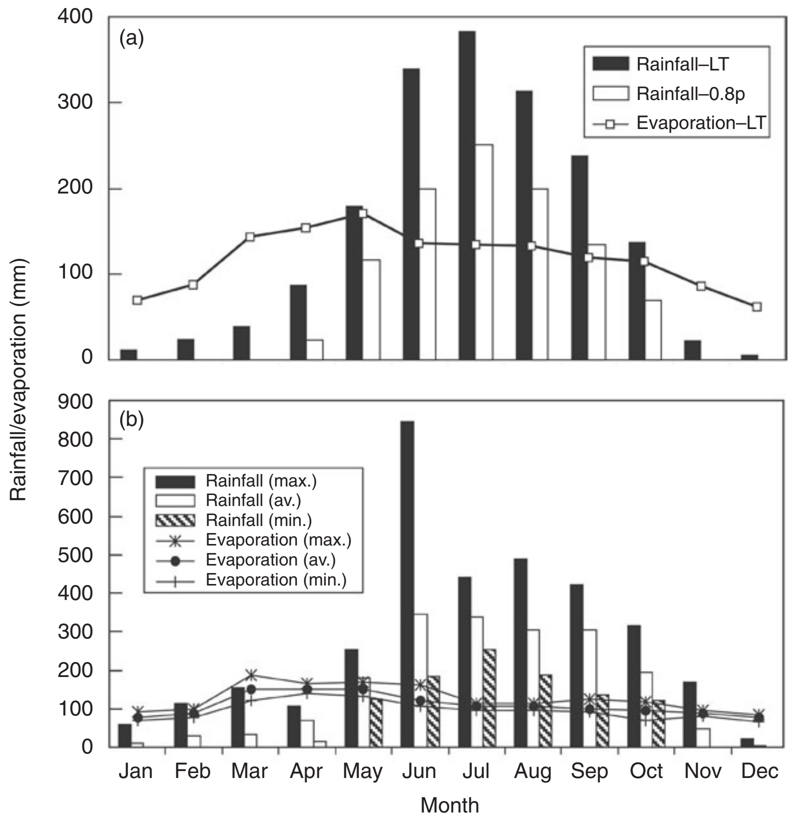

Fig. 6.2. Rainfall and evaporation pattern in Khulna District, 1902–1984 (a) and 1998–2003 (b). LT, long-term average values; 0.8p, values corresponding to 80% probability of exceedence. Source of the long-term data, FAO (1988).

successful in only 10 years and complete damage occurred in another 10. Sesame harvested in the remaining 10 years was partly damaged/rotten and was poor in quality, with a consequent low market price.

Conceptualizing a new cropping system and water management strategy

A new cropping system (Fig. 6.4), with a rainfed rice crop during the wet season and an additional irrigated rice crop during the dry season (from mid-November to mid-April), was conceptualized to increase cropping intensity of the study area. The conceptualization followed the principles described by Tuong *et al.* (1991). It critically assessed agro-hydrological factors in matching the availability of good-quality water and the water requirement of the new rice cropping pattern. The new cropping pattern made use of two principal components, described below.

1. An innovative water management strategy. Rice cultivation in the area after October needs irrigation water. River water is suitable for irrigation until mid-February. To extend irrigation water availability beyond mid-February, river water can be taken into and stored in the on-farm canal network before the water becomes too saline. The stored water can be used to irrigate the dry-season rice until the harvest. For a given area, the larger the amount of the on-farm storage, the longer the irrigation period can be extended.

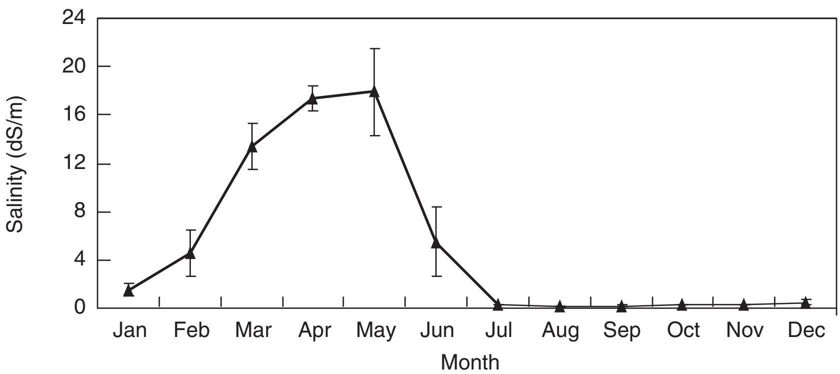

Fig. 6.3. Average monthly salinity of Kazibachha River measured at Kismat Fultola village, Khulna District, 1997–2004. Vertical and capped bars indicate standard error of the means of eight monthly values; each monthly value was the average of 10–20 daily values.

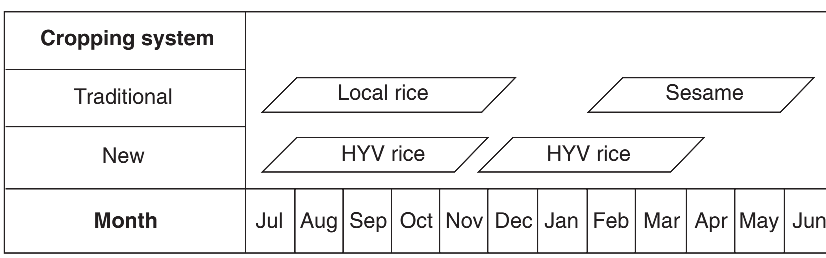

Fig. 6.4. Traditional and new cropping systems at Kismat Fultola, Khulna District. HYV, high-yielding varieties.

2. Use of short-duration HYV of rice. The use of short-duration varieties is critical for increasing the cropping intensity of rainfed lowland rice (Tuong *et al.*, 1991). It was perceived that HYV of rice in the wet season not only gave higher yields (Mondal, 1997) but also reduced the growth span of wet-season rice compared with traditional varieties, and facilitated the advancement of dry-season rice establishment. Early establishment and the use of short-duration HYV in the dry season allowed the crop to be harvested before water salinity reached damaging levels in April and May. We aimed at harvesting the dry-season crop as early as possible to reduce irrigation requirements during the dry season and to avoid salinity damage later in the season.

The participatory process

In 2001, driven by the need for more rice, some farmers in the study area transplanted dry-season rice in February and used river water for irrigation at the end of the cropping season. This resulted in total crop failure because the river water was too saline. In early 2002, we organized a series of meetings with farmers, local leaders and government and non-government organizations (GO-NGO) to investigate the reasons for the 2001 crop failure and to discuss the newly conceptualized cropping system and water management. Twenty-nine farmers agreed to test the new cropping system in the same location where they experienced failure of rice in 2001.

The first step in the farmer–researcher collaboration was a 3-day, hands-on training on cultivating HYV of rice. Details on the participatory experiments (see below) were discussed with individual farmers before each cropping season from 2002 to 2004. Neighbouring farmers, local leaders, social workers, GO-NGO officials, journalists, educators, donors and women's communities were invited to join the field days to participate in evaluating the performance of HYV of rice and the new cropping system during each season.

In the dry season of 2003, we helped organize a farmer-run workshop so that participating farmers could share their research experiences with the extension personnel, researchers, social workers, leaders and elite educators, GO-NGO officials, donors and women's communities. A workshop was organized in June 2004, focusing mainly on extension personnel, journalists and policymakers, to acquaint them with the technologies for wider dissemination.

The experiment

A 3.5 ha area, provided with a sluice gate (a gate that can be opened at high tide for water intake as well as at low tide for drainage) at the south and a flash gate (for water intake only) at the north, was selected for this participatory experiment. The area was divided among 29 participating farmers. In the 2002 wet season, researchers recommended farmers to try 15 HYV of rice developed by the Bangladesh Rice Research Institute (BRRI) (Table 6.1 – hereafter, all varieties/lines will be referred to by their abbreviations shown in Table 6.1). In the 2003 wet season, the advanced line BR6110 was added. Each farmer selected two to five varieties/lines from the recommended ones and grew them on their own land within the experimental field. In addition, all the tested, wet-season rice varieties/lines were grown by three participating farmers in a contiguous area of about 0.2 ha inside the experimental field, named the 'crop museum'.

Farmers transplanted 30-day-old seedlings in the last week of July, when soil salinity was adequately reduced by rainfall. After the harvest of rainy-season crops, farmers transplanted the dry-season rice crop around mid-December. All participating farmers planted variety BD28 in the dry season. In addition, six farmers also grew BD36 in the 2002/3 dry season and BD29 in the 2003/4 dry season. All rice varieties used in the dry season were non-aromatic and photoperiod-insensitive (Table 6.1). The growth duration of BD28 and BD36 was similar, but BD29 had a longer duration.

Rainfall supplied most of the water required for wet-season rice crops. During the occasional droughts in the rainy season, supplemental irrigation was provided during flood tide through the flash gate and irrigation canal networks where water was gravity-fed into the fields. This method of irrigation was also employed to supply water for the dry-season crops from December to mid-February, when the salinity level of the river water remained below 4.0 dS/m. During the last intake, as much water as possible was stored in the canals and in the fields. Water stored in the canals was used to irrigate rice from mid-February to the end of March with the help of a low-lift pump.

Monitored parameters

Climate and water resources

Rainfall and Class-A pan evaporation were measured daily at the study site during the experimental period. Groundwater level was measured weekly from June 2002 to May 2004 at Kismat Fultola, at seven observation wells installed at regular intervals for up to 1 km distance perpendicular to the river, and at a well 500 m south of the experimental site, and about 50 m away from the riverbank. Groundwater salinity in the observation wells was measured weekly by using a portable electrical conductivity meter.

Water salinity of the Kazibachha River was measured daily as far as 500 m north of the intake sluice of the study site during ebb (daily low tide) and flood tide using a portable electrical conductivity meter.

Table 6.1. Characteristics of high-yielding varieties/lines of rice grown in the experimental field (2002–2004) at Kismat Fultola village, Khulna District, Bangladesh (from BRRI, 2004).

Variety/line	Abbreviation	Growth duration (days)	Bred for salinity tolerance?	Other properties
BR10	BR10	150	No	Non-aromatic, slightly photoperiod-sensitive
BR11	BR11	145	No	Non-aromatic, slightly photoperiod-sensitive
BR22	BR22	150	No	Non-aromatic, photoperiod-sensitive
BR23	BR23	150	Yes, low tolerance	Non-aromatic, photoperiod-sensitive
BR25	BR25	135	No	Non-aromatic, photoperiod-insensitive
BRRI dhan30	BD30	145	No	Non-aromatic, slightly photoperiod-sensitive
BRRI dhan31	BD31	140	No	Non-aromatic, photoperiod-insensitive
BRRI dhan32	BD32	130	No	Non-aromatic, photoperiod-insensitive
BRRI dhan33	BD33	118	No	Non-aromatic, photoperiod-insensitive
BRRI dhan34	BD34	135	No	Aromatic, photoperiod-insensitive
BRRI dhan37	BD37	140	No	Aromatic, photoperiod-sensitive
BRRI dhan38	BD38	140	No	Aromatic, photoperiod-sensitive
BRRI dhan39	BD39	122	No	Non-aromatic, photoperiod-insensitive
BRRI dhan40	BD40	145	Yes, medium tolerance	Non-aromatic, photoperiod-sensitive
BRRI dhan41	BD41	148	Yes, medium tolerance	Non-aromatic, photoperiod-sensitive
BR6110-10-1-2[a]	BR6110	145	–	Non-aromatic, photoperiod-sensitive
BRRI dhan28	BD28	140	No	Non-aromatic, photoperiod-insensitive
BRRI dhan29	BD29	160	No	Non-aromatic, photoperiod-insensitive
BRRI dhan36	BD36	140	No	Non-aromatic, cold-tolerant, photoperiod-insensitive

[a] BR6110-10-1-2 was added in 2003.

Monthly values at ebb and flood tides were taken as the average of daily measurements.

Soil salinity

Topsoil salinity of Kismat Fultola village was measured at 15-day intervals in the dry season and at 30-day intervals in the wet season from May 2002 to April 2004. At each sampling time, 17 soil samples were taken randomly from the 0–15 cm soil layer of the experimental field to make a composite sample. Soil salinity of the composite sample was determined by the saturation extract method (ASA and SSSA, 1982).

Yield assessment

Areas of 5 m^2 each, from four different corners and one from the middle of the plot, were harvested from seven to 16 farmers' fields to estimate grain yield, and values were later adjusted to 14% moisture content (BRRI, 1993). This procedure was followed to determine grain yield of the experimental fields as well as that of fields of farmers who did not originally participate in the experiment, but later adopted the new cropping system and used the recommended varieties on their own farms (uptake fields).

Results and Discussion

Agro-hydrological conditions

Figure 6.2b shows monthly rainfall and evaporation at the study site from 1998 to 2003. They did not deviate very much from the long-term (1902–1984) values (Fig. 6.2a) and confirmed that rainfall could supply adequate water to meet crop evapotranspiration from June to October. The dynamics of groundwater depth at two monitoring points at the study site are presented in Fig. 6.5. The water table at 1 km distance from the river was nearer to the ground surface than that closer to the river, suggesting that the further the distance from the riverbank, the more difficult is the drainage.

The groundwater salinity levels are shown in Fig. 6.6. The salinity of the groundwater at the study site was about 4 dS/m throughout the year, but the salinity at the point 500 m south of the study site reached a maximum of 12 dS/m. This implies that groundwater salinity could vary greatly within short distances. The use of groundwater remains a risky venture, owing to high

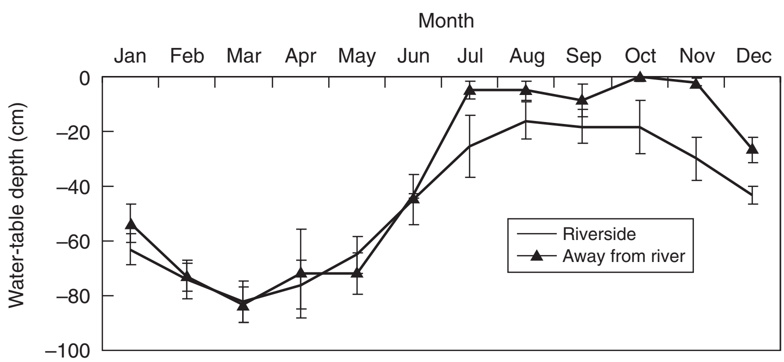

Fig. 6.5. Groundwater fluctuation in the coastal aquifer at the experimental fields (riverside) and at 1 km from the river, Kismat Fultola, Khulna District, 2002–2004. Vertical and capped bars indicate standard deviations of the means of three monthly values; each monthly value was the average of four weekly values.

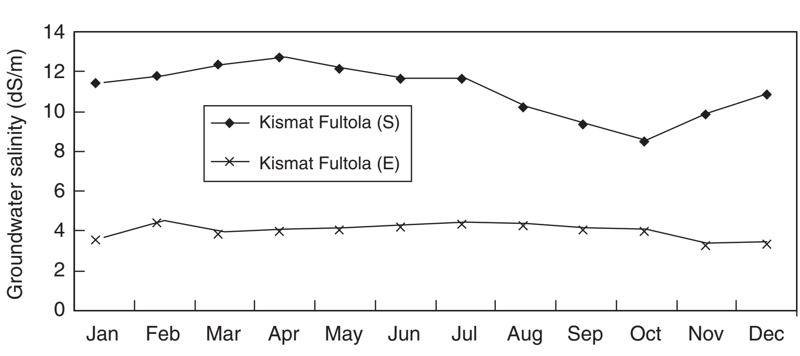

Fig. 6.6. Groundwater salinity in Batiaghata Upazila, Khulna District, at the experimental site (E) and at 500 m south of the site (S), 1996–2003. Both sites are 50 m from the river bank.

spatial variability and the possible intrusion of saline water from the river into the coastal aquifers if the water level of the aquifers is lowered because of excessive withdrawal of water for irrigation.

The dynamics of the salinity of the river water during the dry season (Fig. 6.7) followed the same pattern as that observed from long-term records (Fig. 6.3). Salinity of the river water started to increase in the second half of February and reached maximum values in April/May. There were significant differences in salinity levels of the river water during ebb and flood tides. The average salinity at flood tides reached 4 dS/m in mid-February, but remained below 4 dS/m during ebb tides until the beginning of March.

Variation in soil salinity between cropped and fallow lands

A typical soil salinity pattern of the rice soils at Kismat Fultola is shown in Fig. 6.8. Topsoil salinity in fallow lands varied from 5.0 to 12.0 dS/m in the dry season and remained below 4.0 dS/m in the wet season (when traditional rice is grown under rainfed conditions). But when rice was grown in the dry season by using river water, the dry-season soil salinity level decreased considerably from January to March. The decrease in soil salinity during the dry season under the new cropping system compared with the traditional rice–fallow system was due to the leaching of salts via irrigation water.

Rice grain yields

High-yielding rice varieties in the wet season

Yield of the non-aromatic HYV grown in the wet season varied from 4.0 to 5.0 t/ha (Fig. 6.9) and the aromatic rice varieties yielded about 3 t/ha. The difference in yield was due to the lower yield potential of the aromatic rice varieties (BRRI, 2004). Among the non-aromatic HYV, BD33 and BD39 had the shortest growth duration (about 120 days, Table 6.1), but yielded as well as the varieties with 140–150 day duration (Fig. 6.9). Many tested genotypes yielded more than BR23 and BD41, which were especially bred for salinity tolerance, indicating that salt tolerance is not an absolute requirement for rice grown during the rainy season. This is supported by the low soil salinity level during the rainy season at the study site (Fig. 6.8). All tested HYV yielded much higher than the farmers' traditional varieties. This was attributed to the higher yield potential and harvest index of the HYV (BRRI, 2004), and probably the higher nutrient input and supplementary irrigation in the new cropping system.

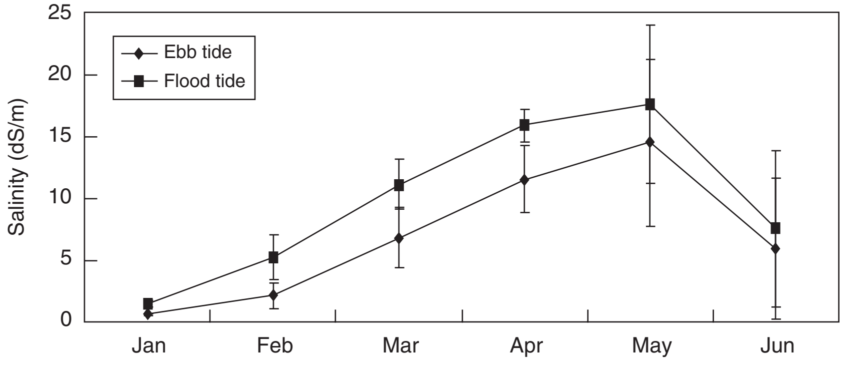

Fig. 6.7. Variation in water salinity of the Kazibachha River during ebb and flood tides at Kismat Fultola, Khulna District (average of 2000, 2003 and 2004). Vertical and capped bars indicate standard error of the means of three monthly values; each monthly value was the average of 10–15 daily values.

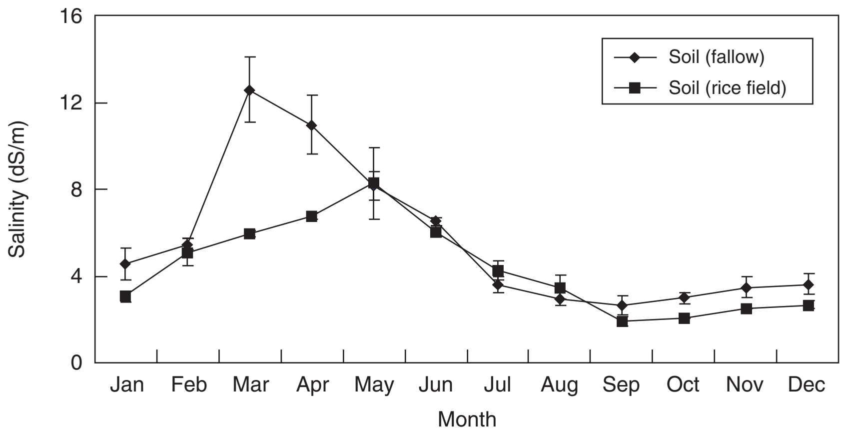

Fig. 6.8. Soil salinity in fallow and rice lands at Kismat Fultola, Khulna District, 1998–2004. Vertical and capped bars indicate standard error of the means of seven monthly values; each monthly value was the average of two measurements.

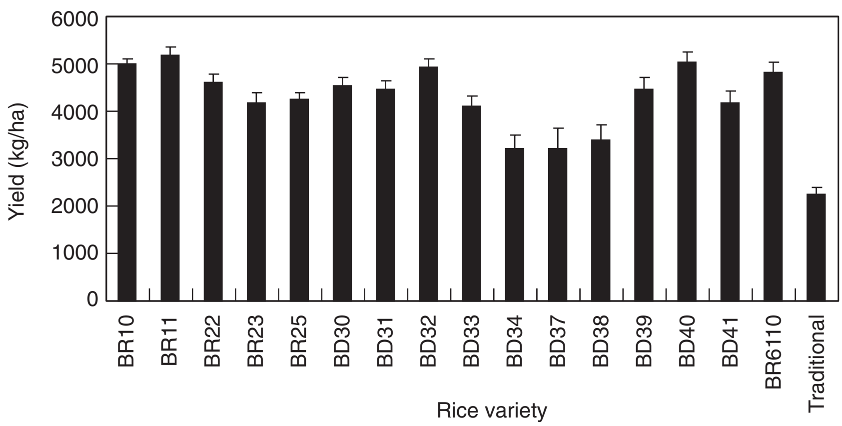

Fig. 6.9. Rice yield in the wet season (average of 2002 and 2003) at Kismat Fultola, Khulna District. Vertical and capped bars indicate standard error of the 2-year mean yields of 6–13 farmers' fields.

High-yielding rice varieties in the dry season

The average yield of BD28 in the 2001/2 and 2002/3 dry seasons was about 3000 kg/ha (Fig. 6.10). This was lower than its potential yield (BRRI, 1993). The main reason was the lack of farmers' experience in managing HYV at the outset, and also an unusual cold spell just after transplanting rice in the 2002/3 dry season (data not shown). The lack of farmers' experience was reflected in the large variation in rice yield of the sampled plots, from as low as 1000 kg/ha to as high as 4625 kg/ha, with about 40% of the experimental area having an average yield of 4300 kg/ha.

BD28 yielded more in the 2003/4 dry season than in the previous year. Average yields of BD28 and BD36 were about 3167 and 3630 kg/ha, respectively (Fig. 6.10). It is interesting to note that neighbouring farmers who used BD28 in the 2003/4 dry season obtained much higher grain yield (4425 kg/ha) than the farmers participating in the research (Fig. 6.10). Among them, five farmers obtained 6314 kg/ha with BD29 and 5326 kg/ha with BD36. The higher yield of BD29 could be attributed to its longer duration (Table 6.1). We do not have a full explanation for the higher yields in the 'uptake fields', but we postulate that the rice fields of the 'uptake' farmers were away from the river and may have had less salinity than the experimental field.

Changes in annual rice production and farmers' income

Farmers in the coastal region usually harvest about 2.0–2.5 t/ha of rice grain per year and earn a benefit of about Tk 15,000–20,000/ha (US$1 = Tk 60, Table 6.2). For farmers who grow sesame during the dry season, total annual grain production in rice equivalence in good years is about 3.0–4.5 t/ha (Table 6.3). By adopting the new cropping system and water management approach, participating farmers can harvest 6.0–8.5 t/ha of rice grain per year.

The additional profit from growing HYV instead of traditional rice varieties in the wet season was Tk 10,000/ha. In the dry season, even with the low average yield obtained in 2002/3, the participating farmers still obtained a profit of about Tk 7500/ha. In total, net yearly benefits from the new cropping system were Tk 32,500–37,500/ha, with a 50–100% increase over the traditional cropping system.

About 40% of the participating farmers have landholdings of less than 1.0 ha and the rest have about 1.0–2.0 ha per family. Almost all farmers have to depend on these land resources for their entire livelihood. Most expenditures are usually met from income from rice. Only about 5–10% of the total land owned by the participating farmers was used in this project, yet about 40% of their total rice production came from within the 3.5 ha project area, where cropping intensity has increased from 100% to 200%.

Environmental impact

Throughout this new system, coastal water resources were productively used for rice cultivation without hampering or disturbing the environment. Integrated pest management (IPM) techniques were adopted for the control of insects and pests, resulting in little use of pesticides despite the enormous pest attack normally experienced during the wet season in the Batiaghata area. In the experimental field, soil salinity in the dry season decreased (Fig. 6.8) because of the use of relatively non-saline river water for dry-season rice cultivation. Conservation of relatively

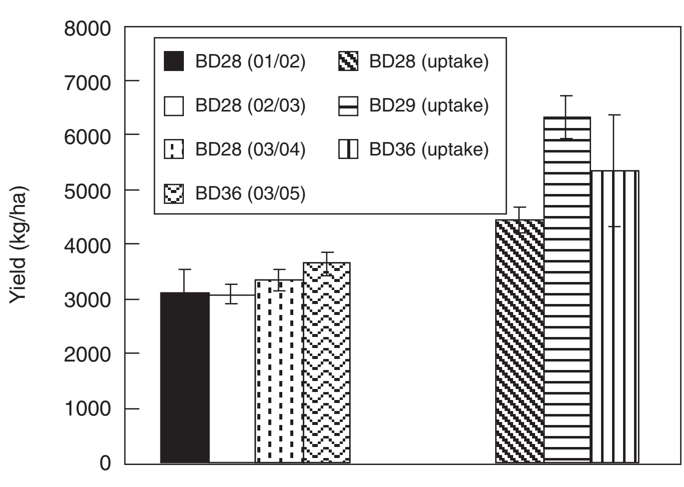

Fig. 6.10. Rice yield in the research (2001–2004) and uptake fields (2003–2004) in the dry season at Kismat Fultola, Khulna District. BD, BRRI dhan; vertical and capped bars indicate standard error of the means of 3 years, 6–19 farmers per year from research fields and 2–17 farmers from uptake farmers' fields in the 2003/4 season.

Table 6.2. Cost–benefit comparison between the traditional and newly developed cropping system using local and non-aromatic HYV of rice.

	Item	Traditional cropping	New cropping
Wet season	Production cost (Tk[a]/ha)	5,000	10,000
	Rice yield (t/ha)	2.0–2.5	5.0–6.0
	Total income (Tk/ha)	20,000–25,000	35,000–40,000
	Profit (Tk/ha)	15,000–20,000	25,000–30,000
Dry season	Production cost (Tk/ha)		15,000
	Rice yield (t/ha)		3.0
	Total income (Tk/ha)		22,500
	Profit (Tk/ha)		7,500
Annual	Rice yield (t/ha)	2.0–2.5	8.0–9.0
	Production cost (Tk/ha)	5,000	25,000
	Profit (Tk/ha)	15,000–20,000	32,500–37,500

[a] US$1 = Taka 60 (approx.).

Table 6.3. Cost–benefit comparison between traditional rice–sesame and the modified rice–rice cropping system using HYV of rice.

	Item	Traditional cropping	New cropping
Wet season	Production cost (Tk[a]/ha)	5,000	10,000
	Rice yield (t/ha)	2.0–2.5	5.0–6.0
	Total income (Tk/ha)	20,000–25,000	35,000–40,000
	Profit (Tk/ha)	15,000–20,000	25,000–30,000
Dry season	Production cost (Tk/ha)	900	15,000
	Sesame[b]/rice yield (t/ha)	0.728	3.0
	Total income (Tk/ha)	9,318	22,500
	Profit (Tk/ha)	8,418	7,500
Annual	Rice and sesame yield (t/ha)	2.7–3.3	8.0–9.0
	Production cost (Tk/ha)	5,900	25,000
	Profit (Tk/ha)	23,418–28,418	32,500–37,500

[a] US$1 = Taka 60 (approx.).[b] Adopted from Mondal (1997), assuming the best yields of sesame.

non-saline river water in natural canals benefited the health of farm animals in the locality, as animals usually depend on canal water for drinking during the dry season. Increased sedimentation owing to the use of river water for supplemental irrigation during the wet season may help improve soil fertility. The microclimate of the area is considerably improved in the dry season because of crop cultivation using stored irrigation water.

Conclusions and Recommendations

This study showed that soil salinity during the wet season was low enough to grow modern rice varieties, even if they are not specifically bred for salt tolerance. In addition, HYV rice can be grown in the dry season using river water stored in on-farm canal networks before it becomes too saline. The stored water is used for irrigating rice in the latter part of the dry season. The modified water management and cropping practices increased the productivity of the coastal saline rice lands and farmers' income by 50–100% over the traditional farmers' practice.

The participatory approach – involving multilevel stakeholders, from farmers to local government officials and policymakers at all stages of the project – used in this study accelerated the uptake of the technology by neighbouring farmers. Rice production during the dry season in coastal ecosystems improves Bangladesh's food security and enhances farmers' livelihoods via increased income. It also helps improve the environment by reducing salt accumulation during the dry season and ameliorating the microclimate via vegetation cover. These are important factors in farmers' preference of the technology over shrimp farming, as evidenced by the fast-paced adoption of the technology, while shrimp area has not increased in the study area.

Many rivers and canal networks lie in the coastal region, especially in the polder areas of coastal Bangladesh, where non-saline river water and rainfall can be conserved for crop production. These offer a good opportunity for improving land productivity and the livelihood of resource-poor farmers in these areas. In our study, the turnaround time between the wet-season crop harvest and dry-season crop establishment is more than a month. There are still more opportunities to advance crop establishment and therefore harvesting of the dry-season crop, which would further reduce the amount of water needed for supplementary irrigation at the end of the dry season. There is also a possibility of dry direct seeding of the rainy-season crop to advance its establishment and harvest even further (My *et al.*, 1995), followed by an earlier dry-season crop. Alternatively, the last river water intake can be extended by about 2 weeks if river water can be pumped into the canal systems at the ebb tide with lower salinity, instead of relying solely on gravity for the intake of river water at the flood tide. This of course will entail more investment. Cost–benefit analysis needs to be performed, and social acceptance of these changes needs to be further studied.

As the rice farmers have no control over open-water bodies (i.e. natural canals, where they can conserve rainwater and non-saline river water) and sluice gates, they cannot properly plan for rice cultivation in the dry season. New management practices should be established to allow farmers to control the sluice gates and open water bodies to irrigate their farms without harming the interests of those who rely on fisheries in the open water for their livelihood. Canal networks need to be excavated to maximize water storage, and water balance studies have to be carried out to determine the maximum rice area that can be irrigated using stored water.

Our study focused on the coastal area of Bangladesh, but the success of the technology at the study site and similar success in Vietnam (Tuong *et al.*, 1991) indicate that the same principles can be applied to increase cropping intensity and improve farmers' livelihoods in many coastal areas in tropical deltas with similar characteristics.

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