7 Improving the Productivity of the Rice–Shrimp System in the South-west Coastal Region of Bangladesh

M.J. Alam,[1] M.L. Islam,[1] S.B. Saha,[1] T.P. Tuong[2] and O. Joffre[3]
[1]Bangladesh Fisheries Research Institute, Brackishwater Station, Paikgacha, Bangladesh; e-mail: alammj_bfri@yahoo.com; [2]Crop and Environmental Sciences Division, International Rice Research Institute (IRRI), Metro Manila, Philippines; [3]WorldFish Center, Penang, Malaysia

Abstract

The production of wet-season rice (mid-August to mid-December) followed by dry-season (mid-December to mid-August) shrimp (*Penaeus monodon*) is a common farming system in the south-western coastal region of Bangladesh. Experiments were conducted in the farmers' fields during the rice- and shrimp-growing seasons of 2004, 2005 and 2006, with the aim of improving the total farm productivity of the rice–shrimp system through technological intervention. During the wet season of 2004, yield responses of different high-yielding (BR23, BRRI dhan 40 and 41, HR1 and 14) and traditional (Horkoz) rice varieties were evaluated for their responses to the prevailing salinity-influenced environment and integrated with: (i) GIFT (genetically improved farmed tilapia) strain of Nile tilapia (*Oreochromis niloticus*) alone; (ii) GIFT and giant freshwater prawn (*Macrobrachium rosenbergii*) at a 1:1 ratio; and (iii) prawn alone at a stocking density of 10,000/ha. In the 2005 rice season, the previous season's best-yielding rice varieties (BR23, BRRI dhan 40 and 41) were cultivated, integrated with a similar aquaculture species combination but at a reduced stocking density of 5000/ha. In the dry seasons of 2005 and 2006, the production of black tiger shrimp (*P. monodon*) was evaluated for three stocking patterns: (i) single stocking (5/m^2); (ii) double stocking (3/m^2 followed by 2/m^2); and (iii) double stocking (2/m^2 followed by 3/m^2). Among the rice varieties, BR23 and BRRI dhan 40 performed best, with similar yields averaging about 5 t/ha. The reduced density of 5000/ha actually gave better fish and prawn yields, resulting in additional average production of 258 kg of GIFT and 71 kg of prawn/ha. The net return from GIFT alone was Tk10,858/ha and that from prawn was marginal or negative. Single and double stocking of shrimp did not show any significant differences in body weight, survival rate and yield, with the values ranging from 20 to 24 g, 26 to 35% and 289 to 380 kg/ha, respectively. There were considerable variations in survival and production within each treatment, particularly because of higher shrimp mortality in the replicate ponds that had comparatively shallower water depth during the culture period. Single stocking resulted in average net returns as high as Tk67,500/ha and was considered more suitable in rotation with rice.

Introduction

The culture of shrimp (particularly black tiger shrimp, *P. monodon*) in Bangladesh started in the 1970s in the low-lying tidal coastal flats within the Bangladesh Water Development Board (BWDB) polders, following the traditional trapping–holding–growing method (Islam, 2003). The increased international demand and lucrative price of shrimp stimulated farmers to focus on shrimp culture as their major farming activity, resulting in an expansion of 0.02 million ha of shrimp farms in 1980 to 0.20 million ha in 2005 (DoF, 2005). About

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75–80% of this area is in the south-western region of the country, where shrimp is cultured during the high saline period of February to mid-August in rotation with rice during the low salinity period of mid-August to December (Islam *et al.*, 2005). In this region, there is a prolonged low-salinity regime, with an average salinity below 1 ppt, during the monsoon (June–September) and post-monsoon (October–November) seasons. The salinity of the river water increases in the winter season (December–February) and reaches a maximum of 13 ppt in the pre-monsoon (March–May) season (Mondal *et al.*, 2006).

The alternate rice–shrimp system is considered to be an ecologically sustainable approach to shrimp farming, with the rice crop providing an ecological buffer between shrimp crops (Brennan *et al.*, 2002). The benefit of rice–aquaculture integration as a low-investment technology for marginal farmers has been demonstrated in inland freshwater areas in Bangladesh (Gupta *et al.*, 1998). Integrated freshwater prawn (*M. rosenbergii*) culture with rice during the rainy season, followed by marine shrimp monoculture in the dry season, increased the incomes of coastal farmers in Vietnam (Hung, 2001). However, the integration of rice–aquaculture in a traditional brackishwater rice–shrimp system is not well developed in the south-west of Bangladesh. Farmers cultivate mainly rice of local varieties, with low yields ranging from 1.0 to 3.0 t/ha (Karim, 2006). Productivity of shrimp monoculture also remains low, ranging between 50 and 250 kg/ha (Islam, 2003), as more than 90% of farmers still practise the traditional extensive method characterized by low stocking density, no feeding and poor water quality management (Islam *et al.*, 2005).

With increasing population pressure, coastal livelihood requirements cannot be met satisfactorily with the existing traditional extensive production systems, but productivity improvements need to take into consideration the existing farming patterns and available coastal resources. With this in mind, experiments were conducted on shrimp production in the dry season and on rice–fish integration in the wet season, with the aim of improving total farm production and the incomes of farmers in the fresh- and saltwater interface areas of south-western Bangladesh.

Materials and Methods

Experimental site and preparation

Experiments during the shrimp and rice seasons in the same calendar year (Fig. 7.1.) were conducted in farmers' rice–shrimp plots (locally termed *gher*) in polder No 16/1 in the Khulna District of Bangladesh. There were nine experimental plots in 2004 and 2005 and 12 in 2006. The area of each experimental plot varied from 910 to 1420 m^2. Attempts were made to weight different-sized plots with different treatments. The fields were connected with the Shibsa River and water exchange occurred with changing tides through sluice gates. All the experimental plots were deepened by excavating the bottom soil to a depth of about 15 cm and the surrounding dykes were raised so that a minimum water depth for shrimp (30–40 cm) and rice–fish (15–20 cm) crops could be maintained. Trenches of 80 cm average depth were constructed along the dykes in each plot. These trenches occupied 8–10% of the plot area. Each experimental plot had a separate water inlet–outlet encircled with nylon fencing.

Rice–fish experiments in the wet season (mid-August to December)

Experimental design

During the rice season (August–December) of 2004 and 2005, the culture of GIFT (genetically

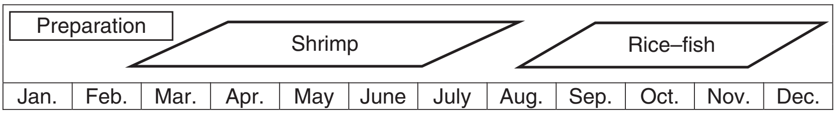

Fig. 7.1. Cropping calendar year for shrimp and rice–fish experiments.

improved farmed tilapia, *O. niloticus*) and giant freshwater prawn (*M. rosenbergii*) integrated with rice cultivation was evaluated. There were three treatment combinations: (i) GIFT alone (T-1); (ii) 1:1 GIFT and prawn (T-2); and (iii) prawn alone (T-3). The total stocking density of cultured species was 10,000/ha in the 2004 rice season, but was reduced to 5000/ha in 2005. Treatment replications were laid out following a completely randomized design. Simultaneously with aquaculture, the performance of six high-yielding varieties (HYVs) of rice (HR1, HR14, BR23, BR23L, BRRI dhan 40, BRRI dhan 41) and a local variety (Horkoz) were evaluated in 2004. HYV rice seeds were collected from the Bangladesh Rice Research Institute (BRRI) seed bank, except for BR23L, which was collected from local farmers. Within each aquaculture treatment plot, the test varieties of rice were planted in randomized subplots, with a minimum of three replications. In 2005, three HYVs, namely BR23, BRRI dhan 40 and BRRI dhan 41, were selected for further testing, based on their superior yield performance in 2004.

Rice crop management

Field preparation activities included ploughing and the application of cow dung, urea and triple super phosphate (TSP) at 2 t/ha, 70 kg/ha and 35 kg/ha, respectively. At the end of August, 1-month-old rice seedlings of the test varieties were transplanted at 23 cm row spacing. A top dressing of urea at 75 and 37.5 kg/ha was applied 24 and 60 days after transplanting, respectively. Nimbicidin (extract of neem seed) was applied at 1.5 l/ha to control the stem borer infestation that had occurred between 20 and 40 days of transplanting in both years. Zinc sulfate was sprayed at a concentration of 3 ml/l in areas affected by leaf blight disease. The rice crop was harvested some time between 100 and 120 days after transplanting.

Aquaculture management

At 8–10 days after transplanting rice, GIFT fry and prawn juveniles, averaging 1.5 g and 3.5 g in body weights, respectively, were stocked in the rice plots according to the experimental layout. After about 120 days of culture, the fish and prawn were harvested and their growth, survival rate and production were estimated. For the entire experiment, no feed was provided either to GIFT or to prawn.

Shrimp production experiments in the dry season (February to mid-August)

Experimental design

Based on observations of local practices of partial stocking and harvesting of shrimp, three stocking patterns of black tiger shrimp (*P. monodon*), namely (i) single stocking at a density of 5/m^2 (T-1), (ii) double stocking at 3/m^2 followed by 2/m^2 (T-2) and (iii) double stocking at 2/m^2 followed by 3/m^2 (T-3), were evaluated during the shrimp-growing season (February–August) following the rice–fish crops in 2005 and 2006. There were three replications for each treatment in the trial of 2005 and four in 2006, based on a completely randomized design layout.

Shrimp crop management

Following the rice harvest, the experimental plots were limed using CaO at 250 kg/ha and filled with tidal river water to a water depth of 60–70 cm at the end of February. Three days later, urea and TSP fertilizers were applied at 2.5 ppm and 3 ppm, respectively. Seven days later, hatchery-reared *P. monodon* postlarvae (averaging 0.007 g in body weight) were stocked in the ponds. The second stocking was done 30–35 days after the first stocking. No regular water exchange was carried out, but any severe water loss as a result of seepage and evaporation was replenished. The ponds were treated with dolomite ($CaMg(CO_3)_2$ at 5–7 ppm) and fertilized with urea (at 1.25 ppm) and TSP (at 1.5 ppm) at 2-week intervals. The shrimps were fed with commercial SABINCO nursery pellet feed (approximate protein content of 35–40%) twice daily at rates of 100, 60, 30 and 10% of the estimated shrimp biomass at the 1st, 2nd, 3rd and 4th weeks of culture, respectively. Thereafter, grow-out feed was supplied at the rate of 2–3% of the estimated standing shrimp biomass. The growth and health condition of the shrimp were monitored periodically using a check tray. Total production and survival rates were estimated at 120–130 days for single stocking and 130–150 days for double stocking, and at final harvest.

Water and soil quality monitoring

During both the rice–fish and shrimp production periods, selected physico-chemical characteristics of the pond water were monitored in the morning between 09.00 and 10.00 at fortnightly intervals. Water depth was measured by a meter gauge set up in each plot. Water transparency, salinity, pH and turbidity were measured using a standard Secchi disc, refractometer, portable pH meter and spectrophotometer, respectively. Dissolved oxygen (DO), alkalinity and hardness were analysed by titrimetric methods, whereas nitrate and phosphate concentrations were estimated by colorimetric methods following Strickland and Parsons (1968) and APHA (1992). Primary productivity was monitored monthly following the standard 'oxygen light and dark bottle' method (APHA, 1992). Collection and quantitative estimation of plankton were carried out following the method of Rahman (1992). Benthos samples from surface sediment were collected monthly by an Ekman grab sampler. The benthic meiofauna were segregated from the sediment by sieving, visually sorted, preserved in buffered formalin and counted. Soil samples from each rice plot were collected, once initially and again at the end of the culture period, and analysed in the laboratory of the Soil Resources Development Institute (SRDI) in Khulna, Bangladesh.

Economic analysis

The gross margin for each crop was calculated based on average market prices and farm production. The cost included all inputs (rice seed, lime and fertilizers, fish fingerlings, prawn juveniles, shrimp postlarvae, shrimp feed, etc.), field preparation, labour, fuel for pumping, and land leasing. Pumping costs and land leasing were allocated to the rice culture during the rainy season crop, which is the main crop for the season. The net return was calculated as the gross margin minus the cost. The benefit cost ratio (BCR) represents the gross margin divided by the cost.

Data analysis

Data were analysed with one-way ANOVA, using Duncan multi-comparison of means and a *t*-test to compare two means, with underlying assumptions of homogeneity of variance and normality of the data. When the data set did not follow normal distribution or if the homogeneity of variance was not assumed, a *K*-sample test was used to compare means. The relationship between water quality parameters and shrimp production was investigated using Pearson's correlation and linear regression methods.

Results and Discussion

Water and soil quality

Mean value ranges of different physico-chemical and biological characteristics of water, monitored during rice and shrimp crop seasons' experiments, are presented in Table 7.1. The differences in values of the water quality parameters were insignificant ($p > 0.05$) for the rice–GIFT/prawn treatments, except for water depth and DO in 2005. Even these variables were not correlated with the primary productivity or aquaculture production. The DO gradually reduced during the rice–fish cropping seasons but remained above the stress threshold value of 2 mg/l for fish and prawn. The water pH was also within the optimum range (7.5–8.1), averting NH_3-N toxicity for prawn (New, 1995).

The treatment differences for the water quality parameters during the shrimp crop seasons in 2005 and 2006 were also not significant (Table 7.1). Variations in water quality during the shrimp culture period were because of management practices, including liming, water exchange and fertilizer

Table 7.1. Ranges of treatment means of physico-chemical and biological water quality parameters during the rice–fish and shrimp crop seasons in 2004, 2005 and 2006.

Water quality parameters	Rice–fish/prawn crop (mid-August to December)		Shrimp crop (March to mid-August)	
	2004	2005	2005	2006
Temperature (°C)	28.31–28.41	26.87–27.24	30.45–30.62	32.08–32.14
Water depth (cm)	15.28–16.59	13.95–19.40	48.50–53.20	33.94–38.39
Salinity (ppt)	0.33–0.33	0.25–0.25	11.95–13.50	15.75–16.41
Transparency (cm)	11.66–12.42	12.49–13.98	21.41–22.63	28.44–30.94
Turbidity (FTU)	128–131	141–182	n/a	40.37–46.56
pH	8.10–8.14	7.72–7.82	8.30–8.34	8.32–8.43
Dissolved oxygen (mg/l)	3.71–3.77	4.36–4.53	5.07–5.12	5.32–5.58
Alkalinity (mg/l)	134–139	140–146	157–159	209–213
NO_3-N (μg-at/l)	n/a	3.84–4.13	n/a	1.96–2.42
PO_4-P (μg-at/l)	n/a	2.61–3.21	n/a	1.19–1.53
Primary productivity (mg-C/l/h)	n/a	0.09–0.17	0.15–0.18	n/a
Phytoplankton (10^3 cell/l)	n/a	33.83–35.16	n/a	20.40–23.69
Zooplankton (10^3 cell/l)	n/a	2.26–2.85	n/a	1.24–1.46
Benthic meiofauna (no./m^2)	2910–3763	2411–3511	1859–2910	1104–2509

application, and also because of rainfall variation. The DO values decreased progressively during the season, but remained above suboptimal levels (> 4 g/l) for shrimp culture (Chanratchakool *et al.*, 1995). Primary production remained generally stable during the culture period.

Variations in soil characteristics during the rice–fish and shrimp farming periods followed a similar pattern to that for water quality and were insignificant for the different treatments (Table 7.2). Variations in values of water and soil quality parameters were within the optimum range for freshwater prawn (New, 1995), tilapia (Boyd and Egna, 1997) and shrimp (Chakraborti *et al.*, 1985; Chanratchakool *et al.*, 1995; Hariati *et al.*, 1996) grow-out operation. The soil quality data were more or less similar for both rice–fish and shrimp crop seasons (Table 7.2), suggesting that the different cropping patterns did not modify the soil properties substantially. However, some residual salinity in the soil (2.3–3.5 ppt), even when the water salinity during the rice cropping period is almost zero (Table 7.1), indicates the need for some minimal salinity-tolerant rice varieties to be grown in this coastal area that are characterized with seasonality in salinity variations (Islam *et al.*, 2005).

Aquaculture production in rice–fish/prawn systems

Production results of Nile tilapia (GIFT) and giant freshwater prawn integrated with the wet-season rice crop are presented in Table 7.3. In 2004, at a total stocking density of 10,000/ha, the freshwater prawn showed significant differences in survival rates ($t(4) = 5.22$; $p < 0.05$) and yield ($t(4) = 6.14$; $p < 0.05$) between treatments T-2 and T-3, but not in average body weight, whereas GIFT showed significant differences between treatments T-1 and T-2 both for survival ($t(4) = 4.29$; $p < 0.05$) and average body weight ($t(4) = 10.55$; $p < 0.05$). The highest survival and average body weights for both GIFT and prawn were found at a 1:1 combination, suggesting that a stocking density of 5000/ha for each may suit the environmental requirements and cultural practices for higher yields of both species.

With a lower stocking density of 5000/ha in the 2005 experiment, the survival rate of GIFT was significantly higher ($t(4) = 2.85$; $p < 0.05$) in mixed culture with prawn than in monoculture, but the yield difference was not significant, even though the stocking density was 50% lower in the mixed culture. However, yield rates of GIFT in monoculture at 5000/ha stocking density were higher than those at 10,000/ha.

Table 7.2. Ranges of treatment means of soil-quality parameters during the rice–fish and shrimp crop seasons.

	Rice–fish/prawn crop (mid-August to December)		Shrimp crop (March to mid-August)	
Soil-quality parameters	2004	2005	2005	2006
pH	7.99–8.08	7.85–7.88	7.85–7.90	7.78–7.86
Salinity (ppt)	2.76–2.83	3.21–3.34	4.75–5.29	5.09–5.66
Organic matter (%)	1.47–1.50	1.35–1.95	1.73–1.99	1.57–1.79
Total nitrogen (%)	0.07–0.08	0.09–0.11	0.10–0.11	0.09–0.11
Phosphorus (μg/g)	9.95–12.38	10.23–13.87	9.22–9.85	9.84–11.54
Iron (μg/g)	63.23–66.20	59.20–60.03	33.99–41.93	52.60–66.59
Zinc (μg/g)	2.34–3.65	0.53–0.62	0.45–0.59	0.66–0.76
Potassium (me/100g)	0.86–0.92	0.99–1.00	1.02–1.10	1.16–1.32

Table 7.3. Production of (mean ± Sd) tilapia (GIFT) and prawn (*M. rosenbergii*) cultured with rice for the period of August–December in 2004 and 2005.

Aquaculture production treatment					
Notation	Species combination	Stocking density (/ha)	Final individual body weight (g)	Survival rate (%)	Yield (kg/ha)
2004					
T-1	GIFT	10,000	78.50 ± 0.36	17.66 ± 1.41	141.30 ± 4.20
T-2	GIFT	5,000	86.30 ± 1.23	22.00 ± 1.42	94.93 ± 1.53
	Prawn	5,000	22.10 ± 1.49	37.00 ± 2.39	40.88 ± 1.98
T-3	Prawn	10,000	22.30 ± 0.91	26.54 ± 2.51	57.87 ± 4.36
2005					
T-1	GIFT	5,000	125.5 ± 42.27	42.15 ± 4.56	258.08 ± 65.39
T-2	GIFT	2,500	164.16 ± 1.89	51.67 ± 3.54	211.98 ± 12.74
	Prawn	2,500	27.17 ± 9.29	42.43 ± 2.36	28.83 ± 10.36
T-3	Prawn	5,000	30.27 ± 8.74	47.91 ± 7.60	70.91 ± 16.47

Production levels of GIFT over the 2 years (2004 and 2005) suggest stability of its production in an integrated rice–fish system in the coastal semi-saline environment. The production level ranging from 141 to 258 kg/ha is also consistent with 125–239 kg/ha for a freshwater rice–fish system (Gupta *et al.*, 1998, 2002). The survival rates of fish and prawn in these experiments seem low, but are not unlikely in the rice–fish system (Haroon *et al.*, 1992; Kohinoor *et al.*, 1995), given its predation and habitat conditions (Haroon and Pittman, 1997).

Prawn in monoculture demonstrated better performance than in mixed culture with GIFT, particularly in 2005 when yields were significantly higher ($t(4) = 3.74$; $p < 0.05$); and survival rates and body weights were apparently higher. As in the case of GIFT, prawn in monoculture has higher yields at the lower stocking density of 5000/ha. Even so, the average prawn yields at the stocking density of 10,000/ha (equivalent to 1/m^2) obtained in this study (58 kg/ha in 2004 and 71 kg/ha in 2005) are higher than the 30 kg/ha yield at a stocking density of 1.2/m^2, reported in a rice–shrimp system in Vietnam (Hung, 2001). In our study, the fish and prawn were reared for about 120 days only, integrated with the *aman* (monsoon/wet)-season rice, without supplemental feeding. Considering these conditions, and based on the results of a study of two seasons, it could be concluded that a total stocking density of 5000/ha is feasible for the expected production, survival and growth rates of both GIFT and prawn (*M. rosenbergii*) in a coastal rice–shrimp environment such as in south-western Bangladesh.

Rice production

Among the seven rice varieties cultivated along with GIFT and prawn in the 2004 wet season, the HYVs (BR23, BRRI dhan 40 and BRRI dhan 41) gave significantly higher yields exceeding 4 t/ha (Fig. 7.2.). These are similar to those of various non-aromatic HYVs grown in the wet season (Mondal *et al*., 2006). The variety BR23 gave the highest average yield of 5.1 t/ha, but the yield from using locally collected seed of the same variety (BR23L) was significantly lower, averaging 4.1 t/ha, possibly as a result of its loss of purity and vigour with time in the farmers' fields. HR1 and HR14 varieties produced lower yields, but the duration of cultivation was shorter (95 days) than the 105–120 days for the other varieties.

Rice yields for the three selected HYVs in 2005 were comparatively lower than in 2004 (Fig. 7.2.), mainly because of waterlogging in the fields caused by unusually heavy and prolonged rainfall. The recorded rainfall in 2005 during the study period was 3003 mm, which was about 1000 mm higher than the long-term average for that locality (Department of Agriculture, personal communication). Despite this, the rice yields obtained were higher than the usually harvested amount of 2.0–2.5 t/ha in the coastal area (Mondal *et al*., 2006).

Increased salinity in the topsoil, because of the expansion of shrimp culture in the coastal areas, has been blamed for the decline in rice production of 1.5 t/ha (Karim, 2006). Figure 7.3 shows that whereas water salinity during the rice season varies from 0.0 to 1.5 ppt, in the experimental *ghers* the soil salinity varies from 2.3 to 3.5 ppt. With this soil salinity, all tested HYVs yielded between 3 and 5 t/ha, suggesting that salinity tolerance was not an absolute requirement for rice grown during the wet season with soil salinity of about 3 ppt (Mondal *et al*., 2006).

Shrimp production

Results of shrimp culture under three stocking patterns, tested in the dry season of 2005

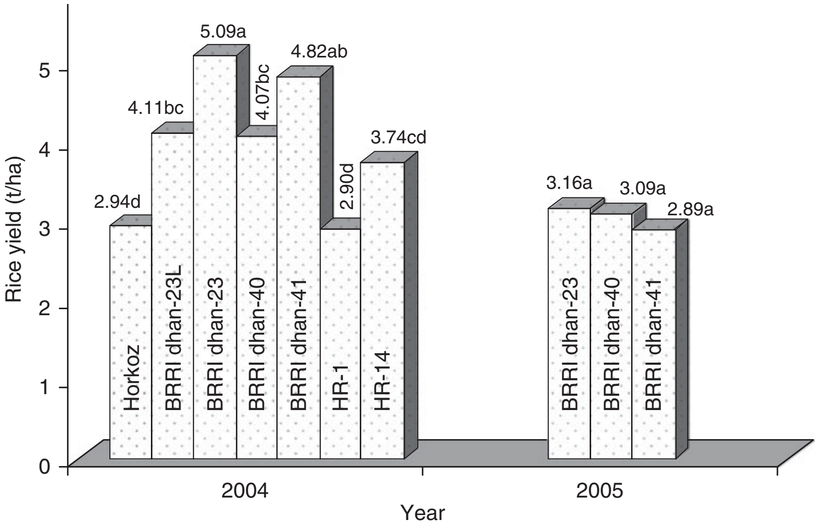

Fig. 7.2. Mean yield of different rice varieties integrated with aquaculture in a rice–shrimp system in the coastal environment. a,b,c and d indicate significant differences ($p < 0.05$).

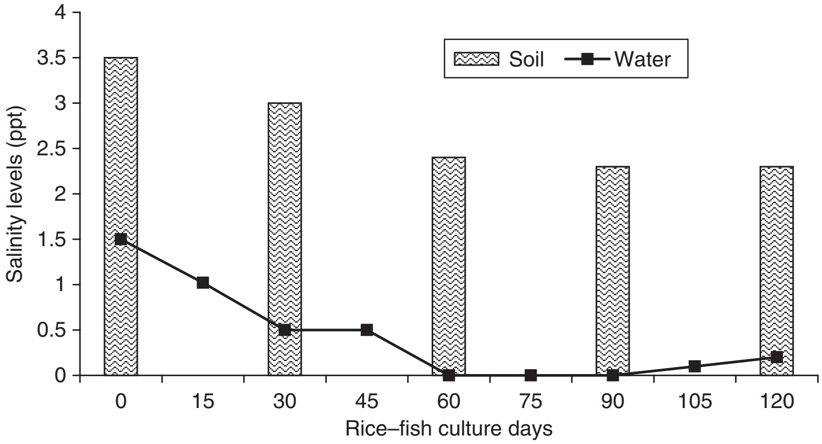

Fig. 7.3. Soil and water salinity variations during rice–fish culture periods (August–December) in rice season experiments.

and 2006, are presented in Table 7.4. There were no significant differences ($F = 1.59$; $p > 0.05$) in performance among the different stocking patterns in terms of growth, survival and yield, although single stocking ponds (T-1) resulted in higher average yields. The average shrimp yields (289–380 kg/ha) obtained in the present study were much higher than those reported by other authors for shrimp farms located in the same region. Nuruzzaman *et al.* (2001) reported yield levels of 74–221 kg/ha for the shrimp farms ranging from extensive to improved extensive scales in the south-west districts of Khulna and Bagerhat. Islam *et al.* (2005) reported similar average yields of 83–204 kg/ha from shrimp farms of different sizes (< 5 and > 10 ha) practising partial stocking at densities of 2–3/m^2 and an extended culture period of 180–200 days. The shrimp yields obtained in this study are also closer to the average production of 343 kg/ha/crop that has been reported at a stocking rate of 5/m^2 in monoculture with supplemental feed and improved water management (Apud *et al.*, 1984).

Attainment of shrimp production levels in the present study (Table 7.4) is attributable to proper management of water depth, pH and primary productivity (Table 7.1). Although the intention was to maintain a minimal water depth of 50 cm in all the experimental *ghers*, it was not possible because of differences in water retention capacity and the soil substrate, and uncontrollable field conditions. Shrimp yield was found to be correlated positively with a water depth ($r = 0.855$; $p < 0.001$) that ranged from 27 to 65 cm. The highest yield range of 521–583 kg/ha, with a corresponding survival rate of 42–58%, was attained in *ghers* with deeper water (47–65 cm depth). Higher mortality and lower growth rates were observed following heavy and prolonged rain in both years, causing a sharp drop in water salinity (Fig. 7.4) and temperature (Fig. 7.5), particularly in the shallower *ghers*.

These sudden changes might have caused physiological stress in shrimp, resulting in disease and/or mortality. Apud *et al.* (1984) reported a mean survival rate of 70.4% in shrimp ponds of 70–100 cm depth, compared to that of 37.5% in ponds of 40–70 cm depth. Truchot (1983) reported that the acid–base balance of crustaceans was affected directly by salinity, whereas New and Singholka (1985) found that an abrupt temperature change of even 1°C might cause mortality in prawns.

Economic analysis

A simple cost–benefit analysis showed that at a total stocking density of 5000/ha, an average

Table 7.4. Shrimp production (mean ± Sd) with different stocking patterns in two seasons' shrimp crop in the coastal rice–shrimp system during March–August 2005 and 2006.

Treatment	Final weight (g/ind)	Survival rate (%)	Yield (kg/ha)
1st trial in 2005 shrimp season			
T-1: single stocking (5/m^2)	20.16 ± 2.34[a]	34.54 ± 22.3[a]	343 ± 212[a]
T-2: double stocking (3 > 2/m^2)	20.75 ± 2.66[a]	27.00 ± 13.0[a]	297 ± 181[a]
T-3: double stocking (2 > 3m^2)	20.56 ± 2.87[a]	26.94 ± 16.1[a]	289 ± 206[a]
2nd trial in 2006 shrimp season			
T-1: single stocking (5/m^2)	23.88 ± 1.3[a]	31.35 ± 11.2[a]	380 ± 161[a]
T-2: double stocking (3 > 2/m^2)	22.99 ± 1.2[a]	27.77 ± 6.1[a]	322 ± 90[a]
T-3: double stocking (2 > 3m^2)	23.06 ± 0.6[a]	26.07 ± 6.9[a]	302 ± 112[a]
Average of 1st and 2nd trials			
T-1: single stocking (5/m^2)	22.28 ± 2.58[a]	32.72 ±15.2[a]	364 ± 168[a]
T-2: double stocking (3 > 2/m^2)	22.03 ± 2.12[a]	27.68 ± 8.8[a]	311 ± 123[a]
T-3: double stocking (2 > 3m^2)	21.99 ± 2.18[a]	26.44 ± 10.0[a]	296 ± 135[a]

[a] Indicates significant difference, $p < 0.05$.

net return of Tk24,640.00 (US$1 = Tk68.00) for integration of rice with GIFT alone was significantly higher ($p < 0.05$) than that of Tk13,290 for rice with prawn alone (Fig. 7.6.).

The estimated BCR of 1.96 for rice–tilapia monoculture was also significantly higher ($F(2; 8) = 22.11$; $p < 0.05$) than for the other treatments. However, the difference in net return between rice–GIFT and rice–GIFT–prawn was insignificant. Monoculture of prawn integrated with rice incurred significantly higher cost than the other treatments ($F(2; 8) = 763.9$; $p < 0.001$), accounting for 50% of the total production cost (mainly because of the high cost of juvenile prawn), but only 36% of the gross and 0% of the net return.

In terms of aquaculture contribution to the integrated rice–fish system output, the 2005 results showed that the treatment T-1 (GIFT in monoculture, RG) gave the highest net return of Tk10,858/ha (43% of total net return from rice–fish) with a BCR of 3.09, compared with Tk8521/ha (37%) and Tk494/ha (0%) for T-2 (RGP) and T-3 (RP), respectively, with corresponding BCR of 1.65 and 0.97.

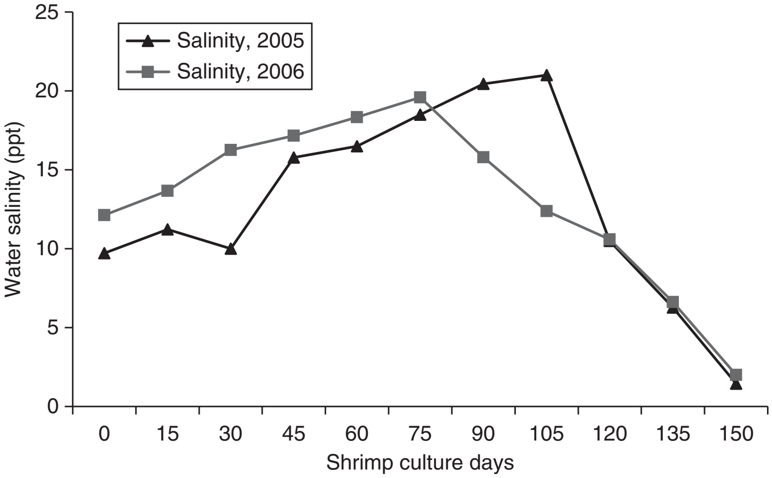

Fig. 7.4. Variations in average water salinity during the shrimp culture period of 2005 and 2006.

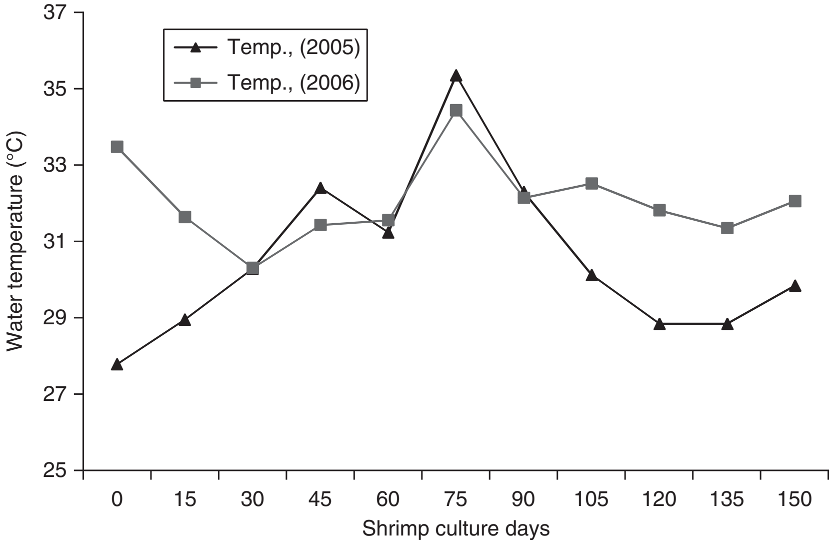

Fig. 7.5. Variations in average water temperature during the shrimp culture period of 2005 and 2006.

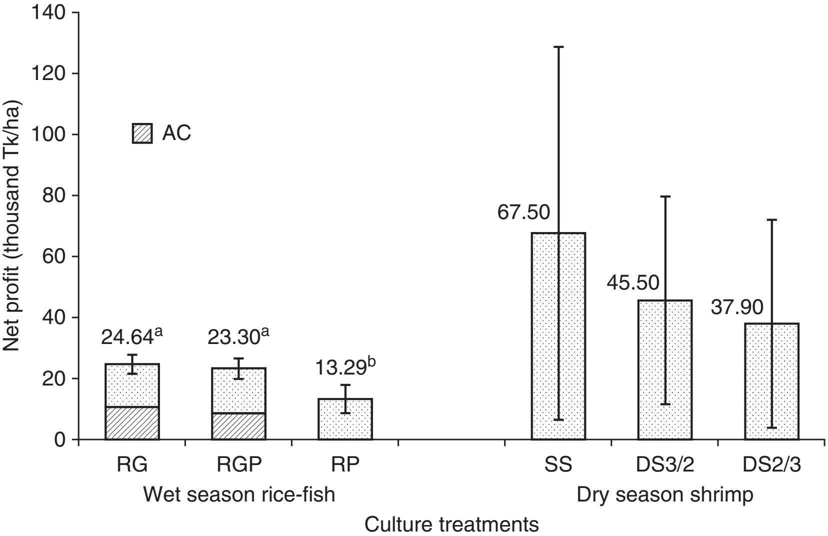

Fig. 7.6. Net economic profit (NP) from different culture treatments for rice–fish (RG, rice–GIFT; RGP, rice–GIFT–prawn; RP, rice–prawn) and shrimp (SS, single stocking at 5/m^2; DS3/2, double stocking at 3 followed by 2/m^2; DS2/3, double stocking at 2 followed by 3/m^2) production in 2005. ^{a} and ^{b} indicate significant differences ($p < 0.05$). AC represents aquaculture contribution in rice–fish/prawn system.

Figure 7.6 also shows that the average net return from single stocking (SS) is higher, although not significantly so, than that from double stocking (DS). The lower market price of the smaller-sized shrimp from the second stocking resulted in lower returns from double stocking. The higher the later stocking rate, the lower the returns. Net profits vary across treatments from a low of Tk11,000/ha to a high of Tk121,000/ha, with corresponding BCR of 1.14–2.58. This variation was particularly a result of low survival rates of shrimp in certain replicate ponds in each treatment. The net benefits from the shrimp culture reported here are generally comparable with, or significantly higher than, those reported elsewhere on shrimp yields under extensive production in south-western Bangladesh – net returns of Tk21,617/ha to Tk57,997/ha have been reported by Islam *et al*. (2005); Tk35,500/ha by Ling *et al*. (2001); and Tk40,200/ha by Rahman *et al*. (2002).

Economic analysis of the entire rice–shrimp production system suggests that average net incomes as high as Tk62,000–92,000/ha could be achieved through practising the integration of rice and GIFT followed by shrimp with either single or double stocking. This represents a 130–190% increase of net farm income compared with existing farming systems in the same agroecological area (Joffre *et al*., unpublished).

Conclusions and Recommendations

This study demonstrates that cultivating HYVs of rice (preferably BR23, BRRI dhan 40 and BRRI dhan 41) along with short-duration fish (preferably GIFT strain of tilapia) and/or prawn during the low-salinity period (August–December), followed by shrimp (*P. monodon*) during the high-salinity period (February–August), with proper water and feed management, would not only reduce the risk of crop loss but also increase total farm productivity and net income. Although the rice crop performance could benefit from the integrated culture of fish and crustacea (Halwart and Gupta, 2004), water management for both rice and fish remains crucial for the rice–shrimp system.

The recommended stocking density of aquaculture species, farmed together with rice, is 0.5/m^2. The short rice-growing period necessitates stocking of larger prawn juveniles (of 4–5 g individual body weight) that are more costly (Tk5.00–6.00/piece), consequently resulting in marginal gross profit and even negative net profit. A more profitable alternative would be to nurse less costly prawn postlarvae for 45–60 days using a hapa nursery (Alam *et al*., 1997) prior to stocking in the rice field.

Management of water productivity and feeding played key roles in increasing shrimp production compared with the existing practice of multiple stocking and harvesting. Despite not obtaining statistically significant results, our study suggests that single stocking of shrimp at the rate of 5/m^2, with improved farm management, may be more suitable for the production system involving rice with fish and/or prawn followed by shrimp culture in south-western Bangladesh. It has been thought that partial stocking would be advantageous because of the phasing of expenditures on input and spreading of the financial risk in the event of crop failure. On the other hand, partial stocking has the risk of introducing a second stock of any pathogen-affected postlarvae that might infect the earlier crop. The main disadvantage of multiple stocking is the requirement for longer culture duration at the expense of delaying the start of the next rice crop.

The positive correlation between shrimp yield and water depth suggests the importance of maintaining a sufficient water depth in the shrimp *ghers*. However, deepening the *gher* may affect the yield of the subsequent rice crop through waterlogging, particularly as a result of prolonged monsoon rain. Therefore, a proper physical infrastructure for well-controlled water intake and discharge needs to be in place to enable managing of optimal water depths for both shrimp and rice–fish farming.

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