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Socioeconomic aspects of rice-fish farming in Bangladesh: opportunities, challenges and production efficiency*

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In spite of the potential for rice-fish farming in Bangladesh, it has been adopted by relatively few farmers because of socioeconomic, environmental, technological and institutional constraints. Rice monoculture remains the main farming system in Bangladesh even though integrated rice-fish farming is the best farming system in terms of resource utilisation, diversity, productivity, production efficiency and food supply. Only a small number of farmers involve in integrated rice-fish farming. This study concludes that rice-fish farming is as production efficient as rice monoculture and that integrated performs better in terms of cost and technical efficiency compared with alternate rice-fish farming. Integrated rice-fish farming can help Bangladesh keep pace with the current demand for food through rice and fish production. However, a lack of technical knowledge of farmers, high production costs and risks associated with flood and drought are inhibiting more widespread adoption of the practice.

Key words: cost efficiency, data envelopment analysis, farmer, fish, production frontier, rice.

1. Introduction

Bangladesh is one of the poorest and most densely populated countries in the world, covering an area of 144,000 km^2 with a population of 164 million. Rice and fish have been an essential part of the life of Bangladeshi people from time immemorial. Rice is the main agricultural crop in Bangladesh with an annual production of 29 million tonnes a year (BRKB 2010), while annual fish production is 2.7 million tons (DOF 2010). The demand for rice and fish is constantly rising in Bangladesh with nearly three million people being added each year to its population (Chowdhury 2009). Nevertheless, integrated rice-fish farming offers a solution to this problem by contributing to food and income.

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The total area of rice fields in Bangladesh is about 10.14 million ha with a further 2.83 million ha of seasonal rice fields where water remains for about 4–6 months (BRKB 2010). The carrying capacities of these lands and waters are not fully utilised, but there exists tremendous scope for increasing fish production by integrating aquaculture (Wahab *et al.* 2008). Integrated rice-fish production can optimise resource utilisation through the complementary use of land and water (Frei and Becker 2005). Integration of fish with rice farming improves diversification, intensification, productivity and sustainability (Nhan *et al.* 2007; Ahmed and Garnett 2007). Integrated rice-fish farming is also being regarded as an important element of integrated pest management (IPM) in rice crops (Berg 2001; Halwart and Gupta 2004).

Rice-fish farming began to receive attention in the 1980s (Nabi 2008). The new technology was perceived to have potential for multiple environmental benefits in Asia. Many reports suggested that integrated rice-fish farming is ecologically sound because fish improve soil fertility by generating nitrogen and phosphorus (Lightfoot *et al.* 1992; Giap *et al.* 2005; Dugan *et al.* 2006). Searching for food by fish in rice fields causes aeration of the water. Fish also play a significant role in controlling pests by consuming aquatic weeds and algae that carry diseases, act as hosts for pests and compete with rice for nutrients. Moreover, fish eat flies, snails and insects and can help control malaria mosquitoes and water-borne diseases (Matteson 2000). On the other hand, rice fields offer fish with planktonic, periphytic and benthic food (Mustow 2002). Shading by rice plants also maintains the water temperature favourable to fish during the summer (Kunda *et al.* 2008). Many fish species prefer the rice fields for their reproduction (Fernando 1993; Little *et al.* 1996; Halwart 1998). The natural aggregation of fish in rice fields has inspired rice-fish farming to increase productivity (Gurung and Wagle 2005).

However, rice-fish farming remains marginal in Bangladesh because of socioeconomic, environmental, technological and institutional constraints (Nabi 2008). Although rice-fish technology has been demonstrated successfully and a considerable number of farmers have been trained through various projects, rice-fish farming has yet to be widely practiced. Traditionally wild fish have been harvested from rice fields, but the introduction of high yielding varieties (HYV) of rice and accompanying pesticides have reduced fish yields (Gupta *et al.* 2002). Nevertheless, important changes have taken place through IPM that has reduced use of pesticides in rice fields (Berg 2002; Lu and Li 2006).

This study describes the rice-fish farming system and its opportunities and constraints to increase food supply in Bangladesh. It further assesses the production efficiency of rice-fish farming as a competitive alternative to rice monoculture. We hypothesise that rice-fish farming, in particular integrated, rice-fish farming can make better use of available inputs and that it can provide socioeconomic and nutritional benefits to the households of poor farmers and, more broadly, food security in Bangladesh. We test this by assessing productivity efficiency of rice monoculture and rice-fish farming households through a two-stage approach. First, we carry out a Data Envelopment Analysis (DEA), and second, a Tobit regression analysis revealing socioeconomic parameters impacting on households' levels of efficiency.

2. Methodology

2.1. Study area

The study was conducted in the Mymensingh district of north-central Bangladesh (Figure 1). Mymensingh has been identified as the greatest potential for rice-fish culture because of favourable resources and climatic conditions, including the availability of low-lying agricultural land, warm climate, fertile soil, and cheap and abundant labour. Hydrological conditions are also favourable for rice-fish farming as this area is located within the monsoon tropics with an average annual rainfall of 2500 mm (FAO 2000). Moreover, the number of fish fingerlings produced has risen rapidly in recent years through private hatcheries. Nevertheless, only a small number of farmers (around 100) involve in rice-fish farming in the Phulpur sub-district in Mymensingh district. These farmers received training in rice-fish farming from the Mymensingh Aquaculture Extension Project, funded by Danish International Development Assistance. Phulpur was therefore selected for the study.

2.2. Data collection and sampling

Field research was conducted for a period of 9 months from September 2007 to May 2008. A combination of participatory, qualitative and quantitative methods was used for primary data collection.

2.2.1. Questionnaire interviews

Questionnaire interviews with rice-fish and rice-only farmers were preceded by preparation and testing of the questionnaire and training of enumerators. Pilot testing of the interview schedule was carried out with 10 rice-fish farmers. The aim of the pilot survey was to ensure that the questions included in the schedule were clear of any ambiguities and that the respondents could answer easily. During the pilot survey, it was observed that a few questions were not clearly understood by respondents. Hence, some questions were dropped, and a number of additional questions were added. The draft schedule was then modified and improved based on experience gained from the pilot survey. The sophistication of the respondents, the level of enumerators and the wording of the questions were matched. A total of 80 rice-fish farmers were interviewed in their houses and/or farm sites. These were selected through stratified random sampling based on culture systems (i.e. alternate and integrated). A more focused comparative examination of two different farming systems was performed. Several visits were made to selected farmers to observe farming practices. This step was also useful for building up rapport

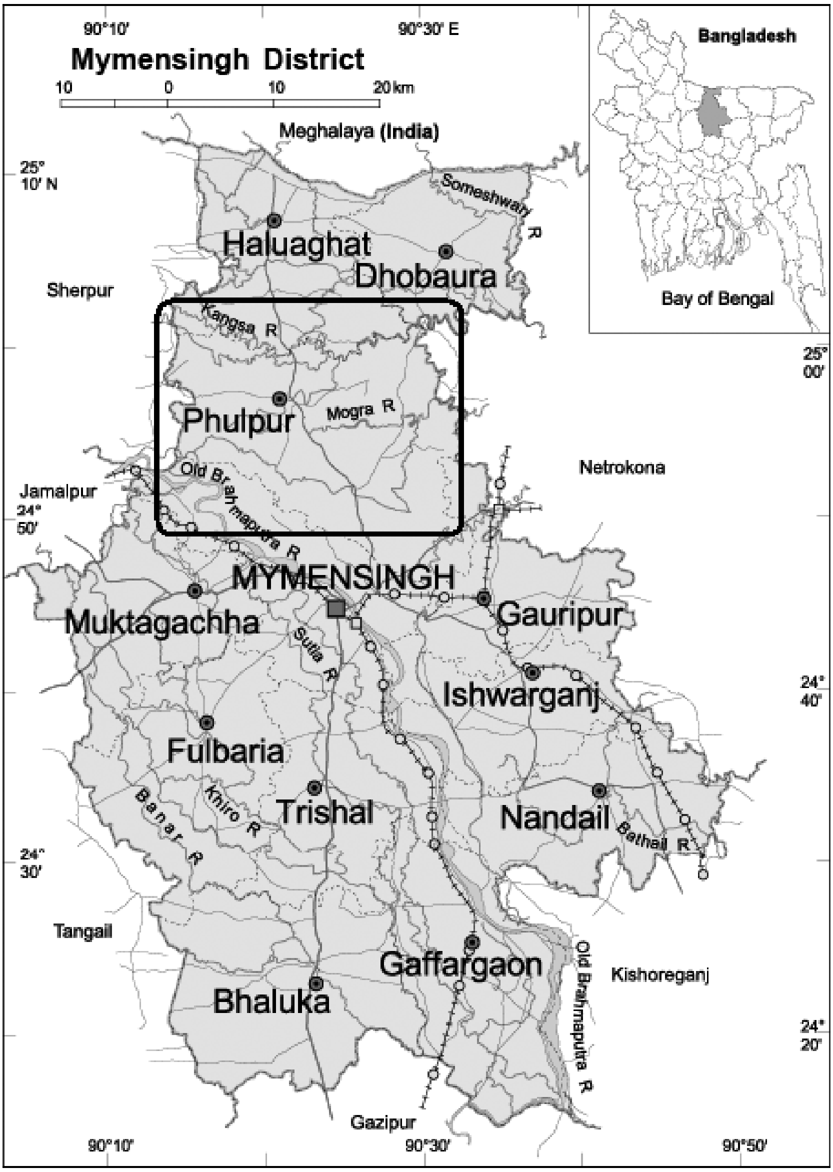

Figure 1 Map of Bangladesh showing the study area.

with farmers to assist questionnaire interviews. The questionnaires focused on rice-fish farming systems, cultural practices, productivity, production costs and returns, constraints on rice-fish farming and socioeconomic benefits.

Additionally, a total of 172 rice-only farmers were selected through simple random sampling. Farmers were interviewed at their houses and/or farm site. A questionnaire was used for interviews, covering rice farming systems, rice productivity, production costs and returns, and identification of bottlenecks and opportunities for involvment in rice-fish farming. The interviews lasted about an hour.

2.2.2. Cross-check interviews with key informants

Key informants are expected to be able to answer questions about the knowledge and behaviour of others, and about the operations of the broader systems. Cross-check interviews were conducted with district and sub-district fisheries officers, agricultural extension officers, local leaders, school teachers, researchers, policymakers and relevant non-government organisation (NGO) workers. Where information was found to be contradictory, further assessments were carried out. Twenty-five key informants were interviewed in their offices and/or houses.

2.3. Data analysis and model specifics

Data from questionnaire interviews were analysed using the statistical software Limdep 9.0. Qualitative information collected through field visits complimented the data analysis and was used to describe rice-fish farming systems.

2.3.1. Data Envelopment Analysis (DEA)

Data Envelopment Analysis is a nonparametric analysis, measuring the relative efficiencies of a homogenous set of decision-makers (in this study farming households) using linear programming (see e.g. Charnes *et al*. 1978; Seiford and Thrall 1990). DEA can estimate production frontiers for multiple inputs/multiple outputs and assess where farming households perform in relation to this frontier. Each farming household thereby produces the same kind of output(s) using the same kind of inputs. A farming household is said to be technically efficient if its performance relative to other households cannot be improved. DEA compares each household with the 'best' one in the group. It is assumed that the 'best', i.e. the most efficient household produces either more output with the same input or the same output with less input than the inefficient decision-makers in the group. The major disadvantage of DEA over parametric approaches (stochastic production frontier) is that it does not account for random variation in the output (Tingley *et al*. 2005). However, many scientists have shown that DEA is a valid statistical methodology, providing a basis for applying a range of formal statistical tests (Banker 1993, 1996) and Sharma *et al*. (1998), among others, found that results from DEA were more robust than from the stochastic frontier approaches. DEA has been used in the past in aquaculture (Sharma *et al*. 1999; Idda *et al*. 2009; Chang *et al*. 2010) and rice (Warud and White 2000; Coelli *et al*. 2002; Reddy and Sen 2004; Balcombe *et al*. 2008; Nassiri and Singh 2009) production sectors, but not for rice-fish farming.

Taking costs into account as an input allows, in addition to technical efficiency (TE), calculation of cost efficiency (CE) and allocative efficiency (AE) (Coelli *et al*. 2002). TE is defined as the maximum output a farmer can produce with the given inputs or the use of the minimum feasible amount of inputs to produce a given level of output. These two measures are known as output-oriented and input-oriented efficiencies. When assuming constant returns to scale (CRS), the two measures are the same while they are likely to vary assuming variable returns to scale (VRS). CRS assumes full proportionality between all inputs and outputs which is often not given. Hence, VRS is the standard assumption in contemporary applications (Greene 2008) and it is the approach we apply in this study. Many studies, including ours, are input based because the decision-making households often have more control over inputs than outputs (see Coelli *et al.* 1998). We assumed that farmers in Bangladesh have limited resources as inputs which they want to reduce and still obtain the largest amount of food possible.

A separate relative efficiency score is obtained for each farming household by the model proposed by Charnes *et al.* (1978) which is based on previous work by Farrell (1957):

$$\max = \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}}$$

$$\text{subject to} \quad \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}} \leq 1 \quad \forall i$$

$$v_k, u_j \geq 0 \quad \forall k, j$$

where y_{ki} is the level of output k produced by farming household i; x_{ji} is the level of input j utilised by household i; v_k is the weight given to output k and u_j is the weight given to input j. The ratio of weighted sums of outputs and inputs is solved by linear programming (Greene 2008). The DEA model to calculate input-oriented TE is given by (Coelli *et al.* 1998; Greene 2008):

$$Min_{\theta_i \lambda} \theta_i,$$

$$\text{subject to:} \quad \sum_k \lambda_k y_k - y_i \geq 0,$$

$$\theta_i x_i - \sum_j \lambda_j x_j \geq 0,$$

$$\sum \lambda = 1$$

where θ_i is a scalar, the input-oriented TE for farming household i, ranging between 0 and 1. A value of 1 means that the farming household is technically efficient. $\sum \lambda = 1$ implies the assumption of VRS.

Cost efficiency, also referred to as economic efficiency, takes into account allocation of money among inputs to obtain the maximum output. A household is said to be cost efficient if it produces a given output at minimum costs.

CE is obtained by solving the following problem (Coelli *et al.* 1998; Greene 2008):

$$Min_{\lambda x_i} w_i' x*_i,$$

$$\text{subject to}: \quad \sum_k \lambda_k y_k - y_i \geq 0,$$

$$x_i^* - \sum_j \lambda_k x_j \geq 0,$$

$$\sum \lambda = 1$$

where w_i is a vector of input prices for each farming household and x_i^* is the cost-minimising vector of input quantities for each household, subjected to the input prices w_i and the level of output y_i. CE for each household i is calculated by the ratio $w'_i x_i^* / w'_i x_i$.

AE is then calculated by the ratio CE/TE.

Bootstrapping is a common method to calculate confidence intervals for the efficiency scores and to overcome the 'absence of a statistical underpinning' (Greene 2008). This is motivated by the fact that the applied sample to obtain the initial DEA scores is unlikely to reflect the absolute level of efficiency of the entire population. A correction of this sampling error should account for this overestimation of efficiency scores, leading to lower levels of efficiencies. We applied the popular method of Simar and Wilson (1998), for which a procedure is conveniently included into Limdep 9.0.

2.3.2. Regression analysis

After the DEA we carried out a Tobit regression analysis to investigate the relative impacts of respondents' socioeconomic backgrounds on the level of efficiency. This is known as a two-stage approach and has been widely used together with DEA (e.g. Tingley and Pascoe 2005; Tingley *et al.* 2005). We applied a Tobit regression because the dependent variable (the efficiency score) ranges only between 0 and 1, i.e. is censored at both tails. The model is estimated using a maximum likelihood procedure (Greene 2003).

3. Results

3.1. Characteristics of rice-fish farming systems

There are two types of rice-fish farming systems in the study area depending on the source of fish: capture and culture. In the capture system, wild fish enter the rice fields from adjacent floodplains during the monsoon and reproduce in inundated rice fields. In the culture system, rice fields are deliberately stocked with fish. Fish culture in rice fields can be broadly classified as alternate (rotational) and integrated (concurrent). In the alternate system, rice and fish are grown rotationally, while they are grown together in the integrated system. Regardless of the farming system employed, the majority of sampled rice-fish farmers (54 per cent) produced fish in rice fields for income generation, while 34 per cent and 12 per cent did so for household consumption and suitable bio-physical conditions, respectively (Table 1).

According to the survey, 54 per cent of rice-fish farmers were involved in integrated rice-fish farming while 46 per cent practised alternate farming (Table 2). In general, integrated culture was practiced on the plains and medium lowlands, while alternate farming was performed in deeply flooded lowland. Integrated farming was found under both rainfed and irrigated conditions. However, because irrigation facilities were poor, only a few farmers (12 per cent) were involved in irrigated rice-fish farming.

Table 1 Major reasons for adoption of fish farming in rice fields by category of farmer

Key reason	Rice-fish farming systems		All rice-fish farmers $n = 80$ (%)
	Alternate $n = 37$ (%)	Integrated $n = 43$ (%)	
Economic return	19 (51)	24 (56)	43 (54)
Household consumption	10 (27)	17 (39)	27 (34)
Suitable bio-physical conditions	8 (22)	2 (5)	10 (12)

n, sample size of farmers.

Table 2 Types of fish culture in rice fields with prevailing conditions and system responses

Farming system	Rice-fish farmers $n = 80$	Prevailing condition	System response
Alternate	37 (46%)	Deeply flooded lowland rice field	Non-diversification
		Highly flooded during the monsoon	Inefficient resource utilisation
		No modification of land for fish culture	No competition between rice and fish
		Less labour intensive	Higher fish production
		Stocking fish with feed and fertiliser	Less productivity of rice
		Long duration of fish culture period	Lower food supply (one rice crop)
Integrated	43 (54%)	Plains and medium lowland rice field	Intensification and diversification
		Water source mainly rainfed	Efficient resource utilisation
		Higher dikes and sump excavation	Mutual benefits of rice and fish
		Labour intensive (mainly family labour)	Increased soil fertility
		Stocking fish with lower feed input	Improved rice productivity
		Short duration of fish culture period	Higher food supply (two rice crops)

n, sample size of farmers.

Alternate farming involves producing fish in rice fields during the monsoon. Fish fingerlings are stocked in June–July and are harvested primarily from November to December, a culture period of around 5–7 months. Alternate farmers avoid cultivation of monsoon season *aman* rice during June to September with fish because of high water levels (up to 1.5 m). It is also thought to reduce fish growth, competing with fish for living space and placing demands on the farmer's limited capital. On the other hand, farmers avoid fish culture with *boro* rice during the dry season from January to April, because of the lower availability of fish fingerlings.

In the integrated system, *aman* rice culture takes place either in deep water or water with the rice floating. Stocking with fish fingerlings occurs in July–August and fish are harvested in November, a culture period of around four months. Farmers' stock fish in rice fields 15–20 days after rice has been planted. Integrated farming requires skills and knowledge to grow rice and fish together. For example, HYV rice needs at least 110 days growing to maturity and a minimum of 100 cm water per crop, while fish require a water depth of 15–20 cm. Nevertheless, integrated farmers avoid fish culture with dry season *boro* rice because of a scarcity of water.

3.1.1. Culture practices

A range of fish species are produced in rice fields, depending on the farming system. Alternate rice-fish farmers mainly stock Indian major carps and exotic carps, including catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhina cirrhosus*), silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and bighead carp (*Aristichthys nobilis*). In integrated culture, the most common species are common carp (*Cyprinus carpio*), silver barb (*Barbodes gonionatus*), Nile tilapia (*Oreochromis niloticus*) and silver carp. However, many rice-fish farmers reported that they avoid common carp because rice plants are consumed and uprooted if the common carp is stocked within 2 weeks of planting seedlings. In general, farmers do not attempt to stock any specific ratio of different fish species. The average annual stocking density of fish fingerlings was reported to be 4917 per ha in alternate farming and 2857 per ha in integrated culture. There was a significant difference ($P < 0.05$) in stocking rates between culture systems. The average size of fingerlings stocked varied between 6 and 10 cm in alternate farming and 4–8 cm in integrated culture.

Farmers strengthen dikes to allow deeper water inside the rice field during the monsoon and to prevent the escape of stocked fish as well as entry of predatory fish. Farmers usually converted 5 per cent of the rice fields into a fish refuge, although some farmers excavated more (6–10 per cent). The refuge can take the form of a ditch or sump in a low-lying part of the rice field, providing fish with sufficient water depth and shelter, even during the dry season. Refuges also make fish easier to catch at the end of rice harvesting. However, provision of a refuge is not practiced by many farmers who have small rice fields.

3.1.2. Inputs

According to respondents, integrated rice-fish farming required a higher labour input to strengthen dikes and excavate refuges. Labour was the least intensive for alternate rice-fish farming, while integrated rice-fish farming was more labour intense than rice monoculture (Table 3).

A variety of fertilisers such as urea, triple super phosphate and muriate of potash were used for rice-fish farming. The purpose of using fertilisers was to grow natural fish food and improve soil fertility, thereby increasing fish and rice yields. The quantity of fertiliser used was related to the farming system. Integrated farmers with two rice crops used less fertiliser annually than alternate farmers with one rice crop (Table 3), because of the increase in soil fertility caused by fish. Farmers growing only rice used the most fertiliser, integrated rice-fish farmers the least. There was a significant difference ($P < 0.05$) in fertilisation rate among culture systems.

Table 3 Inputs and outputs of different farming systems (2007) used in the DEA

Inputs (mean in kg/ha/year) and costs (mean in US$/ha/year)				Outputs (mean in kg/ha/year)	
	Input	Costs*			
Rice					
Boro seeds	192	All seeds	59	*Boro* rice production	4989
Aman seeds	194			*Aman* rice production	4702
Fertiliser	480		119	Total rice production	9691
Labour (man-day/ha/year)†	223		262		
Rice-fish					
Boro seeds	184	All (seeds total)	42	*Boro* rice production	4949
Integrated	186	Integrated	54	Integrated	4917
Alternate	183	Alternate	23	Alternate	4986
Aman seeds	103			*Aman* rice production	2828
Integrated	191			Integrated	5261
Alternate	0			Alternate	0
Fertiliser	409	All	88	Total rice production	8429
Integrated	367	Integrated	87	Integrated	10,178
Alternate	457	Alternate	90	Alternate	4986
Labour (man-day/ha/year)†	211	All	248	Fish production	652
Integrated	238	Integrated	279	Integrated	259
Alternate	179	Alternate	211	Alternate	1108
Fish fingerlings (ha/year)	3810	All (fish input total)	238	Total production (rice + fish)	9081
		Integrated	155		
Integrated	2857	Alternate	335	Integrated	10,438
Alternate	4917			Alternate	6094
Fish feed	752				
Integrated	217				
Alternate	1373				

*All are farm-gate prices of harvested products and current local market prices.
†A man-day was considered to be 8 h of work. DEA, data envelopment analysis.

Supplementary feed was applied by most farmers, although small-scale fish farming in rice fields is an extensive aquaculture system that primarily relies on the natural food (phytoplankton, zooplankton, periphyton and benthos). Alternate rice-fish farmers used about six times more fish feed than integrated rice-fish farmers and also more fish fingerlings (Table 3). In integrated culture, farmers mainly used on-farm inputs, such as rice bran, wheat bran and oil cake. In addition to on-farm inputs, however, a few alternate farmers (16 per cent) use fishmeal and industrially manufactured pelleted feeds. The most common feeding frequency in alternate farming was once per day, while it was once or twice per week in integrated farming. There was a significant difference ($P < 0.05$) in feeding rate among farming systems.

In terms of utilised *boro* rice seeds, there was no significant difference between alternate and integrated rice-fish farming or to rice monoculture. Alternate rice-fish farmers utilised, on average, almost as much *aman* seeds as rice monoculture farmers (Table 3). There was an insignificant difference ($P > 0.05$) in *aman* rice seed used between integrated rice-fish farming and rice monoculture.

Size of farm may play an important role as it can reflect the availability of capital, managerial ability and the potential to operate and use resources efficiently. The highest average farm size was found in integrated farming (0.33 ha), followed by rice monoculture (0.31 ha) and alternate farming (0.29 ha). However, there was no significant difference ($P > 0.05$) between farm size and culture system. Integrated farmers had higher cropping intensity (per cent of total cropped area against land area) at 193 per cent, compared with 182 per cent in rice monoculture and 177 per cent in alternate farming.

3.2. Costs and returns

According to the survey, the highest average annual variable costs were incurred from alternate farming (US$731 per ha) owing to costs associated with fish fingerlings and feed, while the lowest were from rice monoculture (US$517 per ha; Table 4). There was a significant difference ($P < 0.05$) in variable costs among farming categories. Annual fertiliser costs were highest in rice monoculture (US$119 per ha) and similar for alternate and integrated rice-fish farming. It was notable that the costs for fish feed were only about twice as high for alternate farming (US$191 per ha) than for integrated farming (US$72 per ha), although the input was much higher. Labour costs generally constituted the highest single operational cost, accounting for 29 per cent, 43 per cent and 51 per cent of total variable costs in alternate, integrated and rice monoculture, respectively.

Fixed costs included depreciation (i.e. ploughing and pesticide spray equipment, fish net and rice threshing machine), interest on operating capital and land-use cost or lease money. The largest single fixed cost for rice and rice-fish farmers was land costs (rice farmers: US$135 per ha per year; integrated

Table 4 Average production costs and returns (US$/ha/year) of different farming systems, 2007

Cost and return items	Amount (US$/ha/year)			Mean differences test (*t*-test)		
	Alternate	Integrated	Rice monoculture	Alternate	Integrated	Rice monoculture
Variable costs						
Fish fingerlings	143.62 (14%)	83.04 (10%)	–	14.5***	12.7***	–
Rice seedling	26.91 (3%)	54.17 (6%)	59.63 (8%)	7.6**	9.3***	10.2***
Fish feed	191.18 (19%)	72.21 (8%)	–	11.5***	10.6***	–
Fertiliser	90.27 (9%)	86.73 (9%)	119.23 (15%)	6.9***	7.1***	7.7***
Labour (family and hired)	210.59 (20%)	279.36 (30%)	262.45 (33%)	8.4***	9.2***	9.9***
Harvesting and marketing	37.73 (4%)	39.28 (4%)	35.72 (5%)	4.8*	5.7**	5.9**
Miscellaneous	30.46 (3%)	32.79 (3%)	39.84 (5%)	3.9**	4.7**	4.2**
Total variable costs (TVC)	730.76 (72%)	647.58 (70%)	516.87 (66%)	13.9***	12.0***	9.4***
Fixed costs						
Depreciation†	55.17 (5%)	57.43 (6%)	53.89 (7%)	3.5*	3.9*	4.2*
Interest‡	109.35 (11%)	97.72 (10%)	77.53 (10%)	9.7***	8.2***	7.6***
Land-use cost§	124.61 (12%)	127.19 (14%)	135.16 (17%)	10.3***	10.8***	11.7***
Total fixed costs (TFC)	289.13 (28%)	282.34 (30%)	266.58 (34%)	12.5***	11.6***	10.4***
Total costs (TC = TVC + TFC)	1019.89 (100%)	929.92 (100%)	783.45 (100%)	13.9***	13.3***	11.2***
Gross revenue¶						
Rice	1246.19 (48%)	2544.58 (86%)	2422.71 (96%)	11.7***	13.8***	12.5***
Rice straw	58.78 (2%)	114.62 (4%)	102.27 (4%)	5.0*	7.7***	8.7***
Fish	1296.37 (50%)	304.71 (10%)	–	12.8***	6.5**	–
Total gross revenue (GR)	2601.34 (100%)	2963.91 (100%)	2524.98 (100%)	11.4***	13.3***	12.9***
Net return (NR = GR – TC)	1581.45	2033.99	1741.53	10.7***	13.7***	11.6***

***Significant at 1% level ($P < 0.01$); **Significant at 5% level ($P < 0.05$); *Significant at 10% level ($P < 0.10$).
†(Purchase price – salvage value)/economic life.
‡Interest on operating capital at 15% per annum.
§Valuation of land at its rental price. ¶Productivity × farm-gate price.

farmers: US$127; alternate farmers: US$125). Fixed costs accounted for 28 per cent, 30 per cent and 34 per cent of total costs in alternate, integrated and rice monoculture, respectively (Table 4).

The average annual net return was calculated at US$2034 per ha from integrated farming, compared with US$1742 per ha from rice monoculture and US$1581 per ha from alternate farming (Table 4). There was a significant difference ($P < 0.05$) in net return among culture systems because of differences in yield. Integrated farmers obtained the highest net return because of a combination of two rice crops and fish production. In spite of higher fish production, the average annual net return was lowest for alternate farmers because, for a single crop, they had the highest production costs and the lowest rice production.

3.3. Production

The average annual yield of fish reported by respondents was 1108 kg/ha in alternate farming and 259 kg/ha in integrated farming (Table 3). According to the survey, the highest average annual yield of rice per hectare was found in integrated farming (10,178 kg), followed by rice monoculture (9691 kg) and alternate farming (4986 kg). There was a significant difference ($P < 0.05$) in rice yield among farming categories, because of the differences of inputs (seed, fertiliser and labour) and management skills. Table 3 shows that integrated farmers had a higher *aman* rice yield (5261 kg/ha/year) than for *boro* rice (4917 kg/ha/year) as the stocking of fish affected the *aman* rice yield positively. In contrast, farmers of rice alone had a lower *aman* rice yield (4702 kg/ha/year) but slightly more *boro* rice (4989 kg/ha/year). The highest average *boro* rice yield occurred in rice monoculture as a result of higher rates of fertilisation though differences among culture systems were insignificant ($P > 0.05$).

3.3.1. Technical and cost efficiency

Most of the inputs mentioned in Table 3 were included in the DEA, including the variable costs of inputs while no fixed costs were included (Table 4). We tried to minimise the number of inputs to avoid bias towards very high efficiencies (see Sharma *et al.* 1999). We did not include the duration of culture, the farm size and fixed costs that were not directly related to the inputs. The output variable is expressed as the total production (*aman* rice, *boro* rice, fish fingerlings) instead of each individually. The same applied for the inputs; we included a total figure for fertiliser input and a total figure for rice and fish inputs.

Among rice-fish farmers, the overall input-oriented TE was 98 per cent and the CE was 86 per cent. The bias corrected TE was lower, and the confidence interval (CI) of bias corrected TE for rice-fish farmers ranged between 94 per cent and 96 per cent (Table 5). This is reasonable compared with similar studies (Latruffe *et al.* 2005; Balcombe *et al.* 2008). Many rice-fish farmers (41 per

Table 5 DEA and bootstrapping results: means for the sample

Farming system	TE	Bias corrected score	Bias	CI	CE	AE
Rice-fish	0.978	0.945	−0.034	0.936–0.954	0.855	0.874
Alternate	0.979	0.946	−0.033	0.937–0.959	0.913	0.932
Integrated	0.985	0.969	−0.016	0.962–0.976	0.939	0.953
Rice	0.980	0.971	−0.009	0.967–0.975	0.910	0.929

AE, allocative efficiency; CE, cost efficiency; CI, confidence interval; DEA, data envelopment analysis; TE, technical efficiency.

cent) were technically efficient, while the other 59 per cent resided in the category 0.90–0.99 (Figure 2). On the other hand, only a few rice-fish farmers were cost efficient (4 per cent) and the spread of ranges was larger with a minimum of 64 per cent. Separate analyses for alternate and integrated rice-fish systems showed that integrated rice-fish farming is more technically and cost efficient. In comparison, rice monoculture farmers were as technically efficient than alternate rice-fish farmers (98 per cent) but less than integrated rice-fish farmers (Table 5).

3.3.2. Factors explaining efficiencies

Tobit results (Table 6) showed that integrated rice-fish farming (as compared to alternate; coded as dummy variable) had a significant positive impact on CE. Age had a significant negative impact on CE, implying that younger respondents were less cost efficient than older ones. Finally, and surprising, having no formal education had a positive impact on CE. This could be because these respondents were also among the poorer ones and hence were forced to spend as little money as possible on the purchase of inputs.

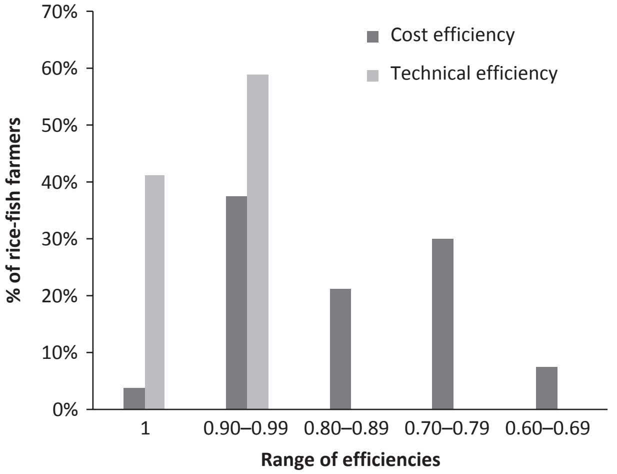

Figure 2 Range of efficiencies for all rice-fish farmers.

Table 6 Tobit model results (censored at both tails [0,1])

Variable	Coefficient	*t*-ratio
Intercept	0.813	18.77
Remote location*	−0.004	−0.41
Ownership	−0.015	−0.83
Integrated system	0.182	16.65
Years of experience	0.002	1.18
Age	−0.002	−2.80
Farm size	0.006	1.22
No formal education	0.023	2.05
High education (> 10 grade)	0.023	0.97
Sigma	0.044	12.65
Log-likelihood	−136.62	
n (sample size of farmers)	80	

*Farmers are located in remote areas far away from the administrative unit of Phulpur sub-district.

3.4. Constraints

There are several problems associated with farming fish in rice fields, including lack of technical knowledge, flood, high production costs and water pollution. Regardless of the rice-fish farming system adopted, 42 per cent of respondents identified a lack of technical knowledge as their single most important constraint (Table 7). The proportion of respondents identifying high production costs was 34 per cent. The cost of fish farming in rice fields was reported to have increased significantly in recent years as a result of increased costs for fish fingerlings, feed, fertiliser and labour. The prices of both fish fingerlings and feed have increased dramatically as fish farming has become widespread in pond systems. Inadequate finance can therefore be a significant constraint for rice-fish farming. Only 19 per cent and 5 per cent of the respondents identified floods and poor water quality, respectively to be the most important constraint. Preventing the escape of fish is very difficult during the floods, especially for small farmers who are reluctant to raise their low and narrow dikes. Farmers also reported higher fish mortality occurred because of poor water quality as a result of water pollution, turbidity, low water levels and high water temperatures. A few farmers reported that they

Table 7 Major constraints for fish farming in rice fields by category of farmer

Key constraint	Rice-fish farming systems		All rice-fish farmers $n = 80$ (%)
	Alternate $n = 37$ (%)	Integrated $n = 43$ (%)	
Lack of technical knowledge	22 (59)	12 (28)	34 (42)
High production costs	10 (27)	17 (39)	27 (34)
Flood	4 (11)	11 (26)	15 (19)
Poor water quality	1 (3)	3 (7)	4 (5)

n, sample size of farmers.

had high fish mortalities when their neighbours used pesticides indiscriminately.

Many rice monoculture farmers seemed unwilling to switch to rice-fish farming because of lack of technical knowledge. According to the survey, 42 per cent of respondents identified a lack of technical knowledge as the single most important reason they were not involved in rice-fish farming, while 25 per cent identified high production costs, 21 per cent floods and 12 per cent drought (lack of irrigation facilities). Farmers suggested that fish decrease rice yields because of the space occupied by the refuge. Farmers also thought that pesticides use for rice crops have decreased fish production. Rice farmers were also reluctant to adopt rice-fish farming because of risks. It was found that the farmers most likely to be active in rice-fish farming were better off than those who grew only rice because they were more willing to take risks. According to key informants, this tendency has been exacerbated by Government Agricultural Extension Officers who target literate and financially better-off farmers because their understanding and adoption of technologies is expected to be better.

4. Discussion

Rice-fish farming practices in the Mymensingh area of rural Bangladesh are traditional. Nevertheless, the integrated rice-fish farming system is better than rice monoculture in terms of a range of social, economic and environmental measures. We found high levels of technical and cost efficiencies in both groups, rice-fish and rice farmers. For rice monoculture farmers, our results confirmed previously found high production efficiencies among rice farmers in Bangladesh (Warud and White 2000; Coelli *et al.* 2002; Balcombe *et al.* 2008). Rice-fish farmers have the advantage of using less input, in particular fertiliser, to obtain the same output which implies better pest management. Thus, the integrated rice-fish farming system can provide a sustainable alternative to rice monoculture, if farmers can take advantage of its environmental benefits. Similar results were found in Rothuis *et al.* (1998).

It has been reported that the cultivation of fish in rice fields increases rice yields by 8–15 per cent (Mishra and Mohanty 2004; Mohanty *et al.* 2004). This study showed that *aman* rice yield (5261 kg/ha/year) in integrated farming is 7 per cent higher than *boro* rice (4917 kg/ha/year) because of the presence of fish. The results also show that *aman* rice yield in integrated farming is 12 per cent higher than the rice monoculture (4702 kg/ha/year). The increase in rice yield was probably because the movement of fish helped increase dissolved oxygen levels, stirred up soil nutrients, enhanced soil organic matter, and controlled plankton, organic detritus, aquatic insects and plants that compete with rice for nutrients and energy. However, the global average rice yield is lower than in Bangladesh (4000 kg/ha/crop) than in Australia, Egypt, Japan and southern Europe (10,000 kg/ha/crop), where rice production is highly mechanised and fully irrigated (Frei and Becker 2005).

According to Nabi (2008), irrigated rice fields in many parts of Bangladesh could produce three crops a year, but irrigation facilities are limited in Bangladesh even though it is potentially more important than rice-fish farming as an innovative technology.

Integrated rice-fish farming can play an important role in increasing households' incomes and food production. Nevertheless, a number of challenges were identified, including the lack of technical knowledge of farmers, high production costs, flood and drought. Despite this potential, however, rice-fish farming technology has not yet improved food security in Bangladesh because of the low level of adoption. To be sustainable, food production in Bangladesh should integrate resource management (Shankar *et al.* 2004). Although rice monoculture is still the dominant farming system in rural Bangladesh, rice-fish integration could provide a social, economic, environmental and nutritionally viable alternative for resource-poor farmers. If integrated rice-fish farming is expanded to 2.83 million ha of inundated seasonal rice fields in Bangladesh, food production would be increased manifold.

It is also necessary to provide institutional and organisational support, training facilities and extension services for sustainable rice-fish farming. Training and technical support would help to increase the knowledge of farmers, improve profitability and reduce risks. The provision of low-interest credit would also help the switch to rice-fish farming by resource-poor farmers. Access to credit at reasonable interest rates and with appropriate repayment schedules will be essential if rice-fish farming is to become accessible to poorer farmers. Thus, the government as well as national banks and NGOs should provide adequate access to interest-free credit or credit at very low interest rates. The *Grameen* Bank, a specialised rural bank providing micro credits that was awarded the Nobel Peace Prize for 2006, is already active in rural Bangladesh and aims to eliminate poverty and food insecurity through developing agriculture (Yunus and Weber 2008).

Despite the income derived from fish production in integrated farming, many farmers perceived rice as the main crop and fish as a by-product. Fish production in rice fields was considered as a bonus to be achieved with additional inputs, but high input costs are a major disincentive (Table 7). Although rice-only farmers are aware of the positive effects of rice-fish farming, lack of capital has prevented many from engaging in integrated farming. The farmers are also risk-averse. At present, rice farmers are not taking risks by investing in rice-fish farming – they are 'staying poor to stay secure' (Wood 2003). The vulnerability of resource allocation and the probability of crop failure as perceived by the rice farmers have a profound influence on decision-making among farmers with few or no back-up resources to fall back on.

The level of success of rice-fish farming in Bangladesh depends on the local agro-ecological situation and the prevailing socioeconomic conditions (Dey *et al.* 2005). The benefits of integrated rice-fish farming technology tend to accrue to better-off farmers, enhancing still further their income and household nutrition. The integrated farmers obtained income both from fish production in rice fields and increased rice production while the nutritional status of rice-fish farming households improved greatly. Thus, the switch from rice monoculture to integrated rice-fish farming is not merely a change in cropping system, it is also a shift to a more balanced diet (i.e. rice and fish).

5. Conclusions

In order to meet the soaring demand for food, there is a need for increased rice and fish production in Bangladesh. We found high levels of technical and cost efficiencies in both groups, rice-fish and rice farmers. Integrated rice-fish farming is most technically and cost efficient, using the least inputs, in particular fertiliser. We conclude that rice-fish integration could be a viable option for diversification. Such farm diversification will enhance food security and can play an important role in the economy of Bangladesh as a sustainable alternative to rice monoculture. A number of significant constraints to rice-fish farming were revealed, particularly the lack of technical knowledge, high production costs, flood and drought. These will need to be overcome if the benefits of rice-fish farming are to reach the millions of rural poor. If rice farmers are persuaded to switch to integrated rice-fish farming, their income and local food supply will increase, and thus, the overall food security will be enhanced. In order to increase food supply, the government should promote integrated rice-fish farming throughout the country.

It is also necessary to provide institutional and organisational support, training facilities and extension services for sustainable rice-fish farming. Training and technical support would help to increase the knowledge of farmers, improve profitability and reduce risks. The provision of low-interest credit would also help to switch to rice-fish farming by resource-poor farmers. Access to credit at reasonable interest rates and with appropriate repayment schedules will be essential if rice-fish farming is to become accessible to poorer farmers. Thus, the government as well as national banks and NGOs should provide adequate access to interest-free credit or credit at very low interest rates.

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