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Integrated Agriculture-Aquaculture: A Way for Food Security for Small Farmers and Better Resource Management and Environment

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Abstract

Traditionally fish have been a natural component of rice-ecosystems. Intensive agriculture has led to degradation of fish habitats, resulting in disappearance of fish from rice fields. The economic viability and impact on the environment of integrating aquaculture with agriculture during rainfed and irrigated rice growing seasons were studied in 256 farms in Bangladesh. Farmers on an average obtained fish production of 230 and 214 kg.ha^{-1} during irrigated and rainfed seasons, respectively. The cost of production was higher in integrated farms by US$ 22.33 and US$ 44.68.ha^{-1} (13.6% and 17.6%) as compared to monoculture rice farms during irrigated and rainfed seasons, respectively. The increase in net benefit from integration amounted to $217.55 and $239.45.ha^{-1}, during irrigated and rainfed seasons, indicating a net increase in benefits to farmers by 61.3% and 80.1% respectively, during the two seasons. Integration resulted in increased rice yields on an average by 10.25-11.58%, in 82% and 56% of integrated farms during irrigated and rainfed seasons respectively, and a decrease in pest population by 40.5-166.7%. Weed infestation in integrated farms was less by 42.9-68.6%.

Keywords

Integrated farming; sustainability; resource management; food security; environment impact; fish culture

Introduction

For 116 million people of Bangladesh, a country with a high population density of 783 people per sq.km, rice and fish are the staple food. Small farmers constitute the bulk of the population and the land holdings are small, being less than 0.4 ha on an average (BBS 1994). Given the scarcity of land and the need to meet the demand of increasing population, alleviate poverty and malnutrition, there was no alternative but to continue intensification of agriculture. The country has made substantial progress in attaining self-sufficiency in food grain production: high yielding rice varieties (HYV) account for half of the rice area and the cropping intensity has increased to 179%. Rice production has increased from 12.5 million t in 1980 to 18.34 million t in 1993. Along with intensification, fertilizer use has increased from 334,690 t in 1978 to 921,650 t in 1990 and pesticides from 5,051 t in 1978 to 7,700 t in 1993. There is increasing concern that intensive agriculture may not be sustainable, due to its high demand for soil nutrients and damage to the environment. Rice yields in recent years are stagnating or declining despite increased use of inputs, suggesting degradation of land and questioning the sustainability of intensive agriculture (Pagiola 1995) and the crop sector is showing negative growth.

Fish is the main source of animal protein, providing 8 $g.day^{-1}$, or 12% of the average per capita total intake of protein (63.5 g) and 71% of the total animal protein intake in Bangladesh (BBS 1988). In spite of the importance of fish in nutrition, per capita intake is very low, estimated at 8.3 $kg.annum^{-1}$. These average consumption figures in reality camouflage the very low intake among rural households. It has been estimated that while per capita fish intake among the high income segment of the urban population is 22 $kg.annum^{-1}$, it is only 4.4 $kg.annum^{-1}$ among the low-income rural population (World Bank 1993). Average per capita daily fish intake in the rural sector has declined from 97% of urban sector intake levels in 1973 to 75% in 1986 (BBS 1988), which is leading to protein deficient malnutrition. Even this low intake in rural areas is mostly obtained by catching fish from open-access capture fisheries.

Fish has been a natural component of rice fields. In the past, farmers used to catch wild fish from flooded rice lands. Some of these fish, such as *Amblypharyngodon mola* are reported to contain very high amounts of vitamin A (Thilsted and Hassan 1993), which is deficient among rural population causing blindness, especially among children. The increasing demand for food is leading to increased pressure on natural resources through intensive agriculture, with concomitant increase in the use of fertilizers and pesticides, which are detrimental to fish populations. This, combined with implementation of flood protection programs, resulted in depletion and degradation of fish habitats and fish populations from rice fields have almost disappeared (Gupta and Mazid 1993).

While intensification of agriculture to meet the needs of the growing population is an inescapable imperative, at the same time it is a pre-requisite to assess the ecological sustainability and look at systems that could provide food security to small farmers through environmentally compatible integrated farming systems and resource management. In view of the above, research was undertaken to assess the feasibility of integrating aquaculture with agriculture by small-holder farmers and the impact of integration, if any, on rice production and environment.

Materials and Methods

There are three rice farming seasons in Bangladesh: (i) irrigated, dry season rice farming, locally known as *boro*, during January-February to May-June, (ii) rainfed rice farming, locally known as *aman* during July-August to November-December, and (iii) a third crop season, locally known as *aus*, in areas where there is sufficient soil moisture, during April-May to July-August. Of these, rainfed rice and irrigated rice are the main crops.

The study was undertaken in 256 farms in Mymensingh district during five rice growing seasons: three rainfed and two irrigated. The area of farms where integrated farming was undertaken was 0.04-1.20 ha. Some of these farms had a sump or a shallow ditch from which the farmers used to catch wild fish. Those who did not have a sump or ditch excavated a ditch in the lower side of the plot as refuge for fish during adverse conditions. The area of the ditch ranged from 8 to 680 m^2, with a depth of 0.5-0.8 m. Twelve varieties of high yielding varieties of rice were transplanted during the irrigated season and 18 varieties during the rainfed season, of which 15 were HYV. Fish fingerlings were stocked 15-20 days after transplantation of rice. Water depth in rice fields was 0-30 cm during the irrigated season and 5-47 cm during the rainfed season. The rearing period of fish varied from plot to plot and from season to season and ranged 34-113 and 42-138 days during the irrigated and rainfed seasons, respectively.

Insect/pest populations were monitored in four integrated and monoculture rice farms each during the irrigated season. Integrated and monoculture rice farms were selected in pairs in the same area, with the same variety of rice and management and of the same farmer. Twenty hills at random (distance between monitored hills was 2 m) from each plot were sampled for insects and the observed insects were collected and identified. In all, five samplings were done, the first 15 days after transplantation of rice and thereafter at weekly intervals, till harvesting of rice. The insects were identified and grouped into pests and useful insects which prey on insects.

For qualitative and quantitative assessments of weeds in integrated and monoculture rice farms, seven farms each were monitored at fortnightly intervals. In all, four samples were taken during the rice growing season, the first about 30 days after transplantation of rice and before weeding by farmers and subsequent samplings at fortnightly intervals. All weeds present in 1 m^{-2} area at three randomly selected places in each farm were collected. The weeds were then identified and their number and weight were noted.

Results

Fish Production

There was wide variation in the fish species cultured and stocking densities practiced by farmers (see table 1). Species selection by farmers mostly depended on availability of fingerlings: common carp (*Cyprinus carpio*) during the irrigated season and silver barb (*Puntius gonionotus*) during the rainfed season. Few farmers stocked Nile tilapia (*Oreochromis niloticus*). Some farmers in addition stocked carps: catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*), silver carp (*Hypophthalmichthys molitrix*) and grass carp (*Ctenopharyngodon idella*). Stocking densities varied widely with an average of 3,864.ha^{-1} (s.d. 2,815) during the irrigated season and 4,534.ha^{-1} (s.d 4,304) during the rainfed season. Fish production averaged 230 (s.d. 198) and 214 (s.d. 247) kg.ha^{-1} during irrigated and rainfed seasons, respectively. Farmers who stocked at higher densities, which was the case mostly with multi-species combination, obtained higher fish production of 577 (s.d. 382) and 485 (s.d. 367) kg.ha^{-1} during the irrigated and rainfed seasons, respectively.

Multiple regression analysis indicated a statistically significant positive correlation between stocking density and fish production, production increasing with increasing density during both seasons. Densities less than 3 000.ha^{-1} resulted in fish productions of 164 and 118 kg.ha^{-1} during dry and wet seasons, respectively, while densities of 3 000-6 000.ha^{-1} gave fish production of 276 and 175 kg.ha^{-1}, respectively. Fish production were highest, 616 and 571 kg.ha^{-1} during the irrigated and rainfed seasons, respectively, when stocking densities were over 6 000.ha^{-1} (see table 1).

Size of fingerlings at stocking varied from species to species and in general was in the range of 3.8-11 cm. Size of fish at harvest varied widely among farms and among species, depending on the length of culture period, water depth in rice fields, stocking density and survival. During the irrigated season, *C. carpio* attained the highest mean weight of 108 g at harvest, with lowest mean recovery of 55.6%, followed by *P. gonionotus* with average mean weight of 85.3 g and 62.5% recovery. Only 8 plots were stocked with *O. niloticus* and they reached an average weight of 76.9g, with 66.3% survival. During the rainfed season, *C. carpio* reached a mean average weight of 74.5 g, with a recovery of 55.8%, while it was 56.1 g and 66.2% in case of *P. gonionotus*.

Though the size of fish at harvest was small due to short rearing period, farmers still consume and are able to get a good market for the small fish.

Multiple regression analysis indicated significant positive correlation between fish culture period and depth of water in rice fields with fish production during the irrigated season, but no such correlation was observed during the rainfed season.

Table 1: Fish Production at Different Stocking Densities in Integrated Farms during Rainfed and Irrigated Seasons

Stocking density (no./ha)	Irrigated season		Rainfed season	
	No. of farms	Fish production ($kg.ha^{-1}$)	No. of farms	Fish production ($kg.ha^{-1}$)
0 - 3,000	103	164 (92)	57	118 (71)
3,000 - 6,000	30	276 (150)	28	175 (134)
>6,000	14	616 (351)	15	571 (396)

Note: Standard deviations are in parentheses.

Rice Production in Integrated Farms

The principal commodity in this farming system is rice and any adverse effect on rice yields would call into question the viability of the integrated system. Hence, the effect of integration on rice production, if any, was studied. Rice yields from integrated farms and monoculture rice farms (control) were monitored. Since production depends on soil fertility, rice variety and management practices, for the purpose of comparison, integrated and monoculture rice plots adjacent to each other, with the same rice variety and management practices and in many cases plots of the same farmer, were selected for monitoring. Integrated farms had higher rice yields in 82.4% cases during the irrigated season and in 56.2% cases during the rainfed season, as compared to monoculture rice farms (see table 2). Increase in rice yields on an average was 10.25% during the irrigated season and 11.58% during the rainfed season.

Table 2: Rice Production in Monoculture Rice Farms and Integrated Farms

Season	No. of farms	Rice yield: monoculture rice farms ($kg.ha^{-1}$)	Rice yield: integrated farms ($kg.ha^{-1}$)	Integrated farms with higher yields (%)	Mean difference from control (%)
Irrigated	34	4,702 (3,046-6,000)	4,980 (3,264-6,571)	82.4	+10.25 (-13.3 - +57.6)
Rainfed	25	3,498 (1,976-6,250)	3,811 (2,058-4,940)	56.2	+11.58 (-21.3 - +66.7)

Note: Ranges are in parentheses.

Economics

Capital costs involved in integrating aquaculture with rice farming are the labor costs towards excavation of a ditch or sump and strengthening of dikes, where necessary, using family labor and/or hired labor. The operational costs include cost of fingerlings, supplementary feeds and fertilizers and irrigation. While fingerlings are cash costs, fertilizers and supplementary feeds are partly non-cash costs, as farmers used partly on-farm wastes. Cost (cash and non-cash) of integrating aquaculture with agriculture amounted to \$72.15 and \$66.52.ha^{-1} during irrigated and rainfed seasons, respectively (see table 3). Cost of fingerlings accounted for 58.7% and 67.2% of total costs during irrigated and rainfed seasons, respectively. Cost of feeds and fertilizers accounted for 10.3% and 21.6% of total costs. Gross and net benefits from fish culture component in integrated farming are given in table 4. Mean net benefit was more or less same during irrigated and rainfed seasons, being \$123.70 and \$119.98.ha^{-1}, respectively. Of the total 144 and 101 integrated farms studied during irrigated and rainfed seasons, 15 (10.4%) and 12 (11.9%) farms, respectively, lost money on fish culture, mostly due to flooding and loss of fish due to escape and theft.

Table 3: Cost (US\$.ha^{-1}) of Fish Production in Integrated Rice-Fish Farming

Season	No. of farms	Feed and fertilizers	Fingerlings	Plot preparation	Irrigation	Total
Irrigated	144	7.40 (7.78)	42.32 (39.38)	18.63 (24.40)	3.80 (6.38)	72.15 (53.00)
Rainfed	101	14.35 (15.07)	44.72 (32.68)	7.20	0.25	66.52 (56.70)

Note: Standard deviations are in parentheses.

A comparison of cost of production of rice in monoculture rice farms and in integrated farms (see table 5) indicated that rice production costs in integrated farms as compared to monoculture rice farms, were lower by 8.8% and 10.7% during irrigated and rainfed seasons, respectively, due to less use of fertilizers and pesticides and less labor for weeding. Cost of fertilizers in integrated farms averaged 14.3% less as compared to monoculture rice farms during the irrigated season and 43.3% during the rainfed season. Average weeding costs in integrated farms were lower by 29.3% during the irrigated season and 23.2% during the rainfed season. Pesticide costs were lower by 86.3% during the irrigated season in integrated farms.

Lower production cost for rice combined with higher yields in integrated farms resulted in increasing net benefit from rice alone to 22.6% and 11.9% in integrated farms during irrigated and rainfed seasons, respectively (see table 6). The net benefit from integration increased to 61.3% and 80.1%, as compared to monoculture rice farms, during irrigated and rainfed seasons, respectively. Though 10.4% and 11.9% of farms incurred loss on fish culture during the irrigated and rainfed seasons, respectively, in none of the cases, was net benefit lower in integrated farms as compared to monoculture rice farms, due to increased benefit from rice.

Table 4: Costs (US$.ha^{-1}) and Benefits of Fish Component in Integrated Rice-Fish Farming

Season	No. of farms	Costs	Gross benefit	Net benefit
Irrigated	144	72.15	195.85	123.70
		(53.00)	(151.93)	(127.35)
Rainfed	101	66.52	186.50	119.98
		(56.75)	(183.20)	(153.68)

Note: Standard deviations are in parentheses.

Table 5: Production Costs (US$.ha^{-1}) of Plots Stocked with Fish and Comparable Unstocked Plots

Season	No. of farms	Cost of production				
		Monoculture: rice (control)	Integrated: rice	% difference from control	Integrated: rice and fish	% difference from control
Irrigated	22	328.45	299.58	-8.8	373.13	+13.6
		(63.45)	(72.73)	(12.6)	(95.85)	(23.1)
Rainfed	10	127.20	113.58	-10.7	149.53	+17.6
		(23.35)	(20.23)	(9.6)	(23.83)	(15.5)

Note: Standard deviations are in parentheses.
Total cost of production for fish and rice in integrated farms on an average was higher by 13.6% and 17.6% as compared to monoculture rice farms, during irrigated and rainfed seasons.

Table 6: Net Benefit (US$.ha^{-1}) from Integrated Farms and Comparable Monoculture Rice Farms

	No. of farms					Net benefit
		Monoculture: rice (control)	Integrated: rice	% difference from control	Integrated: rice and fish	% difference from control
Irrigated	22	355.00	435.13	+22.57	572.55	+61.28
		(114.98)	(139.40)	(24.4)	(187.70)	(38.0)
Rainfed	10	299.05	334.48	+11.85	538.50	+80.07
		(90.13)	(89.85)	(54.7)	(122.23)	(86.0)

Note: Standard deviations are in parentheses.

Pest Infestation and Pesticide Use

During the irrigated season, 35.3% and 10.1% of monoculture and integrated farms, respectively, used pesticides. Use of pesticides was very low during the rainfed season, having been used by only 16.7% of the monoculture rice farmers. Low or non-use of pesticides in integrated farms was attributed by farmers to low infestation of pests.

The study revealed that pest population (larval and adult stages of stemborer, rice bug, green leaf hopper, white leaf hopper, short horned grasshopper, golden cricket, gall midge, rice ear head bug, mole cricket, rice skipper and black bug) was higher in monoculture rice farms as compared to integrated farms by 40.5-166.7% during different times of crop growth (compare figure 1). Of these, major pests were stemborers, grasshoppers and rice bugs. In spite of low or no use of pesticides in integrated farms, pest infestation was low, indirectly indicating a role for the fish in controlling pests, through predation, and integration could lead to integrated pest management (IPM).

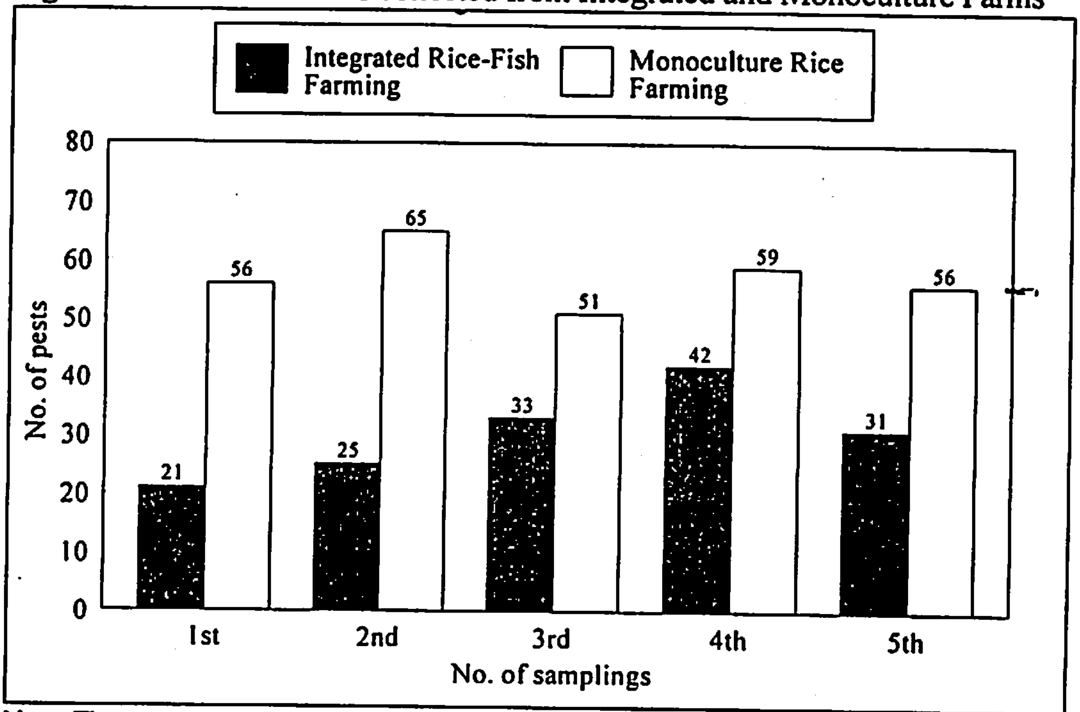
Weed Infestation

Labor costs for weeding were low in integrated farms, the reason for which was given by farmers as low weed infestation, due to grazing and dislodging of weeds by fish. Farmers' perceptions were verified and weed populations were quantified in integrated and monoculture rice farms through a study of the occurrence of weeds in integrated and monoculture rice farms at fortnightly intervals. The quantity of weeds by number and weight was highest before first weeding by farmers, declining during subsequent samplings. Weed infestation in integrated farms was less by 42.9-68.6% by number and 40.6-66.9% by weight as compared to monoculture rice farms, during different samplings (compare figure 2), resulting in lower labor requirement for weeding.

Impact of Research and Adoption by Farmers

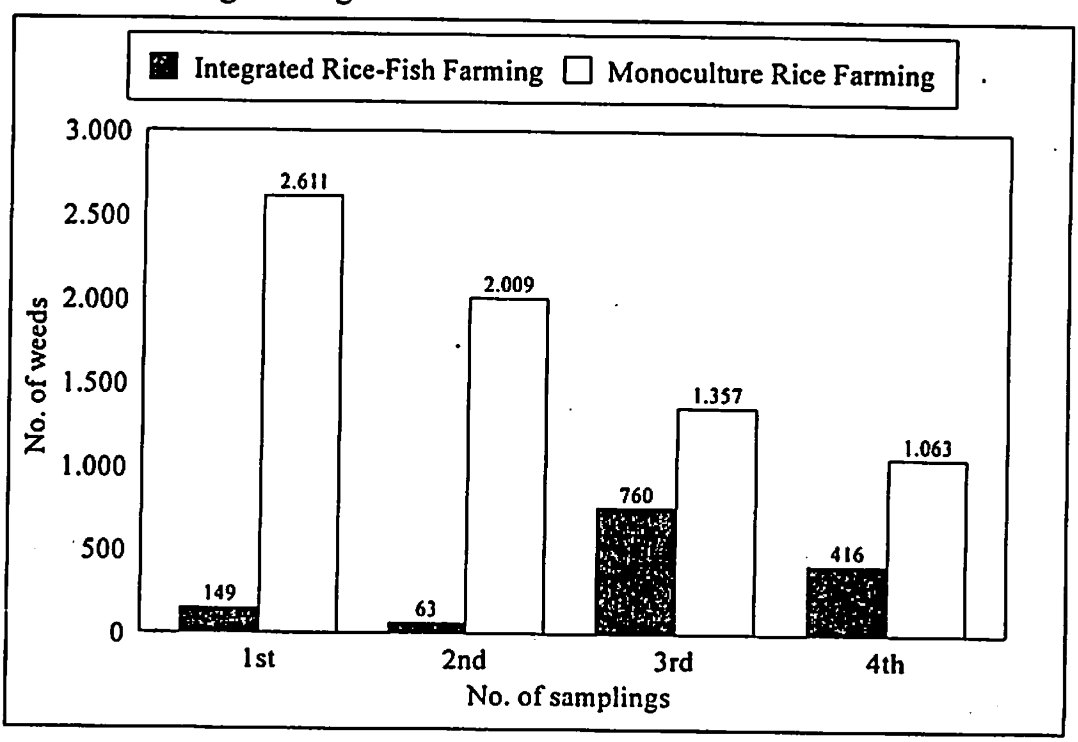
One year after the conclusion of the research, surveys were undertaken in one of the study areas, to assess the adoption of integrated rice-fish farming practices among rice farmers. These surveys revealed that a large number of farmers, having been convinced of the benefits of integration, have and are taking to integration and intensified operations with higher benefits. Intensification included increased stocking densities and higher use of inputs for fish culture, with fish production reaching as high as over 1 $t.ha^{-1}$. It is interesting to note that the farmers who were not involved in research but adopted integration after seeing operations of their neighbors went in for intensification. Besides culturing fish, farmers were able to use the water from refuge ditches for irrigation of rice in case of drought, thus saving the rice crop.

Figure 1: Number of Pests collected from Integrated and Monoculture Farms



Note: The pests were collected from 20 hills each from 4 plots during the irrigated season.

Figure 2: Number of Weeds Collected from a 3 m^2 Area from each of the 7 Plots during the Irrigated Season



Conclusions

Rice and fish are the staple food of many people of Asia. In recent years, there is growing concern of the environmental impact of intensive agriculture. Pesticides used in intensive agriculture are detrimental to fish and the aquatic foodweb that support the fish (Koesoemadinata 1980; Takamura and Yasuno 1986). Pollution from run-off agricultural pesticides has been identified as one of the causes for decline in fish populations of open waters. At a time when rice yields are stabilizing or declining in spite of increased input use, questioning the sustainability of intensive agriculture (Pagiola 1995), the present study has conclusively shown that integration of aquaculture with agriculture can increase rice yields, besides being a viable, low-cost, low-risk, sustainable economic activity, with multiple benefits: production of diversified products, rice and fish from the same land area; increased incomes and nutrition to farm households; reduced labor costs in rice cultivation; lesser use of pesticides and spread of risks due to diversity of produce. Thus integration is economically and ecologically beneficial and is a way for food security for small farmers. In spite of the small size of fish at harvest due to the short rearing period, farmers are continuing integrated farming indicating the sustainability of the system.

Yield declines observed in long-term HYV cropping trials are thought to result from anaerobic conditions in irrigated rice production systems, resulting in declining supply of nutrients to growing crop (Cassman et al., as quoted by Pagiola 1995). Fish by their feeding habits, disturb the soil and thus increase the aerobic layer at the soil-water interface, slowing the denitrification process that leads to volatilization of nitrogen (Fillery et al. 1984).

Overuse and misuse of pesticides are quite high in developing countries. Integrated aquaculture-agriculture could be an entry point for IPM. A "do not spray" strategy could be changed to the more attractive "integrate fish" strategy.

Fish production from open-access capture fisheries is on the decline throughout many parts of the world, due to degradation of fish habitats and over-exploitation of resources. Aquaculture is being looked at as a panacea for increasing production, to meet the needs of a growing population. In the context of rural development, aquaculture is being given importance in developing countries to increase incomes and nutrition of rural households. Since all rural households do not have access to ponds, integration of aquaculture with agriculture could be a way for improving incomes and nutrition and at the same time could lead to a better environment through integrated resource management.

This study revealed that the average area under integrated rice-fish farming in the study area was 0.25 ha per household. Even with low management and low fish production of 200 $kg.ha^{-1}$ per season, it would mean a fish production of 100 kg per household (from 2 crops). The average size of households in Bangladesh is

5.6 persons (BBS 1994). Thus, by integrating aquaculture with agriculture, rural households can have per capita fish-consumption of 17.85 $kg.annum^{-1}$, which is double the national average consumption of 8.3 $kg.annum^{-1}$.

There are some 8 million ha of rice farms in Bangladesh. However, all may not be suitable for integration, due to land topography and soil structure. Even if 5% of these rice farms are brought under integration and with low fish productions of 200 $kg.ha^{-1}$.season, it would mean an annual fish production from rice farms of some 160,000 t, valued at US$160 million per year. To realize this potential, what is needed is the commitment on the part of the planners, administrators and extension workers, to provide information/training to the farmers and ensure easy availability of fingerlings at affordable prices of required size and species at the appropriate time.

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