ON-STATION TRIAL OF DIFFERENT FERTILIZATION REGIMES USED IN BANGLADESH

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ABSTRACT

An on-station trial was conducted in fourteen 100 m^2 earthen ponds at the Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh from July through December 2001. This trial was designed to evaluate different fertilization regimes currently used for Aquaculture in Bangladesh and to compare effects of different fertilization regimes on fish production, water quality, and economic returns. There were five fertilization regimes: A) PROSHIKA fertilization regime, weekly application of 1,000 kg cow dung ha^{-1}; B) Bangladesh Rural Advancement Committee (BRAC) fertilization regime, weekly application of 156 kg cow dung ha^{-1}, 28.125 kg urea ha^{-1}, and 13.1 kg triple superphosphate (TSP) ha^{-1}; C) Caritas fertilization regime, fortnightly application of 1,500 kg cow dung ha^{-1}; D) BAU fertilization regime, fortnightly application of 1,250 kg cow dung ha^{-1}, 31.25 kg urea ha^{-1}, and 15.625 kg TSP ha^{-1}; E) Aquaculture CRSP fertilization regime developed from Nile tilapia (Oreochromis niloticus) ponds, weekly application of 250 kg cow dung (dry matter) ha^{-1} supplemented with urea and TSP to give 28 kg N and 7 kg P ha^{-1} wk^{-1}. The six carp species used in this on-station trial were silver carp (Hypophthalmichthys molitrix), mrigal (*Cirrhinus mrigala*), rohu (*Labeo rohita*), catla (*Catla catla*), grass carp (*Ctenopharyngodon idella*), and common carp (*Cyprinus carpio*) stocked at a ratio of 9:8:6:6:3:2 at a stocking density of 1.02 fish m^{-2}, giving 27, 24, 18, 18, 9, and 6 fish per 100 m^2 pond, respectively. Mean stocking sizes of carps ranged from 6.3 to 10.1 g.

Among all tested fertilization regimes, the Aquaculture CRSP fertilization regime resulted in the highest fish production, followed by the BAU, BRAC, Caritas, and PROSHIKA fertilization regimes ($P < 0.05$). The two fertilization regimes (PROSHIKA and Caritas) using cow dung as the sole nutrient input during the culture period gave very poor fish growth performance and low production due mainly to the low soluble nutrients derived from cow dung. The other three fertilization regimes (Aquaculture CRSP, BAU, and BRAC) using the combinations of organic and inorganic fertilizers resulted in much higher carp production. Analysis of water quality showed that the nutrients from the Aquaculture CRSP fertilization regime were oversupplied probably because this regime was developed in Nile tilapia monoculture with higher intensification compared to the carp polyculture used in the present trial. The BAU fertilization regime gave the highest profitability among all fertilization regimes, followed by the BRAC and Aquaculture CRSP regimes. Therefore, the BAU fertilization regime is the most appropriate for carp polyculture ponds in Bangladesh while the Aquaculture CRSP fertilization regime is suitable for carp polyculture ponds with higher intensification.

INTRODUCTION

Bangladesh is one of the most densely populated countries in the world. Fisheries and aquaculture in particular are vital to Bangladesh's national economy in terms of nutrition, income, employment generation, and foreign exchange earning (Alam et al., 1996). Currently, approximately 80% of the animal protein supply for residents is provided by fish, but population growth is rapidly overwhelming the productive potential of the Bangladesh fishery (O'Riordan, 1992). Since the 1960s, per capita availability of fish has dropped from 12 kg to only 7 kg; moreover, among lower income groups per capita consumption is only 4.4 kg. For the poorest of the poor, fish is simply unaffordable (O'Riordan, 1992). Thus, aquaculture plays a more and more important role in meeting the nutritional needs of Bangladesh people.

Bangladesh has a variety of aquaculture and fisheries projects that have been funded by international aid. Many nongovernmental organizations (NGOs) such as PROSHIKA, Bangladesh Rural Advancement Committee (BRAC) and Caritas have been

Table 1. Fertilization regimes during the pond preparation (one week prior to fish stocking) and the entire culture period in 100 m^2 carp polyculture ponds.

Stage	Inputs	Fertilization regimes				
		PROSHIKA	*BRAC*	*CARITAS*	*BAU*	*CRSP*
Pond Preparation	Lime (kg/pond)	2.5	5.0	5.0	5.0	5.0
	Cow dung (kg/pond)	25	20	25	12.5	2.5*
	MP (g/pond)	--	93	125	--	--
	Urea (g/pond)	--	375	750	312.5	523.4**
	TSP (g/pond)	--	187.5	375	156.25	302.1**
Culture Period	Cow dung (kg/pond)	10 (weekly)	1.56 (weekly)	15 (fortnightly)	12.5 (fortnightly)	2.5* (weekly)
	Urea (g/pond)	--	281.25 (weekly)	--	312.5 (fortnightly)	545.5** (weekly)
	TSP (g/pond)	--	131.00 (weekly)	--	156.25 (fortnightly)	293.0** (weekly)

* Dry weight basis

**Urea and TSP rates were determined based on the nutrient contents in cow dung supplemented with urea and TSP to give 28 kg N and 7 kg P ha^{-1} $week^{-1}$.

promoting aquaculture development independently through their own extension networks in Bangladesh.

Aquaculture is commonly practiced using polyculture of four to seven species of Indian and Chinese carps in manured and/or fertilized ponds (Wahab et al., 1991). In spite of extensive research conducted on fertilization of polyculture ponds for carp in many parts of the world, such information in Bangladesh is rather scanty (Haq et al., 1993). Fish production is quite low in Bangladesh, averaging 2,800 kg ha^{-1} yr^{-1} (DOF, 1999). In rural aquaculture ponds, fish production is often lower than 1,500 kg ha^{-1} yr^{-1}. NGOs have been working with farmers to increase fish production; however, different NGOs recommend different fertilization regimes to farmers, and these regimes do not all seem to increase yields. Fertilization regimes should vary with different local conditions such as soil and source water. In some cases the same farmers receive very different recommendations on fertilization regimes from different extension partners. Both over- and under-fertilization may cause adverse effects on fish production, water quality, pond effluents, and economic returns. It is necessary to evaluate fertilization regimes and recommend appropriate fertilization strategies to farmers in order to maximize fish production, maintain good water quality, reduce environmental impact, and maximize economic returns.

The purposes of this study were to evaluate the different fertilization regimes currently used for aquaculture in Bangladesh, and to compare effects of different fertilization regimes on fish production, water quality, pond effluents, and economic returns.

METHODS AND MATERIALS

This on-station trial was conducted using a completely randomized design in fourteen 100 m^2 earthen ponds at the Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh from July through December 2001. There were five fertilization regimes used as treatments during the culture period: A) PROSHIKA fertilization regime—weekly application of 1,000 kg cow dung ha^{-1}; B) BRAC fertilization regime—weekly application of 156 kg cow dung ha^{-1}, 28.125 kg urea ha^{-1}, and 13.1 kg triple superphosphate (TSP) ha^{-1}; C) Caritas fertilization regime—fortnight application of 1,500 kg cow dung ha^{-1}; D) BAU fertilization regime—fortnight application of 1,250 kg cow dung ha^{-1}, 31.25 kg urea ha^{-1}, and 15.625 kg TSP ha^{-1} (Wahab et al., 1999); E) Aquaculture CRSP fertilization regime developed from Nile tilapia (Oreochromis niloticus) ponds—weekly application of 250 kg cow dung (dry matter) ha^{-1} supplemented with urea and TSP to give 28 kg N and 7 kg P ha^{-1} wk^{-1} (Knud-Hansen et al., 1991a, b) (Table 1). The BAU fertilization regime treatment had two replicates, while all other treatments had three replicates.

The six carp species used in this on-station trial were silver carp (Hypophthalmichthys molitrix), mrigal (Cirrhinus mri-

Table 2. Stocking information of carps in 100 m^2 polyculture ponds fertilized with different regimes. Mean values without any superscript letter in the same row were not significantly different ($P > 0.05$).

Item	Fertilization regimes				
	PROSHIKA	*BRAC*	*CARITAS*	*BAU*	*CRSP*
Mean Weight (g/fish)					
Silver Carp	8.9 ± 0.2	8.6 ± 0.5	8.1 ± 0.1	7.9 ± 0.3	8.6 ± 0.3
Mrigal	10.1 ± 0.1	10.1 ± 0.1	10.1 ± 0.1	10.0 ± 0.1	9.9 ± 0.1
Rohu	7.0 ± 0.5	7.2 ± 0.7	6.7 ± 0.6	8.3 ± 0.2	6.6 ± 0.6
Catla	8.5 ± 0.1	8.6 ± 0.1	8.4 ± 0.0	8.7 ± 0.3	8.4 ± 0.1
Grass Carp	6.7 ± 1.1	6.7 ± 1.4	6.6 ± 1.1	6.8 ± 1.9	6.3 ± 1.1
Common Carp	7.4 ± 0.3	7.7 ± 0.4	7.5 ± 0.4	7.8 ± 0.8	7.5 ± 0.4
Overall Mean Weight (g/fish)	8.5 ± 0.2	8.5 ± 0.2	8.2 ± 0.2	8.5 ± 0.2	8.3 ± 0.2
Total Weight (kg/pond)	0.86 ± 0.04	0.86 ± 0.04	0.84 ± 0.03	0.87 ± 0.03	0.84 ± 0.04
Stocking Density (fish/m^2)	1.02				
Species Ratio	Silver carp : mrigal : rohu : catla : grass carp : common carp = 9:8:6:6:3:2				

Table 3. Survival and mean weight of carps at harvest in 100 m^2 polyculture ponds fertilized with different regimes for 145-day culture.

Item	Fertilization regimes				
	PROSHIKA	*BRAC*	*CARITAS*	*BAU*	*CRSP*
Survival (%)					
Silver Carp	91.4 ± 1.2^{a}	93.8 ± 3.3^{a}	66.7 ± 4.3^{b}	96.3 ± 3.7^{a}	92.6 ± 2.1^{a}
Mrigal	87.5 ± 0.0^{a}	66.7 ± 4.2^{b}	80.6 ± 3.7^{a}	81.3 ± 10.4^{a}	65.3 ± 2.8^{b}
Rohu	59.3 ± 6.7^{d}	92.6 ± 7.4^{a}	64.8 ± 4.9^{bcd}	83.3 ± 5.6^{ab}	77.8 ± 3.2^{bc}
Catla	77.8 ± 3.2^{bcd}	94.4 ± 3.2^{a}	70.4 ± 3.7^{d}	88.9 ± 5.6^{ab}	85.2 ± 6.7^{bc}
Grass Carp	48.2 ± 3.7^{b}	25.9 ± 3.7^{c}	37.0 ± 3.7^{bc}	66.7 ± 11.1^{a}	63.0 ± 3.7^{a}
Common Carp	100.0 ± 0.00^{a}	88.9 ± 11.1^{a}	94.4 ± 5.6^{a}	91.7 ± 8.3^{a}	94.4 ± 5.6^{a}
Mean	79.4 ± 4.9^{a}	81.0 ± 6.4^{a}	69.3 ± 4.5^{b}	86.3 ± 4.9^{a}	79.7 ± 3.3^{a}
Mean weight (g/fish)					
Silver Carp	160 ± 2.6^{d}	215 ± 25.9^{bc}	184 ± 9.0^{cd}	241 ± 19.2^{b}	301 ± 9.4^{a}
Mrigal	64 ± 1.3^{d}	123 ± 10.5^{ab}	84 ± 4.7^{cd}	96 ± 21.9^{bc}	128 ± 2.9^{a}
Rohu	48 ± 3.0^{c}	100 ± 14.5^{ab}	48 ± 9.7^{c}	74 ± 11.3^{bc}	121 ± 1.5^{a}
Catla	57 ± 1.8^{c}	101 ± 17.6^{b}	76 ± 2.8^{bc}	112 ± 17.3^{a}	71 ± 0.9^{bc}
Grass Carp	39 ± 5.4^{b}	66 ± 5.4^{a}	45 ± 5.9^{ab}	62 ± 4.1^{a}	65 ± 7.5^{a}
Common Carp	135 ± 15.3^{d}	257 ± 27.6^{bc}	190 ± 16.6^{cd}	316 ± 3.2^{b}	408 ± 35.1^{a}
Mean	84 ± 11.4^{d}	144 ± 17.8^{b}	105 ± 14.9^{c}	150 ± 23.6^{b}	182 ± 31.4^{a}

Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

gala), rohu (Labeo rohita), catla (Catla catla), grass carp (Ctenopharyngodon idella), and common carp (Cyprinus carpio) stocked at a ratio of 9:8:6:6:3:2 at a stocking density of 1.02 fish m^{-2}, giving 27, 24, 18, 18, 9, and 6 fish per 100 m^{-2} pond, respectively. Mean stocking sizes of carps ranged from 6.3 to 10.1 g (Table 2).

Water depths in the ponds were maintained at about one meter throughout the experimental period. About 20% of stocked carps were sampled by seining monthly and weighed individually. At the end of the experiment, all harvested carps were weighed individually. Water samples integrated from the entire water column were taken biweekly near the center of each pond at approximately 1000 h for analyses of pH, total nitrogen (TN), nitrate-N, nitrite-N, total ammonia nitrogen (TAN), total phosphorus (TP), soluble reactive phosphorus (SRP), chlorophyll a, total suspended solids (TSS), total volatile solids (TVS), and total alkalinity (APHA et al., 1985; Egna et al., 1989). Just before collecting water samples, transparency was measured using a Secchi disk, while temperature and dissolved oxygen (DO) of pond water were measured at three water depths (25 cm below water surface, middle, and 25 cm

Table 4. Production of carps in 100 m^2 polyculture ponds fertilized with different regimes for 145-day culture. Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

Item	Fertilization Regimes				
	PROSHIKA	*BRAC*	*CARITAS*	*BAU*	*CRSP*
Total Weight (kg/pond)					
Silver Carp	3.9 ± 0.05^c	5.3 ± 0.70^b	3.2 ± 0.27^c	6.2 ± 0.26^{ab}	7.5 ± 0.14^a
Mrigal	1.3 ± 0.03^b	2.0 ± 0.27^a	1.5 ± 0.09^b	1.8 ± 0.19^{ab}	2.0 ± 0.08^a
Rohu	0.5 ± 0.04^c	1.6 ± 0.09^a	0.6 ± 0.12^c	1.1 ± 0.24^b	1.7 ± 0.09^a
Catla	0.8 ± 0.05^b	1.7 ± 0.24^a	1.0 ± 0.05^b	1.8 ± 0.16^a	1.1 ± 0.07^b
Grass Carp	0.2 ± 0.04^b	0.2 ± 0.0^b	0.2 ± 0.03^b	0.4 ± 0.09^a	0.4 ± 0.06^a
Common Carp	0.9 ± 0.1^d	1.3 ± 0.05^c	1.0 ± 0.03^d	1.7 ± 0.18^b	2.3 ± 0.16^a
GRAND TOTAL	7.5 ± 0.22^d	12.1 ± 0.22^c	7.4 ± 0.14^d	13.1 ± 0.22^b	15.0 ± 0.16^a
Gross Fish Yield (t ha^{-1} $year^{-1}$)	1.9 ± 0.06^d	3.1 ± 0.06^c	1.9 ± 0.04^d	3.3 ± 0.06^b	3.8 ± 0.04^a
Net Fish Yield (t ha^{-1} $year^{-1}$)	1.7 ± 0.06^d	2.8 ± 0.05^c	1.6 ± 0.04^d	3.1 ± 0.05^b	3.6 ± 0.04^a

above pond bottom) using a YSI model 54 oxygen meter (Yellow Springs Instruments, Yellow Springs, Ohio, USA). Diel measurements of DO, pH, and temperature were conducted monthly at the above mentioned three depths in each pond at 0600, 1000, 1400, 1600, 1800, and 0600 h. Cow dung was sampled weekly to determine contents of moisture, TN, and TP (Yoshida et al., 1976).

The results of fish growth performance and water quality data were analyzed for significant differences among treatments using ANOVA (Steele and Torrie, 1980). Differences were considered significant at an alpha of 0.05. All means were given with ± 1 standard error.

A partial budget analysis was conducted to determine economic returns of different fertilization regimes (Shang, 1990). The analysis was based on market prices in Bangladesh for harvested carps and all other items [expressed in Bangladesh Taka (Tk), (US $1 = Tk 56). Market prices of harvested carps were Tk 45 kg^{-1} for silver carp and Tk 55 kg^{-1} for all other carps. Market prices of carp fingerlings (TK 2 per piece), cow dung (Tk 0.66 kg^{-1}), urea (Tk 5.6 kg^{-1}), TSP (Tk 11.8 kg^{-1}), MP (Tk 12 kg^{-1}), and lime (Tk 7 kg^{-1}) were applied to the analysis.

RESULTS

Mean survival of all carps was significantly lower in the Caritas fertilization regime than in the other fertilization regimes ($P < 0.05$), between which there was no significant difference ($P > 0.05$). Survival of silver carp followed a pattern similar to that of mean survival, while survival of common carp was not significantly different among all fertilization regimes ($P > 0.05$). Survival of mrigal was significantly higher in the PROSHIKA, BAU, and Caritas fertilization regimes than in the BRAC and Aquaculture CRSP fertilization regimes ($P < 0.05$). Survival of grass carp was lowest in the BRAC fertilization regime, intermediate in the PROSHIKA and Caritas fertilization regimes, and highest in the Aquaculture CRSP and BAU fertilization regimes ($P < 0.05$), while survival of catla and rohu was highest in BRAC, intermediate in BAU and Aquaculture CRSP, and lowest in PROSHIKA and Caritas ($P < 0.05$; Table 3).

The Aquaculture CRSP fertilization regime resulted in the highest growth of silver carp, mrigal, rohu, and common carp, compared with other fertilization regimes ($P < 0.05$, Table 3). For the growth of grass carp, the highest growth was achieved in the BRAC, Aquaculture CRSP, and BAU fertilization regimes, intermediate growth was achieved in the Caritas fertilization regime, and the lowest growth was achieved in the PROSHIKA fertilization regime ($P < 0.05$). However, growth of catla in the Aquaculture CRSP fertilization regime was among the lowest, and the highest growth of catla was achieved in the BAU fertilization regime ($P < 0.05$). Generally, the fertilization regimes using cow dung alone (PROSHIKA and Caritas) resulted in poorer carp growth than those using a combination of cow dung and inorganic fertilizers (BAU, BRAC, and Aquaculture CRSP) during the culture period. Mean growth of carps was highest in the Aquaculture CRSP fertilization regime, intermediate in the BAU and BRAC fertilization regimes, and lowest in the Caritas and PROSHIKA fertilization regimes ($P < 0.05$, Table 3).

At harvest the highest total weights of all carps except for catla were achieved by the Aquaculture CRSP fertilization regime, while the highest total weight of catla was achieved by the BAU and BRAC fertilization regimes ($P < 0.05$, Table 4). Again, the fertilization regimes using cow dung alone (PROSHIKA and Caritas) gave the lowest total weights of all carps, compared to those using the various combinations of cow dung and inorganic fertilizers (BAU, BRAC, and Aquaculture CRSP) ($P < 0.05$). For all carps, the total harvest weights and extrapolated gross and net fish yields were highest from the Aquaculture CRSP fertilization regime, followed by the BAU, BRAC, PROSHIKA, and Caritas fertilization regimes ($P < 0.05$, Table 4).

Nutrient inputs in different fertilization regimes were largely different (Table 5). The nutrient inputs in the PROSHIKA fertilization regime were solely from cow dung. The fertilization regime with the lowest nutrient inputs was the PROSHIKA fertilization regime with only 0.63 kg N and 0.25 kg P during the entire 145 d culture, which is equivalent to 0.43 kg N and 0.17 kg P ha^{-1} d^{-1}, followed by the Caritas fertilization regime with 0.88 kg N and 0.28 kg P, which is equivalent to 0.61 kg N and 0.19 kg P ha^{-1} d^{-1}. The fertilization

Table 5. Nutrient inputs and nutrient contribution from inorganic fertilizers in different fertilization regimes applied into 100 m^2 polyculture ponds during the 145-day culture.

Item	Fertilization regimes				
	PROSHIKA	*BRAC*	*CARITAS*	*BAU*	*CRSP*
N Inputs					
Cow Dung	0.63	0.15	0.53	0.41	0.64
Urea	----	2.89	0.35	1.73	5.16
Total	0.63	3.04	0.88	2.14	5.80
Contribution of Urea (%)	----	95.03	39.77	80.71	88.66
N Loading Rate (kg ha^{-1} d^{-1})	0.43	2.10	0.61	1.48	4.00
P Inputs					
Cow Dung	0.25	0.05	0.20	0.16	0.27
Urea	----	0.59	0.08	0.38	1.18
Total	0.25	0.64	0.28	0.54	1.45
Contribution of TSP (%)	----	91.77	28.57	69.84	81.38
P Loading Rate (kg ha^{-1} d^{-1})	0.17	0.44	0.19	0.37	1.00
N:P ratio	2.52	4.75	3.14	3.96	4.00

* Mean values with different superscript letters in the same row were significantly different (P < 0.05).

Table 6. Mean values of water quality parameters measured biweekly at approximately 1000 h in all ponds fertilized with different regimes during the entire experimental period.

Parameters	Fertilization Regimes				
	PROSHIKA	*BRAC*	*CARITAS*	*BAU*	*CRSP*
Temperature (°C)	27.7 ± 0.1^a	27.5 ± 0.1^a	27.6 ± 0.0^a	27.5 ± 0.0^a	27.5 ± 0.1^a
DO at 0600 h (mg l^{-1})	2.88 ± 0.04^b	3.59 ± 0.05^a	2.90 ± 0.04^b	3.45 ± 0.02^a	2.08 ± 0.06^c
pH	7.33 ± 0.05^a	7.41 ± 0.11^a	7.25 ± 0.05^a	7.34 ± 0.04^a	7.43 ± 0.08^a
Total alkalinity (mg l^{-1})	109 ± 1.5^a	114 ± 4.8^a	108 ± 2.7^a	112 ± 0.0^a	115 ± 2.5^a
NO_3-N (mg l^{-1})	0.54 ± 0.02^d	0.89 ± 0.00^c	0.50 ± 0.01^d	1.03 ± 0.04^b	1.60 ± 0.03^a
NO_2-N (mg l^{-1})	0.01 ± 0.00^b	0.01 ± 0.00^b	0.01 ± 0.00^b	0.02 ± 0.00^b	0.05 ± 0.00^a
TN (mg l^{-1})	0.95 ± 0.04^c	1.59 ± 0.04^b	0.89 ± 0.02^c	1.67 ± 0.03^b	2.36 ± 0.01^a
SRP (mg l^{-1})	0.28 ± 0.01^d	0.44 ± 0.01^c	0.27 ± 0.01^d	0.52 ± 0.01^b	1.04 ± 0.01^a
TP (mg l^{-1})	0.52 ± 0.01^d	1.04 ± 0.01^c	0.53 ± 0.02^d	1.14 ± 0.03^b	1.75 ± 0.02^a
TAN (mg l^{-1})	0.23 ± 0.01^d	0.39 ± 0.02^b	0.27 ± 0.02^{cd}	0.38 ± 0.06^{bc}	0.74 ± 0.05^a
Secchi disk visibility (cm)	41 ± 0.9^d	35 ± 0.9^c	41 ± 0.0^d	32 ± 0.5^b	20 ± 1.2^a
TSS (mg l^{-1})	27 ± 0.3^d	45 ± 1.7^c	27 ± 0.3^d	50 ± 2.5^b	90 ± 0.7^a
TVS (mg l^{-1})	7 ± 0.3^c	10 ± 0.6^b	7 ± 0.3^c	11 ± 1.0^b	18 ± 0.6^a
Chlorophyll *a* (µg l^{-1})	41 ± 1.3^d	77 ± 1.1^c	45 ± 0.4^d	88 ± 4.4^b	160 ± 3.3^a

Mean values with different superscript letters in the same row were significantly different (P < 0.05).

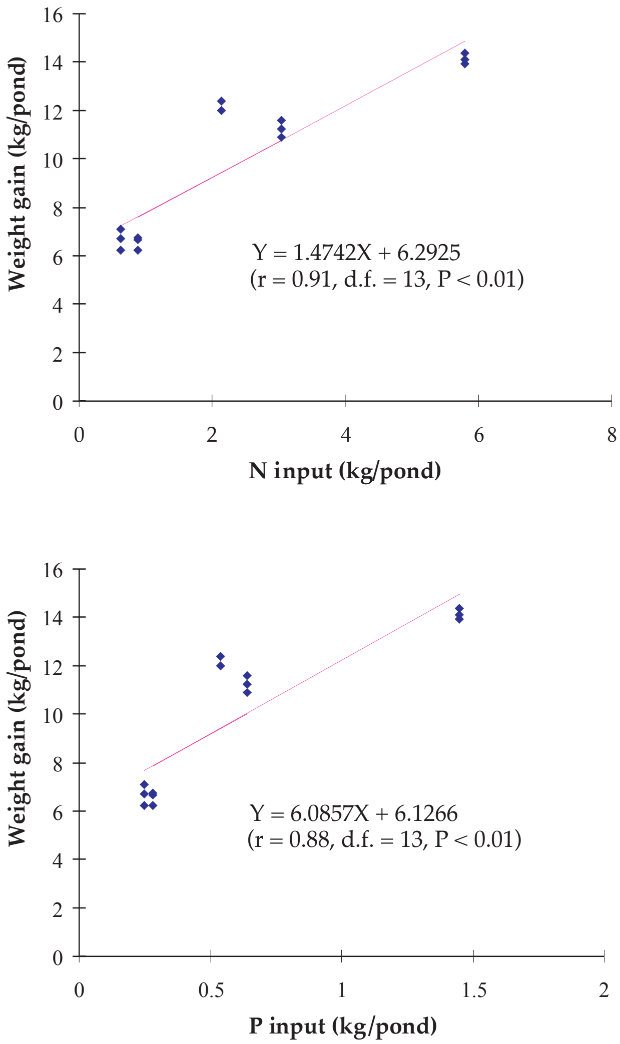

Figure 1. Relationship between nutrient input and fish weight gain in 100 m^2 carp polyculture earthen ponds for 145 d culture period.

regime with the highest nutrient inputs was the Aquaculture CRSP with 5.80 kg N and 1.45 kg P for the 145 d culture, followed by the BRAC fertilization regime with 3.04 kg N and 0.64 kg P, and the BAU fertilization regime with 2.14 kg N and 0.54 kg P, giving nutrient loading rates of 4 kg N ha^{-1} and 1 kg P ha^{-1}, 2.10 kg N ha^{-1} and 0.44 kg P ha^{-1}, and 1.48 kg N ha^{-1} and 0.37 kg P ha^{-1}, respectively. The N:P ratios were 2.52:1, 4.75:1, 3.14:1, 3.96:1, and 4:1 for the PROSHIKA, BRAC, Caritas, BAU, and the Aquaculture CRSP fertilization regimes, respectively. The highest percentage of nutrients contributed from inorganic fertilizers was from the BRAC fertilization regime (95.03% N and 91.77% P), intermediate from the Aquaculture CRSP (88.67% N and 81.38% P) and BAU (80.71% N and 69.84% P) fertilization regimes, and lowest from the Caritas fertilization regime (39.77% N and 28.57% P). Total weight gain (kg per pond) of all stocked carps was positively correlated with total nitrogen input ($r = 0.91$, $df = 13$, $P < 0.01$) and total phosphorus input ($r = 0.88$, $df = 13$, $P < 0.01$, Figure 1).

Mean values of measured water quality parameters are summarized in Table 6. Water temperature, pH, and total alkalinity concentrations were not significantly different among all fertilization regimes ($P > 0.05$). Mean DO concentrations was lowest in the fertilization regime with the highest nutrient inputs (Aquaculture CRSP), intermediate in two organic fertilization regimes with the lowest nutrient inputs (PROSHIKA and Caritas), and highest in the two fertilization regimes with moderate nutrient inputs (BAU and BRAC) ($P < 0.05$). Concentrations of all nutrient parameters (NO_3-N, NO_2-N, TAN, TN, SRP, and TP) in the Aquaculture CRSP fertilization regime were significantly higher than those in other fertilization regimes ($P < 0.05$). There were significant differences in concentration of TSS, TVS, and chlorophyll a among fertilization regimes with the highest values in the Aquaculture CRSP fertilization regime, intermediate in the BAU and BRAC fertilization regimes, and lowest in the PROSHIKA and Caritas fertilization regimes ($P < 0.05$). On the harvest day, the final values of measured water quality parameters in the Aquaculture CRSP fertilization regime, except for temperature, pH, and total alkalinity concentrations, which were not significantly different among fertilization regimes, were significantly higher than those in other fertilization regimes ($P < 0.05$, Table 7). These results imply that effluent wastes in ponds fertilized by the Aquaculture CRSP regime would release higher nutrient contents to the surrounding environment. Dissolved oxygen concentrations were lowest in this fertilization regime, while chlorophyll a concentrations reached their peak value (Figures 2 and 3).

The partial budget analysis indicates that the BAU, BRAC, and Aquaculture CRSP fertilization regimes were the most profitable fertilization strategies for carp polyculture, while the PROSHIKA and Caritas regimes produced a negative net return (Table 8). Although the Aquaculture CRSP fertilization regime resulted in higher fish production, it generated lower profits than the BAU and BRAC fertilization regimes. The highest profitability was achieved by the BAU fertilization regime followed by the BRAC fertilization regime.

DISCUSSION

The main function of animal manure in fish ponds is to release soluble nutrients that are taken up by phytoplankton, thereby providing protein-rich natural foods for filter-feeding fish (Knud-Hansen et al., 1993; Edwards et al., 1994). Cow dung used in the present study contained relatively low nutrient concentrations, only 1.16% N and 0.48% P, which are similar to levels in buffalo manure but lower than levels in all other major animal manures, especially poultry manure, which contains 3.77% N and 1.89% P (Lin et al., 1997). Shevgoor et al. (1994) attributed the relatively poor fish growth in manured ponds to inhibition of phytoplantkon growth by the marked reduction of light penetration into the water column and the relatively low soluble N and P inputs. In the present study, PROSHIKA and Caritas fertilization regimes used only cow dung as nutrient input during the culture period and resulted in low fish growth and production. Compared to other fertilization regimes, greater Secchi disk visibility in ponds fertilized by the the PROSHIKA and Caritas regimes probably reflect poor phytoplankton growth due to low soluble nutrient concentrations. Large ruminant manure from buffalo or cattle used for draught was shown to be a poor fertilizer due to low nutrient content as well as tannin in the manure that stained pond water brown (Edwards et al., 1994). Combinations of organic and inorganic fertilizers have been found to be superior to either organic or inorganic fertilizers alone (Knud-Hansen et al., 1991b; Haq et al., 1993; Lin et al., 1997), and this was also demonstrated by the higher carp production from the Aquaculture CRSP, BAU,

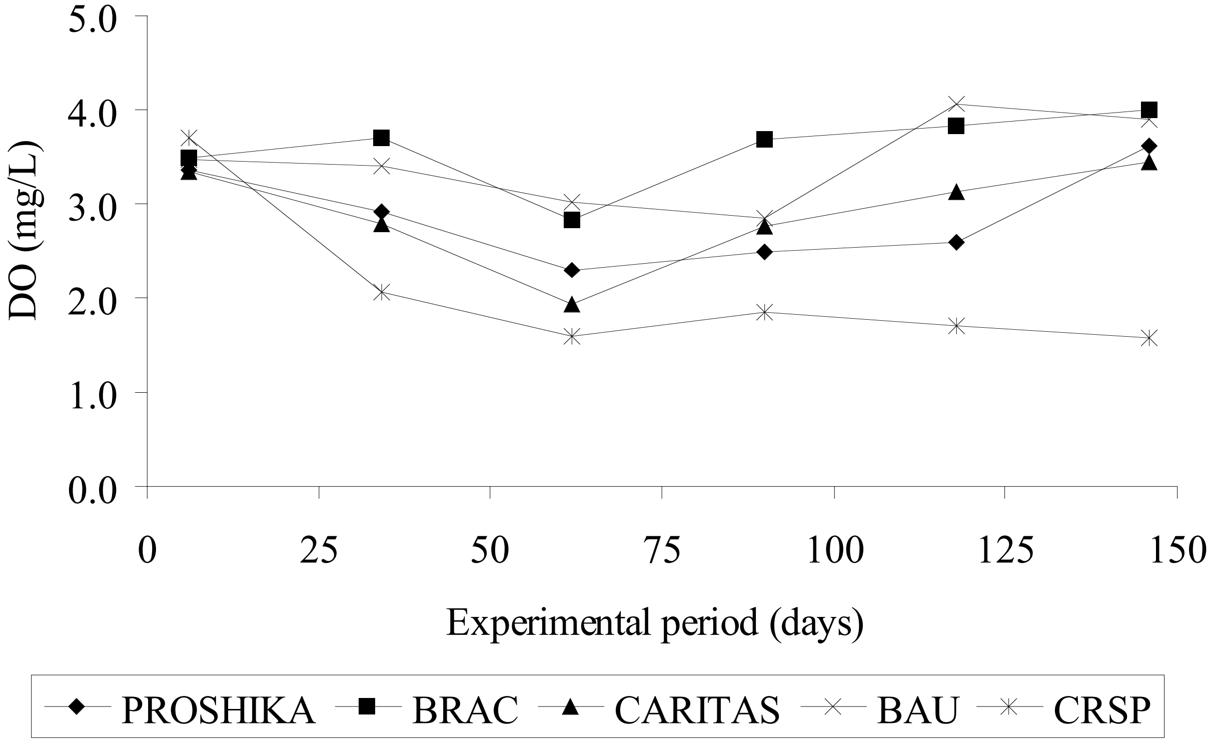

Figure 2. Mean DO concentrations at 0600 h in the carp polyculture ponds fertilized with different regimes over the 145 d experimental period.

Table 7. Final values of water quality parameters measured at approximately 1000 h in all ponds fertilized with different regimes at the end of the experiment.

Parameters	**Fertilization Regimes**				
	PROSHIKA	*BRAC*	*CARITAS*	*BAU*	*CRSP*
Temperature (C)	20.5 ± 0.3^{a}	20.6 ± 0.2^{a}	20.4 ± 0.1^{a}	20.3 ± 0.3^{a}	20.3 ± 0.2^{a}
DO at 0600 h (mg l^{-1})	3.62 ± 0.11^{bc}	4.01 ± 0.05^{c}	3.44 ± 0.22^{b}	3.89 ± 0.12^{bc}	1.57 ± 0.14^{a}
pH	7.33 ± 0.05^{a}	7.41 ± 0.11^{a}	7.25 ± 0.05^{a}	7.34 ± 0.04^{a}	7.43 ± 0.08^{a}
Total Alkalinity (mg l^{-1})	123 ± 7.4^{a}	119 ± 12.1^{a}	120 ± 4.6^{a}	111 ± 12.7^{a}	136 ± 3.5^{a}
NO_3-N (mg l^{-1})	0.73 ± 0.09^{c}	1.23 ± 0.18^{b}	0.80 ± 0.06^{c}	1.60 ± 0.00^{b}	2.93 ± 0.09^{a}
NO_2-N (mg l^{-1})	0.00 ± 0.00^{b}	0.01 ± 0.00^{b}	0.00 ± 0.00^{b}	0.01 ± 0.00^{b}	0.09 ± 0.01^{a}
TN (mg l^{-1})	1.17 ± 0.03^{c}	1.97 ± 0.09^{b}	0.97 ± 0.03^{c}	2.10 ± 0.10^{b}	3.20 ± 0.12^{a}
SRP (mg l^{-1})	0.45 ± 0.04^{c}	0.81 ± 0.06^{b}	0.43 ± 0.06^{c}	0.87 ± 0.07^{b}	1.85 ± 0.06^{a}
TP (mg l^{-1})	0.58 ± 0.03^{d}	1.30 ± 0.05^{c}	0.55 ± 0.05^{d}	1.59 ± 0.07^{b}	2.73 ± 0.06^{a}
TAN (mg l^{-1})	0.37 ± 0.07^{b}	0.37 ± 0.05^{b}	0.24 ± 0.09^{b}	0.37 ± 0.06^{b}	1.14 ± 0.10^{a}
Secchi Disk Visibility (cm)	31 ± 3.5^{b}	28 ± 4.4^{b}	31 ± 2.1^{b}	21 ± 5.0^{b}	9 ± 0.3^{a}
TSS (mg l^{-1})	36 ± 3.0^{c}	61 ± 1.8^{b}	37 ± 2.9^{c}	68 ± 4.0^{b}	157 ± 6.6^{a}
TVS (mg l^{-1})	9 ± 0.9^{c}	13 ± 0.6^{b}	9 ± 1.7^{c}	15 ± 1.0^{b}	30 ± 1.2^{a}
Chlorophyll *a* (µg l^{-1})	48 ± 9.2^{d}	73 ± 5.6^{bc}	56 ± 3.0^{cd}	92 ± 7.2^{b}	242 ± 7.7^{a}

Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

toplankton growth. The Aquaculture CRSP fertilization regime, developed from Nile tilapia monoculture ponds with relatively high stocking density, resulted in the highest carp production; however, due to low stocking density of carp in the present study, nutrient concentrations from this regime exceeded the requirements of phytoplankton and produced phytoplankton biomass beyond the requirement of carps. This result was supported by the significantly higher concentrations of all nutrient-related water quality parameters, greater phytoplankton standing crop expressed by chlorophyll a concentrations, and

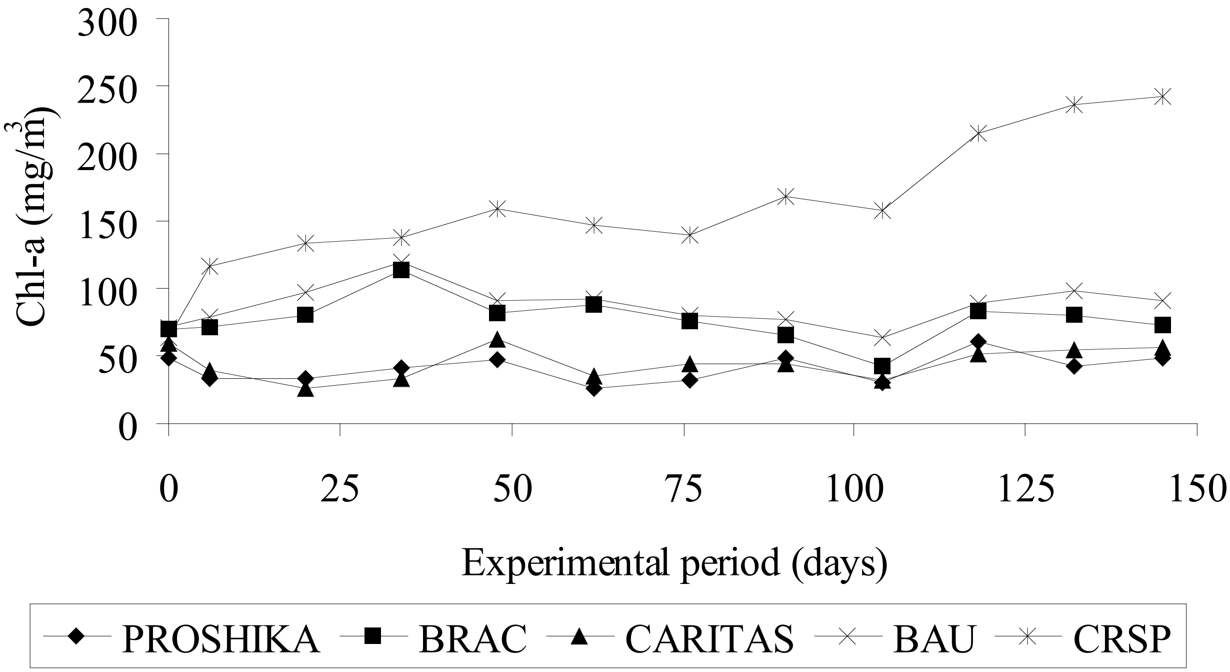

Figure 3. Mean Chlorophyll a concentrations (mg m^{-3}) at 1000 h in the carp polyculture ponds fertilized with different regimes over the 145 d experimental period.

Table 8. Partial budget analysis to compare relative profitability of different fertilization regimes applied in 100 m^2 carp polyculture ponds (unit: Tk 100 m^{-2} per 145 days).

Item	Fertilization regimes				
	PROSHIKA	*BRAC*	*CARITAS*	*BAU*	*CRSP*
Income					
Silver Carp	173.61	239.36	144.14	280.86	338.31
Grass Carp	9.58	8.31	8.35	20.53	20.59
Common Carp	46.77	73.41	54.48	95.72	126.18
Rohu	27.61	89.48	30.94	61.81	93.20
Catla	43.79	93.47	52.74	97.74	60.13
Mrigal	73.89	109.27	83.33	99.77	110.06
Total	375.25	613.30	373.98	656.43	748.47
Added Income (A)	----	238.05	-1.27	281.18	373.22
Cost					
Cow Dung	155.10	34.82	125.40	99.00	164.46
Urea	0	35.18	4.20	21.00	67.20
TSP	0	34.67	4.43	22.13	55.70
MP	0	1.13	1.50	0	0
Lime	17.50	35.00	35.00	35.00	35.00
Fingerlings	204.00	204.00	204.00	204.00	204.00
Working Capital (12%)	18.08	16.55	17.98	18.29	25.26
Total	394.68	361.35	392.51	399.42	551.62
Added Cost (B)	----	-33.33	-2.17	4.74	156.94
Increased Profit (A-B)	----	271.38	0.90	276.44	216.28

and BRAC fertilization regimes compared to the PROSHIKA and CARITAS fertilization regimes in the present study. Usually manures contain low soluble nutrients and unbalanced N:P ratios that are not sufficient to support phytoplankton growth. Adding nutrients from inorganic sources can increase and balance the nutrient availability from manures and stimulate phylower DO in the Aquaculture CRSP regime ponds compared to other fertilization regimes.

Fish production obtained from manured ponds was reported to range from 2,555 to 13,140 kg ha^{-1} yr^{-1} (Buck et al., 1979; Wohlfarth and Schroeder, 1979; Barasch et al., 1982; Wohlfarth and Hulata, 1987; Knud-Hansen et al., 1991b). Almost all the high production levels mentioned above were polycultures with tilapia and Chinese carps, where both common and silver carps accounted for a large portion of the total yield. Most of the extremely high fish production levels were obtained in the intensively manured polyculture ponds in Israel (Lin et al., 1997). Carp production in the Aquaculture CRSP, BAU, and BRAC fertilization regimes was marginally higher than the lower bound of the production range mentioned above but higher than those from the carp polyculture ponds studied by Haq et al. (1994) and Wahab et al. (1999) in the same location, as well as those from Nile tilapia monoculture ponds fertilized with buffalo manure (Edwards et al., 1994). Where fish ponds have been developed in many parts of Asia, production by small-scale rural farmers is usually less than 1 t ha^{-1} yr^{-1} due to the resource-poor nature of most farms in the tropics (Edwards et al., 1997). Appropriate fertilization strategies are clearly very important to improve the livelihood of small-scale rural farmers.

Liming requirements of fish ponds in Bangladesh are always questionable. Despite the great variability in texture, color, and composition of pond soils in Bangladesh, almost all fish ponds are limed prior to filling with water, and the relevant agencies have suggested the same liming rate of 247 kg ha^{-1} for the entire country (DOF, 1998; BFRI, 1999). The results of this study showed that total alkalinity concentrations in all ponds were greater than 100 mg l^{-1} as calcium carbonate ($CaCO_3$) during the entire culture period, despite the different liming rates during pond preparation and fish production. This alkalinity level is higher than that recommended for fish ponds even with higher intensification levels. For example, total alkalinity of 75 mg l^{-1} as $CaCO_3$ was used as an optimal level for Nile tilapia ponds in earlier Aquaculture CRSP research. Thus, the liming requirement of fish ponds should be evaluated in Bangladesh.

Considering the fish production, fertilizer input level, and economic return, the BAU fertilization regime is most appropriate for carp polyculture ponds in Bangladesh while the Aquaculture CRSP fertilization regime could be most suitable to carp polyculture ponds with higher intensification. The results of this on-station trial should be further evaluated using small-scale farmers' ponds.

ANTICIPATED BENEFITS

The results of this study have demonstrated that the BAU fertilization regime is the most appropriate fertilization strategy for polyculture of Indian and Chinese carps for small-scale rural farmers. This information will benefit fish culturists in Bangladesh and other countries in South Asia where carps are commonly used in polyculture.

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