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Growth and Economics of Silver Barb (*Barbonymus gonionotus*) in Rice-fish-vegetable Integrated Culture System at Different Stocking Densities in a Rainfed Arid Zone

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ABSTRACT

Sustainable integrated farming involving the combination of rice-fish-vegetables requires advanced technology to be adopted in crop production in arid zones characterized by red or yellow soil. In the present study, we used suitable and varying stocking densities of Silver barb (*Barbonemus gonionotus*) and evaluated in a structured production and economic framework under four treatments (T_1, T_2, T_3, and T_4) assigned with a stocking density of 10, 20, 30 and 40 fish/decimal, respectively. We used standard methods of water, soil, and plankton monitoring of the rice field. The study showed that lower stocking density provided the fish with more spaces and less competition for food resulting in higher growth performance in T_1 compared to other treatments. Although stocking density did not show any significant ($P>0.05$) effect in rice, straw and vegetable production in all the treatments, the highest rice and straw production at T_4 could be ascribed to the improvement in soil fertility by the accumulation of fish excreta and subsequent release of nutrients from the soil by the higher number of fish in that treatment. The best fitted polynomial regression line obtained between gross yield and net yield with different stocking densities of *Silver barb* described an inevitable fluctuation in net yield of fish with increasing stocking density. Despite stable growth performance of fish in T_1, a combined effect of lower total input cost, higher yield of fish and rice, and economical vegetable production, T_2 showed a significantly ($P<0.05$) higher total return. Furthermore, the benefit-cost ratio (BCR) for rice-fish-vegetables integrated culture system in the rain-fed rice field was also high. In conclusion, this study revealed that maintaining a stocking density of 20 fish/decimal was economically profitable for rice-fish-vegetables integrated culture systems in arid zones on a global scale.

INTRODUCTION

Rice-fish-vegetable culture is vital for the proper utilization of limited land resources as sustainable production of the fish protein with additional income and employment generation **(Jamu and Costa-Pierce, 1995)**. The introduction of fish into the rice fields in a properly managed way has several advantages. For instance, it helps in increasing rice yield by feeding on harmful insects, pests, and weeds **(Coche, 1967)** and improves the farm fertility by generating nitrogen and phosphorus **(Lightfoot *et al.*, 1992; Giap *et al.*, 2005; Dugan *et al.*, 2006)** that promotes species diversity and nutrient recycling **(Coche, 1967; Matteson, 2000)** and ensures a more economical utilization of land resources **(Dang *et al*., 2007)**. Bangladesh retains about 10.14 million hectares of rice fields and more than 2.83 million hectares of seasonal rice fields **(Ahmed *et al*., 2011)**. These seasonal rice fields remain in rainfed condition after the monsoon season, and it forms a unique, temporary, and rapidly changing productive habitat. Unfortunately, the potential benefits from the rice-fish system are not explored well by research, especially in arid zones characterized by red or yellow soil **(Hossain and Joadder, 2011)**.

Thai silver barb or Java barb, *Barbonymus gonionotus* (Bleeker, 1850) is a freshwater and small exotic fish species in Bangladesh. It is locally known as Thai Sharpunti, which is an herbivorous species native to South East Asia. It was first introduced to Bangladesh from Thailand in 1977, owing to its higher-yielding potential **(Rahman *et al.*, 2006)**. This species can withstand at high stocking densities and attain marketable size within 3-4 months **(Gupta and Rab, 1994)**. Even it can grow well in the shallow, turbid ponds and high production can be obtained at a low input cost, which also makes it a suitable candidate species for culture in the rice-fish integrated farming system **(Haroon and Pittman, 1997; Uddin *et al.*, 2000, 2001)**. Stocking density is one of the most crucial production factors that should be considered in aquaculture because it directly influences survival, growth, health, feeding, and net yields of cultured species **(Rowland *et al.*, 2006; Sorphea *et al.*, 2010; Pouey *et al.*, 2011)**.

However, the study for optimization of stocking density of Silver barb in rice-fish-vegetable farming system lacks in the literature, although such information is necessary for the development of sustainable rice-fish farming technology for arid zones characterized by red or yellow soil. Therefore, by considering the above issues, this study was conducted to investigate the production performance and economics of rice-fish-vegetable farming systems under different stocking densities of the Silver barb in a rain-fed arid zone.

MATERIALS AND METHODS

Study area and experimental design

The experiment was carried out for a period of four months (August - November 2015) in nine experimental rice fields of the Department of Agronomy and Agricultural Extension, University of Rajshahi, Bangladesh (Figure 1). These rice fields were rectangular, and all are in the rainfed conditions of an arid zone. The average area of each rice field was 0.024 ha (5.92 decimal). A completely randomized design (CRD) was used to allocate four treatments (T_1, T_2, T_3, and T_4) replicated three times at four levels of stocking density (10, 20, 30 and 40 fish/decimal) and a standard depth of 1 m was maintained in all ditches where the fish was stocked. The rice variety used in this experiment was BRRI-52 (Rice variety developed by Bangladesh Rice Research Institute), and vegetables were cucumber (*Cucumis sativus*) and water spinach (*Ipomoea aquatica)*, with similar-sized standing crops in all the treatments.

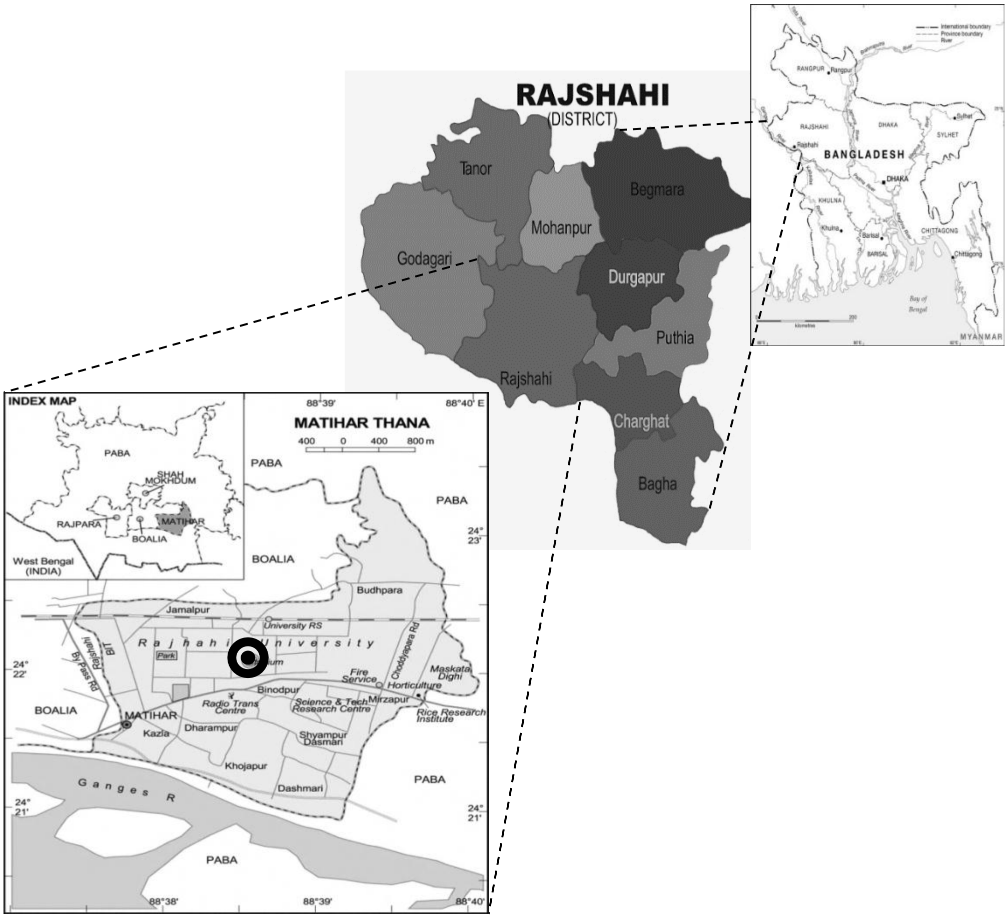

Figure 1: Location of the study area indicating the rice fields (black circle) at the Department of Agronomy and Agricultural Extension, University of Rajshahi, Bangladesh

Management of rice fields

The rice fields were ploughed with the help of a power tiller and then leveled properly by laddering to keep equal water depth throughout the field. Dykes around the land were constructed at the height of 25 cm. Weeds were removed manually from the fields before the transplantation of rice seedling. A small ditch (8 % to the total rice plot) was constructed at the lower part of the field to provide a refuge of fish during high temperatures and low water depth. The rice field was fertilized with different types of fertilizer such as Urea, Triple super phosphate (TSP), murate of potash (MP), and gypsum at the rate of 200, 100, 50, and 20 kg/ha, respectively. Organic fertilizer (cow dung) was also applied at the rate of 1500 kg/ha. The seedlings of rice (BRRI-52) were raised in the separate seedbed close to the selected fields. The seedlings were uprooted carefully for transplanting in the experimental rice field. Alternate row spacing of 35 cm and 15 cm was followed for transplanting rice seedlings following **Hossain *et al*. (1990)**. The plant to plant distance was 20 cm. Fifteen days after transplanting the rice seedlings, fish were stocked in the rice field. The mean weight of *B. gonionotus* was 12.51 g in all the treatments. Fish were harvested, followed by rice harvesting after four months of Days after Transplantation (DAT). Rice harvest was performed manually with the use of harvesting tools using sickles, consisting of a wooden handle and a knife blade. The fish were harvested by repeated netting and finally by dewatering the ditches.

Monitoring of water and sediment quality parameters

Water samples were collected monthly between 10:00, and 11:00 AM for the analysis of various physicochemical parameters using dark bottles. Water temperature and transparency were measured using a Celsius thermometer and a black and white standard color-coded Secchi disc of 30 cm diameter. Water pH was measured using an electronic pH meter (Jenwary 3020) and dissolved oxygen (DO) with a DO meter (Lutron DO-5509). Alkalinity and ammonia-nitrogen were measured using HACH kit (model FF-2, No. 2430-01; Loveland, CO, USA). Phosphate-phosphorus and nitrate-nitrogen concentrations were measured using a Hach Kit (DR/2010, a direct-reading spectrophotometer) with high range chemicals (Phos Ver. 3 Phosphate Reagent Powder Pillows for 25 ml sample for phosphate-phosphorus analysis and Nitra Ver. 5 Nitrate Reagent Powder Pillows for 25 ml sample for Nitrate-nitrogen). Samples of bottom sediment were collected randomly before and after the culture period from each treatment following the procedures described by Bangladesh Soil Research Institute (BSRI). Soil pH was measured by a glass electrode pH meter, organic matter according to **Walkley and Black (1934)**, total nitrogen by **Hesse (1972)**, phosphorus by Modified Olsen method (Hitachi, UV2800) and potassium with the help of a flame photometer. Soil samples were tested in the laboratory of the Soil Resource Development Institute (SRDI), Shyampur, Rajshahi, Bangladesh.

Monitoring of plankton

Collection of plankton was made by sieving 50 liters of habitat water from approximately 10 - 12 cm below the surface level passed through a 25 µm mesh net and finally concentrated to 25 ml and immediately preserved in 4% formalin. One ml from the agitated sample was transferred to a Sedge- wick Rafter counting cell (S-R cell) and observed under a binocular microscope (Olympus, M-4000D) following **APHA (1992)** method. Identification of plankton to the genus level was carried out using the keys from **Ward and Whipple (1959)**, **Prescott (1962)**, and **Bellinger (1992)**. The number of plankton in the S-R cell was derived from the following formula:

$$N = \frac{A \times 100 \times C}{V \times F \times L}$$

Where, N = No. of plankton cells per liter, A = Total no. of plankton counted, C = Volume of final concentrate of samples in ml, V = Volume of a field in cubic millimeter, F = number of the fields counted and L = Volume of original water in liter.

Fish growth parameters

Weight gain (g) = Mean final weight (g) - Mean initial weight (g)

$$\%\ weight\ gain\ (\%) = \frac{\text{Mean final weight (g)} - \text{Mean initial weight (g)}}{\text{Mean initial weight (g)}} \times 100$$

Survival rate (%) = **Error!**× 100

SGR (%, bwd^{-1}) = **Error!**× 100

Average daily weight gain (ADG) = $\frac{\text{Final weight} - \text{Initial weight}}{\text{Culture period}}$

Performance Index (PI) = Survival rate × $\frac{\text{Final weight} - \text{Initial weight}}{\text{Culture period}}$

Gross yield (kg/ha) = Sum of the individual weight of harvested fish

Net yield (kg/ha) = Fish biomass at harvest – Fish biomass at stock

Rice, straw and vegetable yield

Rice, straw, and vegetable yields were determined after harvesting and finally converted into t/ha and kg/ha, respectively.

Economic analysis

At the end of the study period, an economic analysis was performed to estimate the net return and benefit-cost ratio (BCR) for different ditch sizes in the rice-fish-vegetable farming system. The following simple equation was used, according to **Asaduzzaman *et al.* (2010)**:

$$R = I - (FC + VC + Ii)$$

Where, R = net return, I = income from Silver barb sale, FC = fixed/common costs, VC = variable costs and Ii =interest on inputs

The BCR was determined as:

BCR = Total net return/Total input cost

Statistical analyses

Data on water quality, soil quality, fish growth, yield parameters, and economic performance were analyzed by one-way ANOVA at 95 % level of confidence. When a mean effect was significant, the ANOVA was followed by Duncan New Multiple Range Test **(Duncan, 1955)** at a 5% level of significance **(Gomez and Gomez, 1984)**. Sediment quality parameters were compared before and after the culture period by paired sample *t-test*. The percentages and ratio data were analyzed using arcsine transformed data. The statistical packages used for the analysis of data included Microsoft Excel (v. 2010) and SPSS (Statistical Package for Social Science, v. 20.0, IBM Corporation, Armonk, NY, USA).

RESULTS

1.1. Physicochemical water quality assessment

Mean values (mean ± SD) of water quality parameters measured during the study period are shown in Table 1. Mean water temperature ranged from 31.41±0.07 (T_2) to 31.45±0.17 ºC (T_4), transparence from 27.71±0.87 (T_1) to 32.28±0.5 cm (T_4), pH from 7.15±0.05 (T_2) to 7.18±0.06 (T_3), DO from 4.84±0.18 (T_4) to 5.01±0.04 mg/l (T_1), alkalinity from 60.96±0.40 (T_4) to 61.29±0.19 mg/l (T_3), ammonia nitrogen from 0.09±0.01 (T_1) to

0.14±0.01 mg/l (T_4), phosphate-phosphorus from 0.29±0.02 (T_1) to 0.34±0.01 mg/l (T_4) and nitrate-nitrogen ranged from 1.13±0.03 mg/l (T_1) to 1.35±0.03 mg/l (T_4). There were no significant differences ($P>0.05$) in water temperature, pH, dissolved oxygen and alkalinity. However, in the mean values of transparency, ammonia nitrogen, phosphate-phosphorus and nitrate-nitrogen varied significantly ($P<0.05$) across the treatments of different stocking densities.

Table 1: Mean values of the selected water quality parameters (Mean ± SD) in the rice-fish-vegetable fields over four months under rainfed conditions

Parameters	**Treatments**			
	T_1	**T_2**	**T_3**	**T_4**
Water temperature (ºC)	s	31.41±0.07^{a}	31.41±0.12^{a}	31.45±0.17^{a}
Transparence (cm)	27.71±0.87^{d}	29.77±0.45^{c}	31.01±0.60^{b}	32.28±0.54^{a}
pH	7.16±0.04^{a}	7.15±0.05^{a}	7.18±0.06^{a}	7.16±0.05^{a}
Dissolved oxygen (mg/l)	5.01±0.04^{a}	4.91±0.08^{a}	4.85±0.13^{a}	4.84±0.18^{a}
Alkalinity (mg/l)	61.26±0.14^{a}	61.22±0.22^{a}	61.29±0.19^{a}	60.96±0.40^{a}
Ammonia nitrogen (mg/l)	0.09±0.01^{c}	0.10±0.01^{c}	0.12±0.01^{b}	0.14±0.01^{a}
Phosphate-phosphorus (mg/l)	0.29±0.02^{b}	0.30±0.01^{b}	0.31±0.01^{b}	0.34±0.01^{a}
Nitrate-nitrogen (mg/l)	1.13±0.03^{c}	1.15±0.02^{c}	1.22±0.02^{b}	1.35±0.03^{a}

T_1 = 10 fish per decimal, T_2 = 20 fish per decimal, T_3 = 30 fish per decimal and T_4 = 40 fish per decimal. Mean values with different superscript letters in the same row indicate significant differences ($P<0.05$).

1.2. Soil quality assessment

Mean values (mean ± SD) of soil quality parameters before and after the rice-fish-vegetable culture and outcomes of a paired *t-test* comparing the before and after culture condition are shown in Table 2. Organic matter (%), phosphorus (ppm), and potassium (ppm) content of sediment were significantly ($P<0.05$) increased after the rice-fish farming. However, significant changes occurred in soil quality parameters in T_4; whereas the stocking density was the highest, and changes were lower in $T_{1,}$ where stocking density was the lowest. Changes in the mean values of total nitrogen (%) and pH were also observed, but these changes were not significantly different ($P>0.05$) from before to after rice-fish farming.

1.3. Assessment of Plankton Biomass

Variations in the mean cell density of major groups of phytoplankton and zooplankton are shown in Table 3. The phytoplankton population recorded during the study period was divided into four groups viz. *Chlorophyceae*, *Bacillariophyceae*, *Cyanophyceae,* and *Euglenophyceae*, as well as the zooplankton populations into four major groups, viz., *Rotifera*, *Cladocera*, *Copepoda*, and *Crustaceans*. Among the four groups of phytoplankton and zooplankton, *Chlorophyceae* and *rotifers* were the most dominant group in all the treatment during the study period, respectively. There were significant differences ($P<0.05$) in the mean values of total phytoplankton and total zooplankton among the treatments. The mean cell density of total phytoplankton was the highest in T_1 ($18.48\pm0.15\times10^3$ cells/l) and the lowest in T_4 ($6.90\pm0.02\times10^3$ cells/l). Similarly, the mean cell density of total zooplankton was the highest in T_4 ($6.90\pm0.02\times10^3$ cells/l) and the lowest in T_1 ($6.04\pm0.06\times10^3$ cells/l).

Table 2: Comparison of selected soil quality parameters before and after the rice-fish-vegetable culture during the four months of culture period under rainfed conditions

Soil quality parameters	Treatments	Before rice-fish culture	After rice-fish culture	Change (%)	*t-value*	*p-value*
Organic matter (%)	T_1	1.72±0.03^b	2.03±0.02^a	15.43	-13.035**	0.006
	T_2	1.77±0.02^b	2.83±0.11^a	37.57	-15.273**	0.004
	T_3	1.72±0.08^b	3.09±0.04^a	44.17	-34.691***	0.001
	T_4	1.72±0.04^b	3.25±0.15^a	46.92	-14.309**	0.005
Total nitrogen (%)	T_1	0.08±0.01^a	0.09±0.01^a	15.82	-1.387	0.300
	T_2	0.07±0.02^a	0.09±0.01^a	21.11	-2.000	0.184
	T_3	0.08±0.01^a	0.11±0.01^a	28.11	-2.500	0.130
	T_4	0.07±0.02^a	0.11±0.01^a	34.60	-2.619	0.120
pH	T_1	6.07±0.54^a	6.63±0.18^a	8.54	-2.834	0.105
	T_2	6.15±0.83^a	6.89±0.13^a	10.90	-1.698	0.232
	T_3	5.92±0.49^a	6.90±0.28^a	14.11	-2.758	0.110
	T_4	5.96±0.39^a	6.50±0.25^a	8.18	-1.511	0.270
Phosphorus (ppm)	T_1	11.24±0.12^b	12.33±0.40^a	8.72	-4.836*	0.040
	T_2	11.18±0.03^b	12.85±0.24^a	12.98	-11.579**	0.007
	T_3	11.19±0.07^b	13.75±0.20^a	18.60	-16.905**	0.003
	T_4	11.26±0.05^b	14.73±0.14^a	23.56	-35.233***	0.001
Potassium (ppm)	T_1	55.89±0.25^b	75.69±0.16^a	26.15	-78.823***	0.000
	T_2	56.11±0.20^b	77.34±0.73^a	27.45	-56.612***	0.000
	T_3	55.95±0.18^b	78.55±1.08^a	28.76	-31.812***	0.001
	T_4	55.89±0.29^b	81.10±0.24^a	31.08	-91.912***	0.000

T_1 = 10 fish per decimal, T_2 = 20 fish per decimal, T_3 = 30 fish per decimal and T_4 = 40 fish per decimal. Mean values with different superscript letters in the same row indicate significant differences (P<0.05). *P<0.05, **P<0.01, ***P<0.001.

Table 3: Variation in the mean values of cell density (×10^3 cells/l) of major groups of phytoplankton and zooplankton under different treatments.

Groups	Treatments			
	T_1	**T_2**	**T_3**	**T_4**
Chlorophyceae	9.59±0.09^a	9.36±0.03^b	9.19±0.04^c	8.38±0.06^d
Bacillariophyceae	4.57±0.08^a	4.50±0.06^a	4.17±0.05^b	3.64±0.12^c
Cyanophyceae	3.60±0.06^a	3.53±0.03^a	3.36±0.13^b	3.22±0.09^b
Euglenophyceae	0.72±0.04^a	0.57±0.04^b	0.50±0.02^c	0.45±0.03^c
Total phytoplankton	**18.48±0.15^a**	**18.05±0.10^b**	**17.21±0.21^c**	**15.69±0.24^d**
Rotifera	2.41±0.05^b	2.48±0.07^b	2.50±0.15^b	2.79±0.05^a
Cladocera	1.52±0.03^c	1.67±0.04^b	1.66±0.05^b	1.78±0.02^a
Copepoda	1.41±0.08^c	1.47±0.03^{bc}	1.51±0.03^{ab}	1.57±0.02^a
Crustacean	0.69±0.01^b	0.73±0.01^a	0.74±0.03^a	0.76±0.03^a
Total zooplankton	**6.04±0.06^c**	**6.36±0.09^b**	**6.41±0.14^b**	**6.90±0.02^a**

T_1 = 10 fish per decimal, T_2 = 20 fish per decimal, T_3 = 30 fish per decimal and T_4 = 40 fish per decimal. Mean values with different superscript letters in the same row indicate significant differences (P<0.05).

1.4. Account of growth performance, survival rate and yield

Mean values (mean ± SD) of growth, survival rate, performance index, and yield of Silver barb in rice-fish-vegetable culture plots over four months under rain-fed conditions are presented in Table 4 and Figure 2. At the end of the study period, all growth parameters in terms of final weight, weight gain, percent weight gain, average daily gain (ADG) and SGR were significantly ($P<0.05$) decreased from lower (T_1) to higher (T_4) stocking density. The survival rate was significantly ($P<0.05$) lower in T_4 compared to T_1, T_2, and T_3. The performance index of fish in all treatments was significantly ($P<0.05$) different from the highest values observed in T_1 and the lowest in T_4. Although all growth parameters, survival rate, and performance index of fish were the highest in T_1, significantly ($P<0.05$) higher gross and net yield (kg/ha) were recorded from T_2. The linear regression line revealed that weight gain (Figure 3A) and survival rate (Figure 3B) were inversely related to a stocking density of Silver barb. In the case of net fish production, the data was interpreted by the best fitted polynomial regression line analysis to show the relationship between productions at different stocking densities (Figure 4).

Table 4: Growth, survival, performance index, and yield of *B. gonionotus* in rice-fish-vegetable culture fields over four months duration under rainfed culture conditions.

Parameters	Stocking densities (fish/decimal)			
	T_1	T_2	T_3	T_4
Initial weight (g)	12.46±0.25^a	12.44±0.29^a	12.57±0.32^a	12.56±0.29^a
Final weight (g)	130.43±2.50^a	127.40±1.39^a	100.70±10.56^b	71.65±5.96^c
Weight gain (g)	117.97±2.46^a	114.96±1.48^a	88.13±10.59^b	59.09±5.93^c
% weight gain	946.73±25.59^a	924.45±28.32^a	701.68±89.11^b	470.79±48.07^c
Survival rate (%)	90.44±2.68^a	89.50±3.71^a	67.33±5.48^b	60.00±3.95^c
SGR (%/day)	1.96±0.02^a	1.94±0.02^a	1.73±0.10^b	1.45±0.07^c
ADG (g)	0.98±0.02^a	0.96±0.01^a	0.74±0.09^b	0.49±0.05^c
Performance index (PI)	88.88±2.10^a	85.71±2.85^a	49.59±7.88^b	29.42±1.83^c
Gross yield (kg/ha/120 days)	286.56±14.83^d	563.15±19.75^a	503.79±74.57^b	423.21±21.11^c
Net yield (kg/ha/120 days)	255.77±15.03^d	501.68±19.03^a	410.65±73.67^b	299.15±20.42^c

T_1 = 10 fish per decimal, T_2 = 20 fish per decimal, T_3 = 30 fish per decimal and T_4 = 40 fish per decimal. Mean values with different superscript letters in the same row indicate significant differences ($P<0.05$).

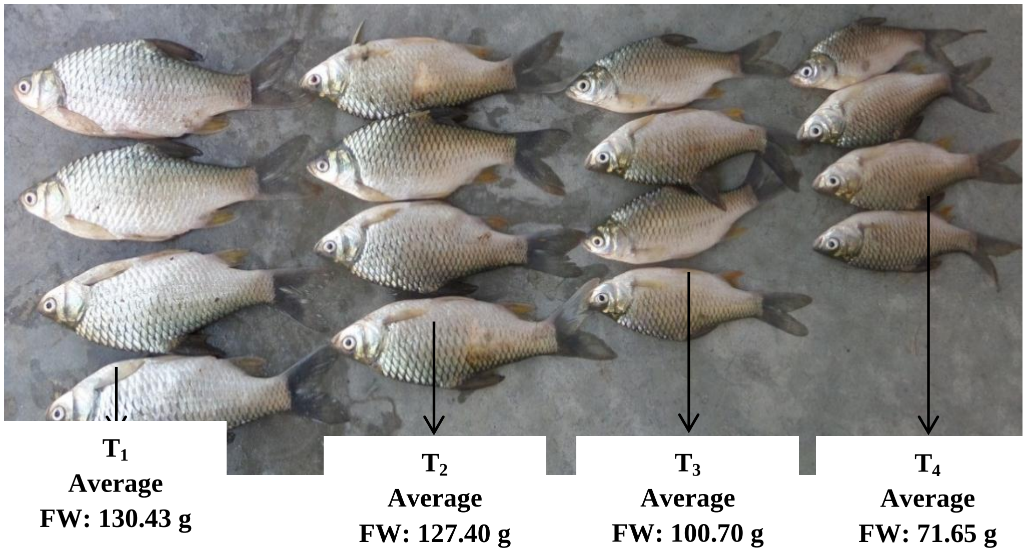

Figure 2: The average final weight of experimental fish at different stocking densities

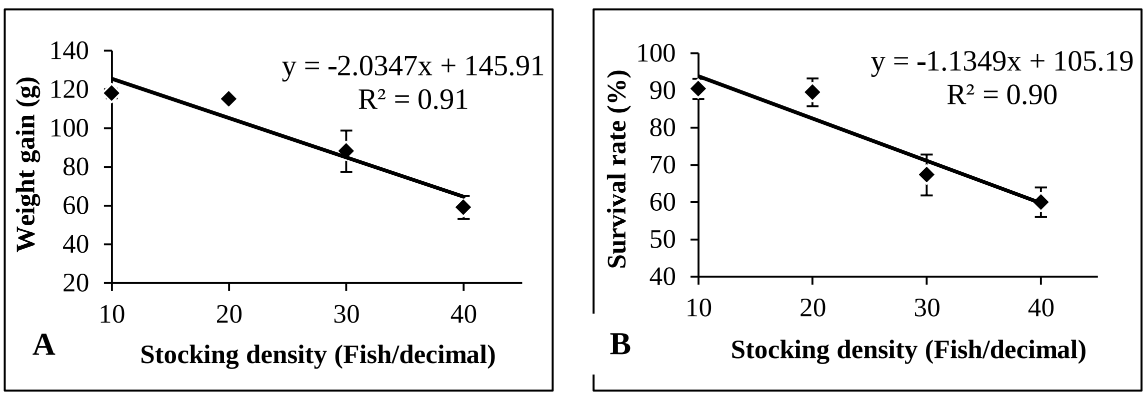

Figure 3: Relationship between weight gain (A) and stocking density (B) of Thai silver barb after 120 days of culture period in the rice-fish-vegetable farming system

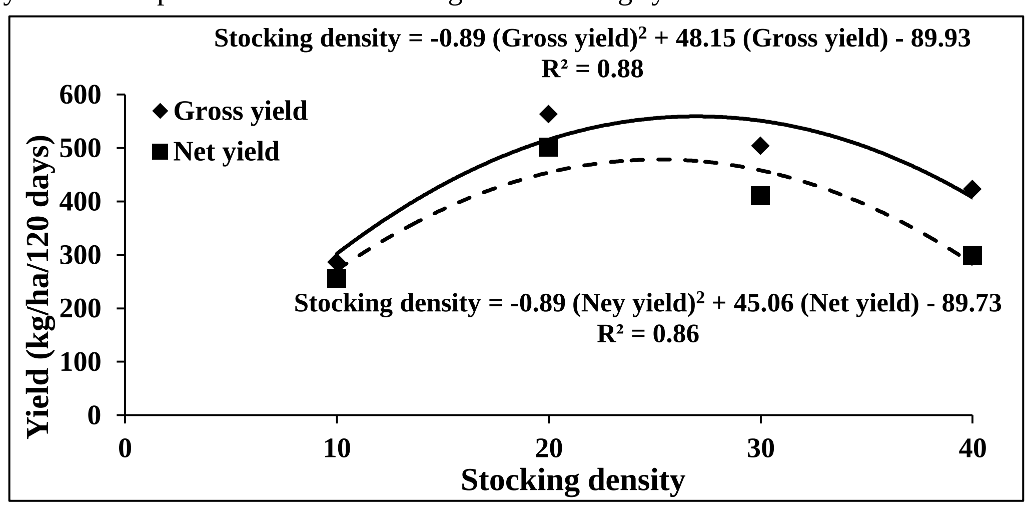

Figure 4: Relationship between net yield and stocking density of Silver barb after 120 days of culture period in the rice-fish-vegetable farming system

1.5. Yield economics and stocking density relationships

No significant difference (P<0.05) was observed in rice, straw, and vegetable production with the increasing stocking density of Silver barb (Table 5). The highest rice production was in T_4 (6.40±0.04 t ha^{-1}) whereas the stocking density was highest followed by T_3 (6.38±0.03 t ha^{-1}), T_2 (6.37±0.03 t ha^{-1}) and T_1 (6.35±0.02 t ha^{-1}). The highest straw production was also observed in T_4 (8.27±0.08 t ha^{-1}) and lowest in T_1 (8.17±0.06 t ha^{-1}). The vegetable production was the highest in T_2 (67.50±3.32 kg ha^{-1}) followed by T_1 (66.96±1.72 kg ha^{-1}), T_4 (66.90±1.48 kg ha^{-1}) and the lowest was in T_3 (66.88±1.88 kg ha^{-1}).

Table 5: Comparison of means of rice, straw, and vegetable yield under different treatments in rice-fish-vegetable culture plots over four months under rainfed conditions.

Parameters	Stocking densities (fish/decimal)			
	T_1	**T_2**	**T_3**	**T_4**
Rice (t/ha)	$6.36±0.02^a$	$6.37±0.03^a$	$6.38±0.03^a$	$6.40±0.04^a$
Straw (t/ha)	$8.17±0.06^a$	$8.21±0.13^a$	$8.25±0.10^a$	$8.27±0.08^a$
Vegetables (kg/ha)	$66.96±1.72^a$	$67.50±3.32^a$	$66.88±1.88^a$	$66.90±1.48^a$

T_1 = 10 fish per decimal, T_2 = 20 fish per decimal, T_3 = 30 fish per decimal and T_4 = 40 fish per decimal. Mean values with similar superscript letters in the same row indicate no significant differences (P<0.05).

Economics of rice-fish-vegetable culture system is shown in Table 6. The results revealed that the total cost of inputs in T_1 was significantly (P<0.05) lower than T_2, T_3, and T_4. On the other hand, significantly (P<0.05) higher gross return was obtained from T_2 followed by T_3, T_4, and T_1. The highest net return was also obtained from T_2 followed by T_3, T_4, and T_1. Although increasing stocking density in T_2 increased net returns by 21.61 %, further increase in stocking density in T_3 and T_4 decreased the net returns by 12.64 % and 18.43 %, respectively, compared to T_2. Overall, the highest benefit-cost ratio (BCR) was obtained in T_2 (2.48) and the lowest in T_4 (1.57).

Table 6. Comparison of economic parameters among the treatments in the rice-fish-vegetable culture system (1 ha rice field and 120 days of experimental duration). Values are in Bangladeshi Taka (BDT). 1 USD = 84.91 BDT.

Variables	Treatments			
	T_1	**T_2**	**T_3**	**T_4**
Variable cost				
Fertilizer	7301.52	7301.52	7301.52	7301.52
Labor	12516.89	12516.89	12516.89	12516.89
Seed (Rice + Fish+ vegetable)	11287.96^d	20193.73^c	29796.27^b	38841.81^a
Land preparation	9387.67	9387.67	9387.67	9387.67
Ditch management	798.70	798.70	798.70	798.70
Post-management cost	928.72	928.72	928.72	928.72
Total variable cost	42221.46^d	51127.23^c	60729.77^b	69775.31^a
Fixed cost				
Land used cost	14326.00	14326.00	14326.00	14326.00
Total cost	56547.46^d	65453.23^c	75055.77^b	84101.31^a
Interest on inputs (4 months)	1884.92^d	2181.77^c	2501.86^b	2803.38^a
Total inputs	**58432.37^d**	**67635.00^c**	**77557.63^b**	**86904.69^a**

Financial return				
Fish	42983.15[c]	84471.93[a]	72042.05[b]	71289.28[b]
Rice	136561.12[b]	139092.96[ab]	139805.04[a]	140161.08[a]
Straw	8633.44[c]	9956.07[b]	10461.62[a]	10504.28[a]
Vegetables	1540.03	1582.98	1545.04	1556.54
Gross return	189717.73[c]	235103.93[a]	223853.75[b]	223511.18[b]
Net return	**131285.36[c]**	**167468.93[a]**	**146296.12[b]**	**136606.50[bc]**
Benefit-cost ratio (BCR)	**2.25[b]**	**2.48[a]**	**1.89[c]**	**1.57[d]**

T_1 = 10 fish per decimal, T_2 = 20 fish per decimal, T_3 = 30 fish per decimal and T_4 = 40 fish per decimal. Mean values with different superscript letters in the same row indicate significant differences ($P<0.05$).

DISCUSSION

Water quality plays a significant role in the consistent biological and physiological functions in fish **(Atique *et al.*, 2020a; Hara *et al.*, 2020; Khanom *et al.*, 2020; Saeed *et al.*, 2020; Haque *et al.*, 2020)** and is largely determined by the density of fish species in the culture and natural ecosystems **(Atique *et al.*, 2020b; Atique and An, 2018, 2019; Bae *et al.*, 2020; Moon *et al.*, 2020; Zhang *et al.*, 1987)**. In this study, the mean water temperature ranged from 31.41±0.07 ºC (T_2) to 31.45±0.17 ºC (T_4), which was more or less similar to the findings of **Hossain *et al.* (2013)**, who recorded water temperature ranged between 31.5 to 31.9 ºC in the rice field for fish culture system. Significantly higher transparency at T_4 during the study period might also be due to the lower abundance of phytoplankton and higher stocking density of fish. Similar findings were also reported by **Wahab *et al.* (2001)** while studying the optimization of stocking density of Silver barb in pond culture conditions. Insignificant variations in pH were obtained during the study period by corroborating with the findings of **Hossain and Joadder (2011)** in their experiment on the rice-fish culture system. An increase in the stocking density reduced the DO in T_4 and signified the presence of a higher amount of fish that grazed a huge amount of phytoplankton and reduced the photosynthetic activity in the rice fields. Increasing the number of fish in T_4 also produced higher metabolic deposition and organic load, which were responsible for higher ammonia nitrogen in the treatment (**Razzak *et al.*, 2009; Iqbal *et al.*, 2020**), who reported an increasing trend of ammonia with an increase in culture days due to higher metabolic deposition and organic load in the rice field. The higher level of phosphate-phosphorus and nitrate-nitrogen in T_4 was also due to the results of bioaccumulation and bioperturbation (can be defied as burrowing, ingestion and defecation of sediment) effects of fish fecal materials **(Razzak *et al*., 2009)**. Overall, the water quality importance to the survival and growth of fish is well-known and should always be considered as a priority regime for management options **(Atique *et al.*, 2019; Kim *et al.*, 2019; Atique and An, 2020).**

Higher stocking density induced accumulation of fish excreta and better stirring and turbulence action was also responsible for changing organic matter (46.92 %), phosphorus (23.56 %) and potassium (31.08 %) content of the soil after fish harvesting at T_4. Similar results were also reported by **Mohanty *et al.* (2004)** and **Mridha *et al*. (2014)**. In contrast, they reported an increase in soil nutrients after fish culture in the rice field. However, the values of soil nutrients obtained in the present study were similar to the values recorded by **Mondol (2001)** and **Kunda *et al*. (2008)**.

Higher stocking densities of fish in the present experiment also affected the phytoplankton in T_4 by their higher consumption rate. The present findings agreed with the findings of **Wahab et al. (2001)** and **Rahman and Monir (2013)**, who reported a decrease in phytoplankton with an increase in stocking density due to the consumption of a higher amount of phytoplankton by the increased number of fishes in the pond.

Lower stocking densities provided the fish with more spaces and less competition for foods that resulted in higher growth performance in T_1 compared to other treatments. These findings are in agreement with **Mohanty *et al*. (2004)**, **Rahman and Verdegem (2010)** and **Mridha *et al*. (2014)**, who stated that high-density fishes face comparatively higher competition for food and space that causes physiological stress to fish that, could be responsible for lower growth performance at higher stocking densities. Higher growth performance and survival at lower stocking density for the same species was also reported by **Mollah *et al.* (2011)** and **Rahman *et al*. (2015)** in earthen ponds, by **Moniruzzaman *et al*. (2015)** in floating cages, and by **Mehboob *et al.* (2017)** and **Khan *et al.* (2018)** in experimental fish tanks. The survival rate of fish was also significantly ($P < 0.05$) decreased with increasing stocking density because of the mortality of fish in the rice field **(Rothuis *et al*., 1998; Mridha *et al*., 2014)**. The lower recovery rate of fish at higher stocking density in the rice-fish production system was also reported by **Ali *et al*. (2006)**. The performance index of the fish significantly ($P < 0.05$) decreased with increasing stocking density as well.

In the present study, the higher fish yield was observed in T_2 (gross and net yields as 547.86±24.35 and 486.40±23.51 kg/ha, respectively), where the stocking density was 20 fish /decimal. These results agreed with the findings of **Hossain and Joadder (2011)**, who also used a stocking density of 4940 tilapia fingerling/ha (20 fish/decimal in 120 days of culture period) and obtained a total yield of 614 kg/ha. Although the fish yield obtained by **Hossain and Joadder (2011)** was slightly higher than the present study, the fish yield obtained in the present study was within the range of 200 to 935 kg/ha reported by **Haroon and Pittman (1997)**, **Frei and Becker (2005)**, **Frei *et al*. (2007)** and **Mridha *et al*. (2014)**. The linear regression revealed a strong inverse relationship between weight gain and survival rate with stocking density. Similar findings were reported by **Moniruzzaman *et al*. (2015)** for the same fish species when studying the effect of stocking density on growth performance and yield of Thai silver barb in floating net cages. During the present study, a best fitted polynomial regression line was obtained ($R^2 = 0.8848$ for gross yield and $R^2 = 0.8642$ for net yield) between gross yield and net yield with different stocking densities of *B. gonionotus*. This regression line described that at a certain level, the net yield of fish increased, and after that, net yield decreased with increasing stocking density. Similar are the reports by **Mridha *et al*. (2014)** for tilapia (*Oreochromis nilotics*) in the rice-fish farming system.

There was no significant ($P < 0.05$) effect of stocking density in rice, straw, and vegetable production in all the treatments. In the present study, the highest rice and straw production was observed in T_4 (6.40±0.04 t ha^{-1} and 8.27±0.08 t ha^{-1}). This could be linked to the improvement of soil fertility by an increased number of fish. A similar observation was also made by **Giap *et al.* (2005)**, **Hossain *et al.* (2010)** and **Mridha *et al*. (2014)**. They stated that fish in rice fields stimulate the activities of microorganisms, which causes increased availability of organic matter by fish excreta and increases the release of nutrients. As a result, better rice production was obtained. No significant effect of stocking density on total vegetable production was found during the study period.

Although the growth performance of fish was found the highest in T_1, and the highest total return and benefit-cost ratio (BCR) were recorded in T_2. It might be due to the combined effect of lower total input cost, higher yield of fish and rice, and moderate vegetable production compared to other treatments. This finding agreed with **Mridha *et al.* (2014)**, who reported that medium-density (20 fish/decimal or 5000 fish/ha) of tilapia in the rice-fish system was more profitable than other higher and lower stocking densities. However, the BCR obtained in the present study was higher than the finding of **Mridha *et al.* (2014)**, which was due to the addition of an extra 1559.32 BDT/ha income from vegetables.

CONCLUSION

We used a combination of rice, fish, and vegetable cultured simultaneously in the rice fields with varying fish stocking densities. The results of our study suggest that Silver barb (*B. gonionotus*) is a suitable candidate fish species for the rice-fish-vegetable integrated farming system in arid zones where rainfed conditions prevail. The best performance of this species could be achieved by the stocking density of 20 fish individuals per decimal (4940 fishes/ha). Therefore, this study recommended that the stocking density of 20 fish per decimal would be a suitable option for farmers to culture fish in integrated farming of rice-fish-vegetable under rainfed conditions around the world. This study highlights the feasibility of integrated fish farming in arid zones with global implications.

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