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Optimization of stocking density and mixture ratio of tilapia and carp in rice-fish culture for higher bio-economic efficiency

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Abstract

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Meeting the demand for carbohydrate and animal protein to feed the ever increasing population of Bangladesh is a huge challenge. Integrated rice-fish farming offers a unique solution to this problem. However, the productivity and profitability of rice-fish culture mostly depend on suitable fish species, mixture ratio in case of polyculture and stocking density among others. The study was, therefore, conducted to evaluate the effect of stocking density and mixture ratio on the productivity of rice cum Nile tilapia and Common carp fish culture. Fifteen different combinations of three stocking densities (8, 16 and 24 fingerlings 10 m^{-2}) and five mixture ratios of nile tilapia and common carp (1:1, 1:0, 0:1, 1:2 and 2:1) along with rice sole culture were considered as experimental treatments arranged in a randomized complete block design with three replications. All the rice yield parameters (except thousand grain weight) were enhanced due to integration of fish which resulted in increased grain weight $hill^{-1}$. Stocking densities of 16 or 24 fingerlings 10 m^{-2} irrespective of mixture ratio produced higher grain weight $hill^{-1}$ than 8 fingerlings 10 m^{-2}. But rice sole and rice-fish culture produced similar grain yield despite higher grain weight $hill^{-1}$ in rice-fish culture, because keeping ditches in rice-fish culture allowed lower no. of hills compared to rice sole culture. Both tilapia and carp showed highest growth rate and survival rate (%) at the lowest stocking density (8 fingerlings 10 m^{-2}) irrespective of mixture ratio. But tilapia showed the highest productivity in monoculture (1:0) at the stocking densities of 24 or 16 fingerlings 10 m^{-2} (764.1 and 687 kg ha^{-1}, respectively); carp on the other hand yielded the highest in monoculture (0:1) at the stocking densities of 8 or 16 fingerlings 10 m^{-2} (828.7 and 747.9 kg ha^{-1}, respectively). Culture of tilapia and carp in 1:2 ratio @ 24 fingerlings 10 m^{-2} with rice resulted in the highest total fish (tilapia+carp) yield (930 kg ha^{-1}). All the rice-fish culture systems resulted in higher gross return and higher net return (except monoculture of carp @ 24 fingerlings 10 m^{-2}) than rice sole culture. Only lowest stocking density irrespective of mixture ratio produced higher Benefit cost ratio (BCR) than rice sole culture. On the other hand, higher stocking densities resulted in lower BCR. Therefore, for higher productivity, mixed culture of tilapia and carp in 1:2 ratio @ 24 fingerlings 10 m^{-2} can be integrated with rice, but from economic view point, monoculture of carp @ 24 fingerlings 10 m^{-2} in rice field may be recommended.

Keywords: Rice-fish farming; stocking density; mixture ratio; tilapia; carp; economics

Introduction

The demand for rice and fish is constantly increasing in Bangladesh with nearly three million people being added each year to the population of the country (Chowdhury, 2009). Nevertheless, integrated rice-fish farming offers a solution to this problem by contributing to food, income and nutrition. Not only the adequate supply of carbohydrate, but also the supply of animal protein is significant through rice-fish farming. Fish, particularly small fish, are rich in micronutrients and vitamins, and thus human nutrition can be greatly improved through fish consumption (Larsen et al., 2000; Roos et al., 2003). Benefits of rice-fish culture go beyond producing additional fish in the paddy field. It is believed that the fish control weeds and pests in the paddy fields, allowing integrated pest management (IPM), and there is a fertilizing effect from the fish excrement, which increases the nutrient availability to the rice crop (Yinhe, 1995; Frei & Becker, 2005). Rice-fish culture preserves an ecological balance in the paddy field and may not only be a higher yielding but also a more sustainable farming system (Berg, 2001, 2002).

Rice-fish culture has long been recognized as an option to improve the productivity of the country's rice based agriculture. The total area of rice fields in Bangladesh is about 10.14 million ha with an additional 2.83 million ha of inundated seasonal rice fields where water remains for about 4-6 months (BRKB, 2010). The carrying capacities of these lands and waters are not fully utilized, but there exists tremendous scope for increasing fish production by integrating rice and fish culture (Wahab et al., 2008).

Stocking density is one of the most important variables in aquaculture because it directly influences survival, growth, behavior, health, water quality, feeding and production. The full utilization of space for maximum fish production through intensive culture can improve the profitability of the fish farm. Fish intensification by increasing stocking density is also found suitable to overcome the problem of land shortage (Khattab et al*.,* 2004). Growth, survival and yield effects of stocking density on aquaculture are well known for a diversity of species (Garr et al., 2011; Khatune-Jannat et al., 2012) and seem to impact production differently. In many studies it has been observed that both growth performance and survival rate of several fish species like African catfish, Thai climbing perch, Silver catfish and Tilapia tended to be higher in lower stocking density (Sorphea et al., 2010; Pouey et al., 2011; Zhu et al., 2011) but only survival is higher under same conditions in *Oreochromis* spp. (Ridha, 2005). Generally high density is considered as a potential source of stress, with a negative effect on fish growth rate (Lefrançois et al., 2001) and survival and feeding rates (Rowland et al., 2006).

Fishes are stocked in rice field at different mixture ratio belong to fish monoculture or polyculture. Polyculture or composite culture is the system in which fast growing compatible species of different feeding habits are stocked in different proportions in the same ponds (Jhingran, 1975). The basic principles of the polyculture species of different feeding habits are culture in the same pond to avoid food competition and best utilization of natural food of different habits without any harm to each other. It is a fact that, polyculture may produce an expected result if the fish with different feeding habits are stocked in proper ratios and combinations (Halver, 1984).

Therefore, stocking density and mixture ratio of different fish species are important determinants for the productivity of rice-fish farming system. But these issues have not been properly addressed by the researchers under Bangladesh context. In view of the above discussion, the present experiment was undertaken to recognize the most suitable stocking density and mixture ratio of nile tilapia and common carp to obtain maximum harvest and economic return from rice-fish farming.

Materials and Methods

Experimental Site

The experiment was conducted at the Agronomy field laboratory of Bangladesh Agricultural University, Mymensingh located at 24°75' N latitude and 90°50' E longitude and at an altitude of 18 meter above the sea level during the period from December 2017 to May 2018 in the Boro season. The experimental area belongs to the non-calcareous dark grey soil under Agro-ecological Zone of the Old Brahmaputra Floodplain (AEZ-9). The land was medium high and well drained with silty-loam texture. The soil of the experimental field was more or less neutral in reaction (pH: 6.64) organic matter content (1.23%), total nitrogen (0.11%), available phosphorous (26.05 ppm), exchangeable potassium (0.16 me%) and the general fertility level of the soil was low. The general climate of the locality is sub-tropical in nature and is characterized by high temperature and heavy rainfall during Kharif season (April to September) and scanty of rainfall associated with moderately low temperature during Rabi season (October to March). The average air temperature, rainfall (monthly total), relative humidity (monthly average) and sunshine hours (monthly total) during the experimental period ranged from 16.8–26.8°C, 0.0– 915.2 mm, 76.1–83.3% and 147–192.4 h, respectively.

Experimental Treatments and Design

Fifteen different combinations of three stocking densities (8, 16 and 24 fingerlings 10 m^{-2}) and five mixture ratios of nile tilapia and common carp (1:1, 1:0, 0:1, 1:2 and 2:1) along with rice sole culture were considered as experimental treatments arranged in a randomized complete block design (RCBD) with three replications. A brief description of the crop variety and fish species used in this experiment (Table 1). Thus total number of plot was 48. Each plot size was 5 m × 3 m. A shallow (50 cm depth) ditch of size 3 m × 0.5 m was kept in each plot.

Rice culture

Healthy and vigorous seeds of rice BRRI dhan 29 were soaked in water for 24 hours and then kept in gunny bags for seed sprouting. Sprouted rice seeds were sown in the wet nursery bed on 5 December 2017. The experimental land was prepared by a power tiller 10 days before transplanting. It was then puddled well with the help of a country plough. Rice field was fertilized with chemical fertilizers and/or compost as per experimental treatments. Compost was applied before rice transplanting following incorporation with soil with the help of a spade. The full doses of TSP, MoP, and gypsum and zinc sulphate were applied before transplanting as basal dose. Urea was top dressed in three equal splits, at 15, 30 and 45 days after transplanting (DATs). Forty days old seedlings were transplanted in the well prepared puddled field on 15 January 2018 at the rate of three seedlings $hill^{-1}$ maintaining row and hill distance of 25 cm and l5 cm, respectively. In case of rice-fish culture, rice seedlings were transplanted in 4.5 m × 3 m area of each individual plot excluding the shallow ditch area of 3 m × 0.5 m. While for rice sole culture, whole plot was transplanted with rice maintaining the same spacing. Weeding was done manually thrice at 20, 40 and 60 DATs. The crop was grown under fully irrigated condition. A water depth of 15–20 cm was maintained throughout the growing season to favor fish culture. While in the shallow pond, the water depth was continuously around 50 cm. There were no remarkable infestations by insect pests or diseases during the crop growth period. Therefore, no plant protection measures were taken. The crop was harvested at full maturity *i.e.* when about 80% of the seeds became golden yellow in color.

Fish culture

A small ditch was constructed to provide refuge during high water temperature and low depth water in the edge of each plot containing fish. The length, width and depth of the ditch were 3 m, 0.5 m and 0.5 m respectively. Before releasing of fingerlings, each experimental plot was enclosed with net very carefully from the bottom of the mud to the top 1 m so that fished could not go away**.** The fingerlings of both nile tilapia and common carp (initial length of 6 cm & 8 cm and weight of 5.75 g & 9.75 g, respectively) were collected from Bangladesh Fisheries Research Institute (BFRI). All fingerlings were released after 15 days of transplanting of rice (30^{th} January, 2018). No artificial feed was supplemented for the growth of fish. The fishes were harvested on 29^{th} June 2018 after 150 days from the releasing date (after harvesting of rice).

Observations made

Five rice hills (excluding border hills) were randomly selected in each plot and uprooted before harvesting for recording the necessary data on various plant characters.

Growth parameters of rice like plant height and total tillers $hill^{-1}$ and yield parameters such as, number of effective tillers $hill^{-1}$, number of grains $panicle^{-1}$, 1000-grain weight, grain weight $hill^{-1}$; straw yield, biological yield and harvest index were recorded. Fish growth was record-

Table 1. A brief description of the crop variety and fish species used in this experiment

Materials	Cultivar/variety	Key features
Rice	BRRI dhan 29 *(Oryza sativa)*	BRRI dhan29 is the most popular high yielding *boro* rice variety developed by the Bangladesh Rice Research Institute. The plant is 80–100 cm in height. It matures within 140–160 days with yield of 5–6 t ha^{-1}. The grains are medium bold with white kernels. It is resistant to sheath blight, leaf blight, stem rot, tungro and blast disease.
Fish	Nile tilapia (*Oreochromis nilotcus*)	Tilapias are saprophyte-feeders, feeding on a diverse range of filamentous algae and plankton. Adults reach up to 60 cm (24 in) in length and up to 4.3 kg (9.5 lb). It lives for up to nine years. It tolerates brackish water and survives temperatures between 8 and 42°C. The Nile tilapia reproduces through mass spawning of a brood within a nest made by the male.
	Common carp (*Cyprinus carpio*)	Common carp prefer large bodies of slow or standing water and soft, vegetative sediments in groups of five or more; naturally live in temperate climates in fresh or slightly brackish water with a pH of 6.5–9.0 and salinity up to about 0.5%, and temperatures of 3 to 35°C. The ideal temperature is 23 to 30°C, with spawning beginning at 17 to 18°C. Common carp are omnivorous. They can eat a herbivorous diet of aquatic plants, but prefer to scavenge the bottom for insects, crustaceans (including zooplankton), crawfish, and benthic worms. An egg-layer, a typical adult female can lay 300,000 eggs in a single spawn.

ed in terms of initial individual fingerling length, initial individual fingerling weight, final length at harvest, final weight at harvest, % length gain, % weight gain, length gain day^{-1}, weight gain day^{-1}, survival rate %. After harvesting, fish yield was recorded and expressed as kg ha^{-1}. Different fish growth parameters were measured with the following formulae:

Length gain (%)

Percent length gain of every fish species was calculated using the following formula:

$$\text{Length gain (\%)} = \frac{\text{(Final length of individual fish – Initial length of individual fish)}}{\text{(Initial length of individual fish)}} \times 100 \ldots\ldots \quad \text{(i)}$$

Weight gain (%)

Percent weight gain of every fish species was calculated using the following formula

$$\text{Weight gain (\%)} = \frac{\text{Final wt. of individual fish – Initial wt. of individual fish}}{\text{Initial wt.of individual fish}} \times 100 \ldots\ldots \quad \text{(ii)}$$

Length gain day^{-1}

Length gain per day of every fish species was calculated using the following formula:

$$\text{Length gain/day} = \frac{\text{Final length of individual fish- Initial length of individual fish}}{\text{Growing period (150 days)}} \times 100 \ldots\ldots \quad \text{(iii)}$$

Weight gain day^{-1}

Weight gain per day of every fish species was calculated using the following formula:

$$\text{Weight gain/day} = \frac{\text{Final wt.of individual fish- Initial wt.of individual fish}}{\text{Growing period (150 days)}} \ldots\ldots \quad \text{(iv)}$$

Survival rate

The survival rate was estimated by the following formula:

$$\text{Survival rate (\%)} = \frac{\text{No.of fishes harvested}}{\text{No.of fishes released}} \times 100 \ldots\ldots \quad \text{(v)}$$

Economic study

Economic performance was evaluated in terms of total variable cost, gross return and net return which was calculated based on the local market price of different inputs, products, by products and labor wages. Benefit cost ratio of different treatments was calculated as follows:

Statistical Analysis

The collected data were compiled and tabulated in the proper form and analyzed statistically. Analysis of variance (ANOVA) was done following the randomized complete block design (RCBD) with the help of computer package MSTAT and the mean differences among the treatments were adjudged by Duncan's Multiple Range Test.

Results and Discussion

Performance of Rice BRRI dhan29

Growth parameters

Plant height and tillering ability of rice BRRI dhan29 were significantly affected by stocking density and mixture ratio of tilapia and carp. At harvest, the tallest plant (87.10 cm) was recorded when tilapia and carp were stocked in 2:1 ratio @ 24 fingerlings 10 m^{-2} and the shortest plant (80.43 cm) was found in sole rice cultivation (control) (Table 2). At harvest, the highest number of total tillers hill^{-1} (9.56) was obtained from carp monoculture (0:1 ratio) @ 24 fingerlings 10 m^{-2} while the lowest one (8.16) was recorded with carp monoculture (0:1 ratio) @ 8 fingerlings 10 m^{-2} (Table 2).

Yield parameters

Number of effective tillers hill^{-1}, number of grains panicle^{-1}, weight of thousand grains, grain weight hill^{-1} of rice BRRI dan29 were significantly affected by stocking density and mixture ratio of tilapia and carp but 1000-grain weight was not affected. The maximum number of effective tiller

Table 2. Effect of stocking density and mixture ratio of tilapia and carp on growth and yield parameter of BRRI dhan29

Treatments		Plant height (cm) at harvest	No. of total tillers hill^{-1} at harvest	No. of effective tillers hill^{-1}	No. of grains	1000-grain weight (g)	Grain weight hill^{-1} (g)
Stocking density	Mixture ratio (Tilapia : Carp)						
8 fingerlings 10 m^{-2}	1:1	81.47 cd	8.33 c	7.300 c	127.0 c-f	20.53	19.11 c-f
	1:0	82.07 b-d	8.53 c	7.16 c	125.7 d-f	20.47	18.58 d-f
	0:1	81.40 cd	8.16 c	7.433 c	131.0 a-d	20.73	20.18 b-f
	1:2	83.00 a-d	8.26 c	7.533 c	128.0 c-f	20.60	19.87 b-f
	2:1	82.50 b-d	8.60 c	7.267 c	124.3 ef	20.50	18.48 ef
16 fingerlings 10 m^{-2}	1:1	84.10 a-d	9.03 b	8.033 b	130.7 a-e	21.03	22.33 a-f
	1:0	83.93 a-d	9.26 ab	8.533 ab	129.3 b-e	21.20	23.43 a-c
	0:1	84.53 a-d	9.16 ab	8.300 ab	132.7 a-c	21.23	23.33 a-d
	1:2	85.03 a-c	9.46 ab	8.600 a	127.0 c-f	20.70	22.22 a-f
	2:1	84.63 a-d	9.43 ab	8.400 ab	135.0 ab	21.53	24.37 ab
24 fingerlings 10 m^{-2}	1:1	85.23 a-c	9.26 ab	8.033 b	131.3 a-d	21.27	22.43 a-f
	1:0	84.90 a-d	9.46 ab	8.233 ab	132.7 a-c	21.50	23.38 a-d
	0:1	86.20 ab	9.56 a	8.600 a	136.3 a	21.53	25.24 a
	1:2	85.60 a-c	9.40 ab	8.167 ab	131.7 a-d	21.43	23.16 a-e
	2:1	87.10 a	9.63 a	8.267 ab	134.7 ab	21.63	24.04 ab
Control		80.43 d	8.23 c	7.300 c	121.7 f	20.20	17.82 f
Sx		1.32	0.146	0.161	1.95	0.341	1.42
Level of sig.		*	**	**	**	NS	**
CV (%)		2.72	2.81	3.52	2.60	2.81	11.34

In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS=Not significant

hill^{-1} (8.60) was recorded when tilapia and carp were stocked in 1:2 ratio @ 16 fingerlings 10 m^{-2} or in carp monoculture (0:1) ratio @ 24 fingerlings 10 m^{-2} and the minimum number of effective tillers hill^{-1} (7.167) was obtained from tilapia monoculture (1:0) @ 8 fingerlings 10 m^{-2} (Table 2). The highest number of grains panicle^{-1} (136.3) was recorded with carp monoculture (0:1) @ 24 fingerlings 10 m^{-2} while the lowest one (121.7) was found in sole rice cultivation (no fish) (Table 2). The highest grain weight hill^{-1} (25.24 g) was recorded when tilapia and carp were stocked in carp monoculture @ 24 fingerlings 10 m^{-2} while the lowest one was found in sole rice cultivation (no fish) (Table 2).

Yield

Grain yield and harvest index were significantly affected by stocking density and mixture ratio of tilapia and carp but straw yield and biological yield were significantly affected**.** The highest straw yield (6.46 t ha^{-1}) was found in sole rice cultivation (no fish) while the lowest one (5.43 t ha^{-1}) was recorded when tilapia and carp were stocked in the ratio of 0:1 or 2:1 @ 8 fingerlings 10 m^{-2} (Table 3).

Performance of Fish

Performance of nile tilapia

All the growth parameters and yield of nile tilapia were significantly affected stocking density and mixture ratio of nile tilapia and common carp. The highest individual length at harvest (15.25 cm) was observed in tilapia monoculture (1:0) @ 8 fingerlings 10 m^{-2} and the lowest one (12.96 cm) was recorded when tilapia and carp were stocked in 1:1 ratio @ 24 fingerlings 10 m^{-2} (Table 4). The highest length gain (154.2%) of tilapia was observed in tilapia monoculture (1:0) @ 8 fingerlings 10 m^{-2} while the lowest one (116.1%) was recorded when tilapia and carp were released in 1:1 ratio @ 24 fingerlings 10 m^{-2} (Table 4).

The highest length gain day^{-1} (0.0617 cm) in tilapia monoculture (1:0) @ 8 fingerlings 10 m^{-2} and the lowest one (0.0464 g) was recorded when tilapia and carp were stocked in 1:1 ratio @ 24 fingerlings 10 m^{-2} (Table 4). The highest individual weight at harvest (89.50 g) was found in tilapia monoculture (1:0) @ 8 fingerlings 10 m^{-2} and the lowest one was recorded when tilapia and carp were stocked in 1:1 ratio @ 24 finger-

Table 3. Effect of stocking density and mixture ratio of tilapia and carp on yield of BRRI dhan29

Treatments		Grain yield, t ha^{-1}	Straw yield, t ha^{-1}	Biological yield, t ha^{-1}	Harvest index, %
Stocking density	Mixture ratio (Tilapia : Carp)				
8 fingerlings 10 m^{-2}	1:1	5.26	5.83 b-d	11.10 bc	47.45
	1:0	5.06	5.66 b-f	10.73 b-d	47.12
	0:1	5.13	5.43 f	10.57 d	48.57
	1:2	5.10	5.96 b	11.07 bc	46.08
	2:1	5.13	5.43 f	10.57 d	48.58
16 fingerlings 10 m^{-2}	1:1	5.23	5.76 b-e	11.00 b-d	47.58
	1:0	5.13	5.60 c-f	10.73 b-d	47.84
	0:1	5.23	5.60 c-f	10.83 b-d	48.30
	1:2	5.10	5.90 bc	11.00 b-d	46.35
	2:1	5.16	5.50 ef	10.67 cd	48.43
24 fingerlings 10 m^{-2}	1:1	5.23	5.53 d-f	10.77 b-d	48.63
	1:0	5.30	5.86 bc	11.17 b	47.48
	0:1	5.23	5.60 c-f	10.83 b-d	48.30
	1:2	5.30	5.53 d-f	10.83 b-d	48.94
	2:1	5.20	5.66 c-f	10.87 b-d	47.84
Control		5.53	6.46a	12.00 a	46.11
Sx		0.123	0.091	0.143	0.759
Level of sig.		NS	**	**	NS
CV (%)		4.07	2.75	2.26	2.75

In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)
** = Significant at 1% level of probability, NS= Not significant

Table 4. Effect of stocking density and mixture ratio of tilapia and carp on length and weight of tilapia

Treatments		Individual length at harvest, cm	Length gain, %	Length gain day^{-1}, cm	Individual weight at harvest, g	Weight gain, %	Weight gain day^{-1}, g
Stocking density	Mixture ratio (Tilapia : Carp)						
8 fingerlings 10 m^{-2}	1:1	14.89 a	148.1 a	0.0592 b	84.22 a-c	1364.8 a-c	0.5233 ab
	1:0	15.25 a	154.2 a	0.0617 a	89.50 a	1456.5 a	0.5600 a
	1:2	15.06 a	151.1 a	0.0604 ab	85.38 a-c	1384.9 a-c	0.5300 a
	2:1	15.04 a	150.7 a	0.0603 ab	86.58 ab	1405.8 ab	0.5400 a
16 fingerlings 10 m^{-2}	1:1	14.22 b	137.1 b	0.0548 c	76.07 cd	1223.0 cd	0.4700 bc
	1:0	13.55 cd	125.8 cd	0.0503 d	64.55 ef	1022.6 ef	0.3933 d
	1:2	14.22 b	136.9 b	0.0548 c	76.67 b-d	1233.4 b-d	0.4733 bc
	2:1	14.03 bc	133.8 bc	0.0535 c	73.04 de	1170.2 de	0.4500 c
24 fingerlings 10 m^{-2}	1:1	12.96 d	116.1 d	0.0464 f	52.35 g	810.4 g	0.3067 e
	1:0	13.23d	120.6 d	0.0482 e	57.22 fg	895.2 fg	0.3433 de
	1:2	13.24 d	120.6 d	0.0482 e	57.51 fg	900.2 fg	0.3467 de
	2:1	13.58 cd	126.4 cd	0.0505 d	63.08 f	997.0 f	0.3833 d
Sx		0.193	3.23	0.0006	3.16	54.92	0.018
Level of sig.		**	**	**	**	**	**
CV (%)		2.38	4.14	4.14	7.58	8.23	8.13

In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)
** = Significant at 1% level of probability

lings 10 m^{-2} (Table 4). The highest weight gain (1456.5%) was observed in tilapia monoculture (1:0) stocked @ 8 fingerlings 10 m^{-2} and the lowest one (810.4%) was recorded when tilapia and carp were stocked in 1:1 ratio @ 24 fingerlings 10 m^{-2} (Table 4). The highest weight gain day^{-1} (0.5600 g) was obtained when tilapia and carp were stocked in 1:0 ratio @ 8 fingerlings 10 m^{-2} and the lowest weight gain day^{-1} (0.3067 g) was recorded when tilapia and carp were stocked in 1:1 ratio @ 24 fingerlings 10 m^{-} (Table 4).

The highest survival rate (86.11%) was recorded with tilapia monoculture (1:0) @ 8 fingerlings 10 m^{-2} and the lowest one (48.61%) was obtained when tilapia and carp were stocked in 2:1 ratio @ 24 fingerlings 10 m^{-2} (Figure 1). The highest yield (764.1 kg ha^{-1}) of tilapia was obtained in tilapia monoculture (1:0) @ 24 fingerlings 10 m^{-2} while the lowest one (170.8 kg ha^{-1}) was recorded when tilapia and carp were released in 1:2 ratio @ 8 fingerlings 10 m^{-2} followed by 1:2 ratio with 16 or 24 fingerlings 10 m^{-2} and 1:1 ratio with 8 fingerlings 10 m^{-2} (Figure 2).

Performance of common carp

All the growth parameters and yield of nile tilapia were significantly affected stocking density and mixture ratio of nile tilapia and common carp. The highest individual length (20.06 cm) at harvest was obtained in carp monoculture (0:1) @ 8 fingerlings 10 m^{-2} and the lowest one (16 cm) of tilapia was recorded when tilapia and carp were stocked in 0:1 ratio

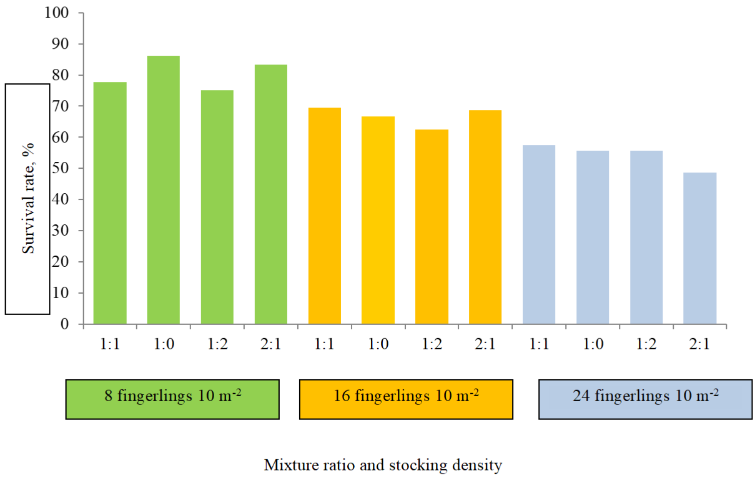

Fig. 1. Effect of mixture ratio and stocking density of nile tilapia and common carp on survival rate of nile tilapia

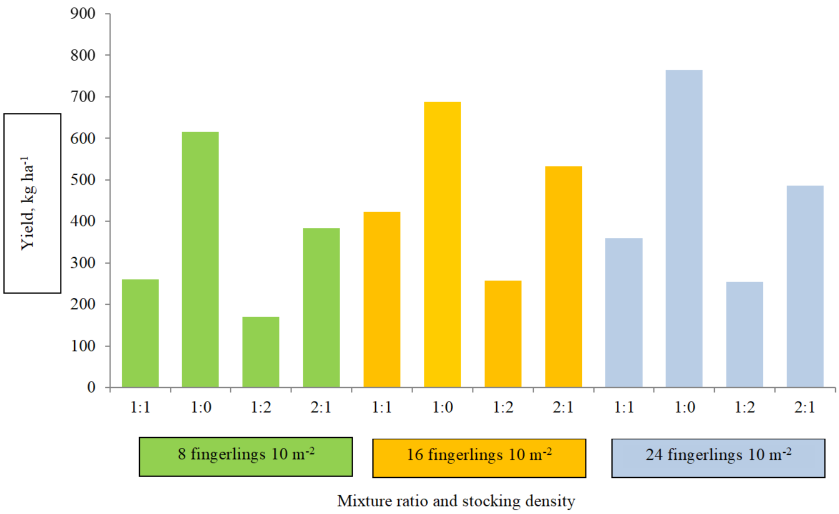

Fig. 2. Effect of mixture ratio and stocking density of nile tilapia and common carp on yield of nile tilapia

Table 5. Effect of stocking density and mixture ratio of tilapia and carp on length and weight of carp

Treatments		Individual length at harvest, cm	Length gain, %	Length gain day^{-1}, cm	Individual weight at harvest, g	Weight gain, %	Weight gain day^{-1}, g
Stocking density	Mixture ratio (Tilapia : Carp)						
8 fingerlings 10 m^{-2}	1:1	19.41 ab	128.4 ab	0.0727 a-c	114.7 ab	1076.3 ab	0.6997 ab
	0:1	20.06 a	136.0 a	0.0770 a	124.1 a	1173.3 a	0.7627 a
	1:2	19.42 ab	128.5 ab	0.0728 a-c	114.7 ab	1076.4 ab	0.6997 ab
	2:1	19.78 ab	132.7 ab	0.0752 ab	119.2 a	1123.0 a	0.7300 a
16 fingerlings 10 m^{-2}	1:1	18.76 a-c	120.7 a-c	0.0684 a-d	103.5 a-d	961.9 a-d	0.6253 a-d
	0:1	17.99 b-d	111.7 b-d	0.0633 b-e	88.31 b-e	805.8 b-e	0.5237 b-e
	1:2	17.93 b-e	110.9 b-e	0.0628 b-e	90.96 b-e	833.0 b-e	0.5413 b-e
	2:1	18.93 a-c	122.7 a-c	0.0695 a-d	106.1 a-c	988.3 a-c	0.6427 a-c
24 fingerlings 10 m^{-2}	1:1	16.52 de	94.39 de	0.0535 e	71.11 e	629.3 e	0.4090 e
	0:1	16.00 e	88.28 e	0.0500 e	64.25 e	559.0 e	0.3633 e
	1:2	17.01 c-e	100.1 c-e	0.0567 de	77.63 de	696.2 de	0.4527 de
	2:1	17.41 c-e	104.8 c-e	0.0593 c-e	83.69 c-e	758.4 c-e	0.4930 c-e
Sx		0.600	7.06	0.0041	8.21	84.21	0.055
Level of sig.		**	**	**	**	**	**
CV (%)		5.69	10.64	10.64	14.73	16.39	16.38

In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)
** = Significant at 1% level of probability

@ 24 fingerlings 10 m^{-2} (Table 5). The highest length gain (136%) was observed in carp monoculture (0:1) @ 8 fingerlings 10 m^{-2} and the lowest one (88.28%) was recorded when tilapia and carp were stocked in carp monoculture (0:1) @ 24 (Table 5). The highest length gain day^{-1} (0.0770 cm) was resulted in carp monoculture (0:1) @ 8 fingerlings 10 m^{-2} while the lowest one (0.0500 g) was obtained in carp monoculture (0:1) @ 24 fingerlings 10 m^{-2} (Table 5).

The highest individual weight (124.1 g) at harvest was observed in carp monoculture (0:1) @ 8 fingerlings 10 m^{-2} while the lowest value was observed (64.25 g) in carp monoculture (0:1) @ 24 fingerlings 10 m^{-2} (Table 5). The highest weight gain percentage (1173.3%) was found in carp monoculture (0:1) @ 8 fingerlings 10 m^{-2} and the lowest one (559%) was recorded with carp monoculture (0:1) @ 24 fingerlings 10 m^{-2} (Table 5). The highest weight gain day^{-1} (0.7627 g) was obtained when tilapia and carp were stocked in 0:1 ratio @ 8 fingerlings 10 m^{-2} while the lowest one (0.3633 g) was resulted in carp monoculture (0:1) @ 24 fingerlings 10 m^{-2} (Table 5).

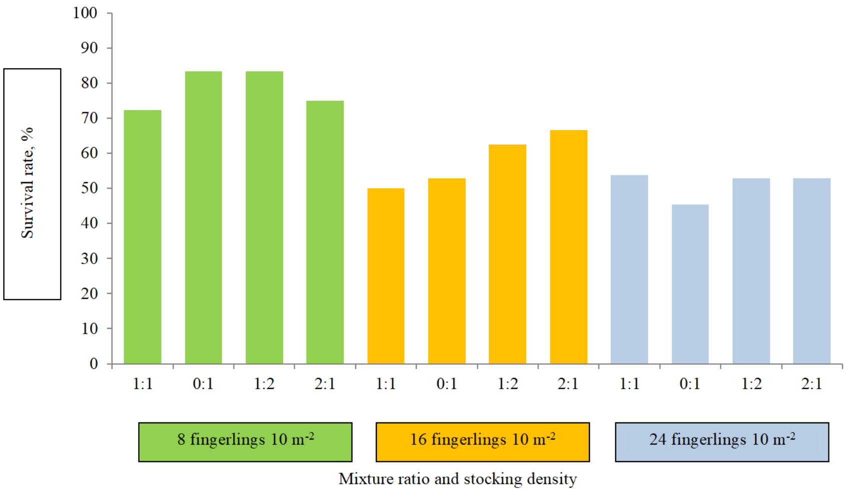

Fig. 3. Effect of mixture ratio and stocking density of nile tilapia and common carp on survival rate of common carp

The highest survival rate (83.33%) was found in carp monoculture (0:1) @ 8 fingerlings 10 m^{-2} or in 1:2 ratio @ 8 fingerlings 10 m^{-2} while the lowest one (45.37%) was found in carp monoculture (0:1) @ 24 fingerlings 10 m^{-2} (Figure 3). The maximum yield (828.7 kg ha^{-1}) was resulted in carp monoculture (0:1) @ 8 fingerlings 10 m^{-2} and the minimum yield (238.5 kg ha^{-1}) was recorded when tilapia and carp were released in 2:1 ratio @ 8 fingerlings 10 m^{-2} (Figure 4).

Total yield of nile tilapia and common carp

The highest total yield (930 kg ha^{-1}) was recorded when tilapia and carp were released in 1:2 ratio @ 24 fingerlings 10 m^{-2} while the lowest one (591.4 kg ha^{-1}) was obtained when tilapia and carp were stocked in 1:1 ratio @ 8 fingerlings 10 m^{-2} (Figure 5).

Economic analysis

All the rice-fish culture systems resulted in higher gross return as compared with rice sole culture. Net return also was recorded higher in rice-fish culture system (except monoculture of carp @ 24 fingerlings 10 m^{-2}) than rice sole culture. It is evident from this study that an additional income ranged from BDT 132296 to BDT 61859 ha^{-1} can be obtained through integration of fish in rice culture. Only

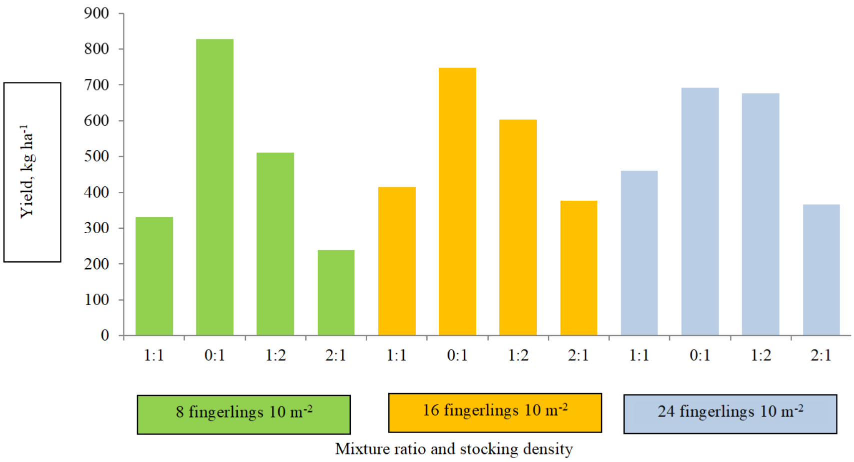

Fig. 4. Effect of mixture ratio and stocking density of nile tilapia and common carp on yield of common carp

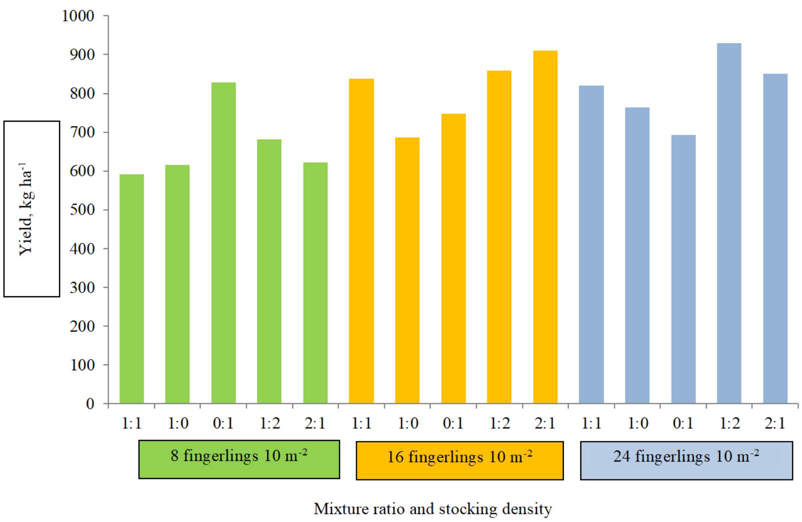

Fig. 5. Effect of mixture ratio and stocking density of nile tilapia and common carp on total yield (tilapia+carp) of fish

Table 6. Cost benefit analysis of different treatments

Treatments		Variable Cost (BDT ha^{-1})			Gross Return (BDT ha^{-1})			Net Return (BDT ha^{-1})	Benefit Cost Ratio
Stocking density	Mixture ratio (Tilapia:-Carp)	Rice	Fish	Total	Rice	Fish	Total		
8fingerlings 10 m^{-2}	1:1	90925	36700	127625	141320	83491	224811	97186	1.76
	1:0	90925	26400	117325	136360	80062	216422	99097	1.84
	0:1	90925	47000	137925	135780	124299	260079	122154	1.89
	1:2	90925	41850	132775	139480	98846	238326	105551	1.79
	2:1	90925	31550	122475	135780	85746	221526	99051	1.81
16 fingerlings 10 m^{-2}	1:1	90925	65400	156325	140220	117216	257436	101111	1.65
	1:0	90925	44800	135725	137140	89307	226447	90722	1.67
	0:1	90925	86000	176925	138940	112192	251132	74207	1.42
	1:2	90925	75700	166625	139000	123794	262794	96169	1.58
	2:1	90925	55100	146025	136880	125956	262836	116811	1.80
24 fingerlings 10 m^{-2}	1:1	90925	94100	185025	138380	115813	254193	69168	1.37
	1:0	90925	63200	154125	142280	99332	241612	87487	1.57
	0:1	90925	125000	215925	138940	103928	242868	26943	1.12
	1:2	90925	109550	200475	139640	134426	274066	73591	1.37
	2:1	90925	78650	169575	138880	117980	256860	87285	1.51
Control (sole rice)		90925	0	90925	151220	0	151220	60295	1.66

BDT = Bangladeshi Taka; 1US$ = BDT 85 (approx.)

lowest stocking density (8 fingerlings 10 m^{-2}) irrespective of mixture ratio produced higher BCR than rice sole culture. The highest BCR (1.89) was recorded with monoculture of carp @ 8 fingerlings 10 m^{-2}, while the lowest one (1.12) was obtained from monoculture of carp @ 24 fingerlings 10 m^{-2}. Higher stocking densities resulted in lower BCR (Table 6).

Discussion

Bangladesh is struggling to feed her ever-growing population. Integration of fish with rice culture could be a viable option to supply both carbohydrate and animal protein from limited land resources, and thus could ensure household nutrition. Moreover, rice-fish farming is eco-friendly and ensures system biodiversity, intensification and diversification. Rice produced from rice-fish integrated farming with reduced levels of agrochemicals is preferred by consumers because such rice has value added in terms of safety for human health (Iguchi et al., 2009). But this integration is yet to be fully explored and practiced widely due to various technological and socioeconomic constraints. Productivity of rice-fish farming mostly depends on the management issues including right selection of fish species, their mixture ratio, stocking density, supplementary feeding etc. In this study, an attempt was made to find out the optimum stocking density and suitable tilapia-carp ratio for integration in rice field.

In this study rice growth, in terms of plant stature and tillering ability, yield parameters and grain weight $hill^{-1}$ were enhanced due to integration of fish in rice culture compared to rice sole culture. But rice yield ha^{-1} was found similar in different rice-fish culture systems and rice sole culture. This was might be due to lower plant population in rice fish culture where rice was not transplanted in ditch area. Higher rice yield in rice –fish farming has been confirmed by many researchers (Halwart & Gupta, 2004; Frei & Becker, 2005). Tsuruta et al. (2011) recorded 20% higher rice yield from rice-fish culture in Japan. Hilbrands et al. (2004) observed that fish culture in rice field increases rice yield by 10 to 15%. Lightfoot et al. (1992) concluded that rice-fish farming offers possibilities of increasing rice yields by up to 15% and harvesting up to 500 kg ha^{-1} of fish. Causes behind higher productivity of rice in rice-fish culture include better control of insect pests, diseases and weeds, increased soil fertility and availability of more plant nutrients.

Herbivorous feeding habits of fish offer a unique opportunity of biological weed control in rice-fish farming (Vinke & Micha, 1985). Fishes uproot/eat weeds resulting in weed death due to disturbance by the browsing habit (Gupta et al., 1998). As stated by Rothuis et al. (1998), better weed control is one of the possible indirect mechanism for realizing increased rice plant growth and yield.

Overgrowth of weeds in rice sole plots reduces nutrient availability in rice fields resulting reduced growth and yield of rice, in rice-fish culture on the contrary, omnivorous or herbivorous fishes decrease weed growth and increases rice yield (Frei & Becker, 2005). Dead weeds also release nutrients after decomposition which might contribute to increased rice yield to some extent.

As confirmed by many researchers (Razzak et al., 2007), by eating different harmful insects, flies, snails and larvae present in rice field fish minimizes pest damage and thus contributes to increased rice yield. Tsuruta et al. (2011) on the other hand, revealed that fish prey on different aquatic insects and the nutrients that might be removed by those insects can be restored to the water via fish. It has also been observed that fish eat older rice leaves usually infested with pathogens and hence ensures better plant health (Halwart, 1991). Thus by allowing integrated pest management (IPM), rice-fish farming not only ensures higher profitability but also maintains an ecological balance in rice field (Berg, 2002).

The fertilizing effect from the fish excrement, which increases the nutrient availability to the rice crop, might also contribute to the increased rice yield (Frei & Becker, 2005; Tsuruta et al., 2011). Moreover, fish metabolizes various natural feed sources and excretes excess nutrients which accelerate the turnover of organically bound nutrients (Lightfoot et al., 1993; Vromant et al., 2001). Fish also plays an important role in the nutrient cycle of the rice field ecosystem. Cagauan (1995) listed four ways how fish may influence soil nutrient status as well as rice productivity. First, by adding more nutrients to the rice field soil through faeces excretion and through decomposition of dead fish. Second, by releasing fixed nutrients from soil to water while swimming by disturbing the soil-water interface. Third, through grazing fish make soil more porous and increase the nutrient uptake by rice and finally, fish help in the recycling of nutrients from photosynthetic biomass and other components by grazing. Although the population of duckweed, zooplankton and benthic invertebrates (crustaceans and oligochaetes) in the rice-fish plots were not monitored in this study, it has been reported that fishes like crucian carp (omnivorous) utilize those as food (Xie et al., 2005) in the paddy field and subsequently defecates the excrements that increase NO_3–N and NH_4–N concentration in the rice-fish plots. Moreover, higher uptake of nitrogen by rice plants in rice-fish integrated culture as compared to rice monoculture has been reported by Oehme et al. (2007). As revealed by Vromant & Chau (2005), fish perturbation of the soil-water interface might lead to a release of fixed nutrients to water from soil and also make the soil porous which facilitates nutrients absorption by the rice roots. Many other reports confirmed that rice-fish culture improve soil fertility by generating nitrogen and phosphorus as well (Lightfoot et al., 1992; Giap et al., 2005; Dugan et al., 2006). Like rice, fish is also benefited in rice-fish culture. Rice fields provide epiphytic and benthic food for fishes (Mustow, 2002) and rice plants provide shade that maintains water temperature favorable for fish during hot days of summer (Kunda et al., 2008), and thus both are mutually benefited.

In this study, survival rate of tilapia or carp widely ranged from 45 to 83% and in general survival rate (%) gradually decreased with the increasing stocking density. That means tilapia and carp cannot survive at extremely high stocking densities. Tina et al. (2008) recorded 83-100% survival rate of carp fish in their study. Raihan (2001) also recorded survival rates between 81% and 90% in a carp-SIS polyculture system.

Ronald et al. (2014) revealed that survival rate of fish decreased when stocking density is higher than a certain limit. Alhassan et al. (2012), on the other hand observed high survival rate of tilapia at high stocking density. El Sherif & El Feky (2009) opined that survival of up to 100% could be linked to good environmental conditions. However, low survival rate at high stocking density could be due to stress, decreasing water quality due to increased biomass, less concentration of dissolved oxygen and other density dependent factors.

In this study, combined effect of stocking density and mixture ratio was evaluated on growth and productivity of tilapia and carp, so their effect cannot be separated. Nevertheless, in general growth and yield of both the fish species decreased with increasing stocking density regardless of mixture ratio. But, within a particular stocking density, role of mixture ratio was not clear.

In fact, stocking density is an important determinant for the productivity and profitability in rice-fish farming because it directly influences survival, growth, behavior, health, water quality, feeding and production as confirmed by many researchers (Ridha, 2005; Sorphea et al., 2010), although contrasting findings have also been reported (Southworth et al., 2009; Osofero et al., 2009) who opined that generally no differences in productivity occurred across different stocking densities. Although yield increases with higher stocking density, this should be compared with the increased mortality and associated increase in costs of stocking. Growth, survival rate and yield effects of stocking density in mixed aquaculture are well documented (Garr et al., 2011; Khatune-Jannat et al., 2012). A positive correlation between stocking density and fish yield has also been reported by Gupta et al. (1998). On the contrary, a negative correlation was found between the stocking density and survival rate with an insignificant decrease in harvest size (Halwart & Gupta, 2004). Generally high density is considered as a potential source of stress, with a negative effect on fish growth rate (Lefrançois et al., 2001) and survival and feeding rates (Rowland et al., 2006). The contrasting findings might be due to variation in the type of culture, fish species used and stocking densities tried as well. The final factor determining the stocking density as mentioned by Halwart & Gupta (2004) is the type of modifications made to rice fields.

In the present study, a clear yield advantage of mixed culture of tilapia and carp over their monoculture is evident. Although at very low stocking density, monoculture of carp yielded the highest, but at higher stocking densities, mixture of tilapia and carp in 1:2 or 2:1 ratio resulted in the highest yield. Karplus et al. (1996) found that weights of both common carp and the tilapia hybrid at harvest were markedly decreased upon the increase in density of their own species. This might be due to the fact that stocking a combination of species makes it possible to take advantage of all the available food niches in the rice field ecosystem. Usually in mixed culture, compatible species of different feeding habits are stocked in different proportions to avoid food competition and best utilization of natural food without any harm to each other for maximum productivity. Success of mixed culture depends on proper ratio and combination of fishes (Halver, 1984).

Conclusion

Rice-fish farming was found more remunerative than rice sole culture because return from fish component was much higher than the cost involved for integrating fish in rice culture; moreover, integration of fish did not reduce rice yield. Higher stocking densities resulted in lower BCR because of high cost of rice fingerlings coupled with poor fish growth and very low survival rate. On the other hand, at the lowest stocking density (8 fingerlings 10 m^{-2}), BCR was very high because cost for fingerlings was very low and at the same time survival rate and fish growth rate was satisfactory resulting high fish yield.

Findings of this study closely resemble to those of others (Islam et al., 1998; Hossain & Joadder, 2011; Mridha et al., 2014) who confirmed higher economic return from rice-fish culture than rice sole culture. Present study confirms that stocking density along with mixture ratio of tilapia and carp has tremendous influence on the productivity and profitability of both rice and fish in rice-fish farming. For higher productivity, mixed culture of tilapia and carp in 1:2 ratios @ 24 fingerlings 10 m^{-2} can be integrated with rice, but from economic view point, monoculture of carp @ 24 fingerlings 10 m^{-2} in rice field may be recommended.

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