Aquaculture Reports 4 (2016) 93–100

Contents lists available at ScienceDirect

Aquaculture Reports

journal homepage: www.elsevier.com/locate/aqrep

Suitability of different fish species for cultivation in integrated floating cage aquageoponics system (IFCAS) in Bangladesh

Hazrat Ali[a,*], Mohammad Mahfujul Haque[b], Khondker Murshed-e-Jahan[c], Md. Lifat Rahi[d], Mir Mohammad Ali[a], Md. Al-Masud[a], Golam Faruque[a]

[a] WorldFish, Bangladesh and South Asia Office, Bangladesh
[b] Department of Aquaculture, Bangladesh Agricultural University, Mymensingh, Bangladesh
[c] International Maize and Wheat Improvement Center (CIMMYT), Bangladesh Country Office
[d] Earth Environment and Biological Sciences School, Queensland University of Technology, Australia

ARTICLE INFO

Article history:
Received 22 March 2016
Received in revised form 16 July 2016
Accepted 20 July 2016
Available online 27 July 2016

Keyword:
Oreochromis niloticus
Anabas testudineus
IFCAS
Shaded pond
Participatory action research
Bangladesh

ABSTRACT

Farmer participatory action research was performed to assess production performance of tilapia (*Oreochromis niloticus*) and Vietnamese perch (*Anabas testudineus*) in monoculture and polyculture systems via integrated floating cage aquageoponics system in Bangladesh. The term aquageoponics is the combination of aqua, geo and ponics which mean pond water, pond mud/soil and cultivation, respectively (Haque et al., 2015). Three treatments, namely T_1 (tilapia), T_2 (Vietnamese perch) and T_3 (tilapia and Vietnamese perch = 1:1) in moderately shaded ponds (MSP) and 3 treatments, namely T_4 (tilapia), T_5 (Vietnamese perch) and T_6 (tilapia and Vietnamese perch = 1:1), in heavily shaded ponds (HSP) were used each with 3 replicates and fish were stocked at a rate of 56 m^{-2} per cage. Fish were fed floating feed twice daily and significantly higher ($P < 0.05$) individual growth rate (161 ± 2.4 g) and productivity (76 ± 1.7 kg) for tilapia were found in T_1 while the individual growth rate (93 ± 12 g) and productivity (49 ± 1.3 kg) of Vietnamese perch was higher in T_2 but this was not significantly different ($P > 0.05$) between treatments. While higher ($P > 0.05$) specific growth rate was observed in monoculture compared with polyculture for tilapia; no significantly difference was observed for Vietnamese perch. There was also no significant difference ($P > 0.05$) in growth performance for Vietnamese perch between the MSP and HSP treatments. While females participated more actively in action research in the HSP condition with production of vegetables and fish in IFCAS; vegetables production were not different ($P > 0.05$) among treatments. The benefit-cost ratio of different treatments was >1, indicating that investment was financially efficient for all treatments.

1. Introduction

Bangladesh is the fifth largest aquaculture producing nation in the world (FAO, 2014), with production reaching approximately 1.85 million tons in 2012–2013 (DoF, 2014). Aquaculture is expanding economically in Bangladesh and the national government supports and intends to develop the export of aquaculture products. But there are a few challenges that this sector has been facing, particularly the conflict between aquaculture and agriculture for land. Due to massive development across the country, productive land and water area are becoming increasingly scarce. Thus, integrated farming systems have been identified as plausible solutions that can ensure effective land use by both sectors leading to increased production and higher profitability (Haque et al., 2015). To date, polyculture technique employing improved traditional and semi intensive farming systems are the most popular techniques and are now widely practiced across Bangladesh. Fish are produced in a variety of production systems but ponds are currently the most frequently used.

The Barisal district located in southern Bangladesh is a major site for aquaculture production, with the highest number (12% of country's total) of freshwater ponds is located in this district (BBS, 2002). A vast number of aquaculture ponds in Bangladesh are situated beside rural houses and are referred to as homestead ponds. In earlier days, such ponds were used as trap ponds (wild fish enter into the pond during the rainy season after flash flooding) and only limited stocking of carp fingerlings used to be conducted that were mainly used for subsistence consumption (Rahman et al.,

* Corresponding author at: WorldFish, Bangladesh and South Asia office, Bangladesh, Road# 7, House# 22/B, Block# F, Banani, Dhaka, Bangladesh.
E-mail address: ali.03ku@yahoo.com (H. Ali).

http://dx.doi.org/10.1016/j.aqrep.2016.07.003
2352-5134/

1992). In order to meet the growing demand of fish and to achieve higher profit, homestead trap ponds in the Barisal district have been modified and traditional farming systems improved, resulting in an increase of aquaculture production by several folds in this area (Haque et al., 2015). In parallel, farmers continuously seek more improvements and innovative techniques, and different governmental, non-governmental and many non-profit research organizations are working to improve the livelihood options of farmers. An integrated floating cage aquageoponics system (IFCAS) has been developed by Haque et al. (2015) for shaded ponds (traditional rural homestead ponds where there are large trees) across the Barisal region of Bangladesh. In this system the term aquageoponics, where aqua, geo and ponics mean pond water, pond mud/soil and cultivation, respectively. The dried pond mud collected from the same pond was used as a holding medium for plants (for details see Haque et al., 2015). This technique allows households to produce fish and vegetables simultaneously from shaded ponds where previously it was not possible to produce vegetables on the dike due to lack of available sunlight and presence of roots of larger trees. This system simplifies the process even during the peak monsoon season when it is difficult to harvest fish from deeper ponds because of the irregular nature of the pond bottom. IFCAS is a promising technique but the effectiveness of this system is yet to be investigated comprehensively under different pond conditions. Incorporation of a cage system for growing both fish and vegetables under existing farming systems could potentially increase productivity and profit. Fish production was found to be low however, in heavily shaded ponds and even in moderately shaded ponds with the existing improved traditional system (Haque et al., 2015). This problem may potentially be addressed by changing the combination of species farmed and using ones with faster growth in the existing aquaculture condition in Bangladesh.

Tilapia (*Oreochromis niloticus*) has ability to survive and be productive under a wide range of environmental condition and has good resistance to poor water quality (Balarin and Haller, 1982; Hussain et al., 1989). However, Bangladesh Fisheries Research Institute (BFRI) introduced the GIFT (Genetically Improved Farmed Tilapia) strain in 1994 and 2005 (Hussain 2009) which is now a fast growing popular cultivable fish species (Shamsuddin et al., 2012). Similarly, the climbing perch (*Anabas testudineus*) is very hardy in nature and can survive in adverse environmental conditions such as low oxygen due to its air breathing ability, wide range of temperature and other poor water conditions (Thakur, 2004; Rahman and Monir, 2013). A very fast growing strain of Vietnamese perch that grows four times faster than normal varieties was introduced to Bangladesh in 2011 from Vietnam and provides a suitable aquaculture species in the Bangladesh context. This perch and mono-sex varieties of tilapia are very high yielding, excellent breeders and efficient converters of organic and agricultural wastes into high quality protein. These are also resistant to disease and can be cultured at relatively high stocking densities (Ahmed et al., 2013). Considering these facts, a participatory action research project was conducted applying a variety of experimental combinations of these two fish species in a broader socio-economic context to assess the potential of IFCAS to increase relative productivity and profitability of fish culture in Bangladesh.

2. Material and methods

2.1. Experimental site and preparation of ponds

A participatory action research program was conducted for a period of 4 months, from July 01 to October 30, 2014, by selecting 18 household ponds in 2 different villages from 2 sub-districts in the Barisal district of Bangladesh (Fig. 1). Experimental ponds were selected based on a number of criteria including: shaded ponds adjacent to a homestead, willingness of household members to participate and to share the input costs for the project. Basic socio-economic data were also collected to assess the impact of the treatments at the end of the trial. Fish farmers actively participated in the research design based on resource availability and also decided to share 40% cost of the total operating costs. The bottom topography of ponds was irregular and it was also not possible to grow vegetables on the dike of any of the selected ponds due to the presence of large tree roots. Initially, undesirable aquatic weeds and floating debris were removed from the selected ponds in June 2014. Ponds were then treated with lime ($CaCO_3$) at the rate of 247 kg ha^{-1}.

2.2. IFCAS preparation and set up

IFCAS cages were made in a welding service shop using locally available raw materials based on the model developed by Haque et al. (2015) and structures were then set up in ponds where sunlight was available. IFCAS cages were rectangular in shape (9 m^2) and made of iron-bars with four concave grooves in the four corners to hold floats made from plastic drums. The structure was covered with a nylon net cage of dimensions 3.66 m length × 2.44 m width × 1.25 m depth. This cage system also held bed (mixture of cow dung and pond bottom soil) for growing vegetables. A plastic mug and bamboo stick were used to prepare a long spoon like device to provide supplementary feed to stocked fishes in the cage from the pond dike. Farmers checked all net cages daily to ensure that fish were feeding and to minimize feed wastage.

2.3. Experimental design

Eighteen selected ponds were divided into two groups: moderately shaded pond (MSP) and heavily shaded pond (HSP). Three different treatments were used with triplicates for each pond group: T_1 (tilapia), T_2 (Vietnamese perch) and T_3 (tilapia and Vietnamese perch = 1:1) for MSP and T_4 (tilapia), T_5 (Vietnamese perch) and T_6 (tilapia and Vietnamese perch = 1:1) for HSP. High quality fingerlings of mono-sex tilapia and Vietnamese perch were collected from a local hatchery and were brought to the experimental ponds in oxygenated polyethylene bags. Fingerlings were first acclimated to pond water and then stocked in the 9 m^2 net cages at a stocking density of 56 m^{-2}. In ponds surrounding the cages, carp species were stocked at a rate of 12,350 ha^{-1} in polyculture with catla (*Catla catla*), rohu (*Labeo rohita*), silver carp (*Hypophthalmic molit*rix), mrigal (*Cirrhinus cirrhosus*), and common carp (*Cyprinus carpio*) at a ratio of 1:2:2:1:1 prior to stocking IFCAS fish. Stinging catfish (*Heteropneustes fossilis*) were also stocked in all ponds at a rate of 11,115 ha^{-1} to understand the potential of this species in shaded ponds under a polyculture system.

2.4. Feeding and pond management

IFCAS fish were fed twice daily (early morning and afternoon) with a commercially produced pelleted floating feed containing 30.11–36.15% crude protein. Feed was applied at the rate of 10%, 7.5% and 5% of total body weight in the first month (July), second month (August) and last two months (September and October), respectively. In parallel, a mixture of rice bran, wheat bran, mustard oil cake and wheat flower or molasses was used to feed carps and stinging catfish in the ponds at a rate of 8% of body weight for the first 3 months (from mid-June to mid-September) and 4% of body weight for the last 3 months (from mid-September to mid-December). In addition, inorganic fertilizer (urea at the rate of 50 kg ha^{-1} and triple super phosphate at the rate of 25 kg ha^{-1}) were applied fortnightly to maintain natural food levels in the

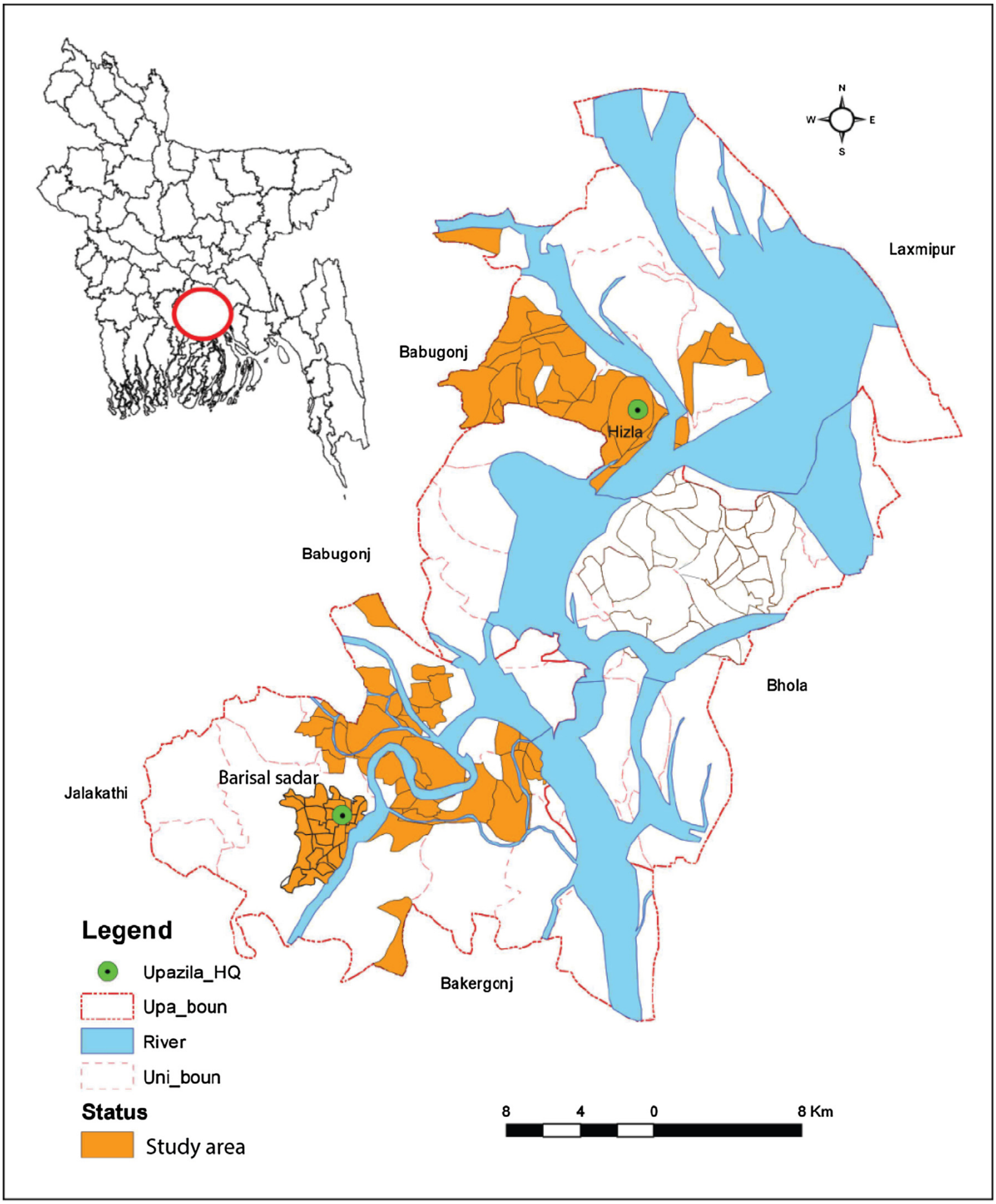

Fig. 1. Map of the Barisal district in Bangladesh showing study area (Barisal sadar and Hizla).

ponds. Lime ($CaCO_3$) was also used to improve pond water quality and for disease prevention at a rate of 247 kg ha^{-1}.

2.5. Water quality monitoring

Water quality parameters including temperature, pH, dissolved oxygen (DO) and transparency of pond water were measured at fortnightly intervals. Water temperature and DO were measured with a DO meter (Digital oxygen meter, model DO-5510, Lutron electronic, PA, USA) and pH was determined with a microprocessor pH meter (Model No. HI 98139, HANNA Instruments Ltd, Germany). Transparency of water was measured using a Secchi disc. Other water quality parameters including Alkalinity (mg/L), NH3-N (mg/L), and NO_2-N (mg/L) were analyzed on the pond dike using test kits (HANNA Test kits, Hanna Instruments Ltd, Germany).

2.6. Fish and vegetable production data recording

A record book was maintained by all farmers to document fish growth rate in IFCAS and ponds, vegetable production, consumption and sale of vegetables and fish as well as inputs used in IFCAS and ponds. Fish were sampled at fortnightly intervals and measured to determine length and weight of individual fish using a centimeter scale and electronic balance (Model HKD-620AS-LED). After the final harvest, survival rate (%), mean weight gain (g), weight gain (%) and specific growth rate (SGR) were calculated for each species.

2.7. Data analysis

Data from the experimental trials were analyzed with statistical software SPSS (Statistical Package for Social Sciences) version 16. One way analysis of variance (ANOVA) was used for statistical analysis of the experimental data followed by Bonferroni Multiple Range Test to determine the significance of variation among the treatment averages. An independent sample T-test was also conducted to assess differences between MSP and HSP in terms of household characteristics, vegetable production in IFCAS, fish production in IFCAS and pond, and water quality parameters. Both the ANOVA and T-test analysis were performed applying a 5% level of significance ($P < 0.05$). An economic analysis was conducted to determine the economic feasibility of this technology for rural farmers (Shang, 1990). All cost items were considered in this analysis except for operational labor inputs because labor was supplied by the farmers themselves as part of the participatory action research that was very minimum, and did not hamper their other household activities.

3. Results

3.1. Characteristics of participating households and ponds

Eighteen households participated in the project and the average age of participating farmers varied between 23–48 years (Table 1) and can be classed as middle aged in Bangladesh context. While agriculture and small business were the primary occupations of the participating households; two farmers worked as mobile fish seed traders. Female members of participating households were housewives and they actively participated in this research after completing their household activities. No significant differences ($P > 0.05$) were observed for pond water, pond surface water area, pond depth, minimum and maximum water depth among treatments. Total sunlight receiving area for MSP was however, higher compared with HSP.

3.2. Water quality parameters

The mean values for water quality parameters with standard error (SE) in the different treatments are shown in Table 2. Over the study period, maximum water temperature (33 °C) was recorded in July in T_1 and minimum (29 °C) was recorded in October in T_3. Average temperature, dissolved oxygen, pH, transparency and alkalinity were not significantly different ($P > 0.05$) among different treatments over the four month trial period. Average highest values of ammonia and nitrate were found in T_6 of HSP but this was not significantly different ($P > 0.05$) from other treatments. Moreover, nitrate content in the water was not significantly different ($P > 0.05$) between MSP and HSP treatments.

3.3. Growth and production of fish under IFCAS and in ponds

Average initial weight of tilapia and Vietnamese perch were 5.3 and 1.7 g, respectively (Table 3). Survival rate of tilapia and Vietnamese koi in MSP were higher (92% and 90%, respectively) than that under HSP (88% and 86%, respectively). Significantly higher individual growth rate of tilapia was found in T_1 (161 ± 2.4) under MSP compared with T_4 (118 ± 8.3) under HSP. A similar trend result was also observed for polyculture of tilapia with Vietnamese perch between MSP and HSP. Individual growth rate of tilapia in IFCAS was also significantly higher ($P < 0.05$) under MSP (135 ± 13) than under HSP (93 ± 12). Individual growth rate of Vietnamese perch under MSP and HSP were found to be (92 ± 6.1) and (78 ± 4.7) g, respectively that were not found significantly different. Mean weight gain of tilapia was significantly higher ($P < 0.05$) for MSP (130 ± 13) compared with HSP (88 ± 12). Mean weight gain of Vietnamese perch under the two conditions (90 ± 6.0 and 76 ± 4.6 g, respectively) was not significantly different (Table 3). Specific growth rate (SGR) of tilapia in T_1 under MSP (2.9 ± 0.02) condition was significantly higher ($P > 0.05$) than all other treatments. SGR in T_2 of MSP was 3.5 ± 0.22 for Vietnamese perch but this was not significantly different from any other different treatment. Feed conversion ratio (FCR) of tilapia in T_1 (1.3 ± 0.04) was highest followed by T_4; but they were not significantly different under MSP and HSP conditions for Vietnamese perch. Production of tilapia was significantly higher ($P < 0.05$) in T_1 (76 ± 1.7 kg) than other treatments. In contrast, production of Vietnamese perch was not significantly different ($P > 0.05$) between MSP and HSP conditions (Table 3). Productivity of tilapia and Vietnamese perch in polyculture was also found to be significantly different ($P < 0.05$) under MSP and HSP conditions. Average total production of fish in IFCAS (kg $9m^{-2}$ $4monhts^{-1}$) was 57 ± 4.8 and 40 ± 3.8 under MSP and HSP conditions, respectively.

Production of carp ranged from 1974 to 4033 kg ha^{-1} (Table 3) and was not significantly different among treatments. In contrast, production of carp was significantly different ($P < 0.05$) under MSP and HSP conditions. Production of stinging catfish however, was not different under HSP and MSP conditions and among treatments (Table 3). Average fish consumption from IFCAS per household was 10 ± 0.85 kg and 9.1 ± 0.74 kg under MSP and HSP conditions, respectively and they were not significantly different ($P > 0.05$) in fish consumption from IFCAS and ponds among treatments and between MSP and HSP households. Farmers sold most of the larger sized fish from IFCAS after completing trials and the remaining small sized fish were released to their ponds to reach larger size.

3.4. Production performances of vegetables in IFCAS

At least two types of vegetables were planted by farmers in two pits of the IFCAS. While the research protocol specified four months to culture fish in IFCAS, vegetable production continued for more than five months where farmers produced two crops, each requiring approximately 2.75 months. During the first crop (July-September), bitter gourd (*Momordica charantia*), snake gourd (*Trichosanthes cucumerina*) and cucumber (*Cucumis sativus*) were produced. Bottle gourd (*Lagenaria siceraria*), tomato (*Solanum lycopersicum*) and flat beans (*Phaseolus vulgaris*) were planted during October-December as a second crop. Productions of vegetables were not significantly different ($P > 0.05$) among treatments and under MSP and HSP conditions (Table 3). All vegetables produced under the different treatments were used by the participating farmers for their own domestic consumption (Fig. 2).

3.5. IFCAS economic analysis

An economic analysis was performed to calculate the related profitability under different treatments and the cost-benefit analysis is presented in Table 4. The structural cost of IFCAS was US$ 11 per year based on depreciation cost. Fish production in IFCAS as a fixed cost for a four month trial was estimated at US$ 3.7. Gross cost of fish production in IFCAS was significantly higher ($P < 0.05$) in T_1 of MSP than in other treatments. Average four month gross income from fish and vegetable production in IFCAS varied from US$ 61 to US$ 144 (Table 4). Average gross income was US$ 119 and US$ 83 for MSP and HSP, respectively which was significantly different ($P < 0.05$) because of the different levels of production. In spite of higher production cost, a significantly higher ($P < 0.05$) net

Table 1
Socio-economic and pond characteristics of IFCAS households.

Characteristics	T_1	T_2	T_3	T_4	T_5	T_6
Age of participants (mean ± SE)	35 ± 4.1	41 ± 2.6	40 ± 4.3	36 ± 6.7	33 ± 3.6	33 ± 1.5
Schooling year of Participants (mean ± SE)	7.7 ± 2.3	8.3 ± 2.0	5.0 ± 1.7	5.7 ± 3.5	8.3 ± 0.67	7.3 ± 1.5
Average household size (mean ± SE hh^{-1})	6.0 ± 1.5	6.7 ± 2.0	5.7 ± 1.7	6.3 ± 0.33	5.3 ± 0.33	4.0 ± 0.0
Average land holding (ha ± SE hh^{-1})	1.0 ± 0.35	0.90 ± 0.21	0.40 ± 0.05	0.70 ± 0.36	0.59 ± 0.25	0.47 ± 0.18
Occupation household head (Frequency)						
Agriculture	1	2	3	1	–	–
Mobile fish seed trader	1	–	–	–	1	–
Petty business	1	1	–	1	2	1
Small job	–	–	–	1	–	2
IFCAS pond characteristics (mean ± SE)						
Pond area including dike (ha)	0.09 ± 0.01	0.05 ± 0.02	0.08 ± 0.00	0.08 ± 0.01	0.07 ± 0.02	0.04 ± 0.01
Water surface area (ha)	0.07 ± 0.01	0.04 ± 0.02	0.06 ± 0.00	0.06 ± 0.01	0.05 ± 0.02	0.03 ± 0.01
Pond depth (m)	3.5 ± 0.10	3.3 ± 0.27	3.2 ± 0.37	3.3 ± 0.10	3.1 ± 0.18	3.2 ± 0.37
Maximum water depth in monsoon (m)	2.7 ± 0.30	2.4 ± 0.18	2.4 ± 0.18	2.6 ± 0.10	2.3 ± 0.20	2.5 ± 0.27
Minimum water depth in monsoon (m)	2.2 ± 0.28	2.1 ± 0.18	2.1 ± 0.18	2.1 ± 0.18	2.0 ± 0.20	2.1 ± 0.18
Area of pond water receiving sunlight (ha)	0.03 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01
Pond distance from homestead (m)	6.6 ± 1.3	10 ± 3.7	11 ± 2.3	8.1 ± 2.7	11 ± 3.2	4.8 ± 0.71

Table 2
Water quality parameters (mean ± SE) under different treatments over the experimental period.

Parameters	T_1	T_2	T_3	T_4	T_5	T_6
Water Temperature (°C)	31 ± 1.2	31 ± 0.12	31 ± 0.55	30 ± 0.58	29 ± 0.33	30 ± 0.28
Dissolved Oxygen (mg/L)	5.3 ± 0.18	5.3 ± 0.29	5.5 ± 0.69	5.1 ± 0.24	5.6 ± 0.15	5.4 ± 0.12
pH	8.0 ± 0.13	7.7 ± 0.04	7.8 ± 0.13	7.5 ± 0.09	7.6 ± 0.07	7.7 ± 0.12
Transparency (cm)	25 ± 3.1	28 ± 3.3	24 ± 1.9	22 ± 3.0	20 ± 1.6	28 ± 8.8
Alkalinity (mg/L)	101 ± 5.3	103 ± 2.0	113 ± 2.8	105 ± 15	109 ± 21	94 ± 12
NH_3-N (mg/L)	0.06 ± 0.03	0.08 ± 0.04	0.18 ± 0.04	0.32 ± 0.08	0.31 ± 0.06	0.35 ± 0.08
NO_2-N (mg/L)	0.04 ± 0.04	0.08 ± 0.04	0.04 ± 0.04	0.14 ± 0.03	0.10 ± 0.06	0.13 ± 0.04

Table 3
Growth and production of tilapia, Vietnamese koi and vegetable with IFCAS and carp in ponds.

Growth and production	Initial weight (g)	Final weight (g)					
		T_1	T_2	T_3	T_4	T_5	T_6
Individual growth (mena ± SE)							
Tilapia in IFCAS							
Tilapia	5.3 ± 0.17	161 ± 2.4^{a}		109 ± 11^{b}	118 ± 8.3^{b}		68 ± 6.0^{c}
Survival Rate (%)		94 ± 1.2^{ab}		89 ± 1.9^{abc}	91 ± 2.5^{abc}		84 ± 2.1^{bc}
Mean weight gain(g)		156 ± 2.2^{a}		103 ± 11^{b}	112 ± 8.2^{b}		63 ± 5.9^{c}
% Weight gain		2930 ± 57^{a}		1933 ± 176^{b}	2104 ± 97^{b}		1179 ± 88^{c}
SGR (% per day)		2.9 ± 0.02^{a}		2.6 ± 0.07^{b}	2.6 ± 0.06^{b}		2.1 ± 0.06^{c}
Vietnamese koi in IFCAS							
Vietnamese koi	1.7 ± 0.33		103 ± 5.0^{a}	82 ± 7.1^{ab}		85 ± 6.4^{ab}	71 ± 4.7^{b}
Survival Rate (%)			92 ± 0.88^{a}	87 ± 2.6^{a}		89 ± 0.58^{a}	84 ± 4.5^{a}
Mean weight gain(g)			101 ± 4.7^{a}	80 ± 6.9^{ab}		83 ± 6.2^{ab}	69 ± 4.5^{b}
% Weight gain			6587 ± 1314^{a}	5143 ± 903^{a}		5378 ± 1033^{a}	4517 ± 960^{a}
SGR (% per day)			3.5 ± 0.22^{a}	3.4 ± 0.24^{a}		3.3 ± 0.15^{a}	3.2 ± 0.17^{a}
FCR (Tilapia and Vietnamese koi)		1.3 ± 0.04^{a}	1.8 ± 0.01^{b}	1.8 ± 0.02^{b}	1.5 ± 0.02^{c}	1.9 ± 0.03^{b}	1.9 ± 0.02^{b}
Total fish production in IFCAS (kg 9 m^{-2} 4 $months^{-1}$)		76 ± 1.7^{a}	49 ± 1.3^{bcd}	46 ± 3.2^{bcd}	53 ± 2.9^{bc}	38 ± 3.6^{bd}	29 ± 3.1^{de}
Vegetable production in IFCAS (kg 9 m^{-2} 4 $months^{-1}$)		20 ± 3.2^{a}	18 ± 3.3^{a}	17 ± 3.2^{a}	15 ± 2.9^{a}	15 ± 2.6^{a}	13 ± 2.7^{a}
Stocking density of carp in pond (individual ha^{-1})		12,350	12,350	12,350	12,350	12,350	12,350
Stocking density of stinging catfish in pond (individual ha^{-1})		11,115	11,115	11,115	11,115	11,115	11,115
Carp production in pond (kg ha^{-1} 6 $months^{-1}$)		3440 ± 346^{a}	3144 ± 378^{a}	3009 ± 264^{a}	2665 ± 256^{a}	2512 ± 393^{a}	2393 ± 287^{a}
Stinging catfish production in pond(kg ha^{-1} 6 $months^{-1}$)		70 ± 10^{a}	66 ± 8.2^{a}	62 ± 16^{a}	64 ± 13.1^{a}	60 ± 9.8^{a}	71 ± 15^{a}

profit was found in T_1 because of higher production value. While investment in IFCAS was financially efficient under all treatments, the benefit cost ratio (BCR) was higher for T_1 and T_2 under MSP.

4. Discussion

Landholding and average household size of MSP households were larger than for HSP households indicating higher involvement of MSP in agricultural activities. Adoption of IFCAS fulfilled nutritional requirements for food including both fish and vegetables, and made MSP households more interested in IFCAS. HSP households mainly depend on non-farm activities because of their limited landholdings and pond resources. Limited resources in HSP households potentially encourage women in families to maximize output from any new intervention. Similar responses have been observed with cereal crop farming among small farmers (Biggs, 1989). The short distance of fish ponds from households encouraged women in HSP household to lead operation of IFCAS compared with MSP. Due to socio-cultural norms, rural women participate in agricultural activities generally within the homestead area rather than to activities at greater distance. Moreover, women in HSP households actively participated in feeding of fish, cultivating and harvesting vegetables and general oversight of IFCAS compared with women in MSP households.

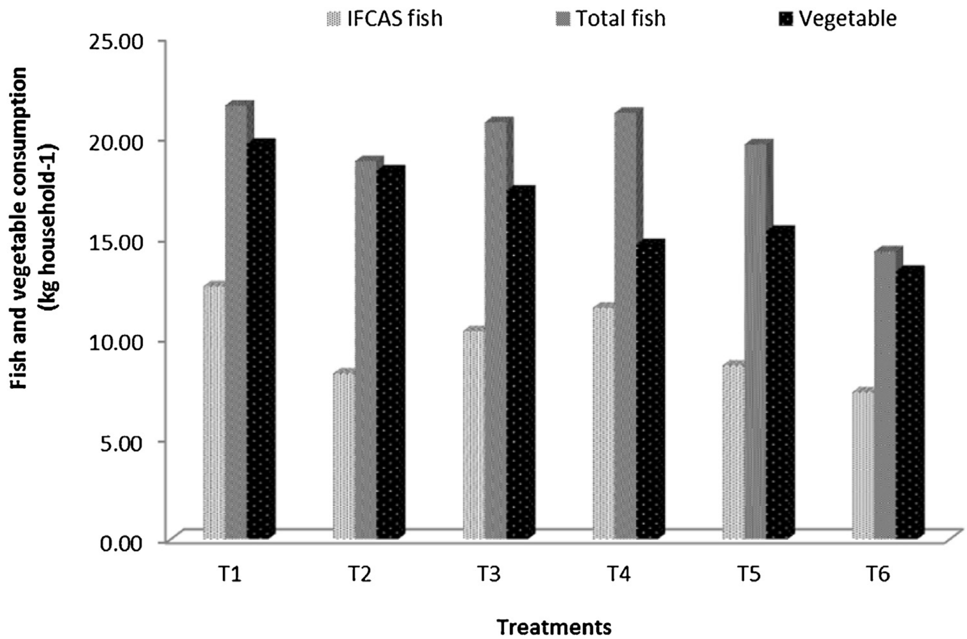

Fig. 2. Average consumption of fish and vegetables from IFCAS and ponds under different treatments over the experimental period.

Table 4
Economic analysis of fish and vegetable production with IFCAS over a four month trial.

	Inputs/items/produce	Cost/revenue (US$)					
		T_1	T_2	T_3	T_4	T_5	T_6
A	IFCAS structure- iron bar and drum						
	Iron bar	31	31	31	31	31	31
	Plastic drum (70 L volume)	15	15	15	15	15	15
	Plastic drum (40 L volume)	3.2	3.2	3.2	3.2	3.2	3.2
	Construction cost	9	9	9	9	9	9
	Total cost	58	58	58	58	58	58
	Per year depreciation cost (10 year of longevity)	5.8	5.8	5.8	5.8	5.8	5.8
B	IFCAS net						
	Nylon net for cage	9.0	9.0	9.0	9.0	9.0	9.0
	Net preparation cost	3.2	3.2	3.2	3.2	3.2	3.2
	Other cost(bamboo, threads etc., for scaffold)	3.9	3.9	3.9	3.9	3.9	3.9
	Total cage net cost	16	16	16	16	16	16
	Per year net/scaffold depreciation cost (3 year of longevity)	5.3	5.3	5.3	5.3	5.3	5.3
C	Depreciation cost of an IFCAS structure						
	Structure cost for a year	11	11	11	11	11	11
	Structure cost for four months	3.7	3.7	3.7	3.7	3.7	3.7
D	Operating cost for IFCAS						
	Fingerling	19	13	16	19	13	16
	Feed	60	54	51	49	44	34
	Vegetable seed/seedlings	0.77	0.77	0.77	0.77	0.77	0.77
	Total operating cost for IFCAS	80	68	68	69	58	51
	Gross cost	83	71	71	72	61	54
E	Revenue from IFCAS						
	Fish production	136	114	87	93	82	56
	Vegetable production	7.6	7.1	6.7	5.6	5.9	5.1
	Gross revenue	144	121	94	99	88	61
F	Net benefit per IFCAS						
	Net benefit = E-D	61	50	23	27	27	7
G	Economic efficiency						
	Benefit cost ratio (BCR) = E/D	1.7	1.7	1.3	1.4	1.4	1.1

Water quality parameters recorded here were similar to data recorded from previous studies of homestead ponds (Sarker et al., 2014). Parameters in different treatments did not differ significantly from the beginning to the end date of the experiment which implies that installation of IFCAS in shaded pond does not result in deterioration of water quality parameters even though the intervention occupies only a small surface area of the pond. The roots of planted vegetables in IFCAS apparently can stabilize water quality by absorbing excess nutrients for their growth, which otherwise could be toxic for aquatic organisms (Sirsat and Neal, 2013). A significant difference ($P < 0.05$) was found however, between the ammonia and nitrite content of water under MSP and HSP conditions. This may result from livestock sourcing shade around HSP ponds and/or decomposition of organic matter particularly the leaves of plants from the pond dike. In the present study, levels of ammonia and nitrite were a little higher than in usually a suitable range for fish culture (Bhatnagar and Devi, 2013). Photoperiod and light intensity can significantly affect growth, reproduction and other biological activities of fish (Ridha and Cruz, 2000) and fish growth rates are significantly reduced under low light intensities (Han et al., 2005).

The survival rates of tilapia and Vietnamese perch in IFCAS in shaded ponds were relatively higher due to stocking good quality and properly acclimated fingerlings. Shade or low light intensity apparently does not affect survival rates of fish (Han et al., 2005). This result is consistent with studies conducted by Mondal et al. (2010) and Habib et al. (2015). Production of tilapia was generally higher under MSP compared with HSP. This condition is direct evidence for lower satiation level of feed intake by tilapia observed in the IFCAS under HSP condition compared with MSP. Reduced growth can be attributed to poor water quality under HSP resulting from decomposition of organic matter which may affect fish health negatively as well as growth rate (Haque et al., 2015). Productivity of fish was higher under monoculture compared with polyculture, an outcome that is similar to other studies (Chakraborty and Nur, 2012). This probably results from lower competition for feed under monoculture and lower survival rates in polyculture due to competition for feed and space. Productivity of Vietnamese perch was not significantly differed under MSP and HSP conditions which indicate potential to culture this species using an IFCAS approach in shaded ponds. In the present study, FCR values in different treatments were within the acceptable range indicating efficient feed utilization, a result that is in line with results from Islam (2002) and Chakraborty and Nur (2012).

The average productivity of carp in IFCAS pond was similar with a study (Ali et al., 2016) for homestead pond in an area in the same region, indicating IFCAS structured did not affect the pond productivity negatively. The individual growth rate for most carp was higher under MSP; however, common carp showed a higher growth rate in HSP which indicates potential to culture this species in homestead shaded ponds. This probably results from availability of decomposing plant debris and insect larvae (chironomids etc.) living in the mud in the pond bottom which is consumed as natural feed by common carp (Billard, 1995). Individual growth of silver carp was found to be much higher under MSP condition than HSP, possibly related to the relative abundance of plankton in MSP. Stinging catfish grow well in heavily shaded ponds and so there is potential to culture this species in non-shaded ponds (Haque et al., 2015). This indicates stinging catfish can be a suitable species for homestead shaded ponds. Production of vegetables was higher under MSP condition compared with HSP, possibly because of higher sunlight availability. Growth rate of snake gourds, bottle gourds and tomatoes however, were found to be similar in both MSP and HSP. Vegetables from IFCAS production supported nutrition in participated households during heavy rainfall when it was very difficult to produce vegetables in the homestead area.

Economic analysis is an important management tool which is necessary for aquaculture business planning and for identifying economically sustainable initiatives. While initial investment in IFCAS was relatively high; when depreciation costs are considered, the investment was economically efficient under both MSP and HSP. Economic efficiency of IFCAS was also high compared with the main agricultural crops in Bangladesh (Afroz and Islam, 2012). The benefit-cost ratio for culturing both tilapia and Vietnamese perch were both higher under monoculture than in polyculture, so it may be concluded that monoculture of these species in general is more profitable. Investment in IFACS however, was also financially efficient in all treatments in both types of ponds.

5. Conclusion

In rural areas of Bangladesh, the vast majority of households own only small or large shaded homestead ponds located next to their dwellings and the pond dikes are covered with large timber trees, a situation where it is quite difficult to produce fish and vegetables on the dikes. Incorporation of appropriate technologies however, can successfully utilize homestead ponds for commercial fish farming that can meet growing protein and nutritional demand. Growth rate, productivity and economic returns from farming tilapia and Vietnamese perch were found to be higher in monoculture compared with polyculture systems in both MSP and HSP types pond; thus, monoculture may be considered to be a more effective technique for producing these fishes in IFCAS. Thus both tilapia and Vietnamese perch offer suitable candidate species for IFCAS production in the shaded ponds in Barisal region of Bangladesh. Further research is needed however to optimize stocking density, optimal scale over a wide range of locations to improve overall productivity of IFCAS in shaded ponds.

Acknowledgements

We are grateful to European Union (EU) funded Agriculture and Nutrition Extension Project (ANEP) for covering the cost of this farmer participatory action research. ANEP is a consortium between International Development Enterprise (iDE), WorldFish, CIMMYT, IRRI, Save the Children International and CODEC. This research paper is a contribution to the CGIAR research program on Aquatic Agricultural Systems (AAS). The authors of the manuscript would like to express our cordial gratitude to Peter B Mather (Adjunct Professor, Queensland University of Technology, Australia) and Christopher Brown, Science leader, WorldFish, Bangladesh and South Asia office for their constructive suggestions and editorial support of this paper. We are also indebted to the participated households for contributing and conducting this research work.

References

Afroz, S., Islam, S., 2012. Economics of Aus rice (Oryza sativa) and jute (Corchorusolitorius) cultivation in some selected areas of Narsingdi district of Bangladesh. Agriculturists 10, 90–97.
Ahmed, G.U., Sultana, N., Shamsuddin, M., Hossain, M.B., 2013. Growth and production performance of mono-sex tilapia (*Oreochromis niloticus*) fed with homemade feed in earthen mini ponds. Pak. J. Biol. Sci. 16 (23), 1781–1785.
Ali, H., Jahan, K.M., Belton, B., Dhar, G.C., 2016. Factors determining the productivity of mola carplet (*Amblypharyngodon mola*, Hamilton, in carp polyculture systems in Bangladesh. Aquaculture (Submitted).
BBS, 2002. Statistical yearbook of Bangladesh. Statistics and information Division. Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.
Balarin, J.D., Haller, R.D., 1982. The intensive culture of tilapia in tanks, raceways and cages. In: Muir, J.F., Roberts, J.J. (Eds.), Recent Advances in Aquaculture. Westview Press Boulder, Colorado, pp. 265–365.
Bhatnagar, A., Devi, P., 2013. Water quality guidelines for the management of pond fish culture. Int. J. Environ. Sci. 3, 1980–2009.
Biggs, S.D., 1989. Resource-poor farmer participation in research: a synthesis of experiences from nine national agricultural research systems. Int. Serv. Natl. Agric. Res. (ISNAR), 37.
Billard, R., 1995. Carp Biology and Culture. INRA, Paris, pp. 322.
Chakraborty, B.K., Nur, N.N., 2012. Growth and yield performance of shingi, *Heteropneustes fossilis* and koi, *Anabas testudineus* in Bangladesh under semi-intensive culture systems. Int. J. Agric. Res. Innov. Technol. 2 (2), 15–24.
DoF, 2014. Fishery Statistical Yearbook of Bangladesh. Fisheries Resources Survey System, Department of Fisheries, Ministry of Fisheries and Livestock, Dhaka, Bangladesh.
FAO, 2016. The State of World Fisheries and Aquaculture: Opportunities and Challenges. Food and Agriculture Organization of the United Nations, Rome, Italy.
Habib, K.A., Newaz, A.W., Badhon, M.K., Naser, M.A., Shahabuddin, A.M., 2015. Effects of stocking density on growth and production performance of cage

reared climbing perch (*Anabas testudineus*) of high yielding Vietnamese stock. World J. Agric. Sci. 11 (1), 19–28.

Han, D., Xie, S., Lei, T.W., Zhu, X., Yang, Y., 2005. Effect of light intensity on growth, survival and skin colour of juvenile Chinese longsnout catfish (Leiocassislongirostris Gqnther). Aquaculture 248, 299–306.

Haque, M.M., Alam, M.R., Alam, M.M., Basak, B., Sumi, K.R., Belton, B., Jahan, K.M., 2015. Integrated floating cage aquageoponics system (IFCAS): an innovation in fish and vegetable production for shaded ponds in Bangladesh. Aquacult. Rep. 2, 1–9.

Hussain, M.G., Rahman, M.A., Akhteruzzaman, M., Kohinoor, A.H.M., 1989. A study on the production of *Oreochromis niloticus* (L.) under semi-intensive system. Bangladesh J. Fish. 12, 59–65.

Hussain, M.G., 2009. A future for the tilapia in Bangladesh. Aquacult. Asia Pac. Mag., 38–40.

Islam, M.S., 2002. Evaluation of supplementary feeds for semi intensive pond culture of Mahaseer, *Tor putitora* (Hamilton). Aquaculture 212, 263–276.

Mondal, M.N., Shahin, J., Wahab, M.A., Asaduzzaman, M., Yang, Y., 2010. Comparison between cage and pond production of Thai climbing perch (*Anabas testudineus*) and tilapia (*Oreochromis niloticus*) under three management systems. J. Bangladesh Agric. Univ. 8 (2), 313–322.

Rahman, S., Monir, M.S., 2013. Effect of stocking density on survival, growth and production of Thai *Anabas testudineus* (bloch) fingerlings under nursery ponds management in northern regions of Bangladesh. J. Exp. Biol. Agric. Sci. 1 (6), 465–472.

Rahman, M.M., Varga, I., Chowdhury, S.N., 1992. Manual on polyculture and integrated fish farming in Bangladesh. Food and Agriculture Organization of the United Nations, Rome, Italy.

Sarker, M.R., Ali, M.M., Monir, M.S., Paul, M., Barman, A.C., 2014. Growth and production performance of tilapia (*Oreochromis niloticus*) polyculture with carps in homestead pond. Mar. Resour. Aquacult. 2 (1), 1–6.

Shamsuddin, M., Hossain, M.B., Rahman, M.M., Asadujjaman, M., Ali, M.Y., 2012. Performance of mono-sex fry production of two Nile tilapia strains: GIFT and NEW GIPU. World J. Fish Mar. Sci. 4, 68–72.

Shang, Y.C., 1990. Aquaculture Economic Analysis: An Introduction. The World Aquaculture Society, Baton Rouge, Los Angels, USA, pp: 211.

Sirsat, S.A., Neal, J.A., 2013. Microbial profile of soil-Free versus in-soil grown lettuce and intervention methodologies to combat pathogen surrogates and spoilage microorganisms on lettuce. Food 2, 488–498.

Thakur, D.P., 2004. New species studied for aquaculture potential by aquaculture CRSP researchers. Aquanews 19 (1), 1–6.