Incorporation of Tilapia (*Oreochromis Niloticus*) and Sahar (*Tor Putitora*) into the Existing Carp Polyculture System of Nepal

Production System Design and Best Management Alternatives/Experiment/09BMA03UM

Madhav K. Shrestha and Ramesh Jaiswal
Institute of Agriculture and Animal Sciences
Rampur, Chitwan, Nepal

Liu Liping
Shanghai Ocean University
Shanghai, China

James S. Diana
University of Michigan
Ann Arbor, Michigan, USA

ABSTRACT

An experiment was conducted for 180 days in 12 earthen ponds, 110-150 m^2 in surface area and 1.0 m in depth, at the Institute of Agriculture and Animal Science (IAAS), Rampur, Chitwan, Nepal to assess the growth, production, and productivity of carps, tilapia (*Oreochromis niloticus*), and sahar (*Tor putitora)* in different polyculture combinations. There were one control and three treatments with three replicates each: (1) Existing carp polyculture (silver carp, bighead carp, common carp, grass carp, rohu, and mrigal in the ratio of 3:2:2.5:0.5:1:1 and stocking density of 7000 fish ha^{-1}) (control); (2) Control + tilapia (3000 ha^{-1}); (3) Control + tilapia (3000 ha^{-1}) + sahar (500 ha^{-1}); (4) Control + tilapia (3000 ha^{-1}) + sahar (1000 ha^{-1}). The ponds were fertilized weekly at 4 kg N and 1 kg P ha^{-1} d^{-1} using diammonium phosphate (DAP) and urea. Fish were fed on alternate days at 0900–1000 h, with a locally made pelleted feed (20% crude protein) at rates of 2% body weight per day. Feed rations were adjusted monthly based on sampling weights.

Survival of carps (68-89%), tilapia (69-83%) and sahar (43-49%) were not significantly different among treatments. All carp species showed better performance in all treatments than sahar or tilapia with a daily weight gain of 1.0 to 2.4 g d^{-1}. The combined net and gross yields of all carps in T_1 and T_2 were significantly higher than T_3 and T_4 ($p<0.05$). The combined net and gross yields were significantly higher in T_2 than other treatments ($p<0.05$), which were not significantly different from each other ($p>0.05$). The overall FCR was significantly lower in T_2 (1.0±0.0) than T_4 (1.4±0.1) ($p<0.05$), whereas there were no significant differences among other treatments. The number of tilapia recruits was significantly higher in T_2 (798±32) than T_3 (676±51) and T_4 (603±72). There were no significant differences in any water quality parameters among treatments. Pond water temperature remained above 20°C throughout the experimental period. Dissolved oxygen concentrations in the T_3 and T_4 ponds were consistently low during most of the experimental period and caused mortality of sahar and silver carps. All treatments produced a positive gross margin, with the significantly highest gross margin in T_2 (NRs 793,800 ha^{-1} $year^{-1}$). Additions of Nile tilapia in the semi-intensive carp polyculture ponds can significantly increase the fish production up to 57% and net returns up to 61%. However, high stocking densities caused by adding sahar to the polyculture reduced economic performance.

INTRODUCTION

Inland aquaculture and fisheries are the only source of fish production in Nepal. Total fish production is 48,230 mt, with 21,500 mt (about 45%) coming from capture fisheries (DoFD, 2010). Current annual fish production of Nepal aquaculture systems is about 3.3 t/ha (DoFD, 2010). Increasing fish productivity as well as total production in country is a challenging task and necessary in order to provide for increasing demand for fish as food without increasing import from neighboring countries. Nile tilapia (*Oreochromis niloticus*) was introduced in Nepal in 1985 (Pantha, 1993), however, it remained in government control for more than 10 years (Shrestha and Bhujel, 1999). We have worked on tilapia and sahar (*Tor putitora*) combinations in polyculture to control excessive recruitment of tilapia and also to provide additional species to increase productivity and to promote culture of high value fish that are indigenous. Sahar can control tilapia fry in mixed sex culture (Paudel et al., 2007; Rai et al., 2007; Yadav et al., 2007). Polyculture of sahar with mixed-sex tilapia increased fish yield significantly compared to tilapia monoculture (Shrestha et al., 2011). Growth of sahar is higher in tropical and subtropical ponds than in cages in lakes near Pokhara and also in suspended cages in ponds (Shrestha et al., 2005; 2007; Bista et al., 2001; 2007).

Semi-intensive carp polyculture is an established and recommended system in tropical and subtropical region of Nepal using fertilized ponds with partial feed supplementation. The species are: common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), grass carp (*Ctenopharyngodon idella*), rohu (*Labeo rohita*), naini/mrigal (*Cirrhinus mrigala*), and Bhakur/Catla (*Catla catla*). Though all seven species are recommended in certain ratios with a combined density of 7000 fish/ha (Pandey et al., 2007), fingerlings of all species are rarely available when needed for stocking. In most of the cases, the number of species cultured ranges from four to six. Addition of well proven species (such as tilapia and sahar) with increased stocking density into the existing carp production system can have a positive impact by increased productivity and economic value.

The purpose of this study was to incorporate tilapia and sahar into carp polyculture to improve production in order to better develop the model for best production and to determine the costs and benefits of various polyculture combinations.

The objectives of this study were:

I. To assess the growth, production and productivity of carps, tilapia and sahar in different polyculture combinations;
II. To assess nutrient recovery in each system
III. To determine cost and benefits of fish production in each polyculture system;
IV. To assess and compare water quality produced by each polyculture treatment;
V. To promote those results in a workshop targeted on polyculture and family nutrition.

METHODS AND MATERIALS

This experiment was conducted in 12 earthen ponds, 110-150 m^2 in surface area and 1.0 m in depth, at the Institute of Agriculture and Animal Science (IAAS), Rampur, Chitwan, Nepal. The experiment was conducted in completely randomized design using one control and three treatments with three replicate each: (1) Existing carp polyculture (7000 fish ha^{-1}) (control); (2) Control + tilapia (3000 ha^{-1}); (3) Control + tilapia (3000 ha^{-1}) + sahar (500 ha^{-1}); (4) Control + tilapia (3000 ha^{-1}) + sahar (1000/ha^{-1}). Ponds were drained and filled with canal water two weeks before fish stocking. They were fertilized at 4 kg N and 1 kg P ha^{-1} d^{-1} for 7 days with diammonium phosphate (DAP) and urea. A feeding tray was placed in each pond to confine feeding. A wooden platform was constructed in the ponds for feeding and water sampling. Water depth was maintained 1.0 m in all ponds by biweekly topping with canal water to replace water loss due to evaporation and seepage. Fish were fed once on alternate days at 0900–1000 h, with a locally made pelleted feed (20% crude protein) at rates of 2% body weight per day. Feed rations were adjusted monthly based on sampling weights. Ponds were fertilized weekly using DAP and urea at rates of 4 kg N and 1 kg P ha^{-1} d^{-1}.

Fingerlings of silver carp, bighead carp, common carp, grass carp, rohu, and mrigal (average weights 24.1±2.2 g, 36.7±4.6 g, 20.4±2.9 g, 39.7±3.8 g, 9.7±1.4 g and 6.9±0.7 g, respectively) were stocked in all ponds. The stocking ratio was 3:2:2.5:0.5:1:1 in all ponds. Similarly, Nile tilapia and sahar (average weights 11.6±1.6 g and 3.4±0.4 g, respectively) were added in treatment ponds. Fish were stocked on 25 February 2011 and harvested on 26 August 2011.

Weekly and biweekly measurements of water quality parameters were conducted at 0600–0800 h starting from 25 February 2011. Water temperature, dissolved oxygen (DO), pH, and Secchi disk depth were measured in situ weekly using a Thermometer (Lutron TM-936 model), DO meter (Lutron DO-5509 model), pH meter (Lutron YK-21 PH model), and Secchi disk, respectively. Water samples were collected biweekly from each pond using a column sampler and analyzed for total alkalinity, total ammonium nitrogen (TAN), nitrite nitrogen (NO_2-N), soluble reactive phosphorous (SRP), and chlorophyll a using standard methods (APHA, 1985).

A simple economic analysis was conducted based on farm-gate prices for harvested fish and market prices for all costs in Nepal (Shang, 1990). Farm gate prices of sahar, tilapia, carp were 300, 200 and 150-200 NRs kg^{-1} (\$1 US = 73 NRs), respectively. Prices for sahar, tilapia, and carps fingerlings were 5, 2 and 2 NRs $piece^{-1}$, respectively. Prices for feed, DAP, and urea were 20, 45, and 30 NRs kg^{-1}, respectively. The calculation for cost of working capital was based on an annual interest rate of 10%.

Data were analyzed statistically by one way analysis of variance (ANOVA), using SPSS (version 16.0) statistical software (SPSS Inc., Chicago). Arcsine transformations were performed on percent data. Differences were considered significant at the 95% confidence level ($P < 0.05$). All means were given with ±1 standard error (S.E.).

RESULTS

The survival rate of stocked Nile tilapia ranged from 69.4 to 83.2%, without significant differences among treatments (Table 1). There were no significant differences in mean harvest weight, daily weight gain, net fish yield (NFY) and gross fish yield (GFY) of tilapia among treatments. The survival of sahar was very low, ranging from 42.9 to 48.5%, without significant differences among treatments (Table 1). The daily weight gain of sahar ranged from 0.3 to 0.4 g d^{-1} (Figure 1), also without significant differences among treatments. The GFY and NFY of sahar ranged from 0.03 to 0.06 and 0.02 to 0.03 t ha^{-1} yr^{-1}, respectively and was significantly different ($p<0.05$) between treatments with high yield at the highest sahar density. The growth trend of Nile tilapia was about 1 g/d (Figure 2).

The survival of individual carps was not significantly different among treatments (Table 2). However, the overall survival of all carps was significantly higher in T_2 than T_4, whereas there were no significant differences among other treatments. All carp species showed better performance than tilapia or sahar in all treatments with a daily weight gain of 1.0 to 2.4 g. The daily weight gain for silver carp ranged from 1.8 to 2.3 g , with a significantly higher mean daily weight gain in T_4 than other treatments ($p<0.05$). Similarly, the daily weight gain of other carps ranged from 1.0 to 2.0 g, with no significant differences between treatments (Table 2). There were no significant differences in GFY or NFY of silver carp, bighead carp, rohu and mrigal among all treatments. The combined net and gross yields of all carps in T_1 and T_2 were significantly higher than T_3 and T_4 ($p<0.05$).

The combined net and gross yields of all species in a treatment were significantly higher in T_2 than other treatments ($p<0.05$, Table 3). The overall food conversion rate (FCR) was significantly lower in T_2 than T_4 ($p<0.05$), whereas there were no significant differences among other treatments (Table 4). The number of tilapia recruits was significantly higher in T_2 (798±32) than T_3 (676±51) and T_4 (603±72) (Table 3). There were no significant differences in the mean weight and NFY of recruits among treatments.

Weekly and fortnightly means of water quality parameters are presented in Table 5 and Figures 3 to 9. Analyses showed that there were no significant differences in any water quality parameters among treatments ($p>0.05$; Table 5). Most water quality parameters tended to fluctuate throughout the experimental period depending upon weather and nutrient supply. Pond water temperature remained above 20°C and increased gradually from 20.7 to 31.9°C throughout the experiment (Figure 3). Dissolved oxygen concentrations in the T_3 and T_4 ponds were consistently low during most of the experiment. Pond water pH ranged from 7.4 to 7.6, total alkalinity from 190.6 to 202.0 mg L^{-1} as $CaCO_3$ and chlorophyll-a from 155.8 to 198.3 mg m^{-3}. Total ammonium nitrogen increased from the beginning to the middle part of the experiment, and then decreased dramatically to the end of the experiment (Figure 7).

Results of economic analysis showed that all treatments produced a positive gross margin (Table 6), with the highest gross margin in T_2 (793800 NRs ha^{-1} $year^{-1}$), intermediate in T_3 (614100 NRs ha^{-1} $year^{-1}$) and T_4 (651500 NRs ha^{-1} $year^{-1}$), and lowest in T_1 (491600 NRs ha^{-1} $year^{-1}$) ($p<0.05$).

Our proposal for this experiment had 5 objectives, and not all were accomplished in the study reported here. Unfortunately, we had difficulties completing the experiment because of flooding at the facility and theft. Therefore, although we have some reasonable results reported here, we have just completed the on-station experiment again, and now we are doing the on farm work. Objective 2, which is a Masters thesis project to assess nutrient recovery, is part of the on-station study which we just completed and will also be part of the on-farm study. The MS student is currently analyzing the pond bottom soil, feed, and fish samples.

A one-day workshop held on January 11 was jointly organized by IAAS and the Nepal Fisheries Society to promote the results of this experiment. The workshop was attended by 47 participants (8 women) including researchers, government and extension officers, farmers, and businessmen. Technical presentations covered recent work on the CRSP tilapia-sahar- carp polyculture system, cage-pond systems for small farmers, and a comparative analysis of production and economics for cage-pond farmers versus pond farmers. An open discussion on how to use these outcomes followed the technical presentations. Government, extension, and research agency representatives showed interest to take up these outcomes.

DISCUSSION

The purpose of this study was to increase the production of existing semi-intensive carp polyculture of Nepal by addition of new species, tilapia, and sahar. The daily weight gain of Nile tilapia was 0.8-1.0 g d^{-1}, which was higher than a grass carp-tilapia polyculture system (0.2-0.5 g) (Pandit et al., 2004), and similar with tilapia-sahar polyculture systems (1.15 g; Acharya et al., 2007, and 0.6-0.9 g; Shrestha et al., 2011). Similarly, the daily weight gain of sahar was 0.3 to 0.4 g, which was similar to tilapia-sahar polyculture system (0.3-0.4 g d^{-1}) (Shrestha et al., 2011) and lower than monoculture (0.55-0.77 g d^{-1}) (Islam, 2002). The survival of sahar was very low, ranging from 43-49%. This survival was lower than that reported by Acharya et al. (2007), but similar to Shrestha et al. (2011) (39-56%) in tilapia-sahar polyculture systems. The lower survival of sahar was due to mass mortality of sahar by low dissolved oxygen. DO in pond water was consistently lower in ponds of T_3 and T_4, and it decreased to a minimum of 0.1 mg L^{-1} on some dates.

Gross carp yields (3.4 to 4.1 t ha^{-1} yr^{-1}) were higher than the average productivity in carp polyculture ponds in Nepal (3.0 t/ha/yr) (DoFD, 2010). Net yields of all carps were significantly higher in carp-tilapia polyculture than in other treatments. Growth performances of carp species were not affected by addition of tilapia, and there was no competition between carp and tilapia for pond resources. We can add Nile tilapia to carp polyculture ponds up to a certain density to enhance overall production.

Most water quality parameters in all ponds were within acceptable ranges for fish culture. Water quality was not drastically affected by stocking densities of fishes. However, frequent DO depletion was observed in the high stocking density treatments, T_3 and T_4. The FCRs recorded were fairly low, probably due to alternate day feeding.

Income in these experiments was estimated by simple budget analysis. Fixed costs were not included in the analysis as we intended to only compare relative differences in efficiency between the treatments, and we assumed fixed costs to be similar for all the treatments. Cost estimation was based on local market prices of fingerlings, fertilizers, lime, and labor wages. Results showed that all treatments produced positive net returns ranging from 491,600 to 793,800 NRs. However, the carp-tilapia combination (T_2) produced significantly higher net return than other treatments.

This study clearly demonstrated that addition of Nile tilapia in the semi-intensive carp polyculture ponds increased production up to 57% and net returns up to 61% without affecting water quality. However, the addition of both tilapia and sahar in semi-intensive carp polyculture ponds caused some water quality problems, especially depleting DO in the pond. Thus, it is necessary to fine-tune the ratio of carps, tilapia, and sahar in polyculture if all of these species are stocked. This new polyculture system provides an alternative species for farmers and allows for diversification of species in carp polyculture ponds. Finally, further research on the improved survival rate and growth of sahar in carp polyculture ponds is needed.

ANTICIPATED BENEFITS

The results of this study will provide an additional species in polyculture systems of Nepal with increased productivity, production, and income. These changes will add high valued fish into the culture system and will supplement income. As carp polyculture is an established system, increasing species will be easy for fish farmers to adopt. If sahar and tilapia are cultured, it will also help in production of sahar and decrease fishing pressure in nature. These changes will benefit fish culturists in south Asia and other countries where carp culture is popular. Knowledge on polyculture and expansion to endemic species not only benefits Nepal, but sustainable aquaculture systems throughout the developed world as well. Immediate impact will be measured by increased production and economic returns in on-farm trials for the different polyculture systems.

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Table 1. Performance of Nile tilapia and sahar in different treatments. Data based on 100 m^2 pond size. Mean values with same superscript in the same row are not significantly different ($p<0.05$).

Parameters	Treatment			
	T_1	T_2	T_3	T_4
Nile Tilapia Stocking				
Total weight (kg)	-	0.2±0.0^a	0.4±0.1^a	0.5±0.2^a
Mean weight (g)	-	8.0±1.8^a	13.3±3.3^a	13.6±2.6^a
Harvest				
Total weight (kg)	-	4.1±0.3^a	3.2±0.5^a	4.2±0.3^a
Mean weight (g)	-	167.7±16.2^a	150.0±9.1^a	200.0±31.0^a
Daily weight gain (g d^{-1})	-	0.9±0.1^a	0.8±0.1^a	1.0±0.2^a
Survival (%)	-	83.2±12.9^a	69.4±9.9^a	71.5±11.2^a
GFY (t ha^{-1} yr^{-1})	-	0.8±0.1^a	0.6±0.1^a	0.8±0.1^a
NFY (t ha^{-1} yr^{-1})	-	0.8±0.1^a	0.5±0.1^a	0.7±0.1^a
Sahar Stocking				
Total weight (kg)	-	-	0.02±0.00^a	0.02±0.00^a
Mean weight (g)	-	-	4.2±0.6^a	2.7±0.1^a
Harvest				
Total weight (kg)	-	-	0.2±0.0^b	0.3±0.0^a
Mean weight (g)	-	-	67.6±1.3^a	62.1±3.0^a
Daily weight gain (g d^{-1})	-	-	0.4±0.0^a	0.3±0.0^a
Survival (%)	-	-	42.9±7.1^a	48.5±3.6^a
GFY (t ha^{-1} yr^{-1})	-	-	0.03±0.00^b	0.06±0.00^a
NFY (t ha^{-1} yr^{-1})	-	-	0.02±0.00^b	0.03±0.00^a

Table 2. Performance of carps in different treatments. Data based on 100 m^2 pond size. Mean values with same superscript in the same row are not significantly different ($p<0.05$).

Parameters	**Treatment**			
	T_1	**T_2**	**T_3**	**T_4**
Silver Carp Stocking				
Total weight (kg)	0.5±0.1 ^{a}	0.5±0.1 ^{a}	0.5±0.0 ^{a}	0.7±0.1 ^{a}
Mean weight (g)	23.1±4.7 ^{a}	20.7±4.3 ^{a}	22.1±0.9 ^{a}	30.4±5.9 ^{a}
Harvest				
Total weight (kg)	5.0±0.9 ^{a}	6.0±0.4 ^{a}	5.5±0.3 ^{a}	5.0±0.6 ^{a}
Mean weight (g)	371.8±26.7 ^{b}	349.0±15.3 ^{b}	362.2±16.5 ^{b}	450.5±12.9 ^{a}
Daily weight gain (g d^{-1})	1.9±0.2 ^{b}	1.8±0.1 ^{b}	1.9±0.1 ^{b}	2.3±0.1 ^{a}
Survival (%)	61.9±14.2 ^{a}	77.3±6.6 ^{a}	66.9±5.4 ^{a}	50.8±7.0 ^{a}
GFY (t ha^{-1} yr^{-1})	1.0±0.2 ^{a}	1.2±0.1 ^{a}	1.1±0.1 ^{a}	1.0±0.1 ^{a}
NFY (t ha^{-1} yr^{-1})	0.9±0.2 ^{a}	1.1±0.1 ^{a}	1.0±0.1 ^{a}	0.9±0.1 ^{a}
Bighead Carp Stocking				
Total weight (kg)	0.5±0.2 ^{a}	0.5±0.1 ^{a}	0.4±0.1 ^{a}	0.7±0.1 ^{a}
Mean weight (g)	34.5±10.7 ^{a}	33.0±9.3 ^{a}	30.4±6.7 ^{a}	48.9±10.5 ^{a}
Harvest				
Total weight (kg)	3.8±0.8 ^{a}	2.7±0.1 ^{a}	3.4±0.2 ^{a}	3.8±0.3 ^{a}
Mean weight (g)	300.0±70.4 ^{a}	206.5±3.2 ^{a}	268.0±24.0 ^{a}	268.8±57.8 ^{a}
Daily weight gain (g d^{-1})	1.5±0.4 ^{a}	1.0±0.0 ^{a}	1.3±0.1 ^{a}	1.8±0.4 ^{a}
Survival (%)	93.1±7.4 ^{a}	94.2±3.2 ^{a}	94.8±2.9 ^{a}	77.2±11.4 ^{a}
GFY (t ha^{-1} yr^{-1})	0.8±0.2 ^{a}	0.5±0.0 ^{a}	0.7±0.0 ^{a}	0.8±0.1 ^{a}
NFY (t ha^{-1} yr^{-1})	0.7±0.2 ^{a}	0.4±0.0 ^{a}	0.6±0.0 ^{a}	0.6±0.1 ^{a}
Common Carp Stocking				
Total weight (kg)	0.3±0.1 ^{a}	0.4±0.0 ^{a}	0.3±0.1 ^{a}	0.5±0.2 ^{a}
Mean weight (g)	19.8±5.3 ^{a}	20.2±1.7 ^{a}	16.0±6.4 ^{a}	25.7±9.4 ^{a}
Harvest				
Total weight (kg)	5.7±0.4 ^{a}	5.2±0.2 ^{a}	3.9±0.7 ^{a}	3.9±0.2 ^{a}
Mean weight (g)	457.4±83.3 ^{a}	309.3±2.4 ^{ab}	316.9±22.5 ^{b}	368.3±7.7 ^{b}
Daily weight gain (g d^{-1})	2.4±0.5 ^{a}	1.6±0.0 ^{a}	1.7±0.1 ^{a}	1.9±0.1 ^{a}
Survival (%)	73.5±9.9 ^{a}	94.6±3.5 ^{a}	73.1±18.3 ^{a}	59.1±3.7 ^{a}
GFY (t ha^{-1} yr^{-1})	1.1±0.1 ^{a}	1.0±0.0 ^{ab}	0.8±0.1 ^{b}	0.8±0.0 ^{b}
NFY (t ha^{-1} yr^{-1})	1.1±0.1 ^{a}	1.0±0.0 ^{ab}	0.7±0.1 ^{b}	0.7±0.0 ^{b}
Grass Carp Stocking				
Total weight (kg)	0.1±0.0 ^{a}	0.1±0.0 ^{a}	0.2±0.0 ^{a}	0.2±0.0 ^{a}
Mean weight (g)	36.6±8.1 ^{a}	32.8±10.2 ^{a}	51.5±6.0 ^{a}	37.9±1.7 ^{a}
Harvest				
Total weight (kg)	1.3±0.2 ^{a}	1.5±0.2 ^{a}	0.8±0.1 ^{a}	0.5±0.3 ^{a}
Mean weight (g)	473.3±46.8 ^{a}	440.0±17.6 ^{a}	408.3±59.1 ^{a}	266.7±16.7 ^{b}
Daily weight gain (g d^{-1})	2.4±0.3 ^{a}	2.3±0.1 ^{a}	2.0±0.3 ^{a}	1.3±0.1 ^{b}
Survival (%)	73.3±13.3 ^{a}	86.7±6.7 ^{a}	53.3±6.7 ^{a}	40.0±20.0 ^{a}
GFY (t ha^{-1} yr^{-1})	0.3±0.0 ^{ab}	0.3±0.0 ^{a}	0.2±0.0 ^{bc}	0.1±0.1 ^{c}
NFY (t ha^{-1} yr^{-1})	0.2±0.0 ^{a}	0.3±0.0 ^{a}	0.1±0.0 ^{b}	0.1±0.1 ^{b}
Rohu Stocking				
Total weight (kg)	0.1±0.0 ^{a}	0.1±0.0 ^{a}	0.1±0.0 ^{a}	0.1±0.0 ^{a}
Mean weight (g)	8.9±3.6 ^{a}	9.1±3.3 ^{a}	10.5±2.2 ^{a}	10.5±4.0 ^{a}
Harvest				
Total weight (kg)	2.4±0.3 ^{a}	2.4±0.1 ^{a}	1.4±0.3 ^{b}	2.0±0.1 ^{a}
Mean weight (g)	318.0±40.1 ^{a}	327.6±11.7 ^{a}	248.9±10.6 ^{a}	327.7±36.4 ^{a}
Daily weight gain (g d^{-1})	1.7±0.2 ^{a}	1.8±0.1 ^{a}	1.3±0.1 ^{a}	1.8±0.2 ^{a}
Survival (%)	96.7±3.3 ^{a}	93.3±3.3 ^{a}	73.3±12.0 ^{a}	80.0±5.8 ^{a}

Parameters	Treatment			
	T_1	T_2	T_3	T_4
GFY (t ha^{-1} yr^{-1})	0.5±0.1 ^{a}	0.5±0.0 ^{a}	0.3±0.1 ^{b}	0.4±0.0 ^{ab}
NFY (t ha^{-1} yr^{-1})	0.5±0.1 ^{a}	0.5±0.0 ^{a}	0.3±0.1 ^{b}	0.4±0.0 ^{ab}
Mrigal Stocking				
Total weight (kg)	0.05±0.02 ^{a}	0.04±0.01 ^{a}	0.06±0.00 ^{a}	0.06±0.00 ^{a}
Mean weight (g)	6.3±2.4 ^{a}	5.6±1.7 ^{a}	8.3±0.2 ^{a}	7.3±0.9 ^{a}
Harvest				
Total weight (kg)	2.2±0.2 ^{a}	2.4±0.1 ^{a}	2.2±0.3 ^{a}	2.7±0.3 ^{a}
Mean weight (g)	366.0±9.9 ^{a}	353.2±17.2 ^{a}	319.5±7.7 ^{a}	340.0±20.8 ^{a}
Daily weight gain (g d^{-1})	2.0±0.1 ^{a}	1.9±0.1 ^{a}	1.7±0.0 ^{a}	1.8±0.1 ^{a}
Survival (%)	80.0±10.0 ^{a}	86.7±3.3 ^{a}	90.0±5.8 ^{a}	100.0±0.0 ^{a}
GFY (t ha^{-1} yr^{-1})	0.4±0.0 ^{a}	0.5±0.0 ^{a}	0.4±0.1 ^{a}	0.5±0.1 ^{a}
NFY (t/ ha^{-1} yr^{-1})	0.4±0.0 ^{a}	0.5±0.0 ^{a}	0.4±0.1 ^{a}	0.5±0.1 ^{a}
Carps Combined				
Gross Fish Yield (t/ha/yr)	4.1±0.1 ^{a}	4.0±0.2 ^{a}	3.4±0.1 ^{b}	3.6±0.3 ^{ab}
Net Fish Yield (t ha^{-1} yr^{-1})	3.7±0.1 ^{a}	3.7±0.1 ^{a}	3.1±0.1 ^{b}	3.2±0.2 ^{b}
Survival (%)	79.8±9.1 ^{ab}	88.8±3.4 ^{a}	75.2±0.6 ^{ab}	67.8±7.7 ^{b}

Table 3. Tilapia recruitment from ponds (100 m^2) in different treatments during the experimental period of 180 days. Mean values with same superscript in the same row are not significantly different ($p<0.05$).

Parameter	Treatments			
	T_1	T_2	T_3	T_4
Mean number (count pond^{-1})	-	798±32 ^{a}	676±51 ^{ab}	603±72 ^{b}
Mean weight (g)	-	8.4±0.5 ^{a}	10.3±1.8 ^{a}	11.8±0.8 ^{a}
Net Fish Yield (t ha^{-1} yr^{-1})	-	1.3±0.1 ^{a}	1.4±0.2 ^{a}	1.4±0.2 ^{a}

Table 4. Combined performance of carps, tilapia and sahar in each treatment. Based on 100 m^2 pond size. Mean values with same superscript in the same row are not significantly different ($p<0.05$).

Parameter	Treatments			
	T_1	T_2	T_3	T_4
Initial Fish Biomass (kg pond^{-1})	1.6±0.1 ^{a}	1.8±0.3 ^{a}	2.0±0.2 ^{a}	2.7±0.6 ^{a}
Final Fish Biomass (kg pond^{-1})	20.3±0.6 ^{b}	24.1±1.0 ^{a}	20.5±1.0 ^{b}	22.4±1.0 ^{ab}
Fish Biomass Gain (kg pond^{-1})	18.7±0.6 ^{b}	22.4±0.8 ^{a}	18.5±0.8 ^{b}	19.8±0.5 ^{b}
Gross Fish Yield (t ha^{-1} yr^{-1})	4.1±0.1^b	4.8±0.2^a	4.1±0.2^b	4.5±0.2^{ab}
Net Fish Yield (t ha^{-1} yr^{-1})	3.7±0.1 ^{b}	4.5±0.2 ^{a}	3.7±0.2 ^{b}	4.0±0.1 ^{b}
AFCR	1.2±0.0 ^{ab}	1.0±0.0 ^{b}	1.2±0.1 ^{ab}	1.4±0.1 ^{a}
Net Fish Yield including tilapia recruits (t ha^{-1} yr^{-1})	3.7±0.1^c	5.8±0.3^a	5.1±0.1^b	5.4±0.2^{ab}

Table 5. Overall mean and ranges of water quality parameters in each treatment.

Parameter	Treatments			
	T_1	**T_2**	**T_3**	**T_4**
Temperature (^oC)	27.3±0.1 (20.8-31.5)	27.3±0.1 (20.7-31.7)	27.3±0.1 (20.7-31.9)	27.3±0.1 (20.7-31.7)
pH	7.5 (7.2-8.7)	7.6 (7.2-8.9)	7.5 (7.1-9.0)	7.4 (7.1-8.9)
DO (mg L^{-1})	2.9±0.8 (0.6-7.2)	3.2±0.7 (0.8-7.1)	2.7±0.4 (0.3-6.7)	1.9±0.5 (0.3-0.5)
Secchi depth (cm)	27.8±1.7 (16.7-45.7)	25.9±0.8 (15.3-42.2)	28.4±2.5 (15.7-42.7)	31.0±2.1 (14.7-50.3)
Total alkalinity (mg L^{-1})	190.6±7.1 (112.2-283.1)	183.2±9.1 (130.1-267.5)	190.6±9.2 (102.3-276.8)	202.0±9.0 (104.4-292.8)
TAN (mg L^{-1})	0.37±0.01 (0.09-0.73)	0.39±0.04 (0.08-0.82)	0.34±0.03 (0.08-0.70)	0.36±0.01 (0.09-0.69)
Nitrite-N (mg L^{-1})	0.25±0.04 (0.13-0.50)	0.22±0.03 (0.13-0.38)	0.23±0.02 (0.13-0.46)	0.21±0.02 (0.13-0.40)
SRP (mg L^{-1})	0.42±0.01 (0.24-0.64)	0.44±0.02 (0.21-0.73)	0.38±0.02 (0.20-0.58)	0.45±0.06 (0.22-0.78)
Chlorophyll-a (mg m^{-3})	198.3±24.0 (21.4-340.4)	156.0±3.0 (34.7-242.4)	179.9±13.9 (47.7-295.8)	155.8±9.2 (33.6-271.2)

Table 6. Comparative economic analysis (in NRs) for ponds in each treatment during the experiment. Mean values with same superscript in the same row are not significantly different ($p<0.05$). 1 US$=73 NRs.

Parameter	Treatments			
	T_1	**T_2**	**T_3**	**T_4**
Gross Return				
Adult Nile tilapia	-	818.9±63.3 ^{a}	630.4±103.7 ^{a}	831.9±65.5 ^{a}
Sahar	-	-	45.6±7.8 ^{b}	92.3±1.7 ^{a}
Carps	3630.6±92.3 ^{a}	3573.1±152.2 ^{a}	2991.7±132.8 ^{b}	3153.7±226.1 ^{ab}
Nile tilapia recruits	-	798.3±31.8 ^{a}	676.0±51.1 ^{ab}	603.3±72.3 ^{b}
Total	3630.6±92.3 ^{c}	5222.1±296.5 ^{a}	4343.5±223.4 ^{b}	4681.3±212.3 ^{ab}
Variable Cost				
Nile tilapia (fingerlings)	-	60.5±0.5 ^{a}	60.5±0.5 ^{a}	60.5±0.5 ^{a}
Sahar (fingerlings)	-	-	26.2±0.6 ^{b}	51.5±1.5 ^{a}
Carps (fingerlings)	199.4±1.8 ^{a}	199.4±1.8 ^{a}	199.4±1.8 ^{a}	199.4±1.8 ^{a}
Lime	100.0±0.0 ^{a}	100.0±0.0 ^{a}	100.0±0.0 ^{a}	100.0±0.0 ^{a}
Feed	437.8±10.6 ^{a}	450.3±34.1 ^{a}	443.6±45.3 ^{a}	551.4±40.3 ^{a}
DAP	173.3±0.0 ^{a}	173.3±0.0 ^{a}	173.3±0.0 ^{a}	173.3±0.0 ^{a}
Urea	155.7±0.0 ^{a}	155.7±0.0 ^{a}	155.7±0.0 ^{a}	155.7±0.0 ^{a}
Cost of working capital	106.6±1.2 ^{b}	113.9±3.5 ^{b}	115.7±4.6 ^{b}	129.4±4.1 ^{a}
Total variable cost	1172.7±13.5 ^{b}	1253.1±38.2 ^{b}	1273.1±50.1 ^{b}	1423.5±45.4 ^{a}
Gross margin (in '000) (NRS pond^{-1})	2.5±0.1 ^{c}	4.0±0.3 ^{a}	3.1±0.2 ^{bc}	3.3±0.2 ^{b}
Gross margin (in '000) (NRS ha^{-1} year^{-1})	491.6±15.7 ^{c}	793.8±52.2 ^{a}	614.1±46.5 ^{bc}	651.5±39.2 ^{b}

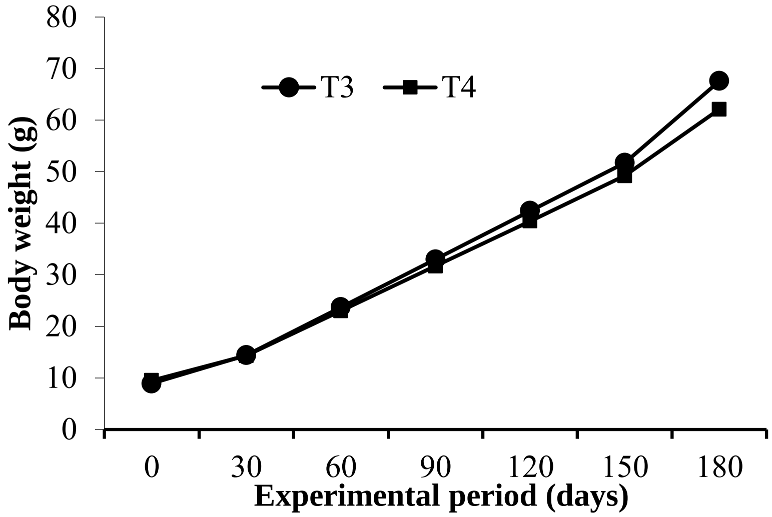

Figure 1. Growth trend of sahar in each treatment during the experiment period of 180 days (25 February to 26 August, 2011).

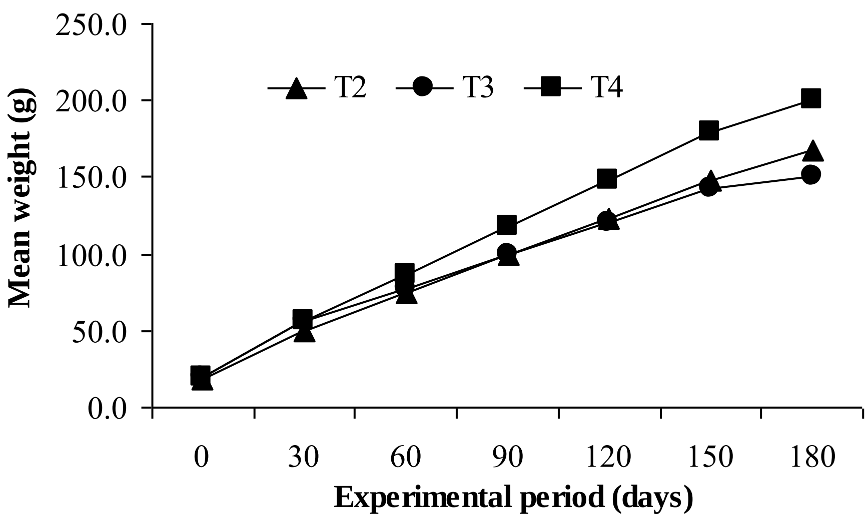

Figure 2. Growth trend of Nile tilapia in each treatment during the experiment periodof 180 days (25 February to 26 August, 2011).

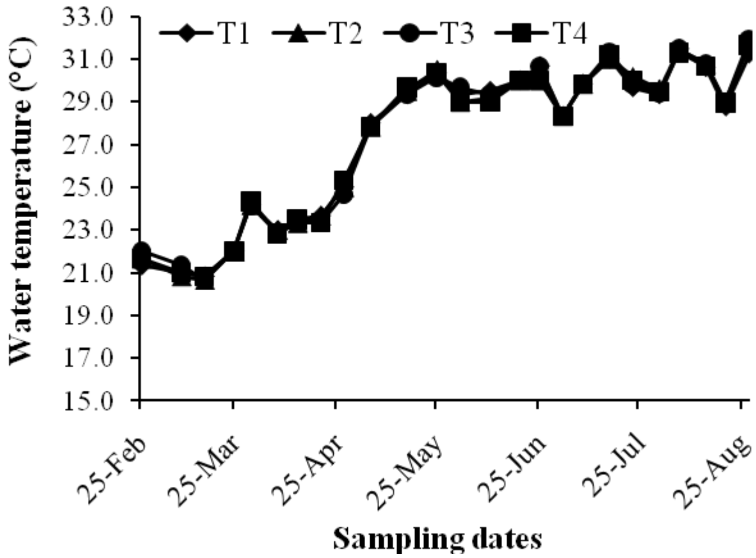

Figure 3. Weekly mean temperature (°C) of pond water at 0600–0800 h in each treatment during the experimental period (25 February to 26 August, 2011).

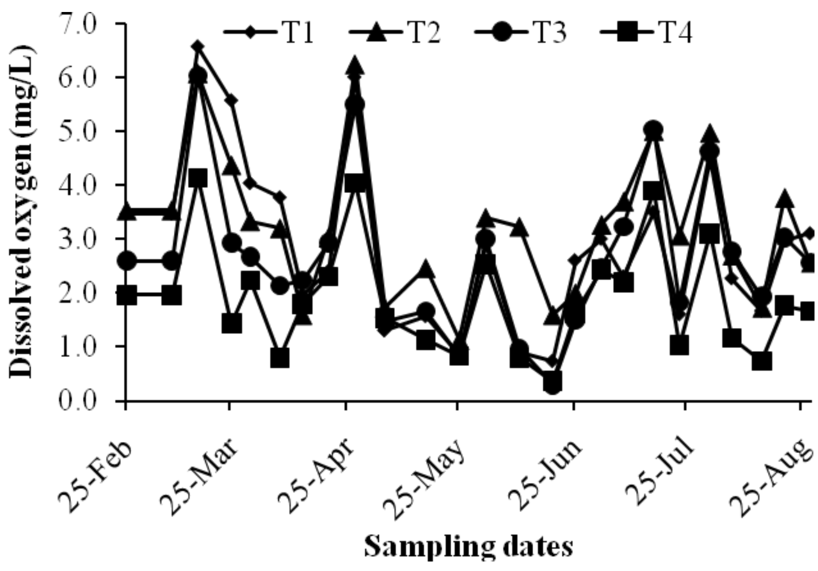

Figure 4. Weekly mean dissolved oxygen (mg L^{-1}) of pond water at 0600–0800 h in each treatment during the experimental period (25 February to 26 August, 2011).

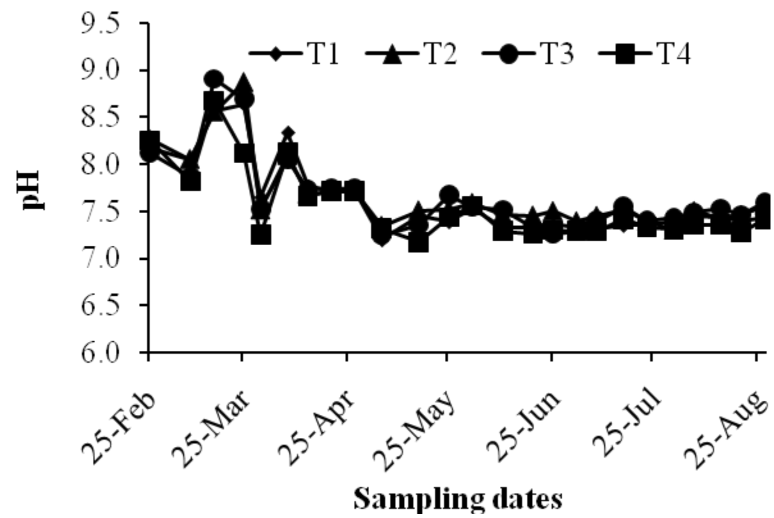

Figure 5. Weekly mean pH of pond water at 0600–0800 h in each treatment during the experimental period (25 February to 26 August, 2011).

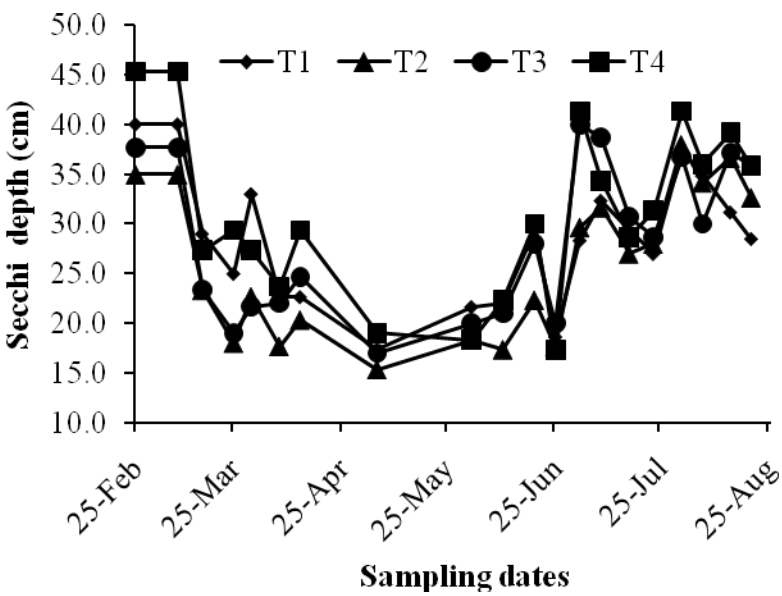

Figure 6. Weekly mean secchi depth (cm) of pond water at 0600–0800 h in each treatment during the experimental period (25 February to 26 August, 2011).

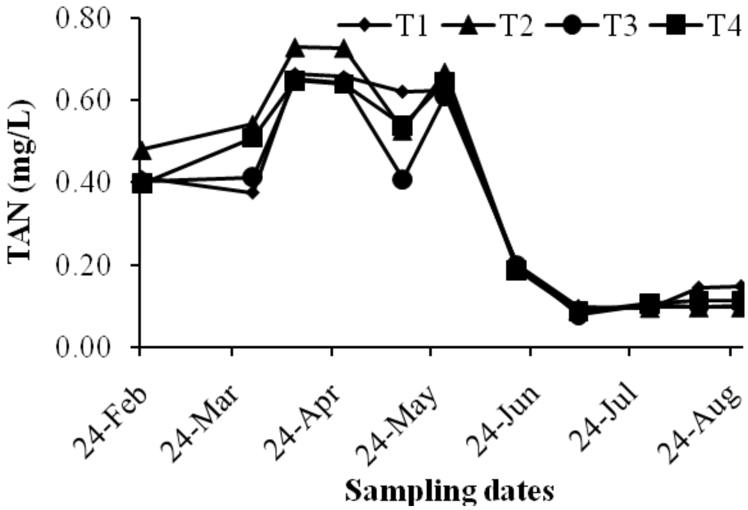

Figure 7. Fortnightly mean total ammonium nitrogen (TAN) (mg L^{-1}) of pond water at 0600–0800 h in each treatment during the experimental period (25 February to 26 August, 2011).

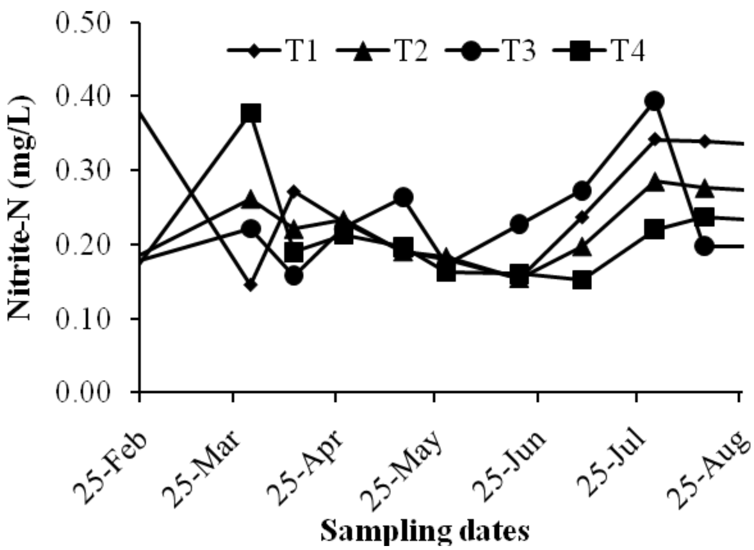

Figure 8. Fortnightly mean nitrite ammonium nitrogen (Nitrite-N) (mg L^{-1}) of pond water at 0600–0800 h in each treatment during the experimental period (25 February to 26 August, 2011).

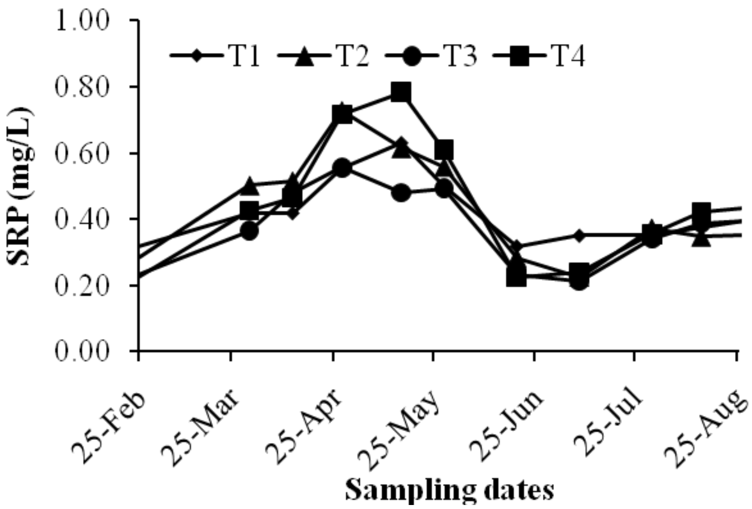

Figure 9. Fortnightly mean soluble reactive phosphorous (SRP) (mg L^{-1}) of pond water at 0600–0800 h in each treatment during the experimental period (25 February to 26 August, 2011).