A Comparison of Monoculture and Polyculture of Tilapia with Carps for Pond Production Systems in Nepal

Production System Design and Best Management Alternatives/Experiment/16BMA03UM

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ABSTRACT

Carp polyculture is a well-established aquaculture system in Nepal but improving productivity of this aquaculture system as well as the introduction of new aquaculture systems is a major concern. Two trials were conducted to demonstrate the value of Nile tilapia and sahar in polyculture ponds, and a culture system with only monosex tilapia. The on-station trial was conducted at the Aquaculture farm of AFU, Chitwan, Nepal in 12 earthen ponds of 150 m^2 for 185 days (1 June to 3 December 2017). The on-farm trial was conducted in 12 earthen ponds of 200 m^2 in a private farm of Kathar, Chitwan, Nepal for 150 days (17 July to 15 December 2017) to demonstrate the culture potential of sahar and tilapia to farmers. Both trials were conducted in a completely random design with four treatments in triplicate: a) Existing carp polyculture (10,000/ha) + mixed-sex tilapia (3,000/ha) + sahar (1,000/ha) (T_1); b) Existing carp polyculture + monosex tilapia (3,000/ha) (T_2); c) Monosex tilapia at 10,000/ha with fertilization only (T_3); and d) Monosex tilapia at 20,000/ha with fertilization and feeding (T_4). Silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) were stocked in all ponds at the ratio of 3.5:1:2.5:0.5:1.5:1.The mean stocking size of silver carp, bighead carp, common carp, grass carp, rohu and mrigal in T_1 and T_2 in on-station trial was 3.2 and 3.3, 0.6 and 0.6, 13.6 and 12.5, 5.9 and 6.2, 21.7 and 20.6,11.1 and 11.9 g, respectively. The mean stocking size of Nile tilapia (*Oreochromis niloticus*) was 1.9, 0.9, 1.2 and 0.9 g, in T_1, T_2, T_3, and T_4, respectively, and of sahar (*Tor putitora*) was 2.1 g. The ponds were fertilized weekly with urea and di-ammonium phosphate at 4 g N and 1 g P m^{-2} day^{-1}. Fish were fed once daily with commercial pelleted feed (26% CP) at 2% body weight. At harvest, the combined net fish yield was significantly higher ($p<0.05$) in T_4 (3.77±0.23 $t \cdot ha^{-1} \cdot crop^{-1}$) compared to T_3 (1.03±0.14 $t \cdot ha^{-1} \cdot crop^{-1}$); whereas, there was no significant difference ($p>0.05$) among T_1 (2.82±0.23 $t \cdot ha^{-1} \cdot crop^{-1}$), T_2 (3.20±0.17 $t \cdot ha^{-1} \cdot crop^{-1}$) and T_4 (3.77±0.23 $t \cdot ha^{-1} \cdot crop^{-1}$). The mean harvest size, daily weight gain, GFY, and NFY of monosex Nile tilapia in T_4 were significantly higher than in T_3 ($p<0.05$).There was no significant difference in average temperature, total alkalinity, total ammonium nitrogen and chlorophyll-a among treatments during the experimental period ($p>0.05$); however, dissolved oxygen was significantly higher in T_4 than other treatments ($p<0.05$). The gross profit margin was significantly higher in T_4 (4418.5±302.9 USD/ha) compared to T_3 (1666.1±341.3 USD/ha) without any significant difference between T_1 and T_2 ($p<0.05$).

In the on-farm trial, mean stocking size of silver carp, bighead carp, common carp, grass carp, rohu, and mrigal in T_1 and T_2 was 44.2 and 45.3, 3.0 and 3.0, 9.9 and 9.7, 3.0 and 3.0, 29.8 and 32.9 g, respectively. Mean size of mixed-sex tilapia was 3.5 g in T_1 and all-male tilapia of 6.5, 6.5, and 3.2 g size were stocked in T_2, T_3 and T_4, respectively. Similarly, the mean stocking size of sahar in T_1 was 7.0 g. Feeding, fertilization and other culture practices were similar to the on-station trial. At harvest, the combined net fish yield was significantly lower in T_3 (0.71±0.02 $t \cdot ha^{-1} \cdot crop^{-1}$) compared to other treatments ($p<0.05$); whereas, there was no significant difference among T_1 (2.49±0.24 $t \cdot ha^{-1} \cdot crop^{-1}$),

T_2 (2.57±0.36 t·ha^{-1}·crop^{-1}) and T_4 (2.54±0.06 t·ha^{-1}·crop^{-1}) ($p>0.05$). The mean harvest size, daily weight gain, GFY and NFY of monosex Nile tilapia in T_4 were significantly higher than in T_3 ($p<0.05$). There was no significant difference in average temperature and Secchi disk depth among treatments during the experimental period ($p>0.05$); however, dissolved oxygen was significantly higher in T_3 than other treatments ($p<0.05$). The gross profit margin was significantly lower in T_3 (1036.9±70.7 USD/ha) compared to other treatments; whereas, there was no significant difference among T_1 (2521.4±411.8 USD/ha), T_2 (2483.2±339.1 USD/ha) and T_4 (3115.6±237.5 USD/ha) ($p>0.05$).We conclude that the carp-tilapia-sahar polyculture, carps and monosex tilapia polyculture, and monosex tilapia culture with fertilization and feeding systems are equivalent practices and better than the presently used carp polyculture system to enhance pond productivity, species diversification and economically viable aquaculture.

INTRODUCTION

Total fish production in Nepal was 83,000 metric tons in 2016, with about 60% originating from aquaculture. Pond culture is the most popular method of aquaculture, but annual pond yield averages only 4.92 t/ha (DoFD, 2017). Carps are popular warm water fish for culture in Nepal, contributing more than 95% of aquaculture production in the country. Tilapia is a globally prominent species for all types of management intensities. Nile tilapia (*Oreochromis niloticus*) was introduced into Nepal in 1985 (Pantha, 1993), but it remained under government control for more than 10 years (Shrestha and Bhujel, 1999). Since 1996, experiments conducted at Institute of Agriculture and Animal Sciences (IAAS) included polyculture of tilapia and common carp (*Cyprinus carpio*; Shrestha and Bhujel, 1999), mixed-size culture of tilapia (Mandal and Shrestha, 2001), polyculture of grass carp (*Ctenopharyngodon idella*) with tilapia (Pandit et al., 2004), and recently additional polyculture experiments conducted on-station and on-farm (Bhandari et al., 2016). Recruitment control remains a problem, as mixed-sex tilapia is most commonly used for culture. Snakehead (*Channa striata*; Yi et al., 2004) and sahar (*Tor putitora;* Shrestha, 1997) have been evaluated for their ability to control tilapia reproduction by predation on tilapia fry. Tilapia and sahar co-culture was attempted to control excessive recruitment of tilapia and provide an additional species to increase productivity of high-valued indigenous fish (Shrestha et al., 2011). Sahar has been overfished in rivers and lakes, which has resulted in declining populations (Rajbanshi, 2001; Joshi et al., 2002) and listing as an endangered species (IUCN, 2017). While sahar can reduce tilapia fry production, overpopulation of tilapia often occurs even when sahar are present (Paudel et al., 2007; Yadav et al., 2007; Shrestha et al., 2011). Growth of sahar is typically higher in tropical and subtropical ponds than in cages reared in Pokhara lakes, as well as suspended cages in ponds (Bista et al., 2007; Shrestha et al., 2004).

Semi-intensive carp polyculture is an established system in tropical and subtropical regions of Nepal, using fertilized ponds with supplemental feed. The carp species include silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), common carp, grass carp, rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*). All 6 species are recommended in certain ratios with a combined density of 10,000 fish/ha, but fingerlings of all species are rarely available when needed for stocking. The typical number of species cultured ranges from four to six. The addition of other proven species (such as tilapia and sahar) with increased stocking density into the existing carp production system could increase productivity up to 57% and net returns by 61% (Shrestha et al., 2012) with no added inputs. Since tilapia consume plankton, they also improve water quality in ponds and in effluents at harvest. Such improvements in water quality, larger economic gain, and production of fish with no further inputs all enhance the sustainability of an aquaculture system environmentally and economically.

In the first phase of the AquaFish Project, we conducted an experiment incorporating tilapia into carp polyculture. The results showed significant increases in yield (29%) and profit margin (81%) when tilapia and sahar were added to carp polyculture (Bhandari et al., 2016). Overall production was still relatively low, about four tons per ha annually. This production is lower than monosex tilapia culture in ponds in Thailand, where we have achieved annual yields of about 5 tons per ha with only fertilizer inputs and up to 20 tons per ha in fed ponds (Diana, 2012). Monoculture of tilapia could possibly outperform polyculture with carps in Nepal, as well, either in terms of total production or in economic returns. It is not possible to directly transfer results on monoculture of tilapia from Thailand to Nepal, given the generally cooler and more seasonal climate in Nepal. Therefore, the purpose of this experiment is to examine monoculture of tilapia along with inclusion of tilapia in polyculture as techniques to best incorporate tilapia into the aquaculture industry in Nepal. Since sahar is an endangered species (IUCN 2017), any success in rearing them could either relieve pressure on wild populations as a food source, or could be used to supplement wild populations by stocking to improving sustainability of aquaculture in Nepal.

The addition of new species to the carp polyculture system and testing of new species under new conditions fit the national aquaculture plans elaborated by government agencies, as well as the *Feed the Future* (FtF) plans for aquaculture improvement. The first FtF research goal is to advance the productivity frontier by both increasing productivity beyond current levels through technology development and extending technology so local production can reach the level of research farms. This study was focused on that goal. Secondly, the national plans for aquaculture and fisheries have goals to improve culture of indigenous fishes and raise yield of ponds from farms to the level of research stations. Again, the present study is in complete alignment with these goals.

This study was intended to expand the technology developed through AquaFish research on carps, tilapia, and sahar production to farmers in order to demonstrate alternative fish production models. In particular, we conducted a new on-farm experiment on monoculture and polyculture systems, using carp with the addition of tilapia and sahar, to determine the most practical system for farm adoption.

OBJECTIVES

The overall goal of this project was to determine if there is a valuable role for tilapia in the aquaculture systems in Nepal. To do this, we had the following objectives:

1. To increase pond productivity through species diversification.
2. To test a carp-tilapia-sahar polyculture and monosex tilapia culture system for outreach potential by private farms.
3. To evaluate the culture potential of sahar and monosex tilapia to farmers.
4. To develop partial enterprise budgets of costs and values of fish crops among treatments.

MATERIALS AND METHODS

Two trials, on-station and on-farm, were conducted simultaneously to evaluate performance of carp-tilapia-sahar polyculture and monosex tilapia culture systems. The on-station trial was conducted at the Aquaculture farm of AFU, Chitwan, Nepal in twelve earthen ponds of 150 m^2 for 185 days (1 June to 3 December 2017). The trial was conducted in a completely randomized design with four treatments in triplicate: a) Existing carp polyculture (10,000/ha) + mixed-sex tilapia (3,000/ha) + sahar (1,000/ha) (T_1); b) Existing carp polyculture and monosex tilapia at 3,000/ha (T_2); c) Monosex tilapia at 10,000/ha with fertilization only (T_3); and d) Monosex tilapia at 20,000/ha with fertilization and feeding (T_4). Silver carp, bighead carp, common carp, grass carp, rohu and mrigal of mean stocking size 3.2 and 3.3, 0.6 and 0.6, 13.6 and 12.5, 5.9 and 6.2, 21.7 and 20.6, 11.1 and 11.9 g, respectively were stocked in T_1 and T_2 at the ratio of 3.5:1:2.5:0.5:1.5:1. Mixed-sex Nile tilapia and sahar of 1.9 and 2.1 g size were added in T_1. Similarly, the stocking size for all-male tilapia in T_2, T_3, and T_4 were 0.9, 1.2, and 0.9 g, respectively. All experimental ponds were completely drained and treated with hydrated lime ($Ca(OH)_2$) at the rate of 450 kg per ha. The ponds were sun dried for 2-3 days then filled with canal water. Ponds were then fertilized at 4 kg N and 1 kg P $m^{-2}day^{-1}$ with di-ammonium phosphate (DAP) (18% N and 46% P_2O_5) and urea (46% N). Fingerlings were stocked one week after pond fertilization. Subsequent fertilizations were done on weekly basis.

Feeding was done with commercial pellet feed (24% CP; Machapuchhre Feed Industry, Kapilvastu, Nepal) at 2% of total carp biomass per day. The proximate composition of feed was 90.0% dry matter, 26.6% crude protein, 8.6% crude fiber, 2.4% ether extract and 5.4% total ash. Feeding was done once in the morning between 0900 and 1000. The quantity of feed was adjusted monthly based on fish sampling. Fertilization with DAP and Urea was done fortnightly in all treatments. Sampling of fish was done monthly from each pond starting 30 days after stocking. During sampling about 10% of the stocked population of each species was weighed to calculate feed quantity for next month, assuming 100% survival. For final harvest, all ponds were drained by pumping and all fish were harvested and weighed.

Weekly and biweekly measurements of water quality parameters were conducted at 0600–0800 h starting from 1 June 2017. Water temperature, dissolved oxygen (DO), pH, and Secchi disk depth were measured in situ weekly using a DO meter (Lutron DO-5519), pH meter (Lutron pH-222) and Secchi disk, respectively. Water samples were collected biweekly from each pond using a plastic column sampler and analyzed for total alkalinity, total ammonium nitrogen (TAN), soluble reactive phosphorous (SRP), and chlorophyll a (APHA et al., 1985). Proximate analysis of feed was done using methods provided in AOAC (1980).

Simple economic analysis was done to determine economic returns from each treatment (Shang, 1990). The economic analysis was mainly based on farm gate price for harvested fish and current local market prices for all other inputs in Nepal. Farm gate prices of sahar, tilapia and carps were 600, 250 and 250 NRs kg^{-1}, respectively. Prices for sahar, mixed-sex tilapia, and monosex tilapia fingerlings were 5, 1, and 2 NRs $piece^{-1}$, respectively. Prices for common carp, silver carp, bighead carp, grass carp, rohu and mrigal fingerlings were 5, 1, 0.5, 2, 5 and 3 NRs $piece^{-1}$, respectively. Prices for DAP, urea and feed was 50, 22 and 20 NRs kg^{-1}, respectively. One $US is equivalent to 105.00 NRs.

The on-farm trial was conducted at the Center for Aquaculture Research and Production (CARP; a private farm), Kathar, Chitwan in twelve earthen ponds of 200 m^2 for 150 days (17 July to 15 December 2017) to verify the culture potential of sahar and tilapia to farmers. The trial was conducted in a completely randomized design with four treatments in triplicate: a) Existing carp polyculture (10,000/ha) + mixed-sex tilapia (3,000/ha) + sahar (1,000/ha) (T_1); b) Existing carp polyculture and monosex tilapia at 3,000/ha (T_2); c) Monosex tilapia at 10,000/ha with fertilization only (T_3); and d) Monosex tilapia at 20,000/ha with fertilization and feeding (T_4). Silver carp, bighead carp, common carp, grass carp, rohu and mrigal of mean stocking size 44.2 and 45.3, 3.0 and 3.0, 9.9 and 9.7, 3.0 and 3.0, 29.8 and 32.9 g, respectively were stocked in six ponds of T_1 and T_2 at the ratio of 3.5:1:2.5:0.5:1.5:1. Mixed-sex Nile tilapia of 3.5 g and sahar of 7.0 g size were added in T_1. Similarly, the stocking size of all-male tilapia in T_2, T_3, and T_4 were 6.5, 6.5, and 3.2 g, respectively. Feeding, fertilization and other culture practices were similar to the on-station trial. The method for economic analysis was similar to that of the on-station trial with slight variation in carp fingerlings. Prices for common carp, silver carp, bighead carp, grass carp, rohu, and mrigal fingerlings were 5, 10, 1, 2, 10, and 5 NRs $piece^{-1}$, respectively.

The data were analyzed by one-way ANOVA using SPSS (V 16.0). For significant differences in growth parameters among different treatments, LSD was used to compare the means. For testing different growth and production parameters of carps, a T-test was used. For all analysis alpha was set at 0.05.

RESULTS

Experiment one: on-station trials

The gross and net fish yields for monosex tilapia without feed was significantly lower than monosex tilapia with feed and carp treatments (Table 1). The production of all carps was not significantly different between T_1 and T_2 ($p>0.05$). The production of monosex tilapia in T_4 was significantly higher than in T_3 ($p<0.05$). Similarly, the extrapolated GFY of tilapia in T_2 was significantly higher than T_1 ($p<0.05$). The combined extrapolated GFY of all species excluding and including tilapia recruits was significantly lower in T_3 than other treatments ($p<0.05$). Similarly, the combined extrapolated NFY of all species excluding tilapia recruits was significantly lower in T_3 than T_4 ($p<0.05$). The apparent food conversion ratio (AFCR) was significantly lower in T_4 compared to T_1 and T_2 without any significant differences between T_1 and T_2 (Table 1).

Table 1. Production parameters (mean ± SE) of different treatments. Mean values in a row with the same superscript are not significantly different ($\alpha = 0.05$).

Parameters	Treatments			
	T_1	T_2	T_3	T_4
Extrapolated GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)				
Carps	2.42 ± 0.20^a	2.58 ± 0.14^a	-	-
Tilapia	0.49 ± 0.04^a	0.72 ± 0.09^b	1.04 ± 0.14^c	3.79 ± 0.12^d
Sahar	0.02 ± 0.00	-	-	-
Combined excluding tilapia recruits	2.93 ± 0.46^b	3.29 ± 0.17^b	1.04 ± 0.14^a	3.79 ± 0.12^b
Combined including tilapia recruits	3.00 ± 0.22^b	3.29 ± 0.17^b	1.04 ± 0.14^a	3.79 ± 0.12^b
Extrapolated NFY ($t \cdot ha^{-1} \cdot crop^{-1}$) excluding tilapia recruits	2.82 ± 0.23^{ab}	3.20 ± 0.17^{ab}	1.03 ± 0.14^a	3.77 ± 0.23^b
AFCR	2.42 ± 0.28^b	2.09 ± 0.14^b	-	1.86 ± 0.07^a

Each carp species showed similar production parameters in all treatments, indicating the addition of tilapia and sahar did not affect overall carp production (Table 2). There were no significant differences in mean harvest weight, total harvest weight, mean daily weight gain (DWG), survival rate, extrapolated GFY, and extrapolated NFY of different carp species among treatments. However, mean harvest size, daily weight gain, GFY and NFY of monosex Nile tilapia in T_4 were significantly higher than in T_3 ($p<0.05$).

Table 2. Growth and production parameters (mean ±SE) in different treatments in on-station trial. Data based on a 150 m^2 pond for 185 days culture period. Mean values in a row with the same superscript are not significantly different ($\alpha = 0.05$).

Parameter	Treatment			
	T_1	T_2	T_3	T_4
Common Carp				
Mean stocking weight (g)	13.6 ± 1.1^a	12.5 ± 0.4^a	-	-
Total stocking weight (kg)	0.51 ± 0.04^a	0.48 ± 0.02^a	-	-
Mean harvest weight (g)	385.6 ± 46.8^a	397.0 ± 10.4^a	-	-
GFY (kg)	9.6 ± 0.7^a	10.6 ± 1.3^a	-	-
DWG ($g \cdot day^{-1}$)	2.01 ± 0.26^a	2.08 ± 0.05^a	-	-
Survival (%)	67.5 ± 8.9^a	71.1 ± 10.6^a	-	-

Parameter	Treatment			
	T_1	T_2	T_3	T_4
GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.64±0.04 [a]	0.71±0.09 [a]	-	-
NFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.61±0.04 [a]	0.68±0.09 [a]	-	-
Silver Carp				
Mean stocking weight (g)	3.2±0.2 [a]	3.3±0.2 [a]	-	-
Total stocking weight (kg)	0.17±0.01 [a]	0.18±0.01 [a]	-	-
Mean harvest weight (g)	319.6±15.8 [a]	370.3±13.6 [a]	-	-
GFY (kg)	6.6±0.3 [a]	5.9±1.2 [a]	-	-
DWG ($g \cdot day^{-1}$)	1.71±0.08 [a]	1.08±0.07 [a]	-	-
Survival (%)	39.0±2.3 [a]	29.6±4.9 [a]	-	-
GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.44±0.02 [a]	0.39±0.08 [a]	-	-
NFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.43±0.02 [a]	0.38±0.08 [a]	-	-
Bighead Carp				
Mean stocking weight (g)	0.6±0.0 [a]	0.6±0.0 [a]	-	-
Total stocking weight (kg)	0.01±0.00 [a]	0.01±0.00 [a]	-	-
Mean harvest weight (g)	470.4±39.6 [a]	473.7±47.0 [a]	-	-
GFY (kg)	4.8±0.1 [a]	4.9±0.2 [a]	-	-
DWG ($g \cdot day^{-1}$)	2.54±0.21 [a]	2.56±0.25 [a]	-	-
Survival (%)	68.9±5.9 [a]	71.1±8.9 [a]	-	-
GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.32±0.00 [a]	0.33±0.01 [a]	-	-
NFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.32±0.00 [a]	0.33±0.01 [a]	-	-
Grass Carp				
Mean stocking weight (g)	5.9±0.3 [a]	6.2±0.4 [a]	-	-
Total stocking weight (kg)	0.05±0.00 [a]	0.05±0.00 [a]	-	-
Mean harvest weight (g)	446.0±195.5 [a]	635.9±47.7 [a]	-	-
GFY (kg)	2.5±1.0 [a]	3.1±0.5 [a]	-	-
DWG ($g \cdot day^{-1}$)	2.38±1.06 [a]	3.40±0.26 [a]	-	-
Survival (%)	79.2±30.1 [a]	62.5±12.5 [a]	-	-
GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.16±0.06 [a]	0.21±0.03 [a]	-	-
NFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.16±0.06 [a]	0.20±0.04 [a]	-	-
Rohu				
Mean stocking weight (g)	21.7±1.2[a]	20.6±0.7[a]	-	-
Total stocking weight (kg)	0.50±0.03[a]	0.47±0.02[a]	-	-
Mean harvest weight (g)	396.3±40.2[a]	411.3±62.5[a]	-	-
GFY (kg)	8.5±0.7[a]	8.9±0.8[a]	-	-
DWG ($g \cdot day^{-1}$)	2.02±0.22[a]	2.11±0.34[a]	-	-
Survival (%)	94.2±5.8[a]	95.7±9.1[a]	-	-
GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.57±0.05[a]	0.59±0.05[a]	-	-
NFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.53±0.05[a]	0.56±0.05[a]	-	-
Mrigal				
Mean stocking weight (g)	11.1±0.3[a]	11.9±0.4[a]	-	-
Total stocking weight (kg)	0.17±0.00[a]	0.18±0.01[a]	-	-
Mean harvest weight (g)	471.1±45.6[a]	480.0±42.1[a]	-	-
GFY (kg)	4.3±0.7[a]	5.2±0.3[a]	-	-

Parameter	Treatment			
	T_1	T_2	T_3	T_4
DWG (g·day^{-1})	2.49±0.25^a	2.53±0.23^a	-	-
Survival (%)	60.0±3.0^a	73.3±3.9^a	-	-
GFY (t·ha^{-1}·crop^{-1})	0.29±0.04^a	0.35±0.02^a	-	-
NFY (t·ha^{-1}·crop^{-1})	0.27±0.04^a	0.34±0.02^a	-	-
Tilapia				
Mean stocking weight (g)	1.9±0.1	0.9±0.0	1.2±0.0	0.9±0.1
Total stocking weight (kg)	0.09±0.01	0.04±0.00	0.18±0.00	0.26±0.02
Mean harvest weight (g)	267.1±28.4	356.5±33.6	152.1±29.2^a	281.7±4.8^b
GFY (kg)	7.42±0.59	10.75±1.30	15.63±2.15^a	56.80±1.77^b
DWG (g·day^{-1})	1.43±0.15	1.92±0.18	0.82±0.16^a	1.52±0.03^b
Survival (%)	62.2±2.3	66.7±2.6	70.0±5.1^a	67.2±1.9^a
GFY (t·ha^{-1}·crop^{-1})	0.49±0.04	0.72±0.09	1.04±0.14^a	3.79±0.12^b
NFY (t·ha^{-1}·crop^{-1})	0.49±0.04	0.71±0.09	1.03±0.14^a	3.77±0.12^b
Sahar				
Mean stocking weight (g)	12.1±1.1	-	-	-
Total stocking weight (kg)	0.18±0.02	-	-	-
Mean harvest weight (g)	35.7±1.9	-	-	-
GFY (kg)	0.37±0.02	-	-	-
DWG (g·day^{-1})	0.13±0.01	-	-	-
Survival (%)	68.9±5.9	-	-	-
GFY (t·ha^{-1}·crop^{-1})	0.02±0.00	-	-	-
NFY (t·ha^{-1}·crop^{-1})	0.01±0.00	-	-	-

There was no significant difference in average temperature, total alkalinity, total ammonium nitrogen and chlorophyll-a among treatments during the experimental period (Table 3, $p>0.05$); however, dissolved oxygen was significantly higher in T_4 than other treatments ($p<0.05$). The soluble reactive phosphorous was significantly higher in T_2 and T_3 than T_4.

Table 3. Water quality parameters (mean ±SE with range in parentheses) of different treatments. Mean values in a row with same superscript are not significantly different ($\alpha = 0.05$).

Parameters	Treatments			
	T_1	T_2	T_3	T_4
Water temperature (°C)	28.3±0.2^a (21.2-32.2)	28.2±0.2^a (21.7-31.6)	28.1±0.1^a (21.5-31.6)	28.1±0.2^a (21.5-31.6)
Dissolved oxygen (mg/L)	2.6±0.1^a (0.7-7.1)	2.7±0.3^a (0.7-6.3)	2.6±0.2^a (0.5-5.7)	3.6±0.3^b (0.7-8.3)
pH	7.2 (6.5-7.9)	7.1 (6.1-8.0)	7.2 (6.2-7.9)	7.2 (6.5-8.2)
Total alkalinity (mg/L as $CaCO_3$)	146.4±13.0^a (86.8-178.5)	143.8±2.2^a (107.5-179.4)	145.3±6.7^a (104.1-199.7)	141.0±9.3^a (104.6-180.9)
Soluble reactive phosphorous (mg/L)	0.43±0.00^{ab} (0.05-0.96)	0.46±0.00^b (0.01-1.08)	0.47±0.02^b (0.14-1.63)	0.37±0.03^a (0.06-0.96)
Total ammonium nitrogen (mg/L)	0.44±0.03^a (0.05-1.27)	0.39±0.02^a (0.08-1.20)	0.42±0.01^a (0.04-1.10)	0.33±0.05^a (0.04-0.88)
Chlorophyll-a (mg/m^3)	78.1±27.7^a (15.9-216.6)	73.7±9.7^a (19.0-210.2)	80.8±10.3^a (12.7-206.3)	48.9±4.8^a (15.1-103.1)

The gross margin for monosex tilapia with feed was significantly higher than monosex tilapia without feed, while carp treatments were intermediate in gross margin. The variable costs in all treatments consisted of seed, feed, lime, urea, and DAP (Table 4). Cost of seed was significantly different among treatments ($p<0.05$), whereas cost of feed was not significantly different among fed treatments ($p>0.05$). There was no significant difference in all other variable costs among different treatments ($p>0.05$). Total input cost and total output were significantly lower in T_3 than other treatments. The gross profit margin was significantly higher in T_4 (4418.5±302.9 USD/ha) compared to T_3 (1666.1±341.3 USD/ha) without any significant difference between T_1 and T_2 ($p<0.05$; Table 4).

Table 4. Economic analysis (in USD) for each treatment. Data based on a 150 m^2 pond area and culture period of 150 days. Mean values in a row with the same superscript are not significantly different ($\alpha = 0.05$).

Variable	Treatment			
	T_1	T_2	T_3	T_4
Seed	$6.3±0.0^d$	$4.5±0.0^b$	$2.9±0.0^a$	$5.7±0.0^c$
Feed	$51.8±3.1^a$	$51.3±1.0^a$	0.0±0.0	$53.9±0.7^a$
Lime	$1.3±0.0^a$	$1.3±0.0^a$	$1.3±0.0^a$	$1.3±0.0^a$
Urea	$2.9±0.0^a$	$2.9±0.0^a$	$2.9±0.0^a$	$2.9±0.0^a$
DAP	$5.1±0.0^a$	$5.1±0.0^a$	$5.1±0.0^a$	$5.1±0.0^a$
Total Input	$67.5±3.1^b$	$65.2±1.0^b$	$12.2±0.0^a$	$69.0±0.7^b$
Total Output	$106.0±8.2^b$	$117.6±6.0^{bc}$	$37.2±5.1^a$	$135.2±4.2^c$
Gross Margin	$38.5±10.2^{ab}$	$52.4±6.7^{ab}$	$25.0±5.1^a$	$66.3±4.5^b$
Gross Margin (ha^{-1})	$2569.1±679.9^{ab}$	$3491.9±449.5^{ab}$	$1666.1±341.3^a$	$4418.5±302.9^b$

Experiment two: on-farm trials

As in the first experiment, the gross and net fish yields in monosex tilapia without feed were significantly lower than monosex tilapia with feed and carp treatments (Table 5). The production of all carps was not significantly different between T_1 and T_2 ($p>0.05$). The production of tilapia in T_4 was significantly higher than T_3 ($p<0.05$). The combined extrapolated GFY of all species excluding and including tilapia recruits was significantly lower in T_3 than other treatments ($p<0.05$). Similarly, the combined extrapolated NFY of all species excluding tilapia recruits was significantly lower in T_3 than other treatments ($p<0.05$). The apparent food conversion (AFCR) was significantly lower in T_4 compared to T_1 and T_2 without any significant differences between T_1 and T_2 (Table 5).

Table 5. Production parameters (mean ± SE) of different treatments. Mean values in a row with the same superscript are not significantly different ($\alpha = 0.05$).

Parameters	Treatments			
	T_1	T_2	T_3	T_4
Extrapolated GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)				
Carps	$2.35±0.25^a$	$2.25±0.02^a$	-	-
Tilapia	$0.34±0.07^a$	$0.60±0.14^b$	$0.78±0.23^b$	$2.60±0.06^c$
Sahar	0.06±0.00	-	-	-
Combined excluding tilapia recruits	$2.75±0.24^a$	$2.85±0.37^a$	$0.78±0.3^b$	$2.60±0.06^a$
Combined including tilapia recruits	$2.81±0.25^a$	$2.85±0.37^a$	$0.78±0.03^b$	$2.60±0.06^a$
Extrapolated NFY ($t \cdot ha^{-1} \cdot crop^{-1}$) excluding tilapia recruits	$2.49±0.24^a$	$2.57±0.36^a$	$0.71±0.02^b$	$2.54±0.06^a$
FCR	$2.23±0.20^b$	$2.24±0.10^b$	0.00	$1.60±0.13^a$

There were no significant differences in mean harvest weight, total harvest weight, mean daily weight gain (DWG), survival rate, extrapolated GFY, and extrapolated NFY of different carp species among treatments (Table 6). However, mean harvest size, daily weight gain, GFY and NFY of monosex Nile tilapia in T_4 were significantly higher than in T_3 ($p<0.05$).

Table 6. Growth and production parameters (mean ±SE) in different treatments in on-station trial. Data based on a 200 m^2 pond for 150 days culture period. Mean values in a row with the same superscript are not significantly different ($\alpha = 0.05$).

Parameter	Treatment			
	T_1	T_2	T_3	T_4
Common Carp				
Mean stocking weight (g)	9.9±1.12 ^{a}	9.7±0.37 ^{a}	-	-
Total stocking weight (kg)	0.50±0.06 ^{a}	0.48±0.02 ^{a}	-	-
Mean harvest weight (g)	310.6±33.4 ^{a}	302.2±44.3 ^{a}	-	-
GFY (kg)	14.3±1.7 ^{b}	9.3±0.9 ^{a}	-	-
DWG (g·day^{-1})	2.00±0.22 ^{a}	1.95±0.30 ^{a}	-	-
Survival (%)	92.0±4.2 ^{b}	63.3±6.6 ^{a}	-	-
GFY (t·ha^{-1}·crop^{-1})	0.71±0.07 ^{a}	0.47±0.05 ^{a}	-	-
NFY (t·ha^{-1}·crop^{-1})	0.69±0.07 ^{a}	0.44±0.05 ^{a}	-	-
Silver Carp				
Mean stocking weight (g)	44.2±0.73 ^{a}	45.3±2.91 ^{a}	-	-
Total stocking weight (kg)	3.09±0.05 ^{a}	3.17±0.20 ^{a}	-	-
Mean harvest weight (g)	216.5±27.6 ^{a}	262.0±18.8 ^{a}	-	-
GFY (kg)	14.57±2.07 ^{a}	14.40±0.34 ^{a}	-	-
DWG (g·day^{-1})	1.15±0.19 ^{a}	1.44±0.14 ^{a}	-	-
Survival (%)	95.7±1.7 ^{b}	79.1±3.9 ^{a}	-	-
GFY (t·ha^{-1}·crop^{-1})	0.73±0.10 ^{a}	0.72±0.02 ^{a}	-	-
NFY (t·ha^{-1}·crop^{-1})	0.57±0.11 ^{a}	0.56±0.02 ^{a}	-	-
Bighead Carp				
Mean stocking weight (g)	3.0±0.14 ^{a}	3.0±0.50 ^{a}	-	-
Total stocking weight (kg)	0.06±0.00 ^{a}	0.06±0.01 ^{a}	-	-
Mean harvest weight (g)	202.3±65.1 ^{a}	164.2±19.5 ^{a}	-	-
GFY (kg)	2.41±0.49 ^{a}	2.37±0.17 ^{a}	-	-
DWG (g·day^{-1})	1.33±0.43 ^{a}	1.07±0.13 ^{a}	-	-
Survival (%)	66.7±14.5 ^{a}	75.0±12.6 ^{a}	-	-
GFY (t·ha^{-1}·crop^{-1})	0.12±0.02 ^{a}	0.12±0.01 ^{a}	-	-
NFY (t·ha^{-1}·crop^{-1})	0.12±0.02 ^{a}	0.12±0.01 ^{a}	-	-
Grass Carp				
Mean stocking weight (g)	3.0±0.33 ^{a}	3.0±0.00 ^{a}	-	-
Total stocking weight (kg)	0.03±0.00 ^{a}	0.03±0.00 ^{a}	-	-
Mean harvest weight (g)	698.2±136.6 ^{a}	658.3±50.0 ^{a}	-	-
GFY (kg)	4.24±0.32 ^{a}	3.89±0.09 ^{a}	-	-
DWG (g·day^{-1})	4.63±0.91 ^{a}	4.37±0.33 ^{a}	-	-
Survival (%)	63.3±6.7 ^{a}	60.0±5.8 ^{a}	-	-
GFY (t·ha^{-1}·crop^{-1})	0.21±0.02 ^{a}	0.19±0.00 ^{a}	-	-
NFY (t·ha^{-1}·crop^{-1})	0.21±0.02	0.19±0.00 ^{a}	-	-

Parameter	Treatment			
	T_1	T_2	T_3	T_4
Rohu				
Mean stocking weight (g)	29.8±1.16 [a]	32.9±1.66 [a]	-	-
Total stocking weight (kg)	0.89±0.03 [a]	0.99±0.05 [a]	-	-
Mean harvest weight (g)	312.9±35.3 [a]	384.5±24.2 [a]	-	-
GFY (kg)	8.72±0.84 [a]	10.87±0.54 [a]	-	-
DWG ($g \cdot day^{-1}$)	1.89±0.23 [a]	2.34±0.17 [a]	-	-
Survival (%)	93.3±1.9 [a]	94.4±2.9 [a]	-	-
GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.44±0.04 [a]	0.54±0.03 [a]	-	-
NFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.39±0.04 [a]	0.49±0.03 [a]	-	-
Mrigal				
Mean stocking weight (g)	17.33±1.17 [a]	17.67±0.33 [a]	-	-
Total stocking weight (kg)	0.35±0.02 [a]	0.35±0.01 [a]	-	-
Mean harvest weight (g)	220.2±30.5 [a]	259.5±31.6 [a]	-	-
GFY (kg)	2.90±0.13 [a]	4.14±0.96 [a]	-	-
DWG ($g \cdot day^{-1}$)	1.35±0.20 [a]	1.61±0.21 [a]	-	-
Survival (%)	68.3±9.3 [a]	78.3±11.7 [a]	-	-
GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.15±0.01 [a]	0.21±0.05 [a]	-	-
NFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.13±0.01 [a]	0.19±0.05 [a]	-	-
Tilapia				
Mean stocking weight (g)	3.5±0.48	6.5±0.00	6.5±4.48 [a]	3.2±0.11 [a]
Total stocking weight (kg)	0.21±0.03	0.39±0.00	1.31±0.90 [a]	1.28±0.04 [a]
Mean harvest weight (g)	196.1±21.6	279.8±47.5	132.6±7.4 [a]	214.3±5.6 [b]
GFY (kg)	6.76±1.40	11.93±2.77	15.55±0.59 [a]	52.08±1.13 [b]
DWG ($g \cdot day^{-1}$)	1.28±0.14	1.82±0.32	0.84±0.07 [a]	1.41±0.04 [b]
Survival (%)	56.7±8.6	72.8±17.1	59.2±4.9 [a]	60.8±2.0 [a]
GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.34±0.07	0.60±0.14	0.78±0.03 [a]	2.60±0.02 [b]
NFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.33±0.07	0.58±0.14	0.71±0.06 [a]	2.54±0.06 [b]
Sahar				
Mean stocking weight (g)	7.0±0.14	-	-	-
Total stocking weight (kg)	0.14±0.00	-	-	-
Mean harvest weight (g)	69.4±2.9	-	-	-
GFY (kg)	1.18±0.01	-	-	-
DWG ($g \cdot day^{-1}$)	0.42±0.02	-	-	-
Survival (%)	85.0±2.2	-	-	-
GFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.06±0.00	-	-	-
NFY ($t \cdot ha^{-1} \cdot crop^{-1}$)	0.05±0.00	-	-	-

There was no significant difference in average temperature and Secchi disk depth among treatments during the experimental period (Table 7, $p>0.05$); however, dissolved oxygen was significantly higher in T_3 than other treatments ($p<0.05$).

Table 7. Water quality parameters (mean ±SE with range in parentheses) of different treatments. Mean values in a row with same superscript are not significantly different (α = 0.05).

Parameters	Treatments			
	T_1	T_2	T_3	T_4
Water temperature (°C)	29.2±0.1^{a} (17.6-32.5)	29.2±0.1^{a} (17.1-32.3)	28.9±0.3^{a} (17.0-34.2)	28.9±0.1^{a} (16.6-31.9)
Dissolved oxygen (mg/L)	5.5±0.1^{a} (3.3-10.0)	5.3±0.3^{a} (2.6-10.8)	6.6±0.2^{b} (2.6-14.1)	5.2±0.3^{a} (1.4-11.2)
pH	7.8 (6.8-8.7)	7.8 (6.7-8.7)	8.3 (7.2-9.8)	8.0 (7.2-9.0)
Secchi disk depth (cm)	27.0±3.0^{a} (13.3-46.7)	29.0±3.1^{a} (18.3-48.3)	34.9±2.9^{a} (20.0±53.3)	37.6±3.2^{a} (25.0-60.0)

All carp polyculture and tilapia monoculture systems differed in economic performance, with the treatment monosex tilapia with feed being most profitable. The variable costs in all treatments consisted of seed, feed, lime, urea, and DAP (Table 8). Cost of seed was significantly different among treatments ($p<0.05$), whereas cost of feed was not significantly different among treatments ($p>0.05$). There was no significant difference in all other variable costs among different treatments ($p>0.05$). Total input cost and total output were significantly lower in T_3 than other treatments. The gross profit margin was significantly lower in T_3 than other treatments, whereas there was no significant difference in gross profit margin among T_1, T_2 and T_4 (Table 8).

Table 8. Economic analysis (in USD) for each treatment. Data based on a 200 m^2 pond area and culture period of 150 days. Mean values in a row with the same superscript are not significantly different (α = 0.05).

Variable	Treatment			
	T_1	T_2	T_3	T_4
Seed	14.9±0.0^{d}	14.5±0.0^{c}	3.8±0.0^{a}	7.6±0.0^{b}
Feed	57.2±7.4^{b}	58.9±2.3^{b}	0.0±0.0	41.6±3.0^{a}
Lime	1.7±0.0^{a}	1.7±0.0^{a}	1.7±0.0^{a}	1.7±0.0^{a}
Urea	3.9±0.0^{a}	3.9±0.0^{a}	3.9±0.0^{a}	3.9±0.0^{a}
DAP	6.9±0.0^{a}	6.9±0.0^{a}	6.9±0.0^{a}	6.9±0.0^{a}
Total Input	84.5±7.4^{c}	85.9±2.3^{c}	16.3±0.0^{a}	61.7±3.0^{b}
Total Output	134.9±11.6^{b}	135.6±7.8^{b}	37.0±1.4^{a}	124.0±2.7^{b}
Gross Margin	50.4±8.2^{b}	49.7±6.8^{b}	20.7±1.4^{a}	62.3±4.7^{b}
Gross Margin (ha^{-1})	2521.4±411.8^{b}	2483.2±339.1^{b}	1036.9±70.7^{a}	3115.6±237.5^{b}

DISCUSSION

This study was carried out to expand the technology developed through AquaFish research on carps, tilapia and sahar production as well as technology of monosex tilapia production to farmers in order to demonstrate alternative fish production models. An on-station and an on-farm experiment on monoculture and polyculture systems, using carp with the addition of tilapia and sahar was conducted simultaneously, to determine the most practical system for farm adoption. In both trials, addition of Nile tilapia and sahar had no adverse effect on growth and production of all carp species, or in pond water quality. This result suggests that tilapia and sahar did not compete for pond resources with any carp species.

In the on-station trial, the daily weight gain of mixed-sex Nile tilapia and sahar were 1.43 and 0.13 g, respectively, which is comparable or slightly higher than in previous experiments. The daily weight gain of Nile tilapia in polyculture was higher than a grass carp-tilapia polyculture system (0.2-0.5 g;

Pandit et al., 2004), carp-tilapia-sahar polyculture system (0.63-0.70 g; Bhandari et al., 2016), tilapia-sahar polyculture system (0.6-0.9 g; Shrestha et al., 2011), and tilapia-sahar polyculture system (1.15 g; Acharya et al., 2007). The quality of feed (low protein; 26.6% CP) may have also contributed to slow growth of sahar. Sundar et al. (1998) reported better growth, survival, and FCR of sahar were achieved from feed with 45.4% crude protein among diets with 21.4% to 50.2% crude protein. In a similar study, Joshi et al. (1989) reported that 35% crude protein was best for growth and feed efficiency of sahar. We used feed with lower crude protein levels (28%) in this experiment and may have limited sahar growth. Good growth rates of all carp species were achieved in all carp treatments. The average growth rate of carp species in all treatments was higher than reported by previous studies in carp polyculture (Rai et al., 2008; Jaiswal, 2010) as well as in our previous on-farm and farmer's field trials (Bhandari et al., 2016).

The combined gross fish yield in carp treatments (5.8-6.5 $t \cdot ha^{-1} \cdot yr^{-1}$) was higher than the national average of carp polyculture (4.9. $t \cdot ha^{-1} \cdot yr^{-1}$) (DoFD, 2017). The hypothesis that addition of tilapia and sahar would increase the yield and profit from polyculture ponds was supported in the on-station trial. However, production and profit of monosex tilapia without feed was quite low. Diana (2012) achieved annual yields of monosex tilapia about 5 tons per ha with only fertilizer inputs. Although the production of monosex tilapia with feed was higher than all carp treatments and monosex tilapia without feed treatment, this was still quite low than reported by Diana (2012). Although the growth rate was satisfactory, the poor production of monosex tilapia in both feed and non-feed systems in the present experiment was associated with poor survival of fish (67-70%, compared to over 90% in other systems).

In the on-farm trial, growth, production, and survival of carps and tilapia were similar to the on-station trial. However, the growth of sahar was higher (0.42 g $fish^{-1}$ day^{-1}) than the on-station trial (0.13 g $fish^{-1}$ day^{-1}). The daily weight gain of sahar in the on-farm trial was still lower than tilapia-sahar polyculture systems (0.3-0.4 g; Shrestha et al., 2011) and growth rates achieved in other culture systems (0.55-0.77 g; Islam, 2002). In the on-farm trial, the combined gross fish yield in carp treatments (6.7-6.9 $t \cdot ha^{-1} \cdot yr^{-1}$) was slightly higher than the on-station trial (5.8-6.5 $t \cdot ha^{-1} \cdot yr^{-1}$) as well as the national average of carp polyculture (4.9 $t \cdot ha^{-1} \cdot yr^{-1}$; DoFD, 2017).

In both trials, the number of tilapia recruits in the carp-tilapia-sahar system was quite low. This is due to piscivorous nature of the stocked sahar. Shrestha et al. (2011) reported there was a significantly lower average recruit number and weight of Nile tilapia in treatments with sahar than in tilapia monoculture. Jaiswal (2010) also showed that the average number and weight of tilapia recruits in treatments with sahar was lower than with tilapia and carp only.

Water quality was not significantly affected by stocking densities of fishes in species combination of carp-tilapia-sahar polyculture in ponds, as water quality parameters did not differ significantly among treatments. Most water quality parameters in both trials were within acceptable ranges for fish culture (Boyd, 1990).

CONCLUSIONS

The results of this study indicates that three of the culture systems (polyculture of carps with mixed sex tilapia and sahar, carps with monosex tilapia, and monosex tilapia with fertilization and feeding) performed similarly and enhanced productivity and income compared to the currently used carp polyculture system in Nepal. Tilapia either in monoculture or in polyculture proved suitable additional species in the aquaculture for Nepal. As carp polyculture is the established culture system, adding species will be easier to adopt by fish farmers. While adoption of monoculture may be more difficult, indications of higher production efficiency and profit will be the first steps in developing that system. Inclusion of sahar in polyculture will also help in controlling tilapia recruitment in mixed sex tilapia culture where monosex fry is not available along with production of sahar, which will help to conserve sahar populations.

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LITERATURE CITED

Acharya, D., D.K. Jha, M.K. Shrestha, and N.R. Devkota. 2007. Polyculture of sahar (*Tor putitora*) and mixed-sex Nile tilapia (*Oreochromis niloticus*) in Chitwan, Nepal. In: R. B. Thapa and M. D. Sharma (eds.) IAAS Research Advances, 1:187-193.

AOAC. 1980. Methods of analysis, 13th edition. Association of Official Analytical Chemists, Washington DC, USA. 1018 p.

APHA. 1985. Standard methods for the examination of water and waste water, 16th edition. American Public Health Association, American Water Works Association. 1015 Fifteenth Street, NW, Washington, D.C. 1268 p.

Bhandari M., R. Jaiswal, N.P. Pandit, R.N. Mishra, M.K. Shrestha, and J.S. Diana. 2016 Demonstrating the value of tilapia and sahar production in polyculture ponds using government farm and on-farm trials. Annual Technical Report. AquaFish Innovation Lab, Oregon State University, Corvallis, USA.

Bista, J.D., S.K. Wagle, M.K. Shrestha, and A.B. Thapa. 2007. Evaluation of growth performance of Himalayan sahar (*Tor putitora*) for aquaculture development in mid hills and southern plain of Nepal. Seventh National Workshop on Livestock and Fisheries Research, June 25-27, 2007. Abstracts, pp.12.

Boyd, C.E. 1990. Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama. 482 p.

Diana, J.S. 2012. Some principles of pond fertilization for Nile tilapia using organic and inorganic inputs. In: Aquaculture Pond Fertilization: Impacts of Nutrient Input on Production, 1st Edition, C.C. Mischke (ed.). John Wiley and Sons, Inc., Hoboken. pp. 163-177.

DoFD. 2017. Annual Report. Directorate of Fisheries Development, Balaju. Department of Agriculture, Ministry of Agriculture and Co-operatives, Government of Nepal.

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

IUCN. 2017. IUCN Red List of Threatened of Species. Accessed from www.iucnredlist.org

Jaiswal, R. 2010. Integration of tilapia (*Oreochromis niloticus*) and sahar (*Tor putitora*) in carp polyculture system. Master of Science Thesis, Institute of Agriculture and Animal Science, Nepal.

Joshi, P.L., T.B. Gurung, S.R. Basnet, and A.P. Nepal. 2002. Domestication of wild golden mahseer (*Tor putitora*) and hatchery operation: An experience paper. In: Cold Water Fisheries in the Trans-Himalayan countries. T. Petr and S.B. Swar (eds.). FAO Fisheries Technical paper 431. FAO, Rome. pp. 173-178.

Joshi, C.B., K.L. Sehgal, and K.C. Malkani, 1989. Experimental trials on feeding of *Tor putitora* with formulated diets at Bhimtal in Kumaon Himalayas. Indian Journal of Animal Science 59:206-209.

Mandal, J.K. and M.K. Shrestha. 2001. Effect of feed supplementation on growth and production of Nile tilapia in mixed size culture system. Journal of Institute of Agriculture and Animal Science Rampur, Chitwan, 21-22 (2000-2001):141-149.

Pandit, N.P., M.K. Shrestha, Y. Yi, and J.S. Diana. 2004. Polyculture of grass carp and Nile tilapia with napier grass as the sole nutrient input in the sub-tropical climate of Nepal. In: New Dimensions in Farmed Tilapia. R. Bolivar, G. Mair and K. Fitzsimmons (eds.) Proceedings of 6th International Symposium on Tilapia in Aquaculture, 12-16 September, 2004, Manila, Philippines. pp. 558-573.

Pantha, M.B. 1993. Aquafeed and feeding strategies in Nepal. In: Farm-made Aquafeed. M.B. New, A.G.J. Tacon, and L. Csavas (eds.) Proceedings of the FAO/AADCP Regional Expert Consultation of Farm-made Aquafeeds, 14-18 Dec. 1992. Bangkok, Thailand. pp. 297-316.

Paudel, J.K., D.K. Jha, M.K. Shrestha and J.D. Bista. 2007. Growth performance of sahar (*Tor putitora*) in different culture systems in Chitwan, Nepal. In: IAAS Research Advances Vol 2. R.B. Thapa and M.D. Sharma (eds.). IAAS, Rampur, Chitwan, Nepal. pp. 195-200.

Rai, S., Y. Yi, Y., M.A. Wahab, A.N. Bart, and J.S. Diana. 2008. Comparison of rice straw and bamboo stick substrates in periphyton-based carp polyculture systems. Aquaculture Research 39:464-473.

Rajbansi, K.G. 2001. Zoo-geographical distribution and the status of cold water fishes of Nepal. In: Symposium on cold water fishes in the Tran-Himalayan region, 10-14th July, Kathmandu, Nepal.

Shang, Y.C. 1990. Aquaculture Economics Analysis: An Introduction. World Aquaculture Society, Baton Rouge, Louisiana. 211 p.

Shrestha M.K., R.L. Sharma, K. Gharti, and J.S. Diana. 2011. Polyculture of sahar (*Tor putitora*) with mixed-sex Nile tilapia. Aquaculture 319:284-289.

Shrestha, M.K., and R.C. Bhujel. 1999. A preliminary study on Nile tilapia (*O. niloticus*) polyculture with common carp (*Cyprinus carpio*) fed with duckweed (*Spirodella*) in Nepal. Asian Fisheries Science 12:83-89.

Shrestha, M.K., R. Jaiswal, L. Liping, and. J.S. Diana. 2012. Incorporation of tilapia (*Oreochromis Niloticus*) and sahar (*Tor Putitora*) into the existing carp polyculture system of Nepal. Technical Report: Investigation 2009-2011. AquaFish Innovation Lab, Oregon State University, Corvallis, Oregon. pp. 38-52.

Shrestha, M.K., Y. Yi, J.S. Diana, C. K. Lin and N. P. Pandit. 2004. Integrated cage-cum-pond culture systems with high-valued sahar (*Tor putitora*) in cages with low- valued carps in open ponds. 7th Asian Fisheries Forum Penang, Malaysia.

Shrestha, T.K. 1997. The mahseer in the rivers of Nepal disrupted by dams and ranching strategies. R. K. Printers, Teku, Kathmandu, Nepal. 259 p.

Sunder, S., H.S. Raina, and U. Naulia, 1998. Preliminary feeding trials on juveniles of golden mahseer, *Tor putitora* (Ham.) at different stocking densities with artificial dry pellet feeds. Indian Journal of Animal Science 68 (4): 410–416.

Yadav, R.K., M.K. Shrestha, and N.P. Pandit. 2007. Introduction of sahar (*Tor putitora*) in cage cum pond integration system of mixed-sex Nile tilapia (*Oreochromis niloticus*). Our Nature 5:52-59.

Yi, Y., J. S. Diana, M.K. Shrestha, and C.K. Lin. 2004. Culture of mixed sex Nile tilapia with predatory snakehead. In: New dimensions in farmed Tilapia. R. Bolivar, G. Mair and K. Fitzsimmons (eds.). Proceedings of the 6th International Symposium on Tilapia in Aquaculture, 12-16 September 2004. Manila, Philippines. pp. 544-557.