TOPIC AREA
PRODUCTION SYSTEMS DESIGN AND BEST MANAGEMENT ALTERNATIVES

POLYCULTURE OF SAHAR (*TOR PUTITORA*) WITH MIXED-SEX NILE TILAPIA (*OREOCHROMIS NILOTICUS*)

Production Systems Design and Best Management Alternatives/ Experiment/ 07BMA02UM

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ABSTRACT

Sahar (*Tor putitora*) were cultured with Nile tilapia (*Oreochromis niloticus*) to control tilapia recruitment in aquaculture ponds. Two experiments were conducted to assess the effects of the sahar to tilapia stocking ratio on the recruitment and growth of mixed-sex Nile tilapia. The first experiment was conducted on station to determine these effects, and the second experiment was conducted on farm to verify the results in working ponds. The on-station experiment was conducted in 100 m^2 earthen ponds at the Institute of Agriculture and Animal Science, Chitwan, Nepal, and the on-farm experiment was conducted in farmers' ponds at Kathar, Chitwan, Nepal. The on-station experiment had four treatments with three replicates each: tilapia monoculture (T1), 1:16 sahar to tilapia ratio (T2), 1:8 sahar to tilapia ratio (T3), and 1:4 sahar to tilapia ratio (T4). Tilapia were stocked at 2 fish m^{-2} (average size 11.3 g), and sahar were stocked at varying densities (15.2 g average size) in each pond. The ponds were fertilized weekly using diammonium phosphate (DAP) and urea at the rates of 0.1 g P m^{-2} d^{-1} and 0.4 g N m^{-2} d^{-1}, respectively. Tilapia were fed with a locally made pelleted feed (27 % crude protein), at the rate of 2 % body weight every other day after attaining a size of 100 g. Results showed significantly increased average harvest size (P<0.05) for treatment 2, when sahar were stocked with tilapia compared to the tilapia monoculture. The number of recruits significantly decreased (P<0.05) when sahar were stocked, and moreover, recruits were inversely proportional to stocking density of sahar. Thus, the results demonstrated that stocking of sahar controls tilapia recruitment in a mixed-sex Nile tilapia pond culture system and

could provide better tilapia growth and production. Stocking at a 1:16 sahar to tilapia ratio showed the best overall performance.

The on-farm experiment was composed of three treatments with three replicates each: tilapia monoculture (T1), 1:33 sahar to tilapia ratio (T2), and 1:16 sahar to tilapia ratio (T3). Ponds were fertilized every two weeks with DAP and urea at the same rate as the on-station experiment, but there was no feeding. On-farm results showed significantly higher tilapia growth with a 1:33 stocking ratio of sahar to tilapia compared to the tilapia monoculture. As with the on-station experiment, the number of recruits decreased with increasing stocking density of sahar. Lower sahar stocking provided higher growth and production of stocked tilapia, though there were fewer recruits at these levels. There might have some growth depression of tilapia by higher sahar stocking. Stocking sahar to Nile tilapia at 1:33 showed better overall performance than the monoculture but not the 1:16 treatment in terms of Nile tilapia growth production, growth of sahar and gross income.

INTRODUCTION

Nile tilapia (*Oreochromis niloticus*) is considered an ideal species for small or large-scale aquaculture (Pillay, 1999). Being a lower trophic level species, it represents the greatest potential for efficiency and is commonly cultured in semi-intensive systems (Welcome, 1996; Shrestha et al., 2000). It was introduced in Nepal in 1985 (Pantha, 1993), but it was confined to government farms until 2000 (Shrestha, 2004). Nile tilapia culture in Nepal is based on mixed-sex culture and is expanding to areas of the central Terai and among small-scale farmers. However, polyculture for controlled management of mixed-sex tilapia culture must be developed (Shrestha, 2004). Overproduction of recruits in mixed-sex culture causes stunted growth and produces undersized fish for the market (Pillay, 1999; Focken et al., 2000). This creates a significant economic pressure to control excessive tilapia recruitment in the culture system.

The sahar (*Tor putitora*) is an economically important indigenous fish species (Rai et al., 1997), and is in decline across much of its native range due to habitat loss and physical changes in Nepal's environment (Desai, 1994; Shrestha, 1997). This has led to efforts to conserve, manage and propagate the species (Shrestha, 1997). It is an omnivorous fish (Shrestha, 1997), but it also shows predatory habits (Acharya, 2004; Paudel, 2007; Yadav et al., 2007). Sahar predation is a simple mechanism that has been proposed to control tilapia recruitment in mixed-sex Nile tilapia culture. Combining sahar and Nile tilapia at a proper ratio could provide new recruits for continuous seeding and maintain a stable sahar population. An additional benefit would be conservation of the declining sahar population in Nepal.

The purposes of this study were to create a polyculture system of sahar with mixed-sex Nile tilapia fitted to the local conditions of Nepal, to assess the appropriate stocking density of sahar to control Nile tilapia recruitment, to grow and produce mixed-sex Nile tilapia in such a pond culture and to verify the best results of the on-station experiment in a working aquaculture pond.

METHODS AND MATERIALS

Two consecutive experiments were conducted in the subtropical climate of Nepal to quantify and optimize the potential benefits from polyculture of sahar and Nile-tilapia. The on-station experiment was conducted from 14 October 2007 to 10 June 2008 (240 d). Data from this trial were then used to inform parameters for the experiment at a working farm, which was carried out from 15 February to 19 July 2009 (151 d).

Experiment One: Pond trials at the Institute of Agriculture and Animal Science

The on-station experiment was conducted at the Institute of Agriculture and Animal Science (IAAS), Rampur, Chitwan, Nepal in twelve 100 m^2 earthen ponds. There were four treatments with three replicates each: tilapia monoculture (control, T1); sahar with tilapia at a 1:16 ratio (T2); sahar with tilapia at a 1:8 ratio (T3); and sahar with tilapia at a 1:4 ratio (T4). The stocking density of tilapia was 2 fish/m^2 in each treatment, and sahar densities were varied according to the treatment. Ponds were randomly assigned a treatment, and tilapia (11.1-11.6 g) and sahar (14.5-16.3 g) were stocked in each. The ponds were fertilized weekly using diammonium phosphate (DAP) and urea at the rates of 0.1 g P m^{-2} d^{-1} and 0.4 g N m^{-2} d^{-1}, respectively. Tilapias were fed with a locally produced pellet feed (27% crude protein) at a rate of 2 % body weight every other day after they attained a size of 100 g.

Weekly and biweekly measurements of water quality parameters were conducted from 06:30 to 07:30 h starting on 14 October 2007. In situ water temperature at 0.2 m depth, dissolved oxygen (DO) at 0.2 m depth, pH, and Secchi disk depth were measured weekly using a Thermo Orion DO Meter ($810A^+$ Model), Microprocessor pH meter (WTW, pH 539 Model) and Secchi disk. Water samples were collected biweekly from each pond using a plastic column sampler (10 cm diameter, 1 m long) and analyzed for total alkalinity (as $CaCO_3$), total ammonium nitrogen (TAN), nitrite nitrogen (nitrite-N), nitrite-nitrate nitrogen (nitrite-nitrate-N), soluble reactive phosphorous (SRP), total phosphorous (TP), and Chlorophyll-*a* (APHA, 1985).

Periodically, fish were netted from the ponds to measure growth using an electronic balance. At least 15% of the fish were netted for sampling and weighed to determine growth. The total weight of sampled fish from each experimental pond was also recorded. All study ponds were harvested on 10 June 2008 by seining three times followed by a complete draining of the pond. At this point, the final total number and weight of each fish species in each pond was determined. Net fish yield (NFY) and apparent food conversion ratio (AFCR) were then calculated. Nile tilapia recruits were also collected, counted, and weighted to determine their growth and density in each pond during final harvest.

Experiment Two: Pond trials on a working aquaculture farm

Based on the results from experiment one, a verification trial was conducted in 12 earthen ponds (90-131 m^{-2}) at a working aquaculture farm in Kathar, Chitwan. The best performing treatment from experiment one and one additional treatment were tested against the tilapia monoculture. The three treatments were: tilapia monoculture control group (T1); sahar with tilapia at a 1:33 ratio (T2); and sahar with tilapia at a 1:16 ratio (T3). The stocking density of Nile tilapia was 2 fish/m^2 in all treatments, with sahar stocking density varying according to treatment. Nile tilapia fingerlings (55.3-55.7 g) and sahar fingerlings (15.1-15.7 g) were stocked on 20-21 February 2009. Each treatment was replicated three times and ponds were randomly assigned a treatment. The water depth was maintained at about 1 m in each pond by filling with canal water to compensate water loss. Ponds were fertilized every two weeks with DAP and urea at the same rate as the on-station experiment.

In situ water temperature, dissolved oxygen, pH, Secchi disk depth and water depth were measured weekly at 07:00–09:00 h as previously described, while total alkalinity, total ammonium nitrogen, soluble reactive phosphorus, and Chlorophyll-*a* were analyzed monthly by collecting water samples from each pond using the plastic column sampler (APHA, 1985). Monthly growth of the Nile tilapia and sahar was determined by netting at least 20 % of the fish from each pond. All study ponds were harvested 19 July 2009 by seining three times followed by complete draining. The total numbers and weights of the Nile tilapia, sahar and tilapia recruits in each pond were then determined. NFY was calculated as kg pond^{-1} crop^{-1} and extrapolated by hectare and year (300-day period).

A partial budget 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 Nile tilapia and sahar were 140 and 250 NRs/kg, respectively (1US$ = 75 NRs), for the harvested sizes in this experiment. Prices for Nile tilapia and sahar fingerlings were 5 and 10 NRs/individual, respectively. Prices for DAP, urea and lime were 35, 18 and 15 NRs/kg, respectively. Daily wages for extra labors were 200 NRs/person. The calculation of working capital cost was based on an annual interest rate of 10%.

Data from both experiments were analyzed statistically by an analysis of variance (ANOVA) using the SPSS statistical software package (SPSS 14.0, SPSS Inc., Chicago). Differences were considered significant at the 95 % confidence level ($P<0.05$). All means are shown ± standard error (SE).

RESULTS

Experiment One: Pond trials at the Institute of Agriculture and Animal Science

The results showed that the survival rate of Nile tilapia ranged from 56.0 to 70.1%, without significant differences ($P>0.05$) among treatments (Table 1). Daily weight gain (DWG) and net fish yield (NFY) were significantly higher ($P<0.05$) in ponds with a 1:16 sahar to tilapia stocking ratio than they were in control ponds (Table 1; Figure 1). However, there were no significant differences in DWG or NFY within the different sahar densities. Moreover, DWG and NFY in the control group were not significantly different from the 1:8 and 1:4 sahar to tilapia treatments (Table 1). The survival rate of sahar ranged from 39.3% to 56.4%. DWG of sahar ranged from 0.28-0.39 g/d and was significantly different ($P<0.05$) among treatments (Table 1; Figure 2). However, the NFY did not differ significantly among treatments and ranged from 60-80 kg/ha.

The extrapolated NFY values were 1.2 ± 0.1, 2.2 ± 0.3, 1.4 ± 0.2 and 1.8 ± 0.2 t ha^{-1} yr^{-1} for control, 1:16, 1:8, and 1:4 sahar to Nile tilapia stocking ratios, respectively. The NFY for the treatment with a 1:16 sahar to tilapia stocking ratio was significantly higher ($P<0.05$) than the control; but it was not significantly different from the 1:8 and 1:4

treatments (Table 1). The apparent food conversion ratio ranged from 0.17-0.24 and was not significantly different among treatments (Table 1).

The number of recruits was significantly higher in control (324 ± 40) than polyculture treatments, ranging from 69-169 recruits (Table 2). There were no differences in the number of recruits among different sahar stocking ratios. However, the number of recruits decreased linearly with increasing stocking density of sahar (r^2 =0.54; P = 0.007, Figure 3) and the size of recruits increased with increased sahar to tilapia stocking ratio (Table2).

Mean values of water temperature, DO, pH, Secchi disk depth, total alkalinity, TAN, SRP, nitrite-N, nitrite-nitrate-N, TP, Chlorophyll-*a*, gross and net primary production were not significantly different among treatments (Table 3). Water temperature during the experimental period fluctuated but remained below 20^{o}C for 3.5 months and below 25^{o}C for almost 5 months, (Figure 4). At one point, DO decreased to a greater extent in the control ponds, reaching a minimum (0.2 mg/L) that was lower than the polyculture treatment minimum (0.7mg/L, Table 3). Secchi disk depth and total alkalinity increased at the beginning, peaked during the first part of the experiment, and then fluctuated depending upon the nutrient supply and fresh water supply during latter half of the experiment. Similarly, TAN, SRP, NO_2-N, NO_3-N, Chlorophyll-*a*, gross and net primary production and TP tended to fluctuate during the experimental period depending upon the nutrient supply.

Experiment Two: Pond trials on a working aquaculture farm

Survival rates of Nile tilapia ranged from 92.9% to 95.1% and were not significantly different among treatments (Table 4). Final mean weight and DWG of T2 was significantly higher *(P*<0.05) than tilapia monoculture (T1), but not significantly different from T3. The mean DWG of Nile tilapia ranged from 0.55-0.87 g/d (Table 4). Polyculture showed a trend of higher Nile tilapia growth rates (*P*<0.05) than monoculture (Figure 5). Survival of sahar ranged from 88.9 - 92.9%. The final mean weight and DWG of sahar in T2 was significantly higher (*P*<0.05) than T3 (Figure 6). However, the NFY of sahar was not significantly different between the two polyculture treatments. The extrapolated total yield of fish was 4.10 ± 0.86 t ha^{-1} yr^{-1}, 6.04 ± 0.52 t ha^{-1} yr^{-1}, and 5.40 ± 0.84 t ha^{-1} yr^{-1} in T1, T2, and T3, respectively (Table 4). The extrapolated total NFY in 1:33 sahar-tilapia polyculture was significantly higher (*P*<0.05) than tilapia monoculture, but was not different from the 1:16 treatment (Table 4).

The mean number of recruits in the control treatment (13.2 ± 4.0 recruits/m^2) was significantly higher than the 1:33 polyculture treatment (3.9 ± 0.3 recruits/m^2, Table 5). The number of recruits decreased with increasing stocking density of sahar. However, the mean total weight of recruits was not significantly different among treatments (Table 5).

The means and ranges of water quality parameters measured during the experimental period are presented in Table 6. Pond water temperature remained above 25^{o}C for most of the experimental period (Figure 7).

The budget analysis showed that polyculture with sahar and Nile tilapia produced a positive gross margin, with net returns between 3800 - 4400 NRs/100 m^2 pond compared to 2600 NRs/100 m^2 pond in the tilapia monoculture ponds (Table 7).

DISCUSSION

In the first experiment, growth rates of the Nile tilapia in polyculture with sahar at different stocking ratios were higher than those in the monoculture system. Nile tilapia gained 0.38-0.42 g/d when stocked with sahar on-station, which was lower than rates on the working aquaculture farm (0.55-0.87 g/d). This discrepancy could have been due to differences in water temperature between the two experiments; during the first experiment water temperatures remained below 20°C almost for 2.5 months while they were above 25°C for the majority of experiment two. The daily weight gains of Nile tilapia in both experiments were lower than the growth rate of Nile tilapia (1.15 g/d, Acharya, 2004) in polyculture with sahar at a 1:1 stocking ratio and conducted in a cement pond. This discrepancy is also likely explained by the duration of temperatures below 25°C (Green et al., 1997), feed type, and feed quantity. Sahar showed density-dependent growth with mean daily weight gains of 0.28-0.39 g/d in experiment one and 0.45-0.62 g/d in experiment two, indicating higher growth at lower stocking density of sahar. The results of Acharya (2004) are consistent with this density-dependence pattern, as they found a low sahar growth rate (0.32 g/d) in polyculture with Nile tilapia at a 1:1. The density dependence suggests that in order to grow well, this fish species requires a relatively large space to accommodate its riverine habits and provide an adequate forage base (tilapia recruits).

The extrapolated combined NFY of sahar and Nile tilapia was 4.37-4.93 t ha^{-1} yr^{-1} in experiment two, which was higher than in experiment one (1.4-2.2 t ha^{-1} yr^{-1}). However, both experiments showed lower yield than 6.0 t ha^{-1} yr^{-1}, obtained by Acharya (2004) in polyculture with sahar at 1:1 ratio. This research reaffirms previous findings that the addition of sahar effectively controls the number of tilapia recruits and increases NFY (Yadav et al., 2007). Furthermore, the mean weight of Nile tilapia recruits was significantly higher at higher sahar densities in both of the experiments, meaning that sahar selectively preyed upon relatively smaller recruits. The dorsal spines in large tilapia may have minimized predation in this size-class. The tilapia recruitment in earthen ponds was higher compared to other cement pond experiments (Mishra, 2002; Acharya, 2004; Yadav et al., 2007). This might have been due to the large quantity of local fish found in the earthen ponds, whose populations were also controlled by sahar (Table 2).

Most of the water quality parameters in both experiments, except water temperature in experiment one, were within acceptable ranges for fish culture (Boyd, 1990). There did not appear to be a relationship between water quality and the stocking ratio of sahar (Tables 3 and 6). Water temperature likely limited tilapia growth during most of experiment one, as it remained below 20°C for about three months (December to February). There was an occasional drop in early morning DO levels to below 0.2 mg/L in the tilapia monoculture pond, which was lower than the minima for the polyculture on-station treatments (0.8 mg/L). DO levels in the on-farm experiment remained fairly high compared to those in the on-station experiment. This might have been due to decreased respiration from the lack of feed in the on-farm experiment. The fluctuations in DO concentration were due to variation in the rate of photosynthesis in different weather as well as the rate of oxygen consumption by the fish and other aquatic heterotrophs through respiration (Boyd, 1982). Nutrient-rich waters with high primary production would fuel high net respiration at night and generate large fluctuations in DO. Previous research supports this explanation, as increasing feed inputs fueled increasing primary production, Chlorophyll-*a* concentration, and fish growth (Diana et al., 1997).

Income in these experiments was estimated by a simple budget analysis. Fixed costs were not included in the analysis as the analysis was intended to only compare relative differences in efficiency between the treatments, and we assumed those to be similar for all treatments. The cost estimation was based on local market prices of fingerlings, fertilizers, lime, and labor wages. Results showed that net returns in the second experiment were higher in polyculture with sahar than tilapia monoculture. Among polyculture treatments, the highest returns were produced by a 1:33 sahar to Nile tilapia stocking ratio generating 4,400 NRs/100 m^2 pond (438,000 NRs/ha, Table 7).

The results of these experiments showed that the polyculture of mixed sex Nile tilapia with sahar has great potential for economic and ecological benefits. Sahar to tilapia stocking ratios between 1:33–1:16 appear to optimize tilapia growth. However, while higher stocking ratios of sahar controlled recruitment more strongly, tilapia growth was also affected. At high sahar densities, this might represent behavioral changes in tilapia to the perceived threat of sahar predation. Polyculture with sahar is the better economical choice, and more profitable in a semi-intensive polyculture system. While the cost of growing fish with fertilization and feeding in polyculture was relatively high, it would provide small scale farmers an opportunity to generate more income with higher valued fish. This system will also help to sustain sahar, whose populations are decreasing in the wild.

Figure 1. Mean weight of Nile tilapia in monoculture (T1), sahar-tilapia polyculture at a 1:16 ratio (T2), polyculture at a 1:8 ratio (T3), and polyculture at a 1:4 ratio (T4) during the experimental period in the on-station experiment.

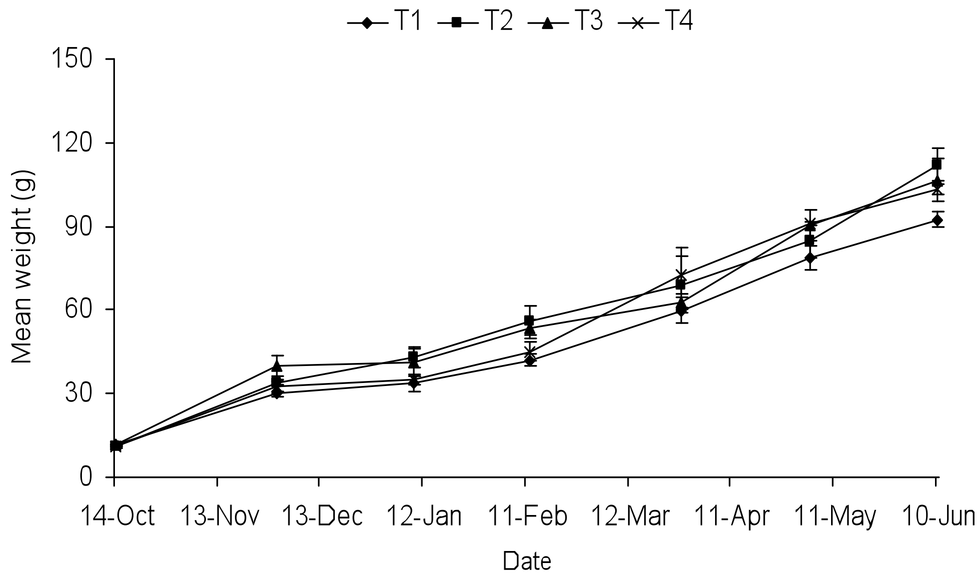

Figure 2. Mean weight of sahar in the three polyculture treatments in the on-station experiment.

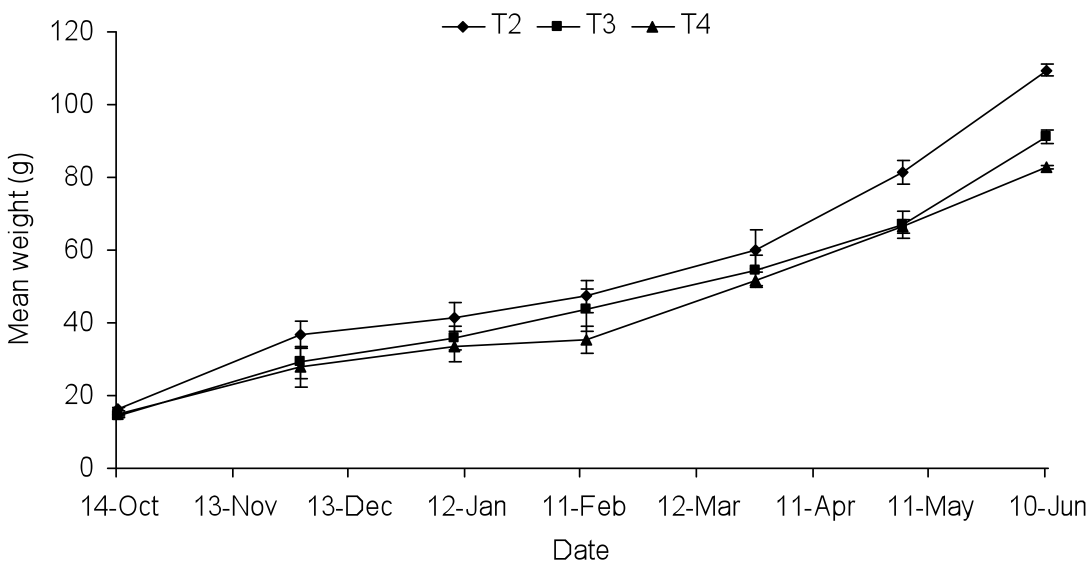

Figure 3. Relationship between sahar to tilapia stocking ratio and tilapia recruits (number m-2) during the experimental period in the on-station experiment.

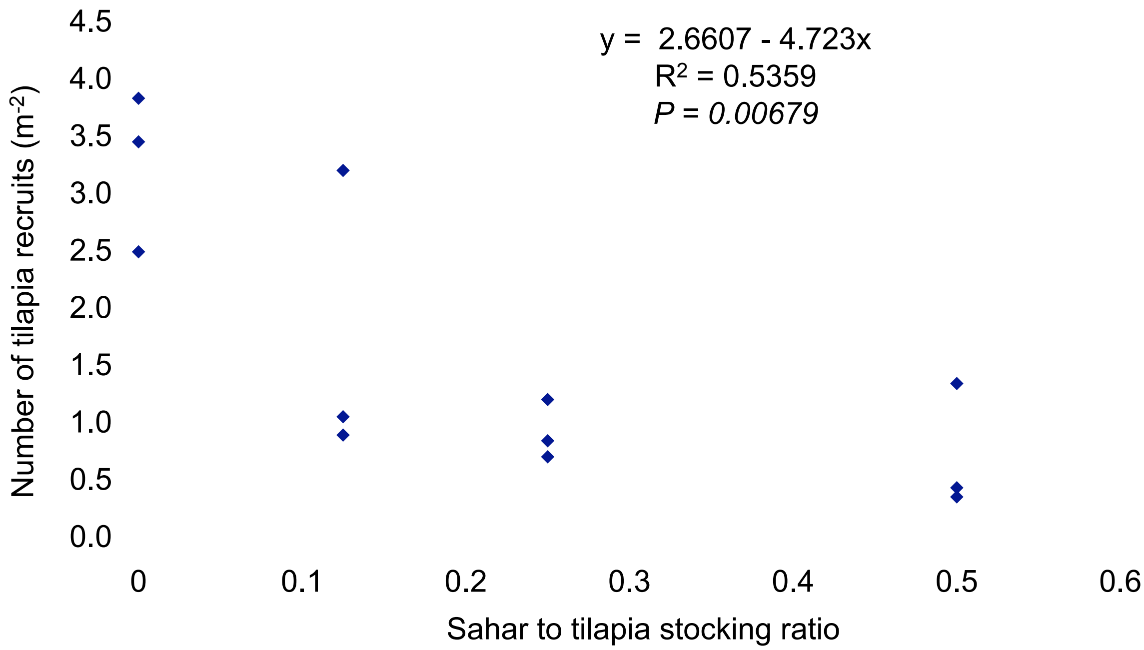

Figure 4. Weekly mean temperature (°C) of pond water at 6:30-7:30 AM for each treatment during the experimental period in the on-station experiment.

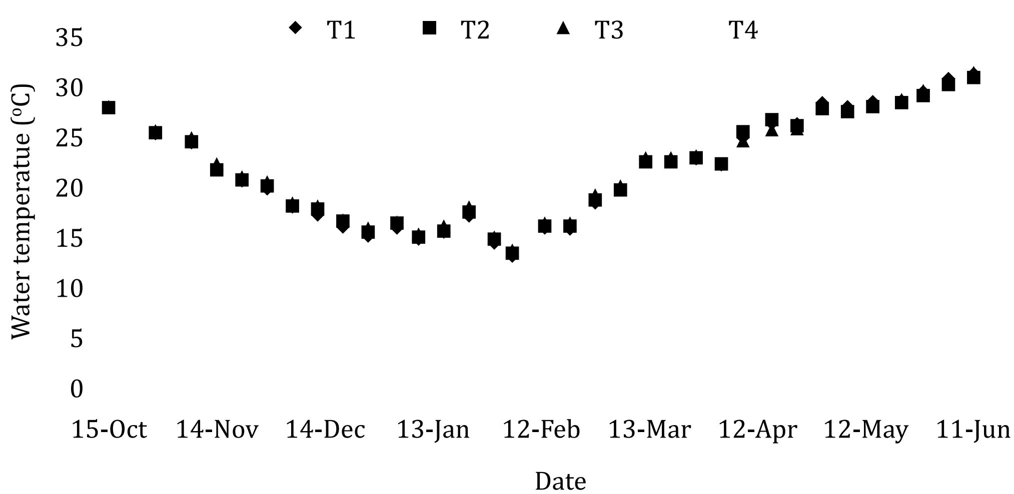

Figure 5. Monthly mean weight of Nile tilapia in the three treatments in the on-farm experiment.

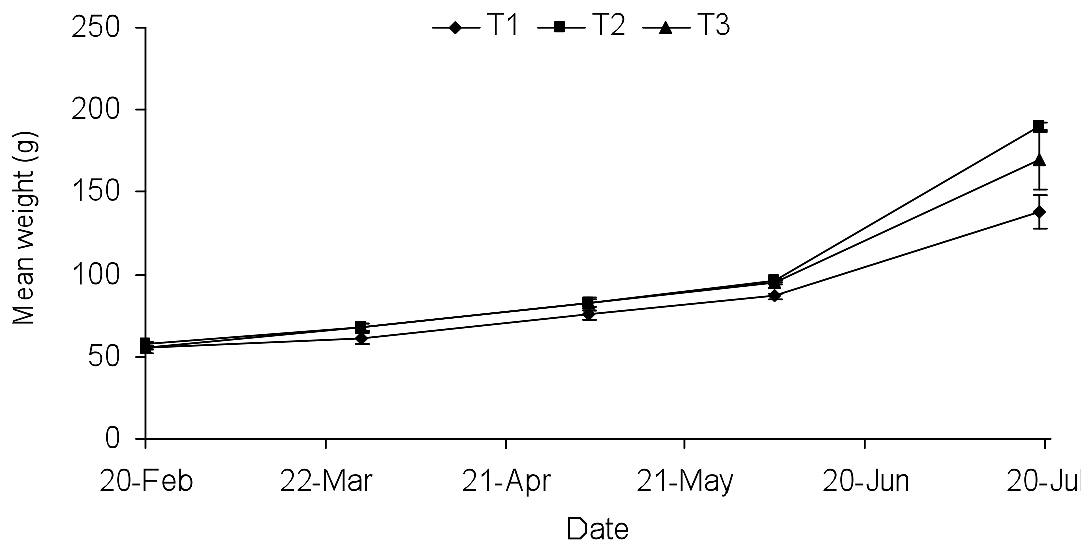

Figure 6. Monthly mean weight of sahar in the two sahar-tilapia polyculture treatments in the on-farm experiment.

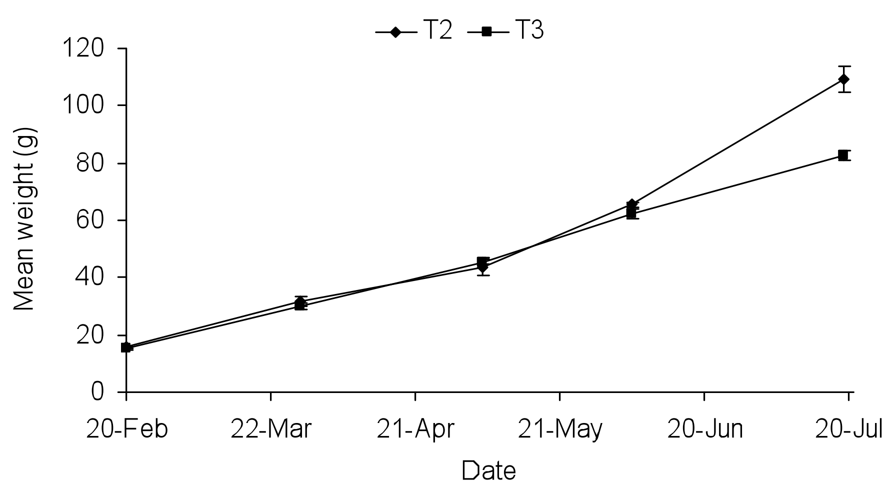

Figure 7. Weekly mean temperature (°C) of pond water at 7:00-8:00 AM the three treatments during the experimental period in the on-farm experiment.

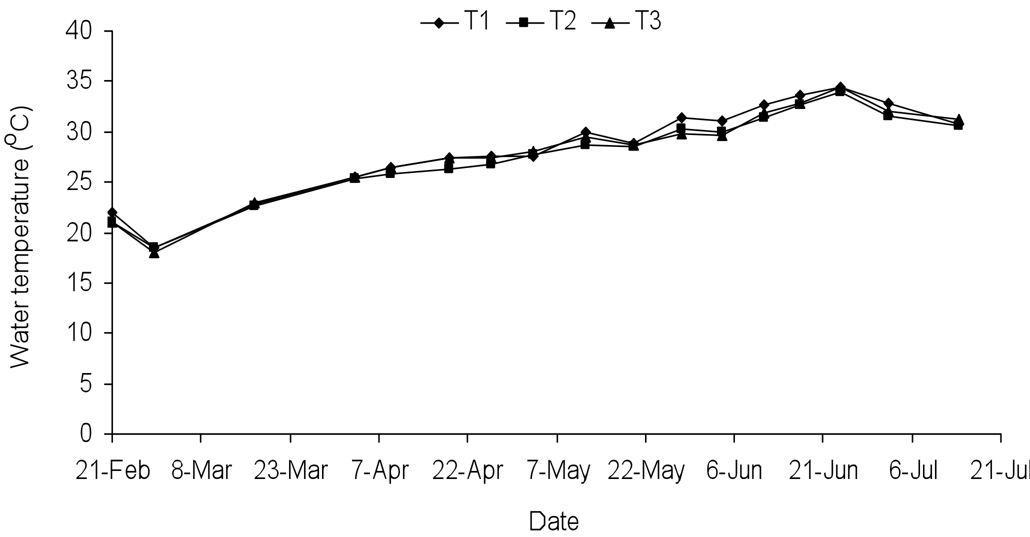

Table 1. Performance of Nile tilapia in monoculture (T1), sahar-tilapia polyculture at a 1:16 ratio (T2), sahar-tilapia polyculture at a 1:8 ratio (T3), and sahar-tilapia polyculture at a 1:4 ratio (T4) in the on-station experiment (Mean ± SE).

Parameters	Treatment			
	T1	T2	T3	T4
Nile tilapia				
Stocking				
Total weight (kg/pond)	2.3 ± 0.04	2.3 ± 0.0	2.3 ± 0.1	2.2 ± 0.1
Mean weight (g/fish)	11.6 ± 0.2	11.3 ± 0.1	11.5 ± 0.4	11.1 ± 0.4
Harvest				
Total weight (kg/pond)	10.4 ± 0.6[a]	15.8 ± 2.0[b]	11.9 ± 0.7[ab]	13.1 ± 1.5[ab]
Mean weight (g/fish)	92.4 ± 2.6[a]	112.0 ± 6.0[b]	106.6 ± 7.4[ab]	103.1 ± 1.6[ab]
Daily weight gain (g $fish^{-1}$ d^{-1})	0.33 ± 0.0[a]	0.42 ± 0.0[b]	0.39 ± 0.0[ab]	0.38 ± 0.0[ab]
Survival (%)	56.0 ± 2.3	70.1 ± 5.0	56.8 ± 7.1	63.8 ± 8.5
NFY (t ha^{-1} yr^{-1})	1.2 ± 0.1[a]	2.1 ± 0.3[b]	1.5 ± 0.1[ab]	1.7 ± 0.2[ab]
Sahar				
Stocking				
Total weight (kg/pond)	-	0.2 ± 0.0[a]	0.4 ± 0.0[b]	0.7 ± 0.0[c]
Mean weight (g/fish)	-	16.3 ± 0.3[a]	14.5 ± 0.5[b]	14.7 ± 0.1[b]
Harvest				
Total weight (kg/pond)	-	0.8 ± 0.1[a]	1.1 ± 0.1[a]	1.5 ± 0.1[b]
Mean weight (g/fish)	-	109.4 ± 1.5[a]	91.1 ± 1.9[b]	82.9 ± 0.4[c]
Daily weight gain (g $fish^{-1}$ d^{-1})	-	0.39 ± 0.0[a]	0.32 ± 0.0[b]	0.28 ± 0.0[c]
Survival (%)	-	56.4 ± 6.7	49.3 ± 5.8	39.3 ± 3.5
NFY (t ha^{-1} yr^{-1})	-	0.10 ± 0.00	0.10 ± 0.00	0.14 ± 0.02
Total NFY (t ha^{-1} yr^{-1})	1.2 ± 0.1[a]	2.2 ± 0.3[b]	1.4 ± 0.2[a]	1.8 ± 0.2[ab]
Mean FCR	0.24	0.17	0.17	0.18

Table 2. Tilapia recruitment and local fish harvested from ponds (100 m^2) in the four treatments during the on-station experiment (Mean ± SE).

Parameter	Treatment			
	T1	T2	T3	T4
Mean number (count/pond)	324 ± 40[a]	169 ± 74[b]	89 ± 15[b]	69 ± 32[b]
Mean weight (g/fish)	3.3 ± 0.2[c]	6.2 ± 0.9[b]	7.9 ± 1.0[b]	10.6 ± 0.9[a]
Local fish (kg/pond)	4.7 ± 1.6	1.7 ± 0.7	2.8 ± 0.4	1.8 ± 0.9

Table 3. Mean (± SE and range) weekly and bi-weekly water quality parameters in each treatment during the on-station experiment.

Parameters	Treatment			
	T1	T2	T3	T4
Temperature (°C)	21.6 ± 0.5	21.7 ± 0.5	21.9 ± 0.5	21.5 ± 0.5
	(12.5-31.4)	(12.6-31.8)	(13.4-31.6)	(12.6-30.9)
Dissolved oxygen (mg/L)	6.2 ± 0.4	6.3 ± 0.4	7.1 ± 0.4	7.3 ± 0.5
	(0.2-14.7)	(0.8-18.4)	(0.7-14.5)	(0.7-17.7)
pH	8.4	8.1	8.4	8.6
	(7.2-9.4)	(6.9-9.2)	(7.3-9.3)	(7.1-9.7)
Secchi disk depth (cm)	21.8 ± 0.8	27.4 ± 1.2	29.8 ± 1.5	22.5 ± 1.1
	(8-55)	(8-56)	(9-70)	(8-60)
Pond water depth (cm)	52.8 ± 0.8	48.1 ± 0.9	49.5 ± 0.6	50.4 ± 0.8
	(40-70)	(30-62)	(34-63)	(30-65)
Total alkalinity (mg/L $CaCO_3$)	110.9 ± 2.2	104.2 ± 2.3	104.6 ± 2.0	103.9 ± 1.4
	(78.7-152.1)	(67.3-134.4)	(73.7-145.2)	(85.9-135.0)
Chlorophyll *a* (mg/m^3)	78.8 ± 8.8	58.1 ± 6.8	46.9 ± 5.4	78.4 ± 9.8
	(5.3-315.4)	(2.7-240.6)	(0.0-200.5)	(2.7-291.4)
Gross primary productivity	5.1 ± 0.3	5.4 ± 0.3	5.4 ± 0.3	5.3 ± 0.4
(g C m^{-2} 12 hr^{-1})	(2.4-12.8)	(1.8-11.8)	(1.5-12.0)	(1.6-13.0)
Net primary productivity (g C m^{-2} 12 hr^{-1})	2.6 ± 0.2	2.6 ± 0.2	2.7 ± 0.2	2.7 ± 0.2
	(1.3-6.8)	(0.8-6.2)	(0.6-6.2)	(0.8-6.3)
Total ammonium nitrogen (mg/L)	0.10 ± 0.0	0.09 ± 0.0	0.10 ± 0.01	0.08 ± 0.0
	(0.01-0.3)	(0.01-0.32)	(0.01-0.35)	(0.01-0.26)
Soluble reactive phosphorus (mg/L)	0.16 ± 0.01	0.12 ± 0.01	0.13 ± 0.01	0.13 ± 0.01
	(0.0-0.42)	(0.0-0.37)	(0.0-0.37)	(0.0-0.37)
Nitrite nitrogen (mg/L)	0.10 ± 0.02	0.15 ± 0.03	0.14 ± 0.02	0.17 ± 0.02
	(0.0-0.57)	(0.0-0.88)	(0.0-0.59)	(0.0-0.70)
Nitrate nitrogen (mg/L)	0.29 ± 0.05	0.30 ± 0.06	0.32 ± 0.05	0.30 ± 0.05
	(0.0-1.27)	(0.01-1.49)	(0.01-1.45)	(0.01-1.29)
Total phosphorus (mg/L)	0.48 ± 0.04	0.39 ± 0.04	0.49 ± 0.04	0.41 ± 0.03
	(0.04-1.36)	(0.04-1.05)	(0.05-1.41)	(0.02-0.97)

Table 4. Performance of Nile tilapia in the four treatments in the on-farm experiment (Mean ± SE).

Parameters	Treatment		
	T1	T2	T3
Nile tilapia			
Stocking			
Total weight (kg/pond)	11.42 ± 1.29	12.45 ± 0.83	12.36 ± 1.01
Mean weight (g/fish)	55.3 ± 3.1	57.4 ± 1.7	55.7 ± 1.4
Harvest			
Total weight (kg/pond)	26.20 ± 1.90[a]	40.57 ± 0.71[b]	35.32 ± 3.02[b]
Mean weight (g/fish)	138.0 ± 10.1[a]	190.0 ± 2.0[b]	169.3 ± 17.8[ab]
Daily weight gain (g $fish^{-1}$ d^{-1})	0.55 ± 0.08[a]	0.87 ± 0.01[b]	0.75 ± 0.11[ab]

Survival (%)	92.9 ± 1.7	94.98 ± 0.8	95.1 ± 2.6
NFY (t ha^{-1} yr^{-1})	2.91 ± 0.54^{a}	4.82 ± 0.01^{b}	4.22 ± 0.76^{b}
Sahar			
Stocking			
Total weight (kg/pond)	-	0.11 ± 0.00^{a}	0.21 ± 0.01^{b}
Mean weight (g/fish)	-	15.7 ± 0.2	15.1 ± 0.5
Harvest			
Total weight (kg/pond)	-	0.71 ± 0.08	1.08 ± 0.24
Mean weight (g/fish)	-	109.5 ± 4.5^{a}	82.5 ± 1.7^{b}
Daily weight gain (g fish^{-1} d^{-1})	-	0.62 ± 0.03^{a}	0.45 ± 0.01^{b}
Survival (%)	-	92.9 ± 4.1	88.9 ± 11.1
NFY (t ha^{-1} yr^{-1})	-	0.11 ± 0.01	0.15 ± 0.03
Total NFY (t ha^{-1} yr^{-1})	2.91 ± 0.54^{a}	4.93 ± 0.01^{b}	4.37 ± 0.74^{ab}

Table 5. Nile tilapia recruitment in the three treatments in the on-farm experiment (Mean ± SE).

Parameter	Treatment		
	T1	T2	T3
Mean number (count/pond)	1371 ± 406^{a}	899 ± 184^{a}	434 ± 31^{b}
Mean number (count/m)	13.2 ± 4.0^{a}	8.0 ± 1.4^{a}	3.9 ± 0.3^{b}
Mean weight (g/fish)	4.4 ± 0.6^{a}	6.6 ± 1.7^{a}	13.1 ± 1.0^{b}

Table 6. Weekly or monthly water quality parameters in the three treatments in the on-farm experiment (mean ± SE range).

Parameters	Treatment		
	T1	T2	T3
Temperature ($^{\circ}$C)	28.4 ± 0.3 (18.5-34.5)	27.3 ± 0.2 (18.4-34.0)	28.0 ± 0.4 (18.0-34.8)
Dissolved oxygen (mg/L)	4.0 ± 0.6 (1.3-5.7)	4.9 ± 0.2 (0.75-8.4)	4.6 ± 1.1 (1.0-7.6)
pH	8.5 ± 0.0 (7.3-9.5)	8.5 ± 0.0 (7.0-9.8)	8.6 ± 0.0 (7.1-9.6)
Secchi disk depth (cm)	29.9 ± 2.3 (21.7-40.7)	24.7 ± 4.6 (19.3-31.0)	20.3 ± 1.2 (14.7-31.0)
Pond water depth (cm)	85 ± 2 (72-102)	82 ± 1 (70-92.5)	85 ± 3 (70-95)
Total alkalinity (mg/L $CaCO_3$)	101.9 ± 5.5 (95.9-107.1)	108.9 ± 1.5 (89.3-137.6)	115.1 ± 3.0 (100.0-141.4)
Chlorophyll - *a* (mg/m^3)	71.0 ± 10.7 (3.6-137.2)	47.7 ± 24.0 (10.0-124.3)	77.0 ± 6.3 (16.9-144.3)
Total ammonium nitrogen (mg/L)	0.095 ± 0.035 (0.015-0.167)	0.078 ± 0.010 (0.055-0.110)	0.096 ± 0.014 (0.068-0.114)
Soluble reactive phosphorus (mg/L)	0.048 ± 0.015 (0.001-0.096)	0.046 ± 0.019 (0.017-0.093)	0.057 ± 0.002 (0.010-0.093)

Table 7. Comparative economic analysis (Mean ± SE) of the three treatments in the on-farm experiment, based on a 100 m^2 pond and Nepalese currency (NRs).

Category	Price	T1	T2	T3
Gross Return				
Adult Nile tilapia	140.0	3,595.7 ± 304.2	5,049.2 ± 23.8	4,532.1 ± 571.7
Sahar	250.0	-	158.3 ± 15.1	236.9 ± 32.9
Nile tilapia recruits	0.50-2.00	685.3 ± 202.9	899.0 ± 184.0	867.3 ± 61.4
Total		4,281.0 ± 503.9^a	6,106.6 ± 192.7^b	5,636.4 ± 597.5^b
Variable Cost				
Lime	15.00	75.0	75.0	75.0
Tilapia (fingerlings)	5.00	1,000.0	1,000.0	1,000.0
Sahar (fingerlings)	10.00	-	70.0	130.0
DAP	35.00	134.8	134.8	134.8
Urea	18.00	93.1	93.1	93.1
Labor	100.00	200.0	200.0	200.0
Cost of working capital	(10 %)	150.3	157.3	163.3
Total Variable Cost		1,653.2	1,730.2	1,796.2
Gross Margin (1,000 NRs/pond)		2.6 ± 0.5^a	4.4 ± 0.2^b	3.8 ± 0.6^{ab}
Gross Margin (1,000 NRs/ha)		262.8 ± 50.4^a	437.6 ± 19.3^b	384.0 ± 59.8^{ab}

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