STOCKING RATIOS OF HYBRID CATFISH (*Clarias macrocephalus x C. gariepinus*) AND NILE TILAPIA (*Oreochromis niloticus*) IN AN INTENSIVE POLYCULTURE

Nguyen Thanh Long[1] and Yang Yi[2]

[1]College of Aquaculture and Fisheries, Cantho University
Cantho, Vietnam

[2]Aquaculture and Aquatic Resources Management
School of Environment, Resources and Development
Asian Institute of Technology
Pathum Thani, Thailand

Abstract

An experiment was conducted in fifteen 5-m^2 cement tanks for 91 days to determine the appropriate stocking ratio of Nile tilapia (*Oreochromis niloticus*) to hybrid catfish (*Clarias macrocephalus x C. gariepinus*) and effects of stocking ratios on the growth of both Nile tilapia and hybrid catfish, water quality, nutrient utilization efficiency and economic returns. Hybrid catfish fingerlings of 25-26 g size were stocked at 20 fish/m^2, while Nile tilapia fingerlings of 20-23 g size were stocked at 0, 1, 2, 3, 4, 5 and 6 fish/m^2, giving stocking ratios of Nile tilapia to hybrid catfish of 0:20, 1:20, 2:20, 3:20, 4:20, 5:20, and 6:20, respectively. The control (0:20) had three replicates, while other treatments had two replicates each. No fertilizers were applied to the tanks. Floating pelleted feed (30% crude protein) was given twice daily at 0830 and 1530 h six days per week. Feed rations were calculated based only on hybrid catfish biomass at feeding rates of 5% and 3% body weight per day for hybrid catfish smaller and larger than 100 g, respectively. All tanks were aerated by airstones throughout the experimental period.

The addition of Nile tilapia into hybrid catfish tanks did not cause any significant effects on survival, growth and yields of hybrid catfish ($P > 0.05$). Survival of tilapia was not significantly different in the polyculture treatments ($P > 0.05$). With increasing stocking ratios of Nile tilapia to hybrid catfish, mean tilapia weights at harvest decreased linearly, while both net and gross tilapia yields increased linearly ($P < 0.05$). FCRs based on either hybrid catfish alone or combined hybrid catfish and Nile tilapia were not significantly different among all treatments ($P > 0.05$). Combined net yields were not significantly different among all treatments ($P > 0.05$), however, combined gross yields increased linearly with increasing stocking ratios of Nile tilapia to hybrid catfish ($P < 0.05$).

The present experiment indicates that intensive polyculture of hybrid catfish and Nile tilapia is feasible technically and economically. However, further research is needed to optimize the stocking ratio of Nile tilapia to hybrid catfish to reduce the nutrient release to the environment.

Introduction

Hybrid catfish (*Clarias macrocephalus x C. gariepinus*) has become one of the most popularly cultured freshwater fish in Southeast Asia. One of the most problematic aspects of intensive hybrid catfish culture is environmental pollution. Uneaten feed and fish feces are the major sources of suspended solids and inorganic nutrients, leading to increase in biochemical oxygen demand (BOD) and eutrophication of receiving water areas (Muir, 1982). The concentration of nutrients in wastes from intensive catfish culture is high (Sundar, 1989). For example, 78.8% of N and 85.5% of P from feed input are released into the surrounding water lost from catfish cage culture (Udomkarn, 1989).

To utilize nutrients in the wastes from intensive hybrid catfish culture, several experiments have been conducted in integrated cage-cum-pond systems (Udormkarn, 1989; Lin, 1990; Lin and Diana, 1995). The results from the integrated cage-cum-pond systems showed that the wastes from caged hybrid catfish can be utilized effectively to produce phytoplankton to support Nile tilapia *(Oreochromis niloticus)* culture in the open pond (Lin, 1990; Lin and Diana, 1995). Yi *et al*. (2003) developed a system and demonstrated that Nile tilapia can effectively recover nutrients contained in the wastewater of intensive catfish culture.

The purposes of this study were to determine the appropriate stocking ratio of Nile tilapia to hybrid catfish and the effects of stocking ratios on the growth of Nile tilapia and hybrid catfish, water quality, nutrient utilization efficiency and economic returns in intensive polyculture.

Materials and methods

This experiment was conducted in fifteen outdoor concrete tanks of 5 m^2 in surface area and 0.9 m in water depth at the Asian Institute of Technology (AIT), Thailand, from 3 March – 2 June 2003. Hybrid catfish were stocked at 20 fish/m^2, while Nile tilapia at 0, 1, 2, 3, 4, 5 and 6 fish/m^2, giving Nile tilapia to hybrid catfish stocking ratios of 0:20, 1:20, 2:20, 3:20, 4:20, 5:20 and 6:20 referred to as T1, T2, T3, T4, T5, T6 and T7, respectively. There were 3 replicates for treatment 1 (control), and 2 replicates for treatments 2 through 7. Treatments were randomly allocated to the tanks. One airstone was placed in each tank, and all tanks were covered by nylon net to prevent fish from jumping out or being prey upon by birds. Water depth in all tanks was maintained at 0.9 m throughout the experiment by adding water weekly to replace evaporation and seepage losses.

Hybrid catfish fingerlings of 25.4±1.2 g in size were stocked in the tanks on 3 March 2003, while Nile tilapia fingerlings of 20.4±1.0 g in size were stocked one week later. Medium and large size floating pelleted feeds (crude protein 30%, Charoen Pokphand Co., Ltd., Thailand) were given twice daily at 0830 and 1530 h 6 days per week. Feed ration was calculated based only on hybrid catfish biomass estimated by biweekly fish sampling and observed mortality. Feeding rates of 5% and 3% body weight per day (%BWD) were used for hybrid catfish smaller and greater than 100 g, respectively. All tanks were harvested on 2

June 2003 after 91 days. Final biomass and numbers were determined. During the experiment, fish growth was determined by biweekly weighing 20 hybrid catfish randomly sampled from each tank and all Nile tilapia.

Diel measurements of water temperature, dissolved oxygen (DO) and pH were conducted monthly at three different water depths (20 cm below water surface, middle, and 20 cm above tank bottom) at 0600, 0900, 1400, 1600, 1800, 2300, and 0600 h. DO and temperature were also measured weekly at 0600 h. Integrated column water samples were taken at 0900-1000 h biweekly from each tank for analyses of total ammonia nitrogen (TAN), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), soluble reactive phosphorus (SRP), total alkalinity, total suspended solids (TSS), total volatile solids (TVS), and chlorophyll *a* (APHA *et al*., 1999). Before taking water samples, temperature and pH in each tank were measured.

Contents of moisture, total nitrogen (TN) and TP were determined for fish and feed (AOAC, 2000). Hybrid catfish and Nile tilapia were randomly selected at stocking (7 each) and at harvest (3 hybrid catfish from each tank and 3 tilapia from each polyculture tank) for the analyses. Each batch of pelleted feeds was sampled for the analyses.

A partial budget analysis was conducted based on the farm-gate prices for harvested fish and market prices for all costs in Thailand (Shang, 1990). Farm gate prices of hybrid catfish and Nile tilapia were 27 and 20 baht/kg for harvested sizes in the present experiment, respectively. Market prices for fingerlings of hybrid catfish and sex-reversed Nile tilapia were 0.2 and 2 baht/piece, respectively. Price for electricity was 2 baht/kw. Prices of feed varied with size, 21 baht/kg for medium size and 19.25 baht/kg for large size. The calculation for cost of working capital was based on an annual interest rate of 8%.

The data were analyzed statistically by one-way analysis of variance (ANOVA) and regression analysis (Steele and Torrie, 1980) using SPSS (version 11.0) statistical software package. Differences were considered significant at an alpha level of 0.05. All means were given with ± standard error (SE).

Results

Survival of hybrid catfish, ranging from 93.67% to 100%, was not significantly different among all treatments ($P > 0.05$, Table 1). Final mean weight of hybrid catfish was 180 - 199 g in polyculture treatments, and 196 g in monoculture. Daily weigh gains (DWG) ranged from 1.70 to 1.90 g/fish/day. Net and gross yields of hybrid catfish were 117.9 - 132.6 and 138.0 - 153.0 t/ha/year, respectively. There were no significant differences in all growth and yield parameters among all treatments ($P > 0.05$, Table 1). FCRs based on hybrid catfish alone, ranging from 1.11 to 1.22, were not significantly different among all treatments ($P > 0.05$, Table 1).

Table 1. Growth performance of hybrid catfish cultured in the monoculture and polyculture system for 91 days.

Parameters	Treatments (Nile tilapia to hybrid catfish ratios)						
	T1 (0:20)	T2 (1:20)	T3 (2:20)	T4 (3:20)	T5 (4:20)	T6 (5:20)	T7 (6:20)
Stocking							
Density (fish/m^2)	20	20	20	20	20	20	20
Mean weight (g/fish)	25±1.2	25±0.7	25±0.7	26±0.6	26±0.3	26±0.1	25±1.8
Total weight (kg/tank)	2.5±0.1	2.5±0.1	2.5±0.1	2.6±0.1	2.6±0.0	2.6±0.0	2.5±0.2
Harvest							
Survival (%)	93.67±3.48	96.50±0.50	100.00±0.00	100.00±0.00	96.00±2.00	95.50±3.50	95.50±4.95
Mean weight (g/fish)	196±5.4	198±3.2	182±4.4	190±2.7	181±0.3	199±12.0	180±0.6
Total weight (kg/tank)	18.4±1.1	19.1±0.2	18.2±0.4	19.0±0.3	17.4±0.3	19.0±0.5	17.2±0.8
DWG (g/fish/d)	1.88±0.06	1.89±0.03	1.72±0.04	1.80±0.04	1.71±0.01	1.90±0.13	1.70±0.03
Net yield (t/ha/year)	127.4±9.5	132.6±1.1	125.3±2.9	131.6±2.7	118.9±2.5	131.4±3.6	117.9±4.7
Gross yield (t/ha/year)	147.6±8.7	153.0±1.7	145.6±3.5	152.1±2.2	139.5±2.7	152.0±3.6	138.0±6.7
FCR	1.15±0.06	1.11±0.02	1.13±0.02	1.18±0.06	1.19±0.09	1.17±0.00	1.22±0.02

Survival of Nile tilapia, ranging from 65.00% to 91.67%, was not significantly different among all treatments ($P > 0.05$, Table 2). Final mean weights of Nile tilapia decreased linearly with increasing stocking density ($y= - 308.52x + 212.2$, $P < 0.01$, $n = 12$, $r^2 = 0.632$). Both net and gross yields of Nile tilapia increased linearly with increasing stocking density ($y = 74.788x + 1.1489$, $P < 0.01$, $n = 12$, $r^2 = 0.8211$, and $y = 93.126x + 1.1613$, $P < 0.01$, $n = 12$, $r^2 = 0.879$, respectively).

Table 2. Growth performance of Nile tilapia cultured in the polyculture system for 84 days.

Parameters	Treatments (Nile tilapia to hybrid catfish ratios)					
	T2 (1:20)	T3 (2:20)	T4 (3:20)	T5 (4:20)	T6 (5:20)	T7 (6:20)
Stocking						
Mean weight (g/fish)	23±0.25	22±0.03	20±0.17	21±0.49	22±1.16	21±0.04
Total weight (kg/tank)	0.11±0.00^{a}	0.22±0.00^{b}	0.30±0.00^{c}	0.41±0.01^{d}	0.55±0.03^{e}	0.63±0.00^{f}
Harvest						
Survival (%)	70.00±10.00	85.00±15.00	83.33±3.33	65.00±25.00	82.00±6.00	91.67±1.67
Mean weight (g/fish)	220±6.90^{a}	155±6.71^{bc}	147±3.50^{cd}	177±13.40^{b}	129±7.35^{cd}	121±5.95^{d}
Total weight (kg/tank)	0.77±0.13^{a}	1.31±0.18^{ab}	1.83±0.03^{abc}	2.37±1.06^{abc}	2.64±0.04^{bc}	3.34±0.08^{c}
Mean weight gain (g/fish)	198±6.64^{a}	133±6.68^{bc}	126±3.68^{cd}	156±13.89^{b}	107±8.51^{cd}	100±5.89^{d}
Daily weight gain (g/fish/d)	2.35±0.08^{a}	1.58±0.08^{bc}	1.50±0.04^{cd}	1.86±0.17^{b}	1.28±0.10^{cd}	1.20±0.07^{d}
Net yield (t/ha/year)	5.7±1.16	9.4±1.52	13.3±0.23	17.0±9.30	18.2±0.13	23.5±0.66
Gross yield (t/ha/year)	6.7±1.17^{a}	11.3±1.52^{ab}	15.9±0.26^{abc}	20.6±9.21^{abc}	22.9±0.38^{bc}	29.0±0.68^{c}

Combined net and gross yields of hybrid catfish and Nile tilapia were 127.4 and 147.6 t/ha/year in monoculture, and 134.0 - 148.2 and 156.1 - 173.2 t/ha/year in polyculture, respectively (Table 3). There were no significant differences in net yields among all treatments ($P > 0.05$). Gross yield in the polyculture treatment with 5:20 ratio was significantly higher than that in monoculture ($P < 0.05$), however there were no significant differences between monoculture and the polyculture treatments except the treatment with 5:20 ratio, and also no significant differences among all polyculture treatments ($P > 0.05$). FCR based on both hybrid catfish and Nile tilapia was not significantly different among all treatments ($P > 0.05$). Combined gross yields increased linearly with increasing stocking density of Nile tilapia ($y = 62.521x + 151.24$, $p < 0.05$, $n = 15$, $r^2 = 0.3796$).

In this experiment, feed was the only added nutrient input. During the 91-day experiment, hybrid catfish in monoculture (treatment 1) incorporated 63.2% nitrogen inputted from feed, which was significantly higher than that in the polyculture treatment of 4:20 ratio ($P < 0.05$), but both were not significantly different from that in other polyculture treatments ($P > 0.05$, Table 4). Nitrogen recovered by Nile tilapia in polyculture increased significantly with increasing stocking density of Nile tilapia ($P > 0.05$). The combined harvested nitrogen percentages by both hybrid catfish and Nile tilapia were not significantly different among all treatments, and percentages of nitrogen contained in wastes were also not significantly different ($P > 0.05$). The percentages of phosphorus utilized by hybrid catfish

Table 3. Combined performance of hybrid catfish and Nile tilapia cultured in the monoculture and polyculture systems for 91 days.

Parameters	Treatments (Nile tilapia to hybrid catfish ratios)						
	T1 (0:20)	T2 (1:20)	T3 (2:20)	T4 (3:20)	T5 (4:20)	T6 (5:20)	T7 (6:20)
Stocking							
Total weight (kg/tank)	2.5±0.1	2.7±0.1	2.8±0.1	2.9±0.1	3.0±0.0	3.1±0.0	3.1±0.3
Harvest							
Total weight (kg/tank)	18.4±1.1[a]	19.9±0.3[ab]	19.5±0.6[ab]	20.8±0.2[ab]	19.8±0.7[ab]	21.6±0.4[b]	20.5±0.9[ab]
Total weight gain (kg/tank)	15.9±1.2	17.2±0.3	16.7±0.5	17.9±0.30	16.8±0.76	18.5±0.4	17.4±0.7
Net yield (t/ha/year)	127.4±9.5	137.9±2.1	134.0±4.3	143.9±2.4	134.6±6.1	148.2±3.5	139.6±5.3
Gross yield (t/ha/year)	147.6±8.7[a]	159.2±2.8[ab]	156.1±4.9[ab]	166.8±2.0[ab]	158.6±5.9[ab]	173.2±3.3[b]	164.7±7.4[ab]
FCR	1.15±0.06	1.07±0.02	1.06±0.03	1.08±0.05	1.05±0.01	1.04±0.00	1.03±0.02

Table 4. Nitrogen and phosphorus utilization efficiency (%) in the monoculture of hybrid catfish and polyculture of hybrid catfish and Nile tilapia.

Parameters	Treatments (Nile tilapia to hybrid catfish ratios)						
	T1 (0:20)	T2 (1:20)	T3 (2:20)	T4 (3:20)	T5 (4:20)	T6 (5:20)	T7 (6:20)
Nitrogen							
Feed input	100	100	100	100	100	100	100
Gain in catfish	63.2±1.7[a]	62.8±5.6[ab]	60.3±2.9[ab]	54.8±1.0[ab]	53.2±3.6[b]	54.3±1.3[ab]	58.5±3.4[ab]
Gain in tilapia	-----	2.5±0.9[a]	3.5±0.8[ab]	5.3±0.2[abc]	6.5±2.4[abc]	6.7±0.8[bc]	7.8±0.1[c]
Total gain	63.2±1.7	65.3±4.7	63.8±2.1	60.1±0.8	59.8±1.2	61.0±2.0	66.3±3.4
Released in wastes	36.8±1.7	34.7±4.7	36.2±2.1	39.9±0.8	40.2±1.2	39.0±2.0	33.7±3.4
Phosphorous							
Feed input	100	100	100	100	100	100	100
Gain in catfish	39.2±2.1	43.3±1.8	42.7±5.4	40.9±1.9	40.2±5.6	42.7±2.5	39.8±1.6
Gain in tilapia	----	1.8±0.5[a]	2.6±0.6[ab]	4.2±0.6[ab]	5.8±4.7[ab]	5.4±0.6[ab]	7.4±0.1[b]
Total gain	39.2±1.2[a]	45.1±0.9[ab]	45.3±4.2[ab]	45.1±1.8[ab]	46.0±0.6[ab]	48.1±2.2[b]	47.2±1.1[b]
Released in wastes	60.8±2.1[a]	54.9±1.2[ab]	54.7±6.0[ab]	54.9±2.5[ab]	54.0±0.9[ab]	51.9±3.1[b]	52.8±1.5[b]

treatments of higher stocking density (5:20 and 6:20 ratios), intermediate in the polyculture treatments of lower stocking density (1-4:20 ratios), and lowest in the monoculture treatment ($P < 0.05$, Table 4). There were no significant differences in all water quality parameters measured at the end of the experiment among treatments ($P > 0.05$, Table 5). Variations within treatments were very large. Water temperature and pH ranged from 28.0 to 31.9 C, and from 5.6 to 8.7, respectively, throughout the experimental period. Measured DO concentrations at early morning decreased from initial levels of 4.6-5.5 mg/L to 0.9 - 2.2 mg/L at the end of the experiment. TAN concentrations fluctuated throughout the period. Concentrations of TKN, nitrate-N, TP, SRP, TSS and TVS increased generally towards the end of the experiment, while NO_2-N and chlorophyll *a* concentrations fluctuated largely through the experimental period.

Average net returns ranged from 7.0-22.6 baht/tank in polyculture, and 0.3 baht/tank in monoculture (Table 6). There were no significant differences in net returns among all treatments due to large variations within treatments. The highest added return was 49.9 baht/tank in the polyculture treatment of 5:20 ratio, while the highest ratio of added return to added cost was 7.0 in the polyculture treatment of 2:20 ratio (Table 6).

Table 5. Mean values of water quality parameters measured at the end of the experiment.

Parameters	Treatments (Nile tilapia to hybrid catfish ratios)						
	T1 (0:20)	T2 (1:20)	T3 (2:20)	T4 (3:20)	T5 (4:20)	T6 (5:20)	T7 (6:20)
DO at dawn (mg/L)	1.2±0.18	1.1±0.02	1.4±0.03	1.3±0.46	1.4±0.09	0.9±0.13	1.0±0.05
Temperature (C)	30.9±0.1	30.8±0.1	30.9±0.0	30.8±0.0	30.9±0.1	30.9±0.0	30.9±0.0
pH	6.54±0.38	7.55±0.11	6.48±0.41	6.76±0.39	6.09±0.34	6.97±0.47	6.44±0.49
Total alkalinity (mg/L as $CaCO_3$)	84±34	18±2	33±13	63±51	48±37	76±54	54±4
TKN (mg/L)	40.31±1.78	49.24±4.04	45.60±0.37	44.96±15.02	45.07±4.52	49.01±9.20	36.42±5.38
TAN (mg/L)	0.24±0.09	2.16±1.86	0.26±0.10	1.38±1.14	2.09±1.88	0.71±0.49	0.25±0.02
Nitrite-N (mg/L)	0.30±0.12	0.08±0.06	0.08±0.01	0.15±0.11	0.10±0.01	0.27±0.05	0.12±0.06
Nitrate-N (mg/L)	9.22±4.04	19.48±2.32	14.02±2.01	13.56±8.44	16.20±2.44	13.34±4.88	12.00±0.12
TP (mg/L)	14.00±0.18	13.87±0.18	13.01±0.10	15.50±0.65	11.67±0.29	13.76±0.78b	12.17±0.75
SRP (mg/L)	8.77±1.13	10.70±0.06	9.41±0.04	10.49±1.65	9.48±0.62	9.22±1.50	8.76±0.12
Chlorophyll *a* (mg/m^3)	588±221	289±103	481±58	343±100	572±58	712±187	557±87
TSS (mg/L)	513±111	364±30	439±17	442±16	276±8	486±60	399±33
TVS (mg/L)	997±44	1,067±79	1,011±27	1,022±48	966±12	1,069±69	1,008±22

Table 6. Partial budget analysis for hybrid catfish and Nile tilapia polyculture in 5-m^2 cement tanks for the 91-day experiment (Unit: Baht; 1US$ = 40 Baht).

Parameters	Treatments (Nile tilapia to hybrid catfish ratios)						
	T1 (0:20)	T2 (1:20)	T3 (2:20)	T4 (3:20)	T5 (4:20)	T6 (5:20)	T7 (6:20)
Gross revenue	497.6±29.4	530.4±8.3	516.3±15.2	548.6±6.8	517.1±12.2	564.5±11.4	531.1±17.1
Variable cost	496.3±17.6	507.8±2.8	498.8±1.1	537.7±11.9	507.6±20.0	546.2±10.7	524.1±14.4
Net return	0.3±20.1	22.6±11.1	17.5±14.2	10.8±18.7	9.5±7.9	18.3±0.7	7.0±2.7
Added cost	----	11.5	2.5	41.4	11.3	49.9	27.8
Added return	----	22.3	17.2	10.5	9.1	17.9	6.6
Ratio of added return to added cost	----	1.9	7.0	0.3	0.8	0.4	0.2

Discussion

Growth of hybrid catfish in polyculture was not significantly different from that in monoculture ($P > 0.05$) in the present experiment. However, the daily weight gains of hybrid catfish in the present experiment ranged from 1.7-1.9 g/fish/day, which are higher than those in wastewater recycling tanks (1.1-1.7 g/fish/day) (Sethteethunynhan, 1998), an integrated cage-cum-pond system (0.65 g/fish/day) (Uddomkarn, 1989), and an integrated cage-cum-tank system (0.8-0.9 g/fish/day) (Ye, 1991), but lower than those in an integrated pen-cum-pond system (2.5-2.6 g/fish/day) (Yi *et al*., 2003) and an integrated cage-cum-pond system (2.1-2.2 g/fish/day) (Lin and Diana, 1995). The main reason of lower daily weight gains in the present experiment is probably the lower feed input, compared to the experiments conducted by Lin and Diana (1995) and Yi *et al*. (2003). Feed was given in the present experiment at lower rates than those in the integrated systems, that is, 8% BWD for 20-50 g size, 5% BWD for 50-100 g size, and 3% BWD for larger than 100 g size (Lin and Diana, 1995; Yi *et al*., 2003), while 5% and 3% BWD was used for smaller and larger than 100 g sizes, respectively, in present experiment. FCRs (1.11-1.22) in the present experiment were better than those reported in the above integrated systems, that is, 1.17-1.21 by Sethteethunynhan (1998), 2.83 by Uddomkarn (1989), 1.48-1.70 by Ye (1991), 1.94-2.24 by Lin and Diana (1995), and 1.31-1.26 by Yi *et al*. (2003). Survival of hybrid catfish in the present experiment (93.6-100%) was similar to those reported by Uddomkarn (1989), Sethteethunynhan (1998), Ye (1991) and Yi *et al*. (2003).

Mean weight of Nile tilapia at harvest decreased linearly with increasing stocking density of Nile tilapia, while net and gross yields increased linearly with the increasing stocking density. Survival at all densities (1-6 fish/m^2) of Nile tilapia indicated that Nile tilapia can be polycultured with hybrid catfish stocked at 20 fish/m^2. The survival of Nile tilapia in the present experiment was similar to those reported in the integrated systems (Uddomkarn, 1989; Ye, 1991; Lin and Diana, 1995; Yi *at al*, 2003). Daily weight gains of Nile tilapia in the present experiment (1.2-2.5 g/fish/day) were higher than those in the integrated systems, that is, 0.7-1.0 g/fish/day by Ye (1991) and 1.1 g/fish/day by Yi *et al*. (2003), probably because Nile tilapia in the polyculture system in the present experiment not only consumed natural foods derived from feeding wastes but also competed with hybrid catfish for the given artificial feed. However, non-significantly different FCRs between the polyculture and monoculture in the present experiment indicated that natural foods play more important roles than artificial feed for the growth of Nile tilapia. Higher DO concentrations due to aeration might also be one of the reasons for higher daily weight gains in the present experiment, compared to the above integrated systems without aeration. Extrapolated combined gross yields of hybrid catfish and Nile tilapia in the present experiment ranged from 156.1 to 173.2 t/ha/year, which were higher than those achieved in the integrated systems (Uddomkarn, 1989; Ye, 1991; Lin and Diana, 1995; Yi *et al*., 2003) when the gross yields in integrated systems were recalculated based on total areas.

All water quality parameters measured at the end of the present experiment were not significantly different among all treatments. This might indicate that the addition of Nile tilapia into the hybrid catfish tanks did not improve water quality, due probably to the insufficient Nile tilapia biomass and/or effects of aeration. Concentrations of nitrogen and phosphorus (TAN, nitrite-N, nitrate-N, TKN, SRP and TP) were much higher than those in the integrated culture systems reported by Uddomkarn (1989), Ye (1991), Lin and Diana (1995) and Yi *et al*. (2003).

There were no significant differences in the percentages of nitrogen incorporated by fish among all treatments in the present experiment. Hybrid catfish alone or together with Nile tilapia incorporated about 60-66% of nitrogen from the feed input. These percentages were much higher than those in the integrated culture systems (Ye, 1991; Sethteethunyahan, 1998; Yi *et al*., 2003) and channel catfish ponds (Boyd, 1985). In the present experiment, the percentages of phosphorus incorporated by hybrid catfish and Nile tilapia in polyculture (45-48%) were higher than that in hybrid catfish monoculture (39%). The phosphorus percentages in the present experiment were also much higher than those reported by Beveridge (1984), Ye (1991), Sethteethunyahan (1998), and Yi *et al*. (2003).

The economic analysis showed that the lower stocking ratios of Nile tilapia to hybrid catfish (1-2:20) gave higher net return and higher ratios of added return to added cost, indicating that the intensive polyculture of hybrid catfish and Nile tilapia is feasible economically. In the present experiment, cost could be reduced by reducing electricity cost for aeration. During the first two weeks, total fish biomass in tanks was low and waste content was also at low levels, thus aeration may not be needed. During the later culture period, aeration could be only provided at nighttime.

Considering growth and yields of both Nile tilapia and hybrid catfish and economic performance, the appropriate ratios of Nile tilapia to hybrid catfish in polyculture are 1-2:20, that is, 1-2 Nile tilapia and 20 hybrid catfish per m^2. However, the percentages of nutrient recovery by Nile tilapia were very low in the present experiment, due to high nutrient load from hybrid catfish wastes. To recover more nutrients from hybrid catfish wastes, more Nile tilapia should be stocked. Therefore, further research is needed to optimize the stocking ratio of Nile tilapia to hybrid catfish to reduce the nutrient release to the environment.

Acknowledgement

The authors wish to thank AIT Aquaculture Lab staff for their field and lab assistance. Special thanks are extended to AIT, West-East-South Project in Cantho University of Vietnam and the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A SCRP) for jointly sponsoring Mr. Nguyen Thanh Long's M. Sc. study. This research was his M. Sc. thesis work sponsored by PD/A CRSP supported by the US Agency for International Development, Grant No. DAN-4023-G-00-0031-00. This is PD/A CRSP Accession No. 1276. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the US Agency of International Development.

References

AOAC. 2000. *Official Methods of Analysis of the Association of Official Analytical Chemists*, 17th edn. Association of Official Analytical Chemists, Inc., VA. USA.

APHA, AWWA and WEF. 1999. *Standard Methods for the Examination of Water and Wastewater*, 20th edn. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC. USA.

Beveridge, C.M. 1984. *Cage and Pen fish Farming: Carrying Capacity Models and Environmental Impacts*. FAO Fisheries Technical Paper NO.255. FIRI/222. Food and Agriculture Organization of the United Nations, Rome.

Boyd, C.E. 1985. "Chemical budgets of channel catfish ponds". *Trans, Amer. Fish. Soc.*, 114: 291-298.

Lin, C.K. 1990. "Integrated culture of walking catfish (*Clarias macrocephalus*) and tilapia (*Oreochromis niloticus*)". *In*: R. Hirano and I. Hanyu (Eds.), *The Second Asian Fisheries Forum*. Asian Fisheries Society, Manila, Philippines, pp. 209-212.

Lin, C.K. and Diana, J.S. 1995. "Co-culture of catfish (*Clarias macrocephalus x C. gariepinus*) and tilapia (*Oreochromis niloticus*) in ponds". *Aquatic Living Resources*, 8:449-454.

Muir, J.F. 1982. "Economic aspects of waste treatment in fish culture". *In*: J.S. Albaster, (Ed.), *Report of the EIFAC Workshop on Fish Farm Effluents*. EIFAC Technical Paper 41: 123-135.

Sethteethunyahan, R. 1998. *Recycling Wastewater from Intensive Hybrid Catfish (Clarias macrocepharus x C. gariepinus) Culture for Semi-intensive Nile Tilapia (Oreochromis niloticus) Culture in Cement Tanks*. Unpublished M. Sc. Thesis, Asian Institute of Technology, Thailand.

Shang, Y.C. 1990. *Aquaculture Economic Analysis: An Introduction*. World Aquaculture Society, Baton Rouge, Louisiana, USA.

Steele, R.G.D. and Torrie, J.H. 1980. *Principles and Procedures of Statistics*, 2nd edn. McGraw-Hill, New York, USA.

Sundar, S. V. 1989. *Intensive Culture of Walking Catfish (Clarias macrocephalus) in an Outdoor Recirculating System Integrated with Tilapia*. Unpublished M. Sc. Thesis, Asian Institute of Technology, Thailand.

Udomkarn, C. 1989. *Integration of Catfish (Clarias macrocephalus) Cage Culture with Tilapia in Earthen Pond*. Unpublished M. Sc Thesis, Asian Institute of Technology, Thailand.

Ye. Q.F. 1991. *Nutrient Budget and Water Quality in Integrated Walking Catfish – Tilapia Culture.* Unpublished M. Sc. Thesis, Asian Institute of Technology, Thailand.

Yi, Y., Lin, C.K. and Diana, J.S. 2003. "Hybrid catfish (*Clarias macrocephalus x C. gariepinus*) and Nile tilapia (*Oreochromis niloticus*) culture in an integrated pen-cum-pond system: growth performance and nutrient budgets". *Aquaculture*, 217: 395-408.