Integrated Recycle System for Catfish and Tilapia Culture

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Yang Yi and C. Kwei Lin
Aquaculture and Aquatic Resources Management
Agricultural & Aquatic Systems and Engineering Program
Asian Institute of Technology
Pathumthani, Thailand

James S. Diana
School of Natural Resources and Environment
The University of Michigan
Ann Arbor, Michigan, USA

Abstract

An experiment was conducted to test using effluents from intensive hybrid catfish (*Clarias macrocephalus* × *C. gariepinus*) ponds as nutrient inputs for Nile tilapia (*Oreochromis niloticus*) culture, which would reduce effluent effects from catfish culture, gain extra fish production at low cost, and possibly make aquaculture more profitable to farmers. Three treatments were done with three replicates each in seven 200-m^2 earthen ponds at the Asian Institute of Technology (AIT), Thailand, for 87 days. The treatments were A) catfish alone (control); B) catfish and tilapia without artificial water circulation; and C) catfish and tilapia with artificial water circulation. The pond used for control treatments was partitioned by 1.0-cm mesh plastic net into three equal compartments with 67 m^2 each for the replicates. The six other ponds were partitioned into two compartments: 1/3 for catfish and 2/3 for tilapia. Sex-reversed all-male Nile tilapia were stocked at 2 fish m^{-2}, and catfish at 25 fish m^{-2}. Catfish were fed twice daily with commercial pelleted feed at rates of 3 to 10% body weight per day. During the first month, tilapia compartments were fertilized weekly using urea and triple superphosphate (TSP) at rates of 28 kg N and 7 kg P ha^{-1} wk^{-1}. In the artificial water circulation treatment, the water in the catfish compartment was continuously circulated by a submersed pump to the tilapia compartment at a rate of one exchange per week, starting the second month.

There were no significant differences in growth performance of catfish among all treatments. Mean catfish weight at harvest ranged from 237.8 to 249.0 g, giving extrapolated net yields of more than 200 t ha^{-1} yr^{-1}. Final mean tilapia weight was 114.9 g in treatment B and 115.0 g in treatment C without significant differences. Although there was no significant difference in survival rates between treatments B (92%) and C (70%), high mortality of tilapia was observed in two replicates of treatment C due to heavy waste loading in the tilapia compartment by artificial water circulation. Extrapolated net tilapia yields (7.2 ± 1.3 t ha^{-1} yr^{-1} in treatment B and 4.9 ± 0.3 t ha^{-1} yr^{-1} in treatment C) obtained by using catfish wastes in this study were comparable to those achieved in organically and inorganically fertilized tilapia ponds. Nutrient budgets showed that total nitrogen and total phosphorus contents in pond effluents in treatments B and C were significantly lower than those in treatment A. Nile tilapia recovered 3.30 and 2.12% of total nitrogen and 1.29 and 0.84% of total phosphorus from feed wastes and fertilizer inputs in treatments B and C, respectively. Concentrations of total Kjeldahl nitrogen (TKN), total phosphorus (TP), and soluble reactive phosphorus (SRP) were also significantly lower in treatments B and C than in treatment A. This experiment indicates that Nile tilapia can effectively recover nutrients contained in wastewater of intensive catfish culture and suggests that natural water circulation between catfish and tilapia compartments can reduce nutrient contents in pond effluents and is cost-effective.

Introduction

Hybrid catfish (*Clarias macrocephalus* × *C. gariepinus*) has been one of the most popularly cultured freshwater fish in Southeast Asia. The present annual production in Thailand is estimated to be 50,000 tons. As an air breather, catfish can be grown at extremely high density (100 fish m^{-2}) with standing crops in pond culture reaching as high as 100 t ha^{-1} (Areerat, 1987). The fish are mainly cultured intensively and fed with trashfish, chicken offal, or pelleted feed, which generally cause poor water quality and heavy phytoplankton blooms throughout most of the grow-out period. To maintain tolerable water quality for fish growth, pond water is exchanged at later stages of the culture cycle (120 to 150 days). The effluents containing concentrated phytoplankton and nutrients are unsuitable to irrigate rice fields because unbalanced N:P ratios (high nitrogen content) can cause fruiting failure in the rice. Wastewater disposal from catfish ponds has become a serious problem, especially in Northeast Thailand where surface waters are in short supply. Farmers often discharge wastewater to adjacent rice fields, which are damaged by this input. To fully utilize the effluents, unproductive wetlands could be excavated for Nile tilapia (*Oreochromis niloticus*) culture. Such diversification and integration are regarded as important practices to enhance aquaculture sustainability (Adler et al., 1996; Pillay, 1996).

The wastes from catfish cultured in cages have been shown to be effective for producing phytoplankton to support Nile tilapia culture in the same pond (Lin et al., 1990; Lin and Diana, 1995). Similarly, tilapia reared in cages, feeding on phytoplankton in intensive channel catfish ponds, were shown

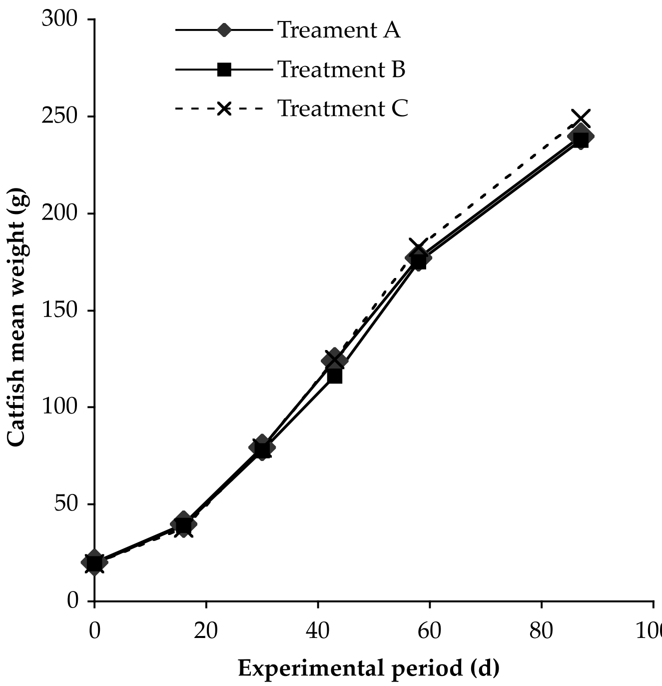

Figure 1. Growth of hybrid catfish in treatments A, B, and C over the 87-day experimental period.

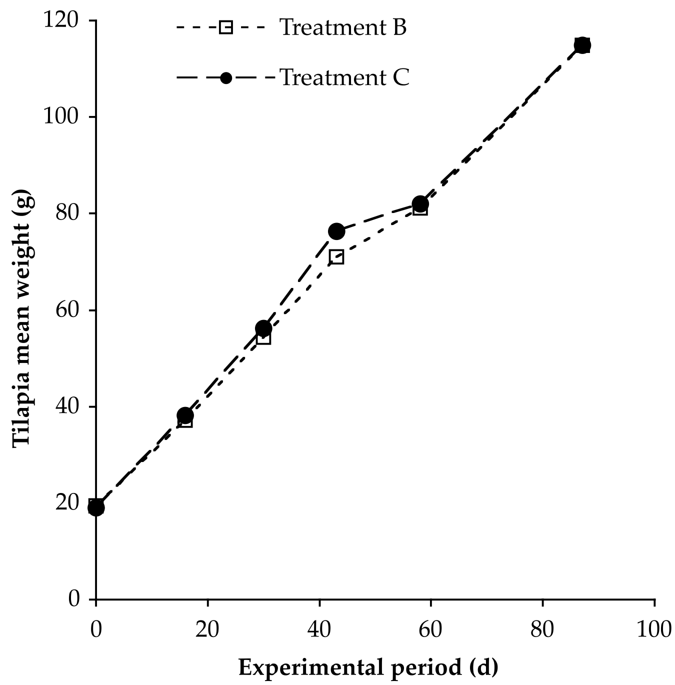

Figure 2. Growth of Nile tilapia in treatments B and C over the 87-day experimental period.

Table 1. Growth performance of hybrid catfish and Nile tilapia in integrated culture for 87 days.

Parameter	Catfish Treatment			Tilapia Treatment	
	A	*B*	*C*	*B*	*C*
STOCKING					
Density (fish m^{-2})	25	25	25	2	2
Total No. of Fish	1,675	1,675	1,675	266	266
Mean Weight (g fish^{-1})	20.0 ± 0.1	19.2 ± 0.2	19.3 ± 0.3	19.5 ± 0.1	19.1 ± 0.1
Total Weight (kg)	33.5 ± 0.2	32.2 ± 0.3	32.3 ± 0.5	5.2 ± 0.0	5.1 ± 0.0
HARVEST					
Mean Weight (g fish^{-1})	239.7 ± 3.8	237.8 ± 1.9	249.0 ± 7.9	114.9 ± 14.1	115.0 ± 13.5
Total Weight (kg)	383.3 ± 6.6	373.3 ± 5.8	394.3 ± 14.5	28.1 ± 4.0	20.7 ± 1.0
FCR (Feed Conservation Ratio)	1.25 ± 0.00[a]	1.31 ± 0.01[b]	1.26 ± 0.02[a]	----	----
SURVIVAL RATE (%)					
Mean	96.3	93.8	94.5	92.8	71.5
Range	79.6–99.4	88.6–97.4	91.6–96.8	65.4–99.3	21.2–99.9
WEIGHT GAIN					
Mean Weight Gain (g fish^{-1})	219.7 ± 3.7	218.6 ± 2.0	229.8 ± 8.0	95.4 ± 14.1	95.9 ± 13.4
Daily Weight Gain (g fish^{-1} d^{-1})	2.53 ± 0.04	2.51 ± 0.02	2.64 ± 0.09	1.10 ± 0.16	1.10 ± 0.15
Total Weight Gain (kg)	349.8 ± 6.8	341.1 ± 6.1	362.0 ± 14.6	23.0 ± 4.0	15.7 ± 1.0
NET YIELD (kg m^{-2} crop^{-1})	5.2 ± 0.1	5.1 ± 0.1	5.4 ± 0.2	0.2 ± 0.0	0.1 ± 0.0
NET YIELD (t ha^{-1} yr^{-1})	219.1 ± 4.3	213.6 ± 3.8	226.7 ± 9.1	7.2 ± 1.3	4.9 ± 0.3
GROSS YIELD (kg m^{-2} crop^{-1})	5.7 ± 0.1	5.6 ± 0.1	5.9 ± 0.2	0.2 ± 0.0	0.2 ± 0.0
GROSS YIELD (t ha^{-1} yr^{-1})	240.0 ± 4.2	233.8 ± 3.6	246.9 ± 9.1	8.9 ± 1.3	6.5 ± 0.3

* Mean values with different superscript letters in the same row within the same compartment were significantly different ($P < 0.05$).

to improve pond water quality as well as produce an extra crop (Perschbacher, 1995).

Therefore, the purposes of this study were to:

1) Use effluents from intensive catfish ponds as nutrients for tilapia culture ponds and thus reduce effluent effects from catfish culture and
2) Gain extra fish production at low cost, making aquaculture more profitable to farmers.

METHODS AND MATERIALS

The experiments were conducted in a completely randomized design in seven 200-m^2 ponds at the Asian Institute of Technology, Thailand. There were three treatments with triplicates each: A) catfish alone (control); B) catfish and tilapia without artificial water circulation; and C) catfish and tilapia with artificial water circulation. One randomly selected pond used for the control was partitioned by 1.0-cm mesh plastic net into three equal compartments of 67 m^2 each. The six remaining ponds were partitioned into two compartments: 1/3 of pond area (67 m^2) for catfish and 2/3 (133 m^2) for tilapia. The ponds were assigned randomly to treatments B and C.

Sex-reversed male Nile tilapia (19.0 to 19.7 g in size) were stocked at 2 fish m^{-2} in tilapia compartments of treatments B and C, and hybrid catfish (18.7 to 20.2 g in size) at 25 fish m^{-2} in treatment A and catfish compartments of treatments B and C on 3 August 1999. Catfish were fed twice daily with small-, medium-, and large-size commercial pelleted feed (crude protein 30%, Charoen Pokphand Co., Ltd., Bangkok, Thailand) at 0830 and 1530 h. Feeding rates of 10% body weight per day (BWD) for fish smaller than 20 g, 8% BWD for 20 to 50 g, 5% BWD for 50 to 100 g, and 3% BWD for fish larger than 100 g were applied six days per week. During the first month, tilapia compartments were fertilized weekly with urea and triple superphosphate (TSP) at rates of 28 kg N and 7 kg P ha^{-1} wk^{-1}. No fertilizers were applied during the rest of the experimental period. No feed was given to tilapia, which depended solely on natural foods. In the artificial water circulation treatment, water in the catfish compartment was continuously circulated at a rate of one exchange per week to the tilapia compartment by a submersed pump, starting the second month. Water depth in all ponds was maintained at 1 m throughout the experiment by adding water weekly to replace evaporation and seepage losses.

Water quality analysis was conducted biweekly by taking integrated column water samples at 0900 h from walkways extending to the center of compartments. Pond water samples were analyzed for pH, total Kjeldahl nitrogen (TKN), total ammonium nitrogen (TAN), nitrite, nitrate-nitrite, soluble reactive phosphorus (SRP), total phosphorus (TP), total alkalinity, chlorophyll *a*, total suspended solids (TSS), and total volatile solids (TVS) using standard methods (APHA, 1985; Egna et al., 1987). Secchi disk visibility, dissolved oxygen (DO), and temperature were measured before taking water samples, the latter two with a YSI model 54 oxygen meter (Yellow Springs Instruments, Yellow Springs, Ohio, USA). Diel measurements for DO, pH, and temperature were conducted monthly for each compartment at three different depths (25 cm below water surface, middle, and 25 cm above pond bottom) at 0600, 0900, 1400, 1600, 1800, and 0600 h. Un-ionized ammonia-nitrogen (UIA) was calculated by a conversion table for given pH and temperature (Boyd, 1990).

The nutrient budgets for nitrogen and phosphorus in ponds were calculated based on inputs from water, stocked fish, fertilizers, and pelleted feed and losses in harvested fish, discharged water, and sediment. Sediment samples were collected with 5-cm-diameter plastic tubes from the top 5 cm of each compartment before initial pond filling and after fish harvest. Total nitrogen and total phosphorus in sediment samples, monthly pelleted feed samples, and fish samples at stocking and harvest were analyzed using the methods described by Yoshida et al. (1976).

During the experiment, 40 Nile tilapia or 100 hybrid catfish were sampled by seining and group-weighed biweekly for each compartment. All fish were harvested on 29 October 1999 after 87 days of culture. Daily weight gain (g $fish^{-1}$ d^{-1}), yield (kg m^{-2} $crop^{-1}$), and extrapolated yield (t ha^{-1} yr^{-1}) were calculated.

Data were analyzed statistically by one-way analysis of variance (Steele and Torrie, 1980) using SPSS (version 7.0) statistical software package (SPSS Inc., Chicago, USA). Differences were considered significant at an alpha level of

Table 2. Moisture, total nitrogen, and total phosphorus composition (%, dry matter basis) of hybrid catfish, Nile tilapia, feed, and sediment.

Variable (%)	At Stocking			At Harvest		
	A	*B*	*C*	*A*	*B*	*C*
CATFISH						
Moisture	72.04	72.04	72.04	71.82	71.58	71.23
TN	11.06	11.06	11.06	9.26	9.10	8.68
TP	1.09	1.09	1.09	2.38	2.31	2.28
TILAPIA						
Moisture	----	74.40	74.40	----	78.42	79.03
TN	----	9.40	9.40	----	10.33	10.12
TP	----	0.67	0.67	----	0.81	0.80
FEED 1						
Moisture	4.50	4.50	4.50	----	----	----
TN	5.47	5.47	5.47	----	----	----
TP	1.04	1.04	1.04	----	----	----
FEED 2						
Moisture	2.07	2.07	2.07	----	----	----
TN	5.43	5.43	5.43	----	----	----
TP	0.91	0.91	0.91	----	----	----
FEED 3						
Moisture	6.66	6.66	6.66	----	----	----
TN	4.59	4.59	4.59	----	----	----
TP	1.37	1.37	1.37	----	----	----
SEDIMENT IN CATFISH COMPARTMENT						
Moisture	59.84	53.21	51.28	62.75	61.25	44.21
TN	0.23	0.24	0.20	0.29	0.32	0.25
TP	0.01	0.01	0.01	0.03	0.03	0.03
SEDIMENT IN TILAPIA COMPARTMENT						
Moisture	----	59.13	54.11	----	62.95	63.28
TN	----	0.22	0.23	----	0.25	0.29
TP	----	0.01	0.01	----	0.04	0.03

0.05. Statistical analyses for survival rates (%) were performed on arcsine transformed data. Survival rates in the text were recalculated and are expressed as actual mean and confidence limits. All other means were given with ± 1 standard error (SE).

A partial budget analysis was conducted to determine the economic feasibility of the integrated catfish-tilapia recycle system (Shang, 1990). The analysis was based on farm-gate prices in Thailand for harvested fish and current local market prices for all other items expressed in US dollars (US$1 = 38 baht). Farm-gate prices of catfish and tilapia were $0.58 and $0.39 kg^{-1}, respectively. Market prices of catfish ($0.017 each) and tilapia ($0.013) fingerlings, urea ($0.20 kg^{-1}), TSP ($0.33 kg^{-1}), small- ($0.51 kg^{-1}), medium- ($0.51 kg^{-1}), and large-size ($0.50 kg^{-1}) pelleted feed were applied to the analysis. Market price of electricity was $0.053 kWh^{-1}, and price of the 1.0-cm mesh plastic net was $0.264 m^{-1}. The calculation for cost of working capital was based on an annual interest rate of 10%.

RESULTS

Both hybrid catfish and Nile tilapia grew steadily in all treatments over the 87-day culture cycle (Figures 1 and 2). There were no significant differences in growth performance of both hybrid catfish and Nile tilapia among all treatments ($P > 0.05$, Table 1). At harvest, hybrid catfish reached 240 ± 3.8, 238 ± 1.9, and 249 ± 7.9 g with daily weight gains of 2.53 ± 0.04, 2.51 ± 0.02, and 2.64 ± 0.09 g $fish^{-1}$ d^{-1} in treatments A, B, and C, respectively. Extrapolated net yields of hybrid catfish were 219.1 ± 4.3, 213.6 ± 3.8, and 226.7 ± 9.1 t ha^{-1} yr^{-1} in treatments A, B, and C, respectively. Survival rates ranged from 93.8 to 96.3%, and there were no significant differences among all treatments ($P > 0.05$). However, the best feed conversion ratios (FCRs) were achieved in treatments A (1.25 ± 0.00) and C (1.26 ± 0.02), between which there was no significant difference ($P > 0.05$), while FCRs in both treatments A and C were significantly higher ($P < 0.05$) than in treatment B (1.31 ± 0.01). Final mean weights of Nile tilapia were 114.9 ± 14.1 g and 115.0 ± 13.5 g in treatments B and C, respectively. Although there were no significant differences in survival rates between treatments B (92%) and C (70%) ($P > 0.05$), high mortality of Nile tilapia was observed in two replicates of treatment C. Extrapolated net yields of Nile tilapia were 7.2 ± 1.3 and 4.9 ± 0.3 t ha^{-1} yr^{-1} in treatments B and C, respectively. The results indicated that neither natural nor artificial water circulation between catfish and tilapia compartments improved the growth of hybrid

Table 3. Nitrogen budgets in different treatments in integrated culture for 87 days.

Parameter (kg)	**Treatment**		
	A	*B*	*C*
INPUTS			
Feed	21.339 ± 0.152	21.388 ± 0.485	21.765 ± 0.614
Fertilizers	----	2.208 ± 0.000	2.208 ± 0.000
Catfish	1.035 ± 0.005	0.997 ± 0.010	0.998 ± 0.016
Tilapia	----	0.125 ± 0.001	0.122 ± 0.001
Water in Catfish Compartment	0.211 ± 0.000	0.187 ± 0.008	0.225 ± 0.008
Water in Tilapia Compartment	----	0.441 ± 0.036	0.446 ± 0.016
Sediment in Catfish Compartment	4.204 ± 0.202	4.935 ± 0.386	4.621 ± 0.072
Sediment in Tilapia Compartment	----	7.413 ± 0.193	9.404 ± 2.014
Total	26.789 ± 0.293	37.695 ± 0.691	39.789 ± 2.492
OUTPUTS			
Catfish	9.768 ± 0.578	9.648 ± 0.492	9.835 ± 0.240
Tilapia	----	0.629 ± 0.102	0.444 ± 0.046
Water in Catfish Compartment	2.440 ± 0.057[a]	0.753 ± 0.108[b]	0.776 ± 0.034[b]
Water in Tilapia Compartment	----	1.243 ± 0.216	1.592 ± 0.067
Sediment in Catfish Compartment	6.885 ± 0.256	6.804 ± 0.401	6.103 ± 0.436
Sediment in Tilapia Compartment	----	9.572 ± 0.291	11.916 ± 1.676
Total	19.094 ± 0.320[a]	28.649 ± 0.505[b]	30.666 ± 1.872[b]
GAIN			
Catfish	8.734 ± 0.582	8.651 ± 0.495	8.837 ± 0.254
Tilapia	----	0.504 ± 0.102	0.322 ± 0.046
LOSS			
Water in Catfish Compartment	2.229 ± 0.057[a]	0.565 ± 0.116[b]	0.551 ± 0.038[b]
Water in Tilapia Compartment	----	0.802 ± 0.186	1.146 ± 0.078
Subtotal in Water	2.229 ± 0.057[a]	1.367 ± 0.302[b]	1.698 ± 0.115[ab]
Sediment in Catfish Compartment	2.682 ± 0.389	1.868 ± 0.142	1.482 ± 0.370
Sediment in Tilapia Compartment	----	2.159 ± 0.321	2.512 ± 0.775
Subtotal in Sediment	2.682 ± 0.389	4.028 ± 0.287	3.994 ± 0.496
UNACCOUNTED	7.695 ± 0.391	9.046 ± 0.220	9.123 ± 1.058

* Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

catfish; however, artificial water circulation caused high mortality of Nile tilapia in two replicates. Based on the pond partition ratio for catfish and tilapia culture (2:1) and the stocking ratio of catfish to tilapia (6.3:1) in the experiment, a 1-ha pond could produce 78 tons of catfish and 6 tons of tilapia per year.

Proximate compositions of inputs, sediments, and fish indicate that the dominant nutrient input was the pelleted feed in all treatments (Table 2). Total nitrogen and total phosphorus contents in effluents in catfish compartments were significantly higher in treatment A than in treatments B and C ($P < 0.05$, Tables 3 and 4). However, artificial water circulation (treatment C) did not significantly increase total nitrogen and total phosphorus contents in tilapia compartments compared with natural water circulation (treatment B) ($P > 0.05$). There were no significant differences in sediments of each treatment for total nitrogen and phosphorus contents of catfish or tilapia compartments ($P > 0.05$). Losses of total nitrogen and total phosphorus in effluents from catfish compartments in treatment A were significantly higher than in treatments B and C ($P < 0.05$), and even significantly higher than the total effluents from both catfish and tilapia compartments in treatment B ($P < 0.05$; Tables 3 and 4). Additional fertilizer inputs in tilapia compartments of both treatments B and C did not result in higher nutrient outputs in effluents or nutrient deposited in sediments.

Hybrid catfish incorporated 40.87, 40.48, and 40.62% of total nitrogen and 50.01, 47.62, and 49.38% of total phosphorus from feed input in treatments A, B, and C, respectively (Table 5). Wastes derived from feed accounted for 59.13, 59.52, and 59.38% of total nitrogen and 49.99, 52.38, and 50.62% of total phosphorus from feed input in treatments A, B, and C, respectively (Table 5). No significant differences in incorporated and wasted nutrients were found among treatments ($P > 0.05$). These wastes fertilized the entire pond at loading rates of 7.32 ± 0.44 and 7.43 ± 0.29 kg N ha^{-1} d^{-1}, and 1.49 ± 0.102 and 1.46 ± 0.01 kg P ha^{-1} d^{-1} in treatments B and C, respectively. Nile tilapia recovered 3.30 and 2.12% of total nitrogen and 1.29 and 0.84% of total phosphorus from feed wastes and fertilizer inputs in treatments B and C, respectively (Table 5). The percentages of nutrient losses in effluent water in treatment A were significantly higher than those in treatments B and C ($P < 0.05$). Total nitrogen losses in effluent water were significantly lower in treatment B than in treatment C while total

Table 4. Phosphorus budgets in different treatments in integrated culture for 87 days.

Parameter (kg)	Treatment		
	A	*B*	*C*
INPUTS			
Feed	4.938 ± 0.088	4.941 ± 0.125	5.033 ± 0.139
Fertilizers	----	0.553 ± 0.000	0.553 ± 0.000
Catfish	0.102 ± 0.001	0.098 ± 0.001	0.098 ± 0.002
Tilapia	----	0.009 ± 0.000	0.009 ± 0.000
Water in Catfish Compartment	0.005 ± 0.000	0.004 ± 0.000	0.005 ± 0.000
Water in Tilapia Compartment	----	0.008 ± 0.000	0.010 ± 0.001
Sediment in Catfish Compartment	0.205 ± 0.035	0.277 ± 0.049	0.283 ± 0.051
Sediment in Tilapia Compartment	----	0.296 ± 0.030	0.488 ± 0.140
Total	5.249 ± 0.118	6.186 ± 0.185	6.478 ± 0.315
OUTPUTS			
Catfish	2.574 ± 0.116	2.447 ± 0.083	2.589 ± 0.158
Tilapia	----	0.050 ± 0.009	0.035 ± 0.002
Water in Catfish Compartment	0.151 ± 0.004[a]	0.057 ± 0.015[b]	0.034 ± 0.006[b]
Water in Tilapia Compartment	----	0.028 ± 0.003	0.029 ± 0.004
Sediment in Catfish Compartment	0.833 ± 0.047	0.721 ± 0.146	0.903 ± 0.158
Sediment in Tilapia Compartment	----	1.305 ± 0.267	1.390 ± 0.295
Total	3.557 ± 0.098	4.608 ± 0.390	4.979 ± 0.541
GAIN			
Catfish	2.472 ± 0.116	2.349 ± 0.083	2.490 ± 0.158
Tilapia	----	0.041 ± 0.009	0.026 ± 0.002
LOSS			
Water in Catfish Compartment	0.146 ± 0.004[a]	0.053 ± 0.015[b]	0.029 ± 0.006[b]
Water in Tilapia Compartment	----	0.020 ± 0.003	0.019 ± 0.005
Subtotal in Water	0.146 ± 0.004[a]	0.073 ± 0.018[b]	0.048 ± 0.010[b]
Sediment in Catfish Compartment	0.628 ± 0.075	0.443 ± 0.105	0.620 ± 0.107
Sediment in Tilapia Compartment	----	1.009 ± 0.260	0.902 ± 0.182
Subtotal in Sediment	0.628 ± 0.075	1.453 ± 0.348	1.522 ± 0.247
UNACCOUNTED	1.693 ± 0.019[a]	1.579 ± 0.270[b]	1.500 ± 0.256[b]

* Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

phosphorus losses in effluent water in treatment B were significantly higher than those in treatment C ($P < 0.05$). No significant differences in nutrient losses in sediment were found among all treatments ($P > 0.05$).

Water temperature and pH throughout the experimental period in all compartments ranged from 27.6 to 31.5°C and 6.6 to 7.4, respectively. At the end of the experiment, pH values in catfish compartments were significantly higher in treatment

Table 5. Distribution (mean and range in percentages) of total nitrogen and total phosphorus in different treatments in the integrated recycle culture for 87 days.

Parameter (%)	Treatment		
	A	*B*	*C*
TOTAL NITROGEN			
Catfish Compartment			
Feed Input	100.00	100.00	100.00
Gain in Catfish	40.87 (30.58–51.58)	40.48 (29.43–52.05)	40.62 (36.23–45.06)
Wastes	59.13 (48.42–69.42)	59.52 (47.95–70.57)	59.38 (54.94–63.74)
Total	100.00	100.00	100.00
Wastes and Fertilizers	100.00	100.00	100.00
Gain in Tilapia	----	3.30 (1.27–6.23)	2.12 (0.84–3.96)
Effluent Water	17.70 (15.81–19.67)[a]	9.90 (2.66–18.20)[b]	11.23 (7.01–16.30)[c]
Loss in Sediment	21.15 (10.29–34.39)	26.91 (22.89–31.13)	26.61 (11.27–45.23)
Unaccounted	61.15 (47.90–73.61)	60.70 (53.64–67.55)	60.04 (37.51–80.54)
Total	100.00	100.00	100.00
TOTAL PHOSPHORUS			
Catfish Compartment			
Feed Input	100.00	100.00	100.00
Gain in Catfish	50.01 (42.81–57.22)	47.62 (37.29–58.06)	49.38 (41.53–57.23)
Wastes	49.99 (42.78–57.19)	52.38 (41.94–62.71)	50.62 (42.77–58.47)
Total	100.00	100.00	100.00
Wastes and Fertilizers	100.00	100.00	100.00
Gain in Tilapia	----	1.29 (0.38–2.64)	0.84 (0.57–1.15)
Effluent Water	5.97 (4.82–7.13)[a]	2.29 (0.80–4.40)[b]	1.54 (0.45–3.16)[b]
Loss in Sediment	25.27 (15.97–35.90)	45.61 (11.36–82.23)	49.24 (17.29–81.55)
Unaccounted	68.76 (59.47–77.35)[a]	50.81 (13.23–87.91)[b]	48.38 (15.88–81.58)[b]
Total	100.00	100.00	100.00

* Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

Table 6. Mean values of water quality parameters measured at the end of the experiment.

Parameter	Catfish Treatment			Tilapia Treatment	
	A	*B*	*C*	*B*	*C*
DO at Dawn (mg l^{-1})	0.20 ±0.00	0.30 ±0.00	0.23 ±0.03	0.27 ±0.03	0.17 ±0.03
Temperature (°C)	27.8–28.3	27.9–28.1	28.0–28.2	27.6–27.8	27.7–28.2
pH	7.1–7.2[a]	6.9[c]	7.0–7.1[b]	7.1–7.2	7.0–7.1
Alkalinity (mg l^{-1})	513 ±7[a]	108 ±7[c]	155 ±14[b]	109 ±12	135 ±9
TKN (mg l^{-1})	36.34 ±0.88[a]	11.16 ±1.58[b]	11.52 ±0.53[b]	9.32 ±1.62	11.75 ±0.47
TAN (mg l^{-1})	3.09 ±0.09	3.43 ±0.07	3.52 ±0.17	3.76 ±0.32[x]	4.13 ±0.06[y]
UIA (mg l^{-1})	0.05 ±0.01[a]	0.03 ±0.00[b]	0.05 ±0.00[a]	0.04 ±0.00	0.04 ±0.01
Nitrite-N (mg l^{-1})	0.01 ±0.00	0.01 ±0.00	0.01 ±0.00	0.01 ±0.00[x]	0.02 ±0.00[y]
Nitrate-N (mg l^{-1})	0.07 ±0.04	0.07 ±0.04	0.05 ±0.01	0.02 ±0.02[x]	0.20 ±0.04[y]
TP (mg l^{-1})	2.25 ±0.06[a]	0.85 ±0.23[b]	0.51 ±0.08[b]	0.42 ±0.05	0.43 ±0.06
SRP (mg l-1)	0.93 ±0.03[a]	0.01 ±0.01[b]	0.00 ±0.00[b]	0.01 ±0.01	0.00 ±0.00
Chlorophyll *a* (mg m^{-3})	44 ±1	72 ±22	132 ±57	90 ±29	131 ±48
TSS (mg l^{-1})	622 ±49	505 ±197	190 ±47	136 ±27	145 ±22
TVS (mg l^{-1})	101 ±5	62 ±24	42 ±6	30 ±5	42 ±11

* Mean values with different superscript letters (a, b, and c, and x and y) in the same row were significantly different among catfish compartments and between tilapia compartments of the treatments, respectively ($P < 0.05$).

A than in treatments B and C, and there were also significant differences in final pH values between the latter two ($P < 0.05$, Table 6). Measured DO concentrations at dawn decreased steadily from initial levels of 1.63–3.93 mg l^{-1} to 0.17–0.30 mg l^{-1} over the 87-d culture period in all compartments, and no significant differences in final DO concentrations were found among all treatments ($P > 0.05$, Figure 3 and Table 6). Concentrations of total alkalinity, TKN, TP, and SRP in catfish compartments were significantly higher in treatment A than in treatments B and C ($P < 0.05$, Table 6). In tilapia compartments, final concentrations of inorganic nitrogen forms (TAN, nitrite-N, and nitrate-N) were significantly lower in treatment B than those in treatment C ($P < 0.05$) while there were no significant differences for other water quality parameters between the two treatments ($P > 0.05$, Table 6). Un-ionized ammonia-nitrogen concentrations fluctuated throughout the experimental period but increased toward the end of the experiment (Figure 3). There were no significant differences in final concentrations of un-ionized ammonia-nitrogen in catfish compartments between treatments A and C ($P > 0.05$), and both were significantly higher than those in treatment B ($P < 0.05$, Table 6). The phytoplankton standing crop as expressed in chlorophyll *a* concentration steadily increased over the first two months and decreased slightly at the end in both catfish and tilapia compartments of treatments B and C (Figure 3). In treatment A, however, it increased sharply and reached the peak at the end of the second month, then decreased dramatically to a level even below those in all other compartments (Figure 3). At the end of the experiment, no significant differences in chlorophyll *a* concentrations were found among all compartments ($P > 0.05$, Table 6).

The partial budget analysis (Table 7) indicated that all of the treatments in the present experiment produced a negative net return, and treatment B had the least negative net return. The high electricity cost made treatment C produce a similar negative net return to treatment A.

DISCUSSION

Water circulation did not improve growth of catfish compared to the control in the present experiment. One of the most unique features of catfish is their air-breathing ability, which enables them to live at extremely high population density and gives great yields in various culture systems (Lin and Diana, 1995). Extrapolated gross catfish yield in this experiment ranged from 233.8 to 246.9 t ha^{-1} yr^{-1}, which was higher than yields achieved in previous experiments (Lin, 1990; Ye, 1991; Lin and Diana, 1995; Sethteethunyahan, 1998) and also higher than those obtained in the traditional pond culture in Thailand (Panayotou et al., 1982; Tonguthai et al., 1993). Although the phytoplankton standing crop (chlorophyll *a* concentration) was significantly higher in the controls than in the water circulation treatments during most of the experimental period, there were no significant differences in growth and yield among treatments. This supported the finding by Pearl (1995) that a phytoplankton-based food chain is relatively unimportant in pond culture that relies on artificial feed to promote rapid fish growth.

Artificial water circulation caused mass mortality of Nile tilapia in two replicates. The reason might be the heavy loading of wastes from the catfish compartment to the tilapia compartment, causing significantly higher concentrations of TAN than that in natural water circulation. The sharp in-

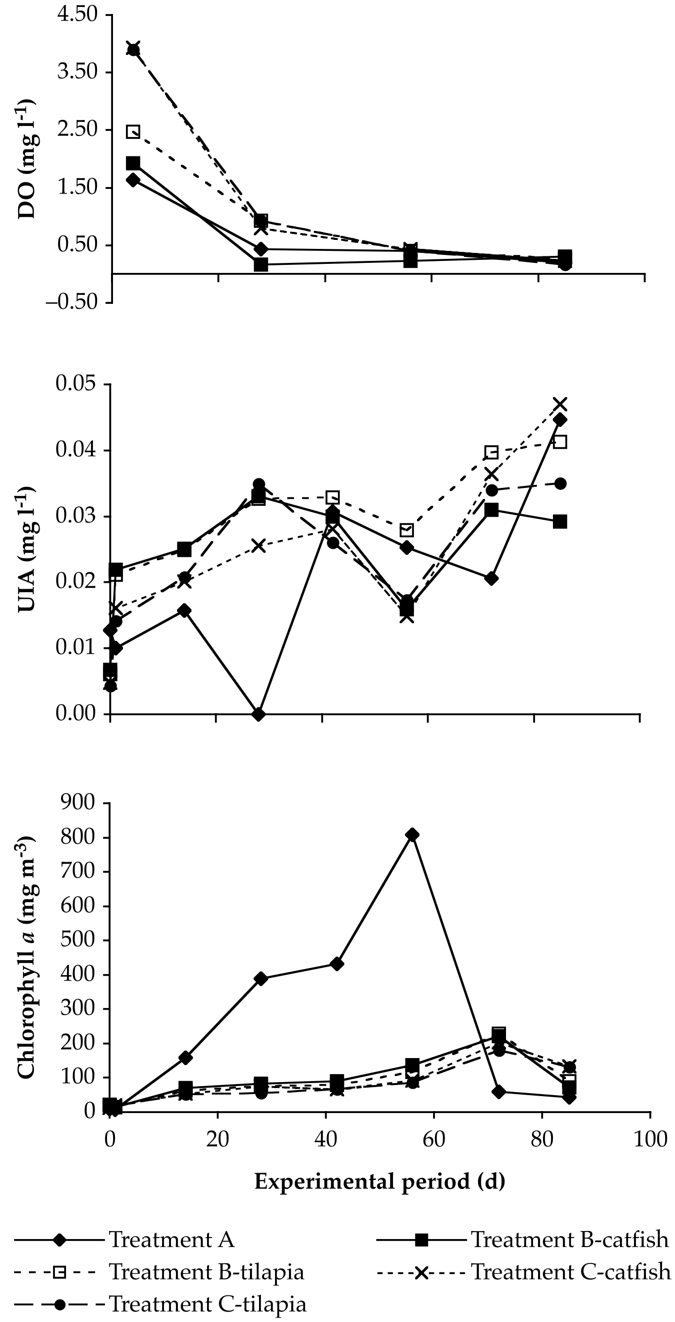

Figure 3. Fluctuations in DO (at dawn), UIA (at 0900 h), and chlorophyll *a* (at 0900 h) in catfish compartments of treatments A, B, and C and in tilapia compartments of treatments B and C over the 87-day experimental period.

creases in TAN concentration, decreases in dissolved oxygen, and possible prolonged exposure to poor water quality were probably the main causes of increased mortality in circulated ponds. The extrapolated tilapia yields in the water circulation treatments were similar to those achieved in conventional integrated fish-livestock systems (AIT, 1986), systems optimally fertilized with chicken manure (Diana et al., 1988) or chemical fertilizers (Diana et al., 1991), and fish-fish integrated culture systems (Lin, 1990; Ye, 1991; Lin and Diana, 1995; Yi et al., 1996; Yi, 1997). However, the fertilization rates by wastes from intensive culture were much higher in the present experiment than those reported by the above authors, due to the high catfish to tilapia ratio (6.3:1). The high loading of catfish wastes caused depletion of water quality after the first month of culture and thus did not result in higher yields of Nile tilapia compared to cultures with lower loading rates. The much higher concentrations of TKN, TAN, and TP also suggested that loading rates of catfish wastes were excessive in the present experiment. Lowering the catfish to tilapia ratio may result in better growth performance of Nile tilapia.

Nutrients released from the catfish compartment were about 59% of TN and 50% of TP in the present experiment. These were less than values reported by Boyd (1985) in channel catfish culture, or by Ye (1991) and Sethteethunyahan (1998) in catfish-tilapia integrated culture (62 to 73% of TN and 55 to 70% of TP). The released phosphorus percentages in the present experiment were also much less than those (79 to 84%) calculated by Beveridge (1984) for intensive cage culture of trout.

Nile tilapia in this integrated culture system recovered nutrients by utilizing natural foods derived mainly from catfish wastes. The nutrient recovery percentages (2.12 to 3.30% of TN and 0.84 to 1.29% of TP) in the present experiment were lower than those (4 to 13% of TN and 5 to 17% of TP) reported by Ye (1991) and Lin and Diana (1995). The main reason for the low nutrient recovery was a much higher catfish to tilapia ratio (6.3:1) in the present experiment, compared to the ratios (2:1 to 5:1) reported by them. Another reason was that the percentages in this experiment included fertilizers applied to promote tilapia growth during the first month when catfish waste loading was low. The percentages in the present experiment were higher than those (0.68 to 1.94% of TN and 0.86 to 2.48% of TP) reported by Sethteethunyahan (1998) due to the higher catfish to tilapia ratio (9:1) in that experiment.

In the present experiment, negative net returns in all treatments occurred mainly because of the expensive commercial pelleted feed. In terms of farmers' practices, however, the most common diets for catfish culture are combinations of chicken offal, trash fish, and pelleted feed, from which farmers generate marginal profits. For one cycle of catfish culture (87 days in the present experiment), tilapia did not reach marketable size and thus were sold at lower prices. The ideal culture period for the integrated recycle system is six months to produce two crops of catfish and one crop of tilapia. If feed cost was lowered by 20% through partially replacing expensive pelleted feed with low-cost diets and the culture period was extended to six months for two crops of catfish and one crop of tilapia, then the catfish monoculture treatment (treatment A) and natural water circulation treatment (treatment B) would be profitable (about \$17 per 200-m^2 pond) while the artificial water circulation treatment (treatment C) would still lose money due to the high cost of electricity.

This integrated recycle system is the first example of an integrated pen-cum-pond culture system, which is based on the same principle of an integrated cage-cum-pond culture system developed and practiced by Lin (1990), Lin and Diana (1995), Yi et al. (1996), and Yi (1997). Compared with the cage-cum-pond culture system, the advantages of the pen-cum-pond culture system are simplicity, convenience, and low cost. However, the biggest disadvantage is that wastes derived from intensive culture may not circulate well to the semi-intensive culture system due to possible restriction of water exchange through netting materials.

The present experiment demonstrated that Nile tilapia can be cultured in such an integrated pen-cum-pond system to

Table 7. Partial budget analysis for hybrid catfish monoculture (treatment A) and integrated catfish-tilapia recycle system (treatments B and C) in the 87-day experiment (based on 200-m^2 ponds).

Item	Unit	Price (US$)	Treatment A		Treatment B		Treatment C	
			Quantity	*Value (US$)*	*Quantity*	*Value (US$)*	*Quantity*	*Value (US$)*
GROSS REVENUE								
Catfish	kg	0.580	1,144.0	663.52	373.3	216.51	394.3	228.69
Tilapia	kg	0.390	0.0	0.00	28.1	10.96	20.7	8.07
Total				663.52		227.47		236.76
VARIABLE COST								
Small-Size Feed	kg	0.510	167.5	85.43	55.3	28.20	55.2	28.15
Medium-Size Feed	kg	0.510	497.3	253.62	162.0	82.62	165.0	84.15
Large-Size Feed	kg	0.500	665.4	332.70	230.8	115.40	235.9	117.95
Urea	kg	0.200	0.0	0.00	4.8	0.96	4.8	0.96
TSP	kg	0.330	0.0	0.00	2.8	0.92	2.8	0.92
Catfish Fingerlings	piece	0.017	5,000	85.00	1,675	28.48	1,675	28.48
Tilapia Fingerlings	piece	0.013	0	0.00	266	3.46	266	3.46
Electricity (Pump)	kWh	0.053	0	0.00	0	0.00	1,212	64.24
Net	m	0.264	0	0	10	2.64	10	2.64
Cost of Working Capital	year	10%	0.25	18.92	0.25	6.57	0.25	8.27
Total				775.67		269.25		339.22
NET RETURN				–112.15		–41.78		–102.46

recycle nutrients in wastes which might be otherwise released into the environment and indicated that artificial water circulation may cause mass mortality of Nile tilapia due to heavy loading of wastes. The catfish to tilapia ratio should probably be lowered to allow Nile tilapia to reuse more nutrients derived from catfish wastes and thus enhance the nutrient utilization efficiency.

ANTICIPATED BENEFITS

This is the first trial to develop an integrated pen-cum-pond culture system. This integrated system can recycle wastes from an intensive culture system into a semi-intensive culture system, thereby reducing the nutrient input for fertilization and minimizing the environmental impacts of pond effluents. This experiment provides a new way—integrated pen-cum-pond system—for the integration of intensive and semi-intensive culture systems, which can be adapted by small-scale farmers and is especially suitable for low capital investment. A portion of ponds can be used to culture high-valued species for more income and to efficiently utilize costly commercial or local feed through recycling feeding wastes. Identification of the optimal catfish to tilapia ratio would maximize the profits and minimize the environmental impact of pond effluents.

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