LOTUS-FISH CULTURE IN PONDS: RECYCLING OF POND MUD NUTRIENTS

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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
University of Michigan
Ann Arbor, Michigan, USA

ABSTRACT

An experiment was conducted in nine 200-m^2 fertilized earthen ponds at the Asian Institute of Technology, Thailand, from January to September 2000. This experiment was designed to assess the recovery of pond mud nutrient by lotus (*Nelumbo nucifera*), to assess pond mud characteristics after lotus-fish co-culture, and to compare fish growth with and without lotus integration. There were three treatments in triplicate: A) lotus-tilapia together; B) tilapia alone; and C) lotus alone. Seedlings (0.39 ± 0.09 kg) of Thai lotus variety were transplanted to ponds of treatments A and C at a density of 25 seedlings $pond^{-1}$, while sex-reversed all-male Nile tilapia (*Oreochromis niloticus*) fingerlings (8.6 to 10.3 g) were stocked at 2 fish m^{-2} in ponds of treatments A and B when the water depth had been increased to 50 cm due to increasing lotus height. Ponds stocked with tilapia (treatments A and B) were fertilized weekly with urea and triple superphosphate (TSP) at a rate of 28 kg nitrogen and 7 kg phosphorus ha^{-1} wk^{-1} after tilapia stocking. There was no fertilization in ponds of treatment C.

Lotus co-cultured with tilapia or cultured alone in ponds was able to effectively take up nutrients from old pond mud (about 300 kg N and 43 kg P ha^{-1} yr^{-1}) and resulted in the reduction of nutrients in mud by about 2.4 t N and 1 t P ha^{-1} yr^{-1}. There were no significant differences in lotus growth performance between treatments A and C, while Nile tilapia cultured alone grew significantly better than when co-cultured with lotus. The partial budget analysis indicates that lotus cultured alone generated the highest net return, and lotus contributed the largest portion of net income in lotus-tilapia co-culture. The present experiment has demonstrated the effectiveness of nutrient removal from old pond mud by lotus and the feasibility of rotation and co-culture of lotus and Nile tilapia technically and economically. Both systems can recycle nutrients effectively within ponds and are environmentally friendly culture systems.

INTRODUCTION

Regular fertilization and feeding in fish ponds result in nutrients being deposited in pond mud. One hectare of old pond mud was reported to have the equivalent of 1.85 tons of urea and 2.30 tons of triple superphosphate (TSP; Shrestha and Lin, 1997) or 2.8 tons of urea and 3.0 tons of TSP (Yang and Hu, 1989). Pond muds are a major sink for phosphorus, and adsorption capacity is related to mineral composition and clay content of pond muds (Shrestha and Lin, 1996). Release of adsorbed-P to the water column is minimal, and phytoplankton are not as effective in utilizing adsorbed-P as rooted crops. Roots extended in interstitial water of soil provide a better opportunity to extract P from soil (Denny, 1972; Boyd, 1982; Smart and Barko, 1985), and hence, nutrient-rich mud removed from fish ponds has been widely used to fertilize rooted land crops such as mulberry (Hu and Yang, 1984), forage crops (Yang and Hu, 1989), and maize (Christensen, 1989). However, removing pond mud is labor intensive and its practicability is questionable (Edwards et al., 1986; Little and Muir, 1987).

Alternatively, aquatic macrophytes may utilize reserve nutrients in muds by either rotation between two crops or co-culture with fish. Although in actual practice fish and aquatic macrophytes are rarely raised together in the same system, the co-culture and rotated culture of lotus (*Nelumbo nucifera*) and fish have been practiced in China for many years. Hoffmann (1934, cited by Edwards, 1987) reported that a farmer reared fish in the same pond as lotus in China but with only 50% of the usual number of fish because they grew more slowly than when raised alone. The rotation of fish and aquatic macrophytes may give farmers two crops to market rather than one and could sustain them if a loss occurred in one of the two ventures (Edwards, 1987).

Lotus is an aquatic emergent plant that grows as tall as 1.5 meters. Lotus is an important and popular cash crop in many Asian countries. Lotus has multiple uses, for example, stems as fresh vegetables; rhizomes as fresh vegetables, canned food, dessert, and starch; seeds as dessert and medicine; flowers as religious ornaments; and several parts as raw materials to produce cosmetics. It is commonly planted in fields or ponds with nutrient-rich mud and has a growing season of three to five months for the Chinese rhizome variety that does not flower or produce, and five to eight months for the Thai variety. It can extract nutrients from old pond mud efficiently.

Water levels of ponds can be increased as lotus grows. Fish can be stocked when water levels reach 30 cm and harvested four to five months after lotus is planted. Additionally, lotus shoots provide substrate for growth of epiphytic algae that are consumed by tilapia (Bowen, 1982; Lowe-McConnell, 1982; Shrestha and Knud-Hansen, 1994).

The purposes of this study were to:

1) Assess the pond mud nutrient recovery by lotus plants;
2) Assess pond mud characteristics after lotus-fish co-culture; and
3) Compare fish growth with and without lotus integration.

METHODS AND MATERIALS

The experiment was conducted using a randomized complete block design in nine 200-m^2 earthen ponds at the Asian Institute of Technology (AIT), Thailand, from January to September 2000. There were three treatments in triplicate: A) lotus-tilapia co-culture, B) tilapia alone, and C) lotus alone.

All ponds were used for intensive fish culture with commercial pelleted feed prior to this experiment. The ponds were dried for one month and filled with water to 10 cm deep one day prior to lotus transplanting. Seedlings of Thai lotus variety, purchased from a local farm, were transplanted to ponds of the lotus-tilapia and lotus alone treatments (A and C) at a density of 25 seedlings pond^{-1} on 22 January 2000. The average length and weight of the transplanted lotus seedlings were 1 m and 0.39 ± 0.09 kg, respectively. After lotus seedlings were transplanted, water was added weekly to all ponds and water depth increased as the height of lotus increased. Sex-reversed all-male Nile tilapia (*Oreochromis niloticus*) fingerlings (8.6 to 10.3 g in size), obtained from AIT Hatchery, were stocked at 2 fish m^{-2} in the lotus-tilapia and tilapia-alone treatments (A and B) on 9 March 2000, when water depth reached 50 cm. Water depth was increased continuously up to 1 m with the growth of lotus, and it was maintained at 1 m throughout the rest of the experimental period by adding water weekly to replace evaporation and seepage losses. Ponds stocked with tilapia (treatments A and B) were fertilized weekly with urea and TSP at a rate of 28 kg nitrogen (N) and 7 kg phosphorus (P) ha^{-1} wk^{-1} after tilapia stocking. There was no fertilization in ponds of the lotus-alone treatment (treatment C).

During the experiment there was no fish sampling and no removal of dead lotus parts such as dead leaves from ponds. Matured lotus pods with seeds were harvested periodically and air-dried to separate seeds (with husk). On 14 September 2000, all ponds were drained. Tilapia were harvested after 189 days of culture, while different parts of lotus (flower, pod, leaf, stem, and root) were harvested separately (after 236 days of cultivation).

Integrated water samples were taken biweekly from the entire water column near the center of each pond at about 0900 h for analyses of pH, alkalinity, total ammonium nitrogen (TAN), nitrite-N, nitrate-N, total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), chlorophyll *a*, total suspended solids (TSS), and total volatile solids (TVS) (APHA et al., 1985; Egna et al., 1987). Water temperature and dissolved oxygen (DO) were also measured at the time of collecting water samples with a YSI model 54 oxygen meter (Yellow Springs Instruments, Yellow Springs, Ohio).

The nutrient budgets for nitrogen and total phosphorus in ponds during the experimental period were calculated based on inputs from water, stocked tilapia fingerlings, transplanted lotus seedlings, fertilizers, and soil as well as on losses in harvested tilapia and lotus, discharge water, and mud. Mud samples were collected with 5-cm-diameter plastic tubes from the top 10 cm of pond bottom before lotus introduction and after fish and lotus harvest. Total nitrogen (TN) and TP in samples of mud and different parts of lotus and tilapia at the beginning and end of the experiment were analyzed using the methods described by Yoshida et al. (1976).

Data were analyzed statistically by analysis of variance and t-test (Steele and Torrie, 1980) using SPSS (version 7.0) statistical

Table 1. Growth performance of Nile tilapia cultured alone and integrated with lotus for 189 days in 200-m^2 ponds. Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

Parameters	Treatment A (*Lotus-Tilapia*)	Treatment B (*Tilapia Alone*)
STOCKING		
Density (fish m^{-2})	2	2
Total No. of Fish	400	400
Mean Weight (g fish^{-1})	9.2 ± 0.4	9.6 ± 0.4
Total Weight (kg)	3.7 ± 0.2	3.9 ± 0.2
HARVEST		
Mean Weight (g fish^{-1})	58.4 ± 3.1 ^{a}	117.5 ± 6.4 ^{b}
Total Weight (kg)	10.0 ± 1.3 ^{a}	38.5 ± 1.2 ^{b}
Survival Rate (%)	42.6 ± 3.7 ^{a}	82.3 ± 3.5 ^{b}
WEIGHT GAIN		
Mean Weight Gain (g fish^{-1})	49.1 ± 3.5 ^{a}	107.8 ± 6.1 ^{b}
Daily Weight Gain (g fish^{-1} d^{-1})	0.26 ± 0.02 ^{a}	0.57 ± 0.03 ^{b}
Total Weight Gain (kg)	6.3 ± 1.4 ^{a}	34.6 ± 1.2 ^{b}
Net Yield (kg ha^{-1} yr^{-1})	608.7 ± 134.8 ^{a}	3,344.6 ± 113.4 ^{b}
Gross Yield (kg ha^{-1} yr^{-1})	964.3 ± 123.3 ^{a}	3,717.0 ± 113.2 ^{b}

Table 2. Growth performance of lotus cultivated alone and integrated with Nile tilapia for 236 days in 200-m^2 ponds. Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

Parameters	Treatment A (*Lotus-Tilapia*)	Treatment C (*Lotus Alone*)
TRANSPLANTING		
Density (seedlings pond^{-1})	25	25
Total Biomass (kg pond^{-1})	9.90 ± 0.10	9.38 ± 0.48
HARVEST		
Leaf (kg pond^{-1})	429.93 ± 37.07	450.19 ± 36.03
Pod (kg pond^{-1})	11.50 ± 0.74	14.25 ± 1.61
Flower (kg pond^{-1})	5.10 ± 2.86	7.16 ± 1.63
Root and Stem (kg pond^{-1})	159.13 ± 14.92	177.33 ± 6.34
Total Biomass (kg pond^{-1})	605.67 ± 32.89	648.92 ± 28.10
BIOMASS GAIN (kg pond^{-1})	595.77 ± 32.87	639.55 ± 28.17
NET YIELD (t ha^{-1} yr^{-1})	46.07 ± 2.54	49.46 ± 2.18
GROSS YIELD (t ha^{-1} yr^{-1})	46.84 ± 2.54	50.18 ± 2.17

software package (SPSS Inc., Chicago, Illinois). Differences were considered significant at an alpha level of 0.05. All means were given with ± 1 standard error (SE).

A partial budget analysis was conducted to determine economic returns of lotus-tilapia integrated culture, tilapia alone, and lotus alone (Shang, 1990). The analysis was based on farm-gate prices in Thailand for harvested tilapia and lotus products (seeds and flowers) and on current local market prices for all other items expressed in US dollars (US$1 = 40 baht). Farm-gate price of Nile tilapia varied with size: \$0.250 kg^{-1} for size 50 to 100 g and \$0.375 kg^{-1} for size 100 to 200 g. Farm-gate prices of lotus seeds and flowers were \$0.75 kg^{-1} and \$0.125 $piece^{-1}$, respectively. Market prices of sex-reversed all-male Nile tilapia fingerlings (\$0.0125 $piece^{-1}$), lotus seedlings (\$0.125 $piece^{-1}$), urea (\$0.1875 kg^{-1}), and TSP (\$0.3125 kg^{-1}) were used. The calculation for cost of working capital was based on an annual interest rate of 8%.

RESULTS

All growth performance parameters showed that Nile tilapia grew significantly better in the tilapia-alone treatment (B) than in the lotus-tilapia treatment (A), indicating that lotus had significantly negative effects on tilapia growth when they were cultured together ($P < 0.05$, Table 1). Lower survival coupled with slower growth caused only a marginal gain of tilapia biomass in the lotus-tilapia treatment (A, Table 1). Although there were no nutrient inputs in ponds of the lotus-alone treatment (C), lotus growth performance was slightly higher in treatment C than in the lotus-tilapia treatment (A), but this was not significant ($P > 0.05$, Table 2). The addition of chemical fertilizers did not increase lotus biomass production in the present experiment.

The proximate compositions of Nile tilapia, lotus, and mud are summarized in Table 3. The nutrient budgets indicate that the dominant nutrient source was mud in all treatments (Table 4). At the end of the experiment, mud in all treatments still contained the most TN and TP, followed by lotus, while tilapia only contained a small fraction of nutrients from mud or fertilizers (Table 4). In treatments with lotus (A and C), there were no significant differences in nutrient contents between each output component ($P > 0.05$), which were significantly different in nutrient content from the treatment without lotus ($P < 0.05$, Table 4). The largest portion of both TN and TP that disappeared from ponds was not accounted for, and the unaccounted TN and TP contents were significantly higher in the lotus-tilapia treatment than in the tilapia-alone and lotus-alone treatments ($P < 0.05$, Table 4). There were no significant differences in amounts of nutrients recovered by lotus between the lotus-tilapia treatment and the lotus-alone treatment

Table 3. Moisture (%) and TN and TP composition (mg g^{-1}, dry matter basis) in Nile tilapia, lotus, and mud for each treatment.

Parameters	Beginning			End		
	A	*B*	*C*	*A*	*B*	*C*
TILAPIA						
Moisture	75.50	75.50	----	79.80	78.20	----
TN	100.15	100.15	----	102.00	95.97	----
TP	9.20	9.20	----	11.27	10.56	----
LOTUS SEEDLING						
Moisture	62.80	----	62.80	----	----	----
TN	5.65	----	5.65	----	----	----
TP	5.35	----	5.35	----	----	----
LOTUS LEAF						
Moisture	----	----	----	73.11	----	74.86
TN	----	----	----	31.16	----	30.94
TP	----	----	----	3.53	----	3.52
LOTUS FLOWER						
Moisture	----	----	----	77.63	----	75.98
TN	----	----	----	22.76	----	24.45
TP	----	----	----	3.54	----	3.72
LOTUS POD						
Moisture	----	----	----	74.24	----	74.22
TN	----	----	----	17.35	----	19.63
TP	----	----	----	2.41	----	2.89
LOTUS STEM AND ROOT						
Moisture	----	----	----	86.05	----	85.90
TN	----	----	----	14.96	----	13.06
TP	----	----	----	6.33	----	6.73
MUD						
Moisture	40.41	44.01	37.58	58.13	54.14	58.82
TN	2.18	1.79	2.12	0.34	0.94	0.35
TP	1.12	0.94	0.98	0.34	0.62	0.35

($P > 0.05$), while the amount of nutrients recovered by tilapia was significantly higher in the tilapia-alone treatment than in the lotus-tilapia treatment ($P < 0.05$, Table 5). The inclusion of lotus in ponds resulted in the significantly greater reduction of nutrient contents in mud compared to ponds without lotus ($P < 0.05$, Table 5). However, the application of chemical fertilizers in the lotus-tilapia treatment did not cause significantly greater amounts of nutrients to remain in pond mud than were present in the lotus-alone treatment, in which no chemical fertilizers were added ($P > 0.05$, Table 5). In the lotus-alone treatment (without adding fertilizers), lotus could recover about 301 kg N and 43 kg P ha^{-1} yr^{-1}, which resulted in the reduction of nutrients contained in mud by 2.38 t N and 0.91 t P ha^{-1} yr^{-1} (Table 5).

The mean and final values of water quality parameters indicated that DO concentrations at dawn were significantly higher in the tilapia-alone treatment than in the treatments with lotus throughout the experimental period ($P < 0.05$, Table 6, Figure 1). The pH fluctuated during the experimental period and was significantly lower in treatment A than in treatments B and C at the end of the experiment ($P < 0.05$). Mean pH values were not significantly different among treatments ($P > 0.05$). Water temperature ranged from 26.0 to 32.2°C over the experimental period, and the mean values were significantly lower in the treatments with lotus than in the tilapia-alone treatment ($P < 0.05$, Figure 1). Alkalinity in the treatments with tilapia decreased over time and was significantly lower than in the treatment without tilapia ($P < 0.05$, Figure 2). Concentrations of different nitrogen forms were significantly higher in the tilapia-alone treatment, intermediate in the lotus-tilapia treatment, and lower in the lotus-alone treatment ($P < 0.05$, Figure 2), while there were no significant differences in TP and SRP concentrations among treatments. Concentrations of chlorophyll *a* and solids (TSS and TVS) were also significantly higher in the tilapia-alone treatment, intermediate in the lotus-tilapia treatment, and lowest in the lotus-alone treatment ($P < 0.05$, Figure 3).

The partial budget analysis (Table 7) indicated that the lotus treatments produced positive net returns, while tilapia alone had a negative net return. The lotus-alone treatment produced the highest net return because there were no other inputs except lotus seedlings.

DISCUSSION

It is feasible to co-culture tilapia and lotus in the same ponds. Compared with Nile tilapia growth in most semi-intensive culture, Nile tilapia grew quite slowly even in the tilapia-alone treatments, which might be related to the decreasing alkalinity throughout the experimental period due to no liming in this experiment. The significantly lower growth and higher mortality of tilapia in the lotus-tilapia treatment might result from shading by lotus leaves, which could reduce phytoplankton production and cause low DO concentration in ponds. Dead lotus leaves were not removed from ponds, and the decomposition further worsened the water quality, especially DO. If the lotus density is optimized and dead lotus vegetation is well managed, such an integrated lotus-tilapia coculture system may have potential in many Asian countries where lotus is commonly cultivated.

The production of lotus biomass in ponds without fertilization was not significantly different from that in ponds stocked with tilapia and fertilized. This indicates that the nutrient content in the old pond mud was sufficient or exceeded the amount required for lotus growth. Shrestha and Lin (1997) reported that nutrients diluted by 50% in old pond mud were sufficient to support the growth of cowpea (*Vigna unguiculata* L. Walp.), a terrestrial legume, and taro (*Colocasia esculenta* L. Schott), a semi-aquatic crop, in pot experiments. The extrapolated lotus

Table 4. Nitrogen and phosphorus budgets in different treatments over the 236-day experimental period. Mean values of nutrient outputs and gains with different superscript letters in the same row within each nutrient category were significantly different ($P < 0.05$).

Parameters (kg)	Total Nitrogen			Total Phosphorus		
	A	*B*	*C*	*A*	*B*	*C*
INPUTS						
Fertilizers	14.90 ± 0.00	14.90 ± 0.00	----	3.70 ± 0.00	3.70 ± 0.00	----
Lotus	0.02 ± 0.00	----	0.02 ± 0.00	0.02 ± 0.00	----	0.02 ± 0.00
Tilapia	0.09 ± 0.00	0.10 ± 0.00	----	0.01 ± 0.00	0.01 ± 0.00	----
Water	0.27 ± 0.01	0.35 ± 0.01	0.28 ± 0.01	0.04 ± 0.00	0.05 ± 0.00	0.04 ± 0.00
Mud	36.06 ± 2.98	31.67 ± 1.59	35.04 ± 3.63	18.86 ± 1.49	17.18 ± 1.61	16.13 ± 1.76
Total	51.34 ± 2.99	47.02 ± 1.57	35.34 ± 3.63	22.63 ± 1.49	20.95 ± 1.61	16.19 ± 1.76
OUTPUTS						
Lotus	3.94 ± 0.54	----	3.92 ± 0.12	0.56 ± 0.05	----	0.58 ± 0.03
Tilapia	0.22 ± 0.03 [a]	0.79 ± 0.01 [b]	----	0.02 ± 0.00 [a]	0.09 ± 0.01 [b]	----
Water	0.51 ± 0.03 [a]	1.85 ± 0.19 [b]	0.46 ± 0.18 [a]	0.07 ± 0.02	0.06 ± 0.00	0.06 ± 0.01
Mud	5.68 ± 0.84 [a]	14.84 ± 1.77 [b]	4.27 ± 0.55 [a]	5.35 ± 0.52 [a]	9.68 ± 0.68 [b]	4.39 ± 1.14 [a]
Total	10.34 ± 1.33 [a]	17.48 ± 1.57 [b]	8.64 ± 0.75 [a]	6.00 ± 0.54 [a]	9.84 ± 0.68 [b]	5.03 ± 1.17 [a]
GAINS						
Lotus	3.92 ± 0.54	----	3.90 ± 0.12	0.54 ± 0.05	----	0.56 ± 0.03
Tilapia	0.13 ± 0.04 [a]	0.70 ± 0.01 [b]	----	0.02 ± 0.00 [a]	0.08 ± 0.01 [b]	----
Water	0.23 ± 0.02 [a]	1.50 ± 0.19 [b]	0.18 ± 0.18 [a]	0.03 ± 0.02	0.01 ± 0.00	0.02 ± 0.01
UNACCOUNTED	41.00 ± 3.05 [a]	29.54 ± 0.89 [b]	26.69 ± 2.90 [b]	16.63 ± 1.03 [a]	11.12 ± 1.12 [b]	11.16 ± 0.67 [b]

Table 5. The efficiency of nutrient removal from applied fertilizers and mud in different treatments over the 236-day experimental period. Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

Parameters	Treatments		
	A	*B*	*C*
NITROGEN			
Recovered by Lotus			
(kg pond^{-1})	3.92 ± 0.54	----	3.90 ± 0.12
(kg ha^{-1} yr^{-1})	303.05 ± 41.56	----	301.20 ± 9.49
(%)	7.78 ± 1.21 ^{a}	----	11.29 ± 0.83 ^{b}
Recovered by Tilapia			
(kg pond^{-1})	0.13 ± 0.03 ^{a}	0.70 ± 0.01 ^{b}	----
(kg ha^{-1} yr^{-1})	9.71 ± 2.69 ^{a}	54.02 ± 0.42 ^{b}	----
(%)	0.25 ± 0.07 ^{a}	1.50 ± 0.05 ^{b}	----
Total Recovered			
(kg pond^{-1})	4.04 ± 0.57 ^{a}	0.70 ± 0.01 ^{b}	3.90 ± 0.12 ^{a}
(kg ha^{-1} yr^{-1})	312.78 ± 44.20 ^{a}	54.02 ± 0.42 ^{b}	301.20 ± 9.49 ^{a}
(%)	8.03 ± 1.28 ^{b}	1.50 ± 0.5 ^{c}	11.29 ± 0.83 ^{a}
Reduction in Mud			
(kg pond^{-1})	30.38 ± 2.71 ^{a}	16.84 ± 0.94 ^{b}	30.77 ± 3.09 ^{a}
(t ha^{-1} yr^{-1})	2.35 ± 0.21 ^{a}	1.30 ± 0.07 ^{b}	2.38 ± 0.24 ^{a}
(%)	84.24 ± 2.06 ^{a}	53.37 ± 3.70 ^{b}	87.87 ± 0.32 ^{a}
PHOSPHORUS			
Recovered by Lotus			
(kg pond^{-1})	0.54 ± 0.05	----	0.56 ± 0.03
(kg ha^{-1} yr^{-1})	41.87 ± 3.87	----	43.44 ± 2.35
(%)	2.41 ± 0.21 ^{a}	----	3.53 ± 0.29 ^{b}
Recovered by Tilapia			
(kg pond^{-1})	0.02 ± 0.00 ^{a}	0.08 ± 0.01 ^{b}	----
(kg ha^{-1} yr^{-1})	1.17 ± 0.15 ^{a}	6.13 ± 0.62 ^{b}	----
(%)	0.07 ± 0.01 ^{a}	0.39 ± 0.06 ^{b}	----
Total Recovered			
(kg pond^{-1})	0.56 ± 0.05 ^{a}	0.08 ± 0.01 ^{b}	0.56 ± 0.03 ^{a}
(kg ha^{-1} yr^{-1})	43.04 ± 4.02 ^{a}	6.13 ± 0.62 ^{b}	43.44 ± 2.35 ^{a}
(%)	2.48 ± 0.22 ^{b}	0.39 ± 0.06 ^{c}	3.53 ± 0.29 ^{a}
Reduction in Mud			
(kg pond^{-1})	13.51 ± 1.02 ^{a}	7.50 ± 1.12 ^{b}	11.74 ± 0.69 ^{a}
(t ha^{-1} yr^{-1})	1.04 ± 0.08 ^{a}	0.58 ± 0.09 ^{b}	0.91 ± 0.05 ^{a}
(%)	71.70 ± 1.06 ^{a}	43.25 ± 3.33 ^{b}	73.56 ± 3.89 ^{a}

biomass gain was about 11 dry t ha^{-1} yr^{-1} in this experiment, which was similar to that (11 to 16 t ha^{-1} yr^{-1}) of lotus planted in an old pond (calculated from Mon, 2000) and that (10 to 12 t ha^{-1} yr^{-1}) of cowpea in pots but lower than that (35 to 46 t ha^{-1} yr^{-1}) of taro planted in pots filled with old pond mud (calculated from Shrestha and Lin, 1997).

One hectare of old pond mud has been reported to contain the equivalent of 1.85 t urea and 2.30 t TSP (Shrestha and Lin, 1997) or 2.8 t urea and 3.0 t TSP (Yang and Hu, 1989). The old mud of ponds used in this experiment contained higher nutrient concentrations, which were equivalent to 3.44 to 3.92 t urea and 4.11 to 4.81 t TSP ha^{-1}. After 236-day cultivation of lotus, pond mud nutrients decreased by about 1.53 t N ha^{-1} and 0.63 t P ha^{-1} (more than 80% of N and 70% of P contained in old pond mud), which are equivalent to 3.33 t urea and 3.22 t TSP. This reduction was much higher than that reported by Mon

Table 6. Final and mean values of water quality parameters measured in different treatments over the experimental period. Mean values with different superscript letters in the same row were significantly different among treatments ($P < 0.05$).

Parameters	Treatments		
	A	*B*	*C*
FINAL VALUES			
DO (mg l^{-1})	1.23 ± 0.12 ^{a}	4.27 ± 0.57 ^{b}	0.81 ± 0.40 ^{a}
Temperature (°C)	27.0 ± 0.2	27.7 ± 0.1	27.0 ± 0.6
pH	6.3 ± 0.1 ^{a}	6.7 ± 0.2 ^{b}	6.8 ± 0.1 ^{b}
Alkalinity (mg l^{-1} as $CaCO_3$)	23 ± 10.5 ^{a}	15 ± 1.8 ^{a}	125 ± 20.7 ^{b}
TKN (mg l^{-1})	2.72 ± 0.18 ^{a}	10.18 ± 1.14 ^{b}	2.51 ± 0.96 ^{a}
TAN (mg l^{-1})	0.59 ± 0.43 ^{a}	3.06 ± 0.12 ^{b}	0.05 ± 0.05 ^{a}
Nitrite-N + Nitrate-N (mg l^{-1})	0.09 ± 0.04 ^{a}	0.37 ± 0.08 ^{b}	0.00 ± 0.00 ^{a}
TP (mg l^{-1})	0.36 ± 0.11	0.34 ± 0.01	0.32 ± 0.04
SRP (mg l^{-1})	0.17 ± 0.12	0.04 ± 0.02	0.19 ± 0.06
Chlorophyll *a* (mg m^{-3})	21 ± 5.1 ^{a}	57 ± 8.9 ^{b}	19 ± 2.5 ^{a}
TSS (mg l^{-1})	20 ± 1.0 ^{a}	61 ± 6.9 ^{b}	10 ± 2.4 ^{a}
TVS (mg l^{-1})	10 ± 0.8 ^{a}	14 ± 1.4 ^{b}	7 ± 1.5 ^{a}
MEAN VALUES			
DO (mg l^{-1})	1.81 ± 0.16 ^{a}	4.35 ± 0.27 ^{b}	1.40 ± 0.26 ^{a}
Temperature (°C)	28.5 ± 0.1 ^{b}	29.8 ± 0.0 ^{a}	28.0 ± 0.2 ^{c}
pH	6.9 ± 0.0	7.0 ± 0.1	7.0 ± 0.1
Alkalinity (mg l^{-1} as $CaCO_3$)	61 ± 5.7 ^{a}	45 ± 1.9 ^{a}	98 ± 4.2 ^{b}
TKN (mg l^{-1})	3.22 ± 0.12 ^{a}	6.32 ± 0.46 ^{b}	1.96 ± 0.45 ^{a}
TAN (mg l^{-1})	2.14 ± 0.26 ^{b}	3.42 ± 0.22 ^{a}	0.23 ± 0.02 ^{c}
Nitrite-N + Nitrate-N (mg l^{-1})	0.55 ± 0.13 ^{a}	0.56 ± 0.05 ^{a}	0.12 ± 0.01 ^{b}
TP (mg l^{-1})	0.27 ± 0.03	0.18 ± 0.01	0.20 ± 0.03
SRP (mg l^{-1})	0.07 ± 0.04	0.01 ± 0.00	0.08 ± 0.03
Chlorophyll *a* (mg m^{-3})	22 ± 0.9 ^{b}	40 ± 2.2 ^{a}	14 ± 1.5 ^{c}
TSS (mg l^{-1})	22 ± 1.6 ^{b}	49 ± 1.5 ^{a}	14 ± 1.7 ^{c}
TVS (mg l^{-1})	9 ± 0.4 ^{a}	12 ± 0.5 ^{a}	7 ± 0.2 ^{b}

(2000; 1.16 t N ha^{-1} and 0.39 t P ha^{-1}), due probably to the shorter cultivation period (119 days) in that experiment. Lotus incorporated about 12.8% N and 4.4% P from pond mud in the present experiment. Lotus did take up N by 0.30 t ha^{-1} yr^{-1} and P by 0.04 t ha^{-1} yr^{-1}, which are rates similar to those taken up by lotus (0.30 to 0.44 t N ha^{-1} yr^{-1} and 0.04 to 0.05 t P ha^{-1} yr^{-1}) reported by Mon (2000), but lower than amounts taken up by cowpea and taro (0.68 t N ha^{-1} yr^{-1} and 0.06 t P ha^{-1} yr^{-1}, and 0.73 t N ha^{-1} yr^{-1} and 0.09 t P ha^{-1} yr^{-1}, respectively) in pot experiments (calculated from Shrestha and Lin, 1997).

In the aquatic macrophyte–fish co-culture system, the main problem we found was the low water quality for fish growth due to the shading effects of lotus. The shading effects of macrophytes may lead to reduced phytoplankton production, lower DO concentration, and increased concentration of free carbon dioxide in the water column with a concomitant fish kill (Edwards, 1980). In the present experiment, we believe the shading effects of lotus leaves caused lower phytoplankton standing crop and lower DO concentrations, resulting in the poor performance of Nile tilapia in the lotus-tilapia co-culture system. However, lotus might help maintain higher alkalinity and lower TAN levels, which might potentially benefit the co-cultured fish. Thus the lotus-tilapia co-culture system needs further testing.

The net return from selling lotus seeds and flowers was highest in the ponds without fertilization but with lotus alone; sale of lotus seeds and flowers contributed to the largest portion of net return from ponds with lotus and tilapia. If the experimental period were adjusted or extended for two months to cover the cool season for developing lotus rhizomes, the net return would be much higher because lotus rhizomes fetch a good price. In an experiment using the Chinese vegetable variety of lotus to recover nutrients from old pond mud, the extrapolated rhizome production from 6-m^2 compartments in a 200-m^2 pond for four-month cultivation of lotus reached 38 t ha^{-1} yr^{-1} and a value of about US$12,000 (Mon, 2000).

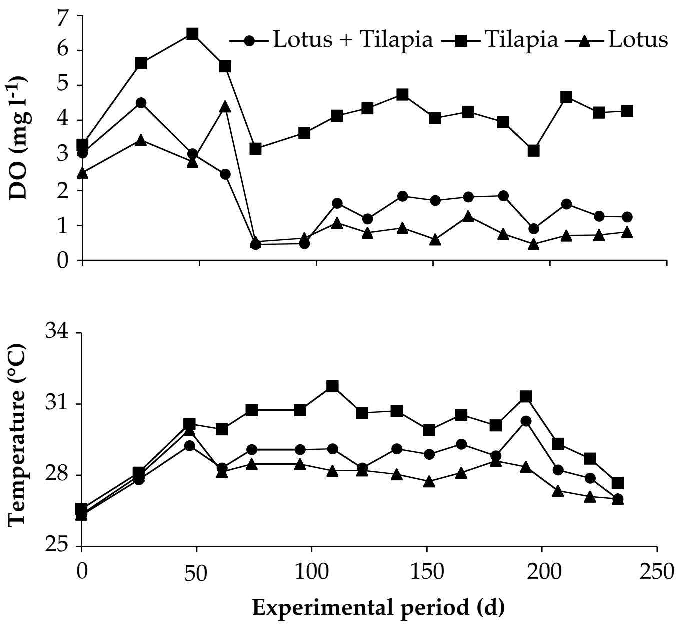

Figure 1. Mean DO and temperature (0900 h) in all treatments over the 160-day experimental period.

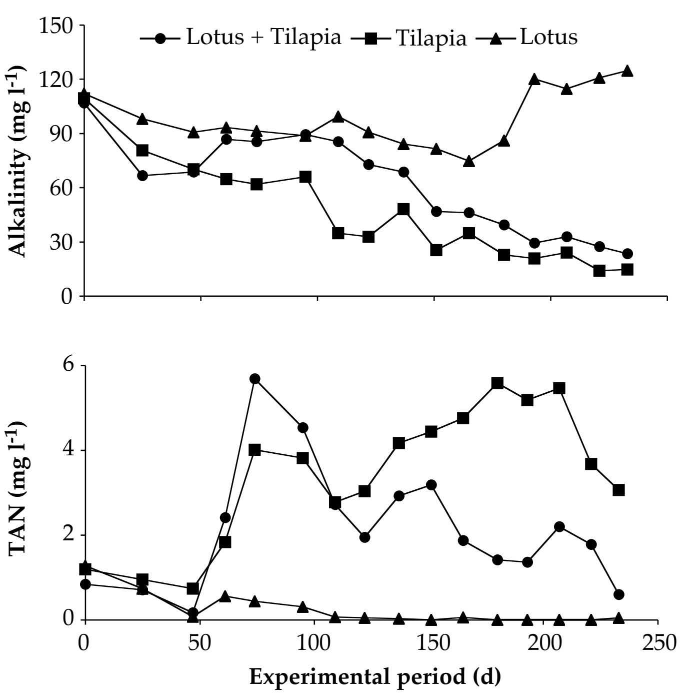

Figure 2. Mean total alkalinity and TAN (0900 h) in all treatments over the 160-day experimental period.

The practice of rotating fish with macrophytes is reported to have at least declined considerably in China due to greater profitability from raising fish year-round, while rotation of fish and agricultural crops was done much less frequently in Eastern Europe due to the wider use of fertilizers (Edwards, 1987). However, with the high net economic return from cultivating lotus in fish ponds shown by Mon (2000) and the present experiment, economic incentives may make the rotation or co-culture of lotus and fish attractive to farmers. For example, some farmers in China have changed their ponds from culturing fish to cultivating lotus in recent years because Chinese carp culture is less profitable than lotus cultivation due to oversupply of fish (Yang Yi, personal observation).

The present experiment has demonstrated the effectiveness of nutrient removal from old pond mud by lotus and the feasibility of rotation and co-culture of lotus and Nile tilapia. Both systems can recycle nutrients effectively within ponds and are environmentally friendly culture systems. Further research is needed to refine the lotus-tilapia co-culture system and make it profitable.

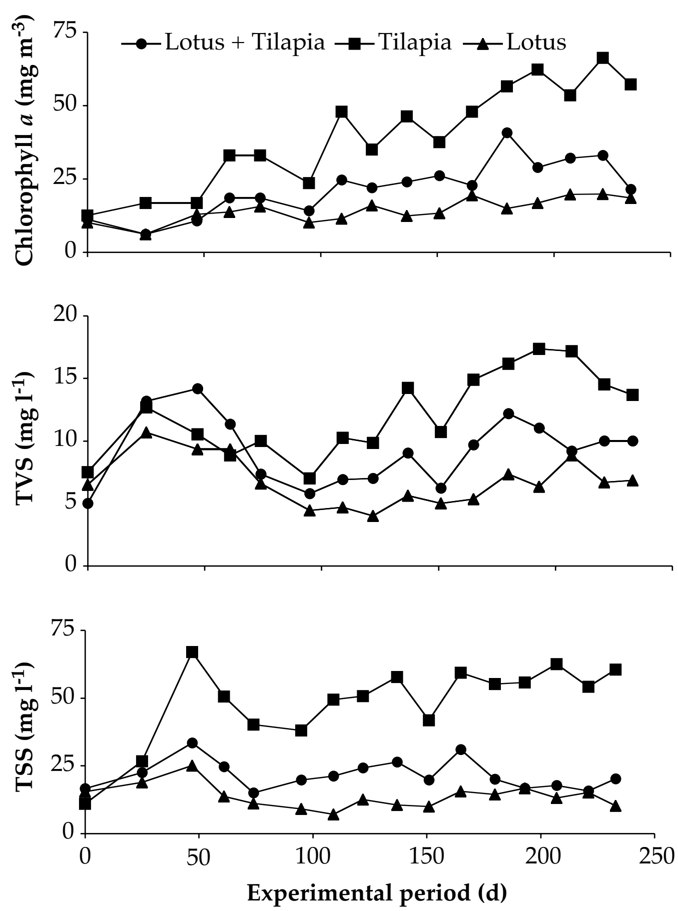

Figure 3. Mean chlorophyll *a*, TVS, and TSS (0900 h) in all treatments over the 160-day experimental period.

Table 7. Partial budget analysis for integrated lotus-tilapia co-culture (treatment A), tilapia alone (treatment B), and lotus alone (treatment C) in the 236-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								
Tilapia	kg	0.25–0.375	10.0	2.50	38.5	14.44	----	----
Lotus Seed	kg	0.75	5.11	3.83	----	----	5.33	4.00
Lotus Flower	piece	0.13	138	17.25	----	----	139	17.38
Total				23.58		14.44		21.37
VARIABLE COST								
Urea	kg	0.1875	32.4	6.08	32.4	6.08	----	----
TSP	kg	0.3125	18.9	5.91	18.9	5.91	----	----
Tilapia Fingerling	piece	0.0125	400	5.00	400	5.00	----	----
Lotus Seedling	piece	0.125	25	3.13	----	----	25	3.13
Cost of Working Capital	yr	8%	0.65	1.04	0.65	0.88	0.65	0.16
Total				21.15		17.86		3.29
NET RETURN				2.44		-3.42		18.09

ANTICIPATED BENEFITS

Results of the experiment will provide information on lotus-fish co-culture and rotation system to recycle pond mud nutrients that are otherwise wasted. The experiment generated information on bottom mud characteristics altered by rooted plants. It may benefit small-scale farmers in Asian countries for resource utilization where lotus is commonly grown as a cash crop.

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CULTURE OF MIXED-SEX NILE TILAPIA WITH PREDATORY SNAKEHEAD

Ninth Work Plan, New Aquaculture Systems/New Species Research 2 (9NS2)
Final Report

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
University of Michigan
Ann Arbor, Michigan, USA

ABSTRACT

An experiment was conducted in eighteen 200-m^2 fertilized earthen ponds at the Asian Institute of Technology, Thailand, from March through October 2000. This experiment was designed to assess the efficiency of snakehead (*Channa striata*) in controlling recruitment of mixed-sex Nile tilapia (*Oreochromis niloticus*) in ponds and to assess growth and production characteristics of Nile tilapia in monoculture and polyculture with snakehead. There were six treatments: A) monoculture of sex-reversed all-male tilapia; B) monoculture of mixed-sex tilapia; C) polyculture of snakehead and mixed-sex tilapia at 1:80 ratio; D) polyculture of snakehead and mixed-sex tilapia at 1:40 ratio; E) polyculture of snakehead and mixed-sex tilapia at 1:20 ratio; F) polyculture of snakehead and mixed-sex tilapia at 1:10 ratio. Sex-reversed and mixed-sex Nile tilapia were stocked at 2 fish m^{-2} at sizes of 10.5 to 11.6 g and 7.2 to 8.1 g, respectively.

Results show that snakehead were able to completely control Nile tilapia recruitment at all tested predator:stocked-prey ratios, and the best predator:stocked-prey ratio was 1:80. The addition of snakehead into Nile tilapia ponds did not result in significantly greater tilapia growth, but it significantly lowered total net and gross yields of adult plus recruited tilapia. Snakehead growth was density-dependent, decreasing significantly with increasing stocking densities. While snakehead biomass gain was not significantly different at stocking densities from 0.025 to 0.1 fish m^{-2}, the gain was significantly lower at a stocking density of 0.2 fish m^{-2}. The present experiment demonstrates that snakehead are able to control Nile tilapia recruitment completely and provide an alternative technique for Nile tilapia culture.

INTRODUCTION

The aquaculture of species at lower trophic levels, such as tilapia, presents the greatest potential for efficiency (Welcomme, 1996). However, overpopulation of tilapia in confined ponds causes stunted growth due to shortage of natural food, particularly in semi-intensive culture. Various methods of population control have been applied (Mair and Little, 1991), such as culture in cages, culture with predators, intermittent harvesting, hybridization, induction of sterility, and production of super-male fish (YY-male). However, population control of tilapias by culture with predators has been practiced worldwide but not well studied. Various predatory fish species have been used with varying success in combination with different tilapia species depending on their availability. These species include snakehead (*Channa striata* or *Ophiocephalus striatus*) (Pongsuwana, 1956; Chimits, 1957; Tongsanga, 1962; Chen, 1976; Cruz and Shehadeh, 1980; Hopkins et al., 1982; Wee, 1982; Balasuriya, 1988); *Ophiocephalus obscuris* (de Graaf et al., 1996); *Micropterus salmoides* (Swingle, 1960; Meschkat, 1967; McGinty, 1985); *Lates niloticus* (Meschkat, 1967; Planquette, 1974; Lazard, 1980; Bedawi, 1985; El Gamal, 1992); *Hemichromis fasciatus* (Bardach et al., 1972; Lazard, 1980); *Cichla ocellaris* (Lovshin, 1977; McGinty, 1983; Verani et al., 1983); *Clarias* sp. (Meecham, 1975; Bard et al., 1976; Lazard, 1980; Janssen, 1985; de Graaf et al., 1996); *Cichlasoma managuense* (Dunseth and Bayne, 1978); *Elops hawaiiensis* (Fortes, 1980); and *Megalops cyprinoides* (Fortes, 1980). However, the difficulty in breeding or obtaining predators of the correct size often resulted in limited application of this population control method (Balarin and Hatton, 1979; Penman and McAndrew, 2000).

Snakehead have long been regarded as valuable food fish and widely cultured in the Far East (Wee, 1982). It was reported to be used in polyculture with tilapia to control tilapia population or with carps to keep out other extraneous pest fish in the pond system (Wee, 1982). Snakehead are highly predacious as they swallow their prey whole (Diana et al., 1985) and have been shown to effectively prey on live tilapia fry (Kaewpaitoon, 1992). A population including 5% (predator:stocked-prey ratio of 1:20) snakehead with tilapia has been demonstrated to control tilapia recruitment (Balasuriya, 1988). Negligible tilapia recruitment was generally found during harvest where snakehead existed in tilapia ponds.

The purposes of this study were to assess:

1) The efficiency of snakehead in controlling overpopulation of mixed-sex Nile tilapia (*Oreochromis niloticus*) in ponds and
2) The growth and production of Nile tilapia in monoculture and polyculture with snakehead.