STOCKING DENSITIES AND FERTILIZATION REGIMES FOR NILE TILAPIA (*Oreochromis niloticus*) PRODUCTION IN PONDS WITH SUPPLEMENTAL FEEDING

James S. Diana[1], Yang Yi[2] and C. Kwei Lin[2]

[1]School of Natural Resources and Environment
University of Michigan
Ann Arbor, USA

[2]Aquaculture and Aquatic Resources Management
School of Environment, Resources and Development
Asian Institute of Technology
P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand

Abstract

The purposes of the study, consisting of two experiments, were to determine the upper limits to tilapia production utilizing supplemental feeding and appropriate fertilization regimes for controlling nutrient addition and maintaining good water quality. In order to test these, Nile tilapia fingerlings were stocked at 3, 6, and 9 fish m^{-2}. The fish were supplementally fed to 50% satiation during culture of 155 and 194 days for experiments 1 and 2, respectively. While ponds were fertilized at fixed rates (4 kg nitrogen and 1 kg phosphorus per hectare per day) throughout experiment 1, ponds in experiment 2 were fertilized at various rates to balance nutrient contents of feeding wastes, bringing nutrient loading to the same levels as in experiment 1. The experiments were conducted at the Ayutthaya Freshwater Fisheries Station, Thailand.

Growth, survival, yield, and water quality were evaluated during both experiments. Growth continued in a linear fashion throughout the experiments. Survival also differed significantly among treatments in both experiments, with lowest rate at the highest density. Feeding rates averaged 1.86% and 1.65% of the body weight per day in experiments 1 and 2, respectively, and were not significantly different among treatments in each experiment. Feed conversion rates averaged 1.18 and 1.38 for experiments 1 and 2, respectively, and also were not significantly different among treatments. Most water quality parameters were not significantly different among treatments, and did not deteriorate at least during the initial 155 days. The reduced growth and survival in high density ponds appears to be a behavioral or physiological response to density itself, not to water quality. Partial economic analyses indicated that the 3 fish m^{-2} treatments were profitable, while the 6 or 9 fish m^{-2} treatments were unprofitable in both experiments. At present, the best system seems to be culturing at 3 fish m^{-2} with intensive feeding and balanced fertilization.

Introduction

Pond carrying capacity is largely determined by management practices. Earlier work on semi-intensive culture of Nile tilapia (*Oreochromis niloticus*) using manure or inorganic fertilizers indicated that carrying capacity might reach 2,000 to 3,000 kg ha^{-1} (Diana *et al.*, 1991a; 1991b; Knud-Hansen *et al.*, 1991). As stocking density increases in fertilized ponds, carrying capacity remains largely the same and density-dependent growth occurs (Diana *et al.*, 1991b). Thus, the ultimate size of fish at harvest is largely related to density stocked in fertilized ponds, while biomass at harvest is more consistent regardless of stocking density. Maximum size at harvest from these fertilized ponds is approximately 250 g for fish grown over five months.

Increasing the carrying capacity or size at harvest of Nile tilapia requires more intensive management, which largely involves supplemental feeding. Experiments with supplemental feeding indicated that Nile tilapia can reach 500 g in 5 months when feed and fertilizers are provided in combination (Diana *et al.*, 1994, 1996). Such experiments were done at stocking density of 3 fish m^{-2}, in which density-related declines in fish growth in fertilized ponds can occur. However, the addition of supplemental feed increased the growth rate of fish stocked at high density, and resulted in a higher carrying capacity for the pond. The limit on such feeding and density increases is reached when conditions in ponds climb to limiting levels due to increased oxygen demand, build up of metabolites, or other factors which produce poor water quality. Such a limit to Nile tilapia production was demonstrated for Honduran ponds stocked at 3 fish m^{-2} (Green, 1992) while Diana *et al.* (1994) found no decline of water quality in Thai ponds stocked at the same density. In the latter study, concomitant fertilization probably helped maintain reasonable water quality.

The purpose of this study was to determine the upper limits to Nile tilapia production utilizing supplemental feeds. In order to test this relationship, Nile tilapia were stocked at 3, 6, and 9 fish m^{-2}. These fish were supplementally fed to 50% satiation for the entire culture period.

Materials and methods

Data for this study were collected at the Ayutthaya Freshwater Fisheries Station located at Bang Sai (140° 45' N, 100° 32' E), approximately 60 km northwest of Bangkok, Thailand. This study was repeated twice. The nine ponds used in each experiment were 280 m^2 in surface area and normally filled to a depth of 1 m. Sex-reversed all-male Nile tilapia averaging 15-19 g were stocked on 19 October 1994 for experiment 1 and on 28 July 1995 for experiment 2 (Table 1). The ponds were divided randomly into three treatments, with triplicate ponds for each treatment receiving either 3, 6 or 9 fish m^{-2} (840, 1,680 and 2,520 fish pond^{-1}). Fish were fed to satiation from 0800-1000 hr and 1500-1700 hr every Monday. Maximum consumption was determined using floating pelleted feed (30% crude protein) and was estimated individually for each pond. The average consumption for each treatment was used to set the feeding rate at 50% of that level for the remainder of the week.

Table 1. The biomass (kg), number, and mean size (g) of Nile tilapia stocked and harvested in each experimental pond for two experiments.

Pond	At stocking			At harvest		
	Number (fish/pond)	Biomass (kg/pond)	Mean size (g/fish)	Number (fish/pond)	Biomass (kg/pond)	Mean size (g/fish)
Experiment 1						
A1	840	15.4	18.3	737	307.0	416.6
A2	840	15.5	18.5	744	345.5	464.4
A3	840	15.0	17.9	745	342.9	460.3
B1	1680	30.2	18.0	1,355	426.3	314.6
B2	1,680	31.8	18.9	1,248	395.5	316.9
B3	1,680	33.0	19.6	1,103	308.5	279.7
C1	2,520	47.9	19.0	1,471	381.4	259.3
C2	2,520	48.0	19.1	1,782	526.3	295.3
C3	2,520	48.7	19.3	1,723	450.3	261.4
Experiment 2						
A1	840	12.8	15.2	678	335.2	494.4
A2	840	12.8	15.2	735	445.1	605.6
A3	840	15.0	14.5	669	313.9	469.2
B1	1,680	26.3	15.6	1,155	502.5	435.1
B2	1,680	26.6	15.8	1,357	652.8	481.1
B3	1,680	26.4	15.7	1,351	567.6	420.1
C1	2,520	38.1	15.1	1,352	417.4	315.0
C2	2,520	40.3	16.0	1,382	452.5	327.4
C3	2,520	41.1	16.3	1,634	533.5	326.5

In addition to feeding, ponds were also fertilized weekly using urea and triple superphosphate (TSP). In experiment 1, ponds were fertilized at the fixed rates of 28 kg N ha^{-1} wk^{-1} and 7 kg P ha^{-1} wk^{-1}. In experiment 2, fertilization was done to balance input of N and P generated in fish wastes, giving the same N and P rates as in experiment 1. The amounts of N and P in fish wastes were estimated weekly from total feed inputs and fish biomass, based on N and P contents of dry matter of feed and fish carcasses (feed = 10% moisture, 4.2% N, and 1.2% P; fish = 78% moisture, 2.2% N, and 0.6% P).

Physical and chemical data were collected in a similar manner to earlier experiments (Diana *et al.*, 1991a; 1994). Meteorological data, including solar radiation, rainfall, and wind speed were collected daily. For the most analyses, a combined water sample encompassing the entire water column was taken from three locations of each pond. Pond water analyses, including temperature, dissolved oxygen (both taken at the top, middle, and bottom of the water column), ammonia, nitrate-nitrite, orthophosphate, total phosphorus, alkalinity, pH, Secchi-disk depth, and chlorophyll *a* content were conducted biweekly using standard methods (APHA *et al.*, 1985; Egna *et al.*, 1987). Vertical distribution of dissolved oxygen, temperature, pH, alkalinity, and ammonia was determined at 0600 hr, 0900 hr, 1400 hr, 1600 hr, 1800 hr, 2300 hr, and 0600 hr in each pond. These diel analyses were repeated monthly in water from 25 cm below water surface, middle, and above the pond bottom. For experiment 2, dissolved oxygen concentrations were also evaluated regularly by data loggers in two ponds of each treatment. Readings were taken near the surface (25 cm below) and bottom (25 cm above) of each pond at hourly intervals of most days (121 out of 194 days) of the experimental period.

Primary production was determined by oxygen changes in the ponds, using methods described by Piedrahita (1988). Daily oxygen production was corrected for diffusion and nocturnal respiration. The overall oxygen production (gross primary production) was then converted to carbon synthesis by relative molecular weights.

Ponds were harvested on 23 March 1995 after 155 days for experiment 1, and on 7 February 1996 after 194 days for experiment 2. Final biomass and numbers were determined. Overall individual growth (g day^{-1}) and net yield (kg) were calculated. During the experiments, fish were sampled biweekly for size. About 40 fish were seined from each pond, measured, and weighed. Biomass in the pond was estimated biweekly by extrapolating the number of fish in the pond linearly from stocking to harvest and multiplying this number by the average size of fish.

Economic analyses were based on local market prices in Thailand in 1996 during which feed price was \$0.50 kg^{-1}, urea was \$0.24 kg^{-1}, TSP was \$0.36 kg^{-1}, and sex-reversed fry was \$0.009 each. Market value of Nile tilapia varied with size: \$0.48 kg^{-1} for fish between 100-299 g, \$0.60·kg^{-1} for fish between 300-499 g, and \$0.80 kg^{-1} for fish above 500 g. Facility costs and labor were not included in the analysis, because the intent was only to compare relative differences in efficiency among treatments, and it is assumed that the previous costs would be similar for all treatments. Statistical analyses were conducted using SYSTAT (Wilkinson, 1990). Overall growth (g day^{-1}), net yield (kg), and present survival were calculated for each pond. Feeding rate (% BW day^{-1}) was estimated biweekly, while feed conversion rate (FCR) was calculated for overall data and for biweekly data. Average overall values for physical and chemical parameters and total food input were also calculated. Multiple regressions between growth and density were done to test main effects. Because many of the chemical variables were interrelated, residuals of the above regression were correlated to each physical or chemical variable. Variables which were significantly correlated to the residuals were then examined for autocorrelation, and acceptable variables were used as input for multiple regression to evaluate additional determinants of variations in fish growth, survival, or yield. Variables were included in the regression if $p < 0.10$. Treatment effects on fish or chemical variables were tested with the biweekly data set by ANOVA and Tukey's multiple range test. Differences were considered significant at an alpha of 0.05.

Results

Fish growth rate proceeded in a linear fashion throughout the two experiments (Fig. 1). Overall growth rate differed significantly among treatments ($P < 0.05$) for both experiments. In experiment 1, the low density treatment had higher growth than the intermediate density treatment, which was higher in growth than the high density treatment ($P < 0.05$; Table 2). Survival was also significantly different among treatments in experiment 1 ($P < 0.05$; Table 2). However, in experiment 2, the low and intermediate density treatments had higher growth than the high density treatment ($P < 0.05$; Table 2) but not being significantly different from one another ($P > 0.05$; Table 2). Similarly, survival was varied among treatments, with lowest survival in the high density treatment but without significant differences between the two lower density treatments ($P > 0.05$; Table 2). There were no significant differences for net fish yield among treatments in experiment 1 ($P > 0.05$; Table 2). However, in experiment 2, net fish yield was significantly higher in the intermediate density treatment than in the other two treatments ($P < 0.05$; Table 2).

Feeding rate was initially high but then declined in all treatments for both experiments. Overall feeding rates averaged 1.86% BW day^{-1} and 1.65% BW day^{-1} for experiments 1 and 2, respectively, and did not differ significantly among treatments ($P > 0.05$). Feed conversion rate averaged 1.19 and 1.40 for experiments 1 and 2, respectively, and also did not differ significantly among treatments ($P > 0.05$). In experiment 2, the average fertilizer inputs used for balancing fish wastes were 31.4 kg urea ha^{-1} week^{-1} and 28.8 kg TSP ha^{-1} week^{-1}, which were lower than the fixed fertilization rates used in experiment 1 (61 kg urea and 35 kg TSP ha^{-1} week^{-1}).

Table 2. Growth performance of Nile tilapia from each pond in both experiments.

Pond	Growth (g fish^{-1} day^{-1})	Survival (%)	Net yield (kg/pond)	Feed applied (kg/pond)	FCR	Annual net yield (kg ha^{-1} year^{-1})
Experiment 1						
A1	2.57	87.7	291.6	304	1.04	24,524
A2	2.88	88.6	330.0	332	1.01	27,753
A3	2.86	88.7	327.9	328	1.00	27,577
B1	1.91	80.7	396.1	399	1.01	33,313
B2	1.92	74.3	363.7	410	1.13	30,588
B3	1.68	65.7	275.5	393	1.42	23,170
C1	1.55	58.4	333.5	533	1.60	28,048
C2	1.78	70.7	478.3	566	1.18	40,226
C3	1.56	68.4	401.6	512	1.27	33,775
Experiment 2						
A1	2.47	80.7	322.4	463	1.44	21,663
A2	3.04	87.5	432.3	505	1.17	29,048
A3	2.34	79.6	301.7	458	1.52	20,273
B1	2.16	68.8	476.2	624	1.31	32,001
B2	2.40	80.8	626.2	783	1.25	42,080
B3	2.08	80.4	541.2	712	1.32	36,369
C1	1.55	52.6	379.3	590	1.55	25,490
C2	1.61	54.8	412.1	660	1.60	27,701
C3	1.60	64.8	492.4	689	1.40	33,090

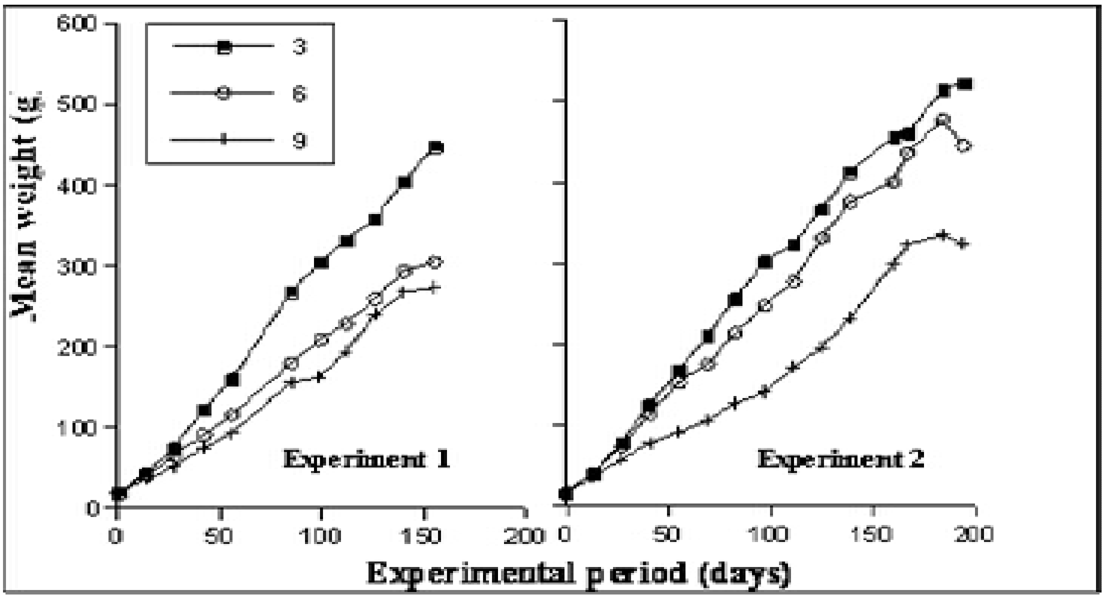

Figure 1. Changes in mean weight of Nile tilapia during experiments 1 and 2.

Most physical and chemical variables showed no significant differences among treatments in both experiments. In experiment 1, exceptions were chlorophyll *a*, which was higher in the two high density treatments, and total volatile solids, which was higher in the high density treatments. Chlorophyll *a* content differed among treatments (Fig. 2), and was also strongly correlated to total volatile solids. However, there was no significant difference among treatments in primary production, which was measured less frequently than chlorophyll *a*. Chlorophyll *a* was strongly correlated to a number of physical and chemical variables which changed over the experiment. The strongest correlation was with total phosphorus (r^2=0.70, $P < 0.01$). Total phosphorus was also correlated to several physical and input variables; the most notable was feed input (r^2=0.49, $P < 0.001$). These results suggest that phosphorus was a limiting factor to primary production and was supplemented by high feeding rates. In experiment 2, however, exceptions were alkalinity, which was significantly different in all three treatments ($P < 0.05$; Fig. 3), as well as un-ionized ammonia-nitrogen (Fig. 4) and dissolved inorganic nitrogen (DIN), which were significantly higher in the high density treatment than in the other two treatments ($P < 0.05$). Alkalinity was highest in the intermediate density treatment (224 $CaCO_3$ mg L^{-1}), intermediate in the low density treatment (169 $CaCO_3$ mg L^{-1}), and lowest in the high density treatment (141 $CaCO_3$ mg L^{-1}). Alkalinity and DIN differed among treatments. Both were also significantly ($P < 0.05$) correlated to one another using overall data but not with biweekly data. This relationship is difficult to understand. Dissolved oxygen levels in experiment 2 were difficult to analyze due to the large volume data produced by the datalogger. Mean DO at dawn was significantly different among treatments ($P < 0.05$), with low and intermediate density treatments having similar levels (1.58 and 1.31 mg L^{-1}, respectively), while intermediate and high density also had similar levels (1.31 and 1.08 mg L^{-1}, respectively; Fig. 5). However, there was no significant difference ($P >$ 0.05) among treatments for the mean DO at dawn during the initial 155 days (total culture days for experiment 1). There were significant differences ($P < 0.05$) in the total number of data logged hours when DO was less than 1 mg L^{-1}; mean values were similar at low and mid densities (210 and 401, respectively) and at mid and high densities (401 and 629, respectively). However, on average 30% of those low DO events occurred during the last 39 days of the 194-day culture period. These results indicate that the significant depletion of water quality occurred after the 155th day.

Growth rate was significantly correlated to density ($r^2 = 0.81$, $P < 0.001$ in experiment 1; $r^2 = 0.79$, $P < 0.001$ in experiment 2; Table 3). Residuals of this regression were not significantly correlated to any physical or chemical variables ($P > 0.05$). Survival was also significantly related to density ($r^2 = 0.74$, $P < 0.01$ in both experiments; Table 3). Residuals of this regression were also not significantly correlated to any physical or chemical variable ($P > 0.05$). Finally, yield was not significantly related to density ($P > 0.05$) in either experiments.

The economic analysis indicated that the grow outs at 3 fish m^{-2} were profitable in both experiments ($1180 and $2171 ha^{-1} year^{-1} in experiment 1 and 2, respectively) (Table 4). Fish in all treatments except for the treatment at 3 fish m^{-2} in experiment 2 did not reach 500 g at harvest, which would produce a higher market price. If price per kg of fish were the same ($0.80) for each treatment, then all treatments were profitable with the highest at 3 fish m^{-2} in experiment 1 ($6762 ha^{-1} year^{-1}), followed by the treatments at 6 and 9 fish m^{-2} in experiment 1 ($5818 and $4601 ha^{-1} year^{-1}, respectively), and 6, 3 and 9 fish m^{-2} in experiment 2 ($5312, $2171 and $911 ha^{-1} year^{-1}, respectively).

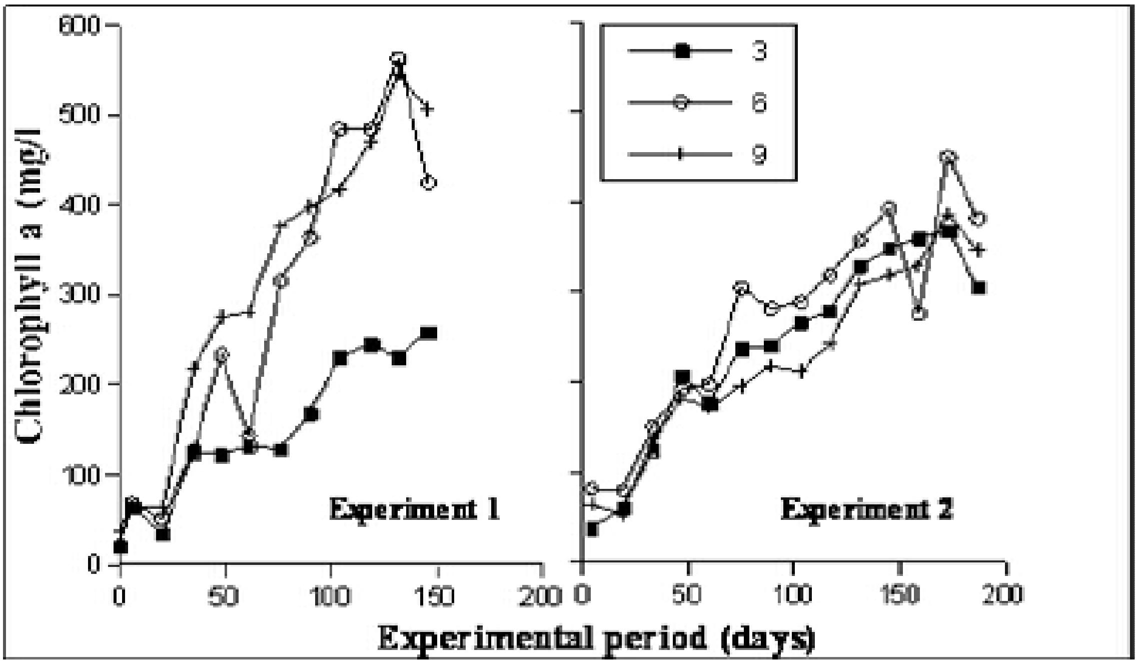

Figure 2. Changes in chlorophyll *a* content of pond water during experiments 1 and 2.

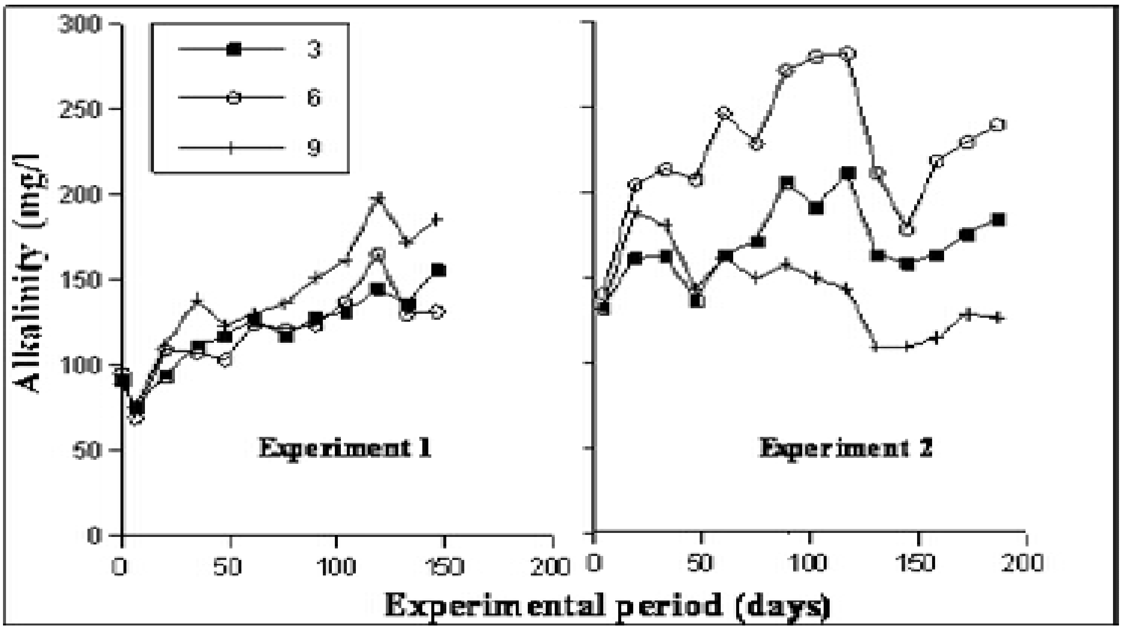

Figure 3. Changes in alkalinity content of pond water during experiments 1 and 2.

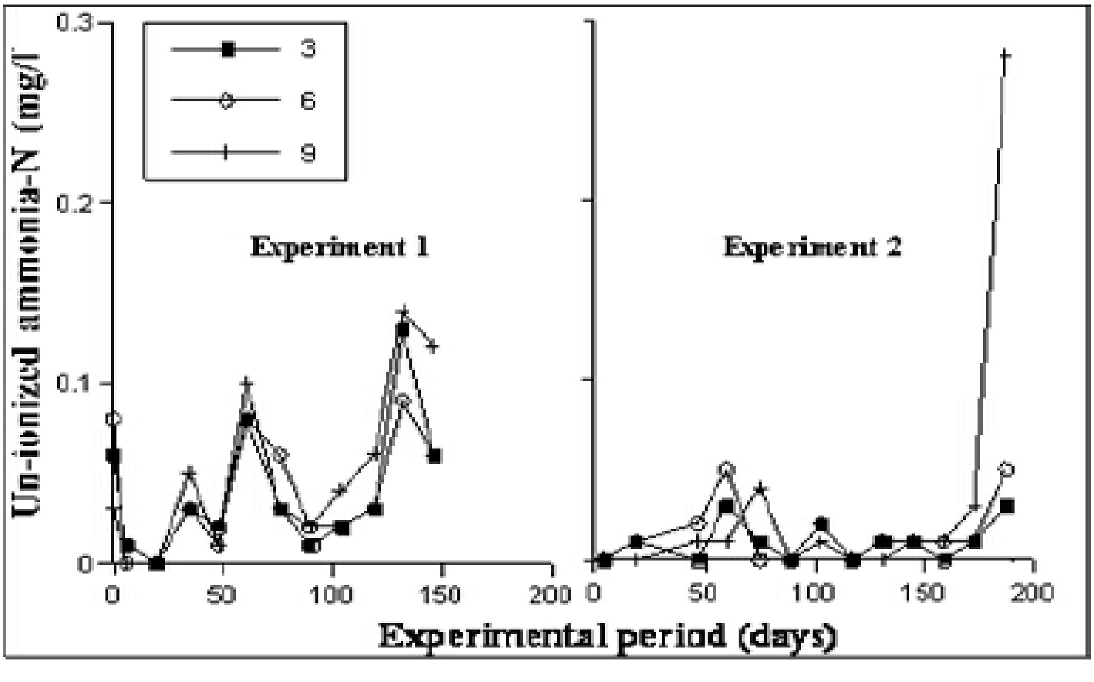

Figure 4. Changes in un-ionized ammonia nitrogen content during experiments 1 and 2.

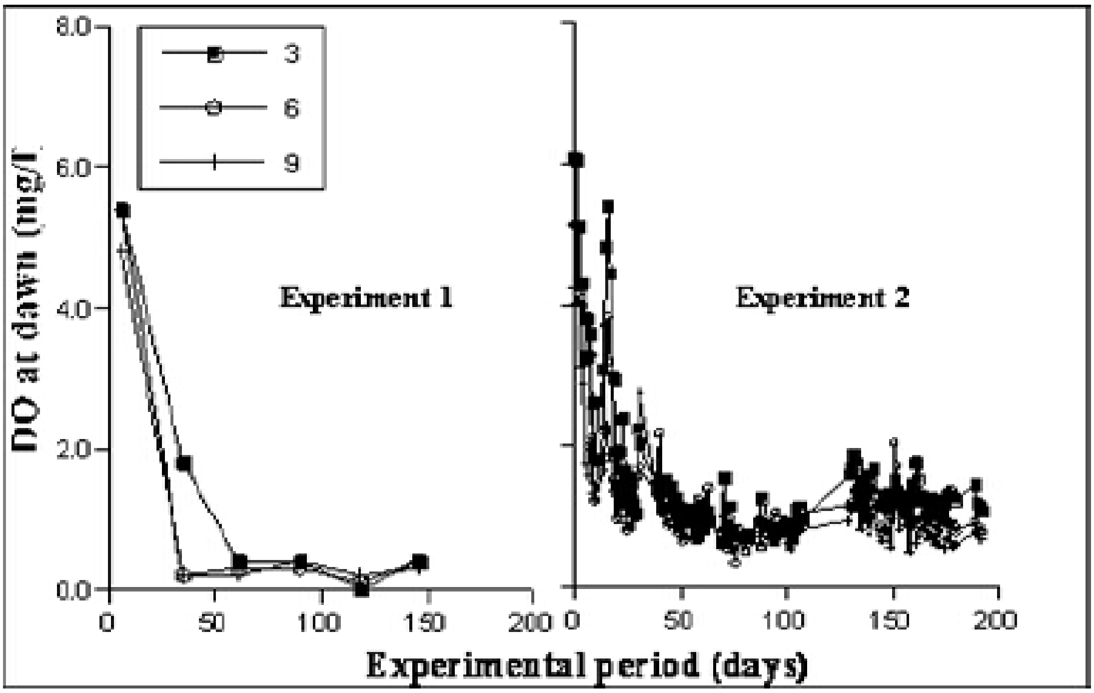

Figure 5. Changes in dissolved oxygen content of pond water at dawn during experiments 1 and 2.

Table 3. Multiple regression results for main effects (density) related to fish growth (g day^{-1}), survival (%), and yield (kg).

Variable	Coefficient	*P*
	Experiment 1	
	Growth Rate ($r^2 = 0.811$, $P < 0.001$)	
Constant	3.42	0.001
Density	-0.210	0.001
	Survival ($r^2 = 0.739$, $P < 0.001$)	
Constant	0.984	0.001
Density	-0.038	0.002
	Yield ($r^2 = 0.281$, P > 0.05)	
Constant	267.39	0.001
Density	14.66	0.082
	Experiment 2	
	Growth Rate ($r^2 = 0.789$, $P < 0.001$)	
Constant	3.169	0.001
Density	-0.172	0.001
	Survival ($r^2 = 0.736$, $P < 0.001$)	
Constant	0.978	0.001
Density	-0.042	0.002
	Yield ($r^2 = 0.281$, P > 0.05)	
Constant	366.78	0.006
Density	12.61	0.408

Table 4. Calculation of annual profit for each stocking density in both experiments.

Density (fish m^{-2})	Fry (number)	Urea (kg)	TSP (kg)	Feed (kg)	Gross yield (kg)	Fish size (g)	Profit ($)
Experiment 1							
3	70,645	3,129	1,825	27,037	24,508	447	1,180
6	141,290	3,129	1,825	33,704	38,590	304	- 520
9	211,935	3,129	1,825	45,079	31,434	272	- 7,581
Experiment 2							
3	56,443	1,606	1,507	31,999	24,508	523	2,171
6	112,887	1,493	1,197	47,509	38,590	445	- 2,406
9	169,330	1,869	1,584	43,386	31,434	323	- 5,375

Discussion

Growth and survival of tilapia differed as expected among treatments in both experiments, with best growth and survival at the lowest density. Trends in growth rate among treatments were clearly differentiated by the first month sampled. Growth was rapid in all ponds and reached rates near the maximum measured for Nile tilapia cultured in ponds. Reductions in growth which occurred at high density during the entire culture period of experiment 1 and in the initial 155 days of experiment 2 did not appear to be due to poor water quality, because water quality did not differ significantly among treatments except for chlorophyll *a* in experiment 1 and alkalinity in experiment 2. However, chlorophyll *a* is a measure of natural food density, not poor water quality, and alkalinity is probably not a crucial parameter affecting fish growth in ponds with main food source coming from artificial feed. Thus, the reduced growth and survival in high density ponds appears to be a behavioral or physiological response to density itself, not to water quality.

The density-dependent growth in this study was interesting because it occurred under *ad-libitum* feeding. Voluntary appetite suppression or behavioral interactions must have been involved in the reduced growth, or very subtle changes in water quality parameters may have influenced growth. Reduced growth due to declining water quality could be managed by aeration or water exchange, while behavioral or physiological reductions in growth defy management action. Since growth declined at high density without concomitant declines in water quality, it is possible that feeding rates were too low in the high density ponds. However, there were no significant differences in feeding rates, which averaged 1.86% BW day^{-1} in experiment 1 and 1.65% BW day^{-1} in experiment 2. Because feeding rates were determined by actual food consumption, increased agonistic activity in high density ponds likely increased in energy expenditures and decreased growth rates. This was also somewhat expressed in feed conversion data, as the most efficient conversion occurred at lowest density, although differences among densities were not significant.

Concentrations of un-ionized ammonia nitrogen (Fig. 4) and chlorophyll *a* (Fig. 2) were much higher in experiment 1 than in experiment 2. Chlorophyll *a* levels were higher in the ponds with higher density in experiment 1, however, there were no significant differences among treatments in experiment 2. The fertilizer/fish waste balancing of nutrient inputs in experiment 2 appeared to be a successful way to control nutrient addition and maintain high water quality.

Under normal conditions, profit was generated by fish grown at 3 fish·m^{-2} ($1180 and $2171 ha^{-1} year^{-1} in experiment 1 and 2, respectively). Even the annual yields in the 3 fish m^{-2} treatment of experiment 1 was higher than those of experiment 2, the profit of the later was higher than that of the former because fish in the 3 fish m^{-2} treatment of experiment 1 had reached 500 g in size and thus fetched the higher market price.

The application of this study to tilapia management is not entirely clear. Most rapid growth, highest survival and positive economic return occurred at 3 fish m^{-2}. The optimal feeding system at present appears to be with tilapia stocked at 3 fish m^{-2}. The fertilizer·fish waste balancing of nutrient inputs successfully controlled nutrient addition and maintained high water quality in experiment 2, however, the reduced fertilization rates probably could not produce adequate natural foods for tilapia because FCRs in experiment 2 were higher that those in experiment 1. The results indicated that further fine-tuning of fertilizer balance may be necessary at each stocking and feeding level.

Acknowledgement

The authors wish to thank Mr. Y. Manoj and Mr. P. Supat for their field and laboratory assistance. This research is a component of the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) supported by the US Agency for International Development, Grant No. DAN-4023-G-00-0031-00, and by contributions from the University of Michigan and the Asian Institute of Technology. This is PD/A CRSP Accession No. 1275. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the US Agency of International Development.

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