Stocking Density and Supplemental Feeding

Work Plan 6, Study 6

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

C. Kwei Lin and Yang Yi
Asian Institute of Technology
Bangkok, Thailand

(Printed as Submitted)

Introduction

Pond carrying capacity is largely determined by management practices. Earlier work on semi-intensive culture of tilapia using manure or inorganic fertilizers indicated that carrying capacity might reach 2,000 to 3,000 kg/ha (Diana et al. 1991a, b; Knud-Hansen et al. 1991). As stocking density is increased 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 for these fertilized ponds is approximately 250 g for fish grown five months.

Increasing the carrying capacity or size at harvest of tilapia requires more intensive management, which largely involves supplemental feeding. Experiments with supplemental feeding indicated that tilapia can reach 500 g in 5 months when feed and fertilizer are provided in combination (Diana et al. 1994, 1995). Such experiments were done at fish densities of 3 fish per m^2, which would cause density-related declines in growth for fish in fertilized ponds. 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 would occur when conditions in the ponds reach limiting levels due to increased oxygen demand, build up of metabolites or other factors which produce poor water quality. Such a limit to tilapia production was demonstrated for Honduran ponds at 3 fish/m^2 (Green 1992), while Diana et al. (1994) found no decline in water quality for tilapia stocked at 3 fish/m^2 in Thai ponds. In the latter study, concomitant fertilization probably helped maintain reasonable water quality.

The purpose of this experiment was to determine the upper limits to tilapia production utilizing supplemental feeds. In order to test this relationship, fish were stocked at 3, 6, and 9 fish per m^2. These fish were supplementally fed to satiation for 146 days.

Materials and Methods

Data for this study were collected at the Ayutthaya Freshwater Fisheries Station located at Bang Sai (14° 45' N, 100° 32' E), approximately 60 km northwest of Bangkok, Thailand. The 9 ponds used in the experiment were 280 m^2 in surface area and normally filled to a depth of 1 m. Sex-reversed Nile tilapia *Oreochromis niloticus* averaging 19 g were stocked on 19 October 1994 (Table 1). The ponds were divided into three treatments, with triplicate ponds for each treatment receiving either 3, 6, or 9 fish per m^2 (840, 1680, and 2520 fish per pond). Fish were fed daily to satiation. Feeding rates were readjusted on a weekly basis. Maximum consumption was determined using floating feed, and was estimated individually for each pond. The average consumption for each treatment was then used for the feeding rate over the remainder of the week.

In addition to feeding, ponds were also fertilized weekly to bring a balance of P and N addition to 4 and 1 $kg \cdot ha^{-1} \cdot d^{-1}$, respectively. This required 1.68 kg urea and 1.0 kg triple super phosphate per week.

Table 1. The biomass, number, and mean size of tilapia stocked and harvested from each pond.

Pond	At Stocking			At Harvest		
	Number	Biomass	Mean Size	Number	Biomass	Mean Size
A1	840	15.4	18	737	307.0	417
A2	840	15.5	18	744	345.5	465
A3	840	15.0	18	745	342.9	460
B1	1680	30.2	18	1355	426.3	315
B2	1680	31.8	19	1248	395.5	317
B3	1680	33.0	20	1103	308.5	280
C1	2520	47.9	19	1471	381.4	259
C2	2520	48.0	19	1782	526.3	295
C3	2520	48.7	19	1723	450.3	261

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 most analyses, combined water samples encompassing the entire water column were taken from walkways extending to the center of the ponds. 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 (see APHA 1980 and Egna et al. 1987 for detailed descriptions of methods). 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 diurnal analyses were repeated biweekly on water from the top (25 cm), middle, and 25 cm above the bottom of the water column. Temperature and oxygen differentials were calculated as the difference between top and bottom measurements at 1600 hr.

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 146 days. Final biomass and numbers were determined. Overall growth (g/d) and net yield (kg) were calculated. During the experiment, 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.

Statistical analyses were conducted using SYSTAT (Wilkinson 1990). Overall growth (g/day), net yield (kg), and percent survival were calculated for each pond. Feeding rate (%BW/d) 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, total days of culture, 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 auto correlation, and acceptable variables input to the 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.

Table 2. Growth (g/d), survival (%), yield (kg), feed applied (kg), feed conversion rate (FCR), and forecasted annual yield ($kg \cdot ha^{-1} \cdot yr^{-1}$) for tilapia from each pond.

Pond	Growth	Survival	Yield	Feed Applied	FCR	Annual Yield
A1	2.71	0.877	291.6	262	0.897	26036
A2	3.04	0.886	330.0	285	0.863	29464
A3	3.01	0.887	327.9	284	0.867	29277
B1	2.00	0.807	396.1	349	0.881	35366
B2	2.00	0.743	363.7	360	0.991	32473
B3	1.71	0.657	275.5	344	1.247	24598
C1	1.55	0.584	333.5	464	1.391	29777
C2	1.84	0.707	478.3	495	1.035	42705
C3	1.60	0.684	401.6	444	1.105	35857

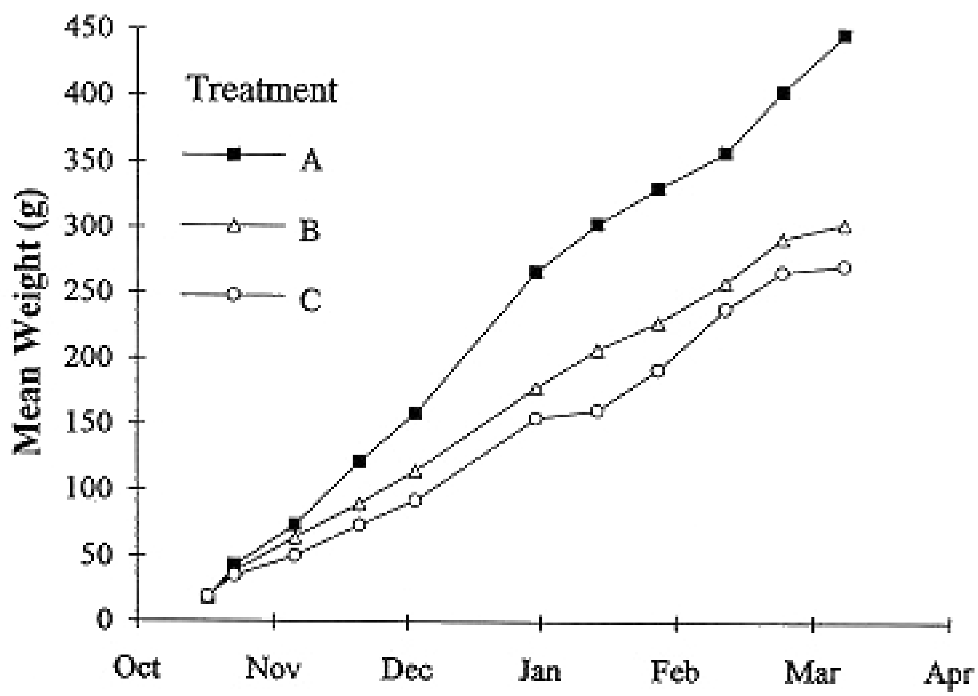


Figure 1. Changes in mean weight of tilapia during culture under 3 treatments; A = 3, B = 6, and C = 9 fish $/m^2$

Table 3. Multiple regression results for main effects (density) related to fish growth (g/d), survival (%), and yield (kg).

Variable	Coefficient	P
	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

Results

Fish growth rate proceeded in a linear fashion throughout the experiment (Figure 1). Overall growth rate differed significantly among treatments (ANOVA, $p < 0.05$) with the low density treatment having higher growth than at intermediate density, which was higher in growth than the high density treatment (Tukey's test, $p < 0.05$, Table 2). Survival was also significantly different among treatments.

Feeding rate was initially high, then declined in all treatments (Figure 2). Overall feeding rate averaged 1.9%BW/d and did not differ significantly among treatments. Feed conversion rate averaged 0.89 and also did not differ significantly among treatments. Feed conversion rate varied over time, increasing to a peak after 45 days, then declining to zero in the intermediate and high density treatments.

Most physical and chemical variables showed no significant differences among treatments. 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.

Growth rate was significantly correlated to density ($r^2 = 0.881$, $p < 0.001$, Table 3). Residuals of this regression were not significantly correlated to any chemical or physical variables. Survival was also significantly related to feed input ($r^2 = 0.739$, $p < 0.001$). Residuals of this regression were not significantly correlated to any physical or chemical variable. Finally, yield was not significantly related to density ($p > 0.05$).

Chlorophyll-*a* content differed among treatments (Figure 3), 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 ($r^2 = 0.701$, $p < 0.01$, Figure 4). Total phosphorus was also correlated to several physical and input variables; the most notable was feed input ($r^2 = 0.487$, $p < 0.001$, Figure 5). These results suggest that phosphorus was a limiting factor to primary production and was supplemented by high feeding rates.

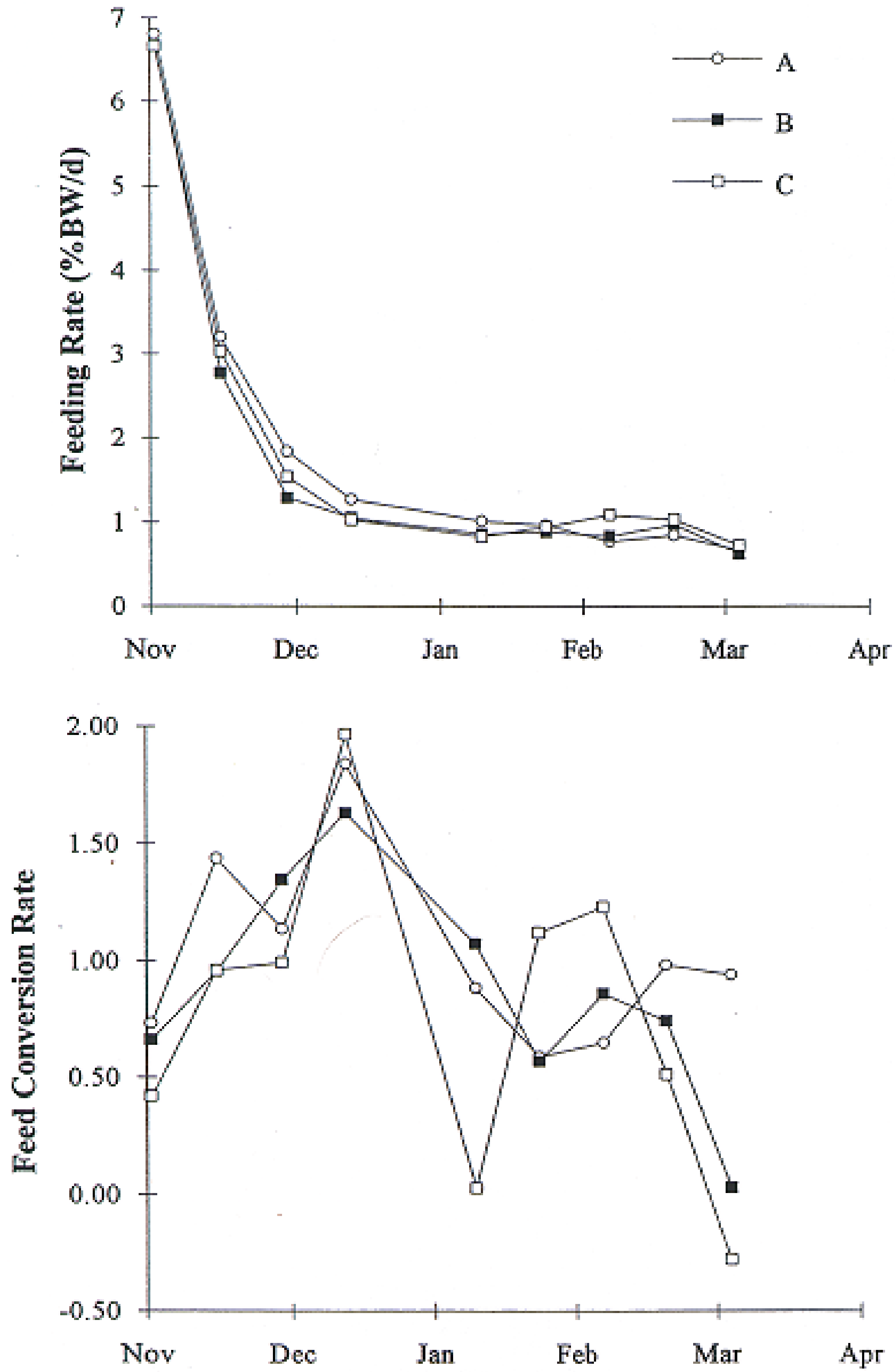
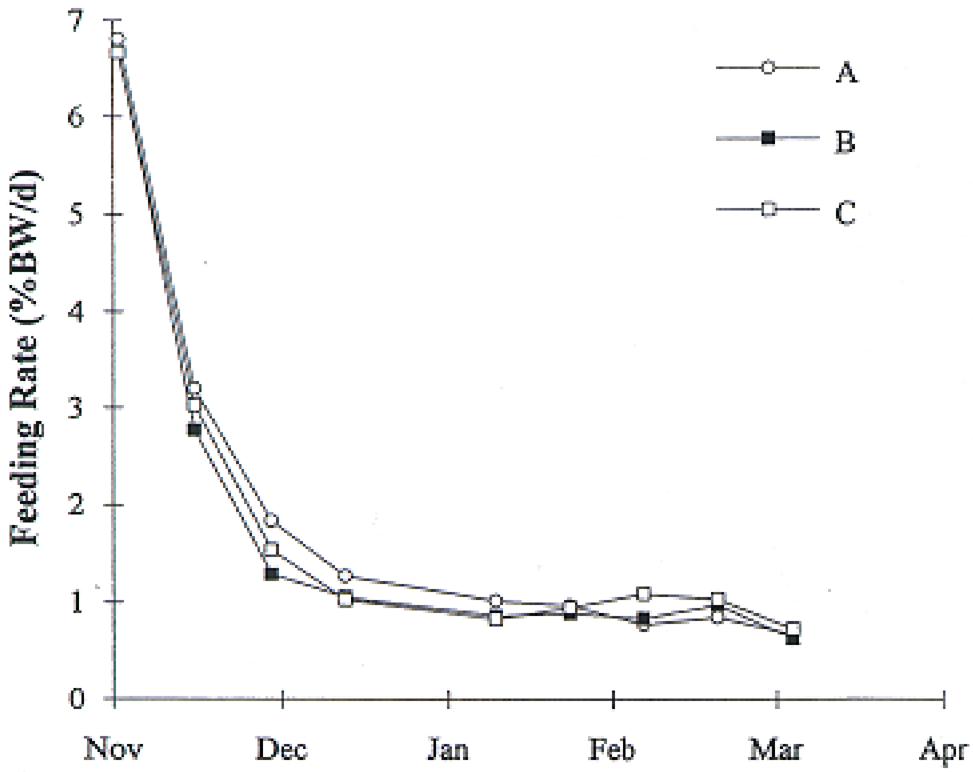
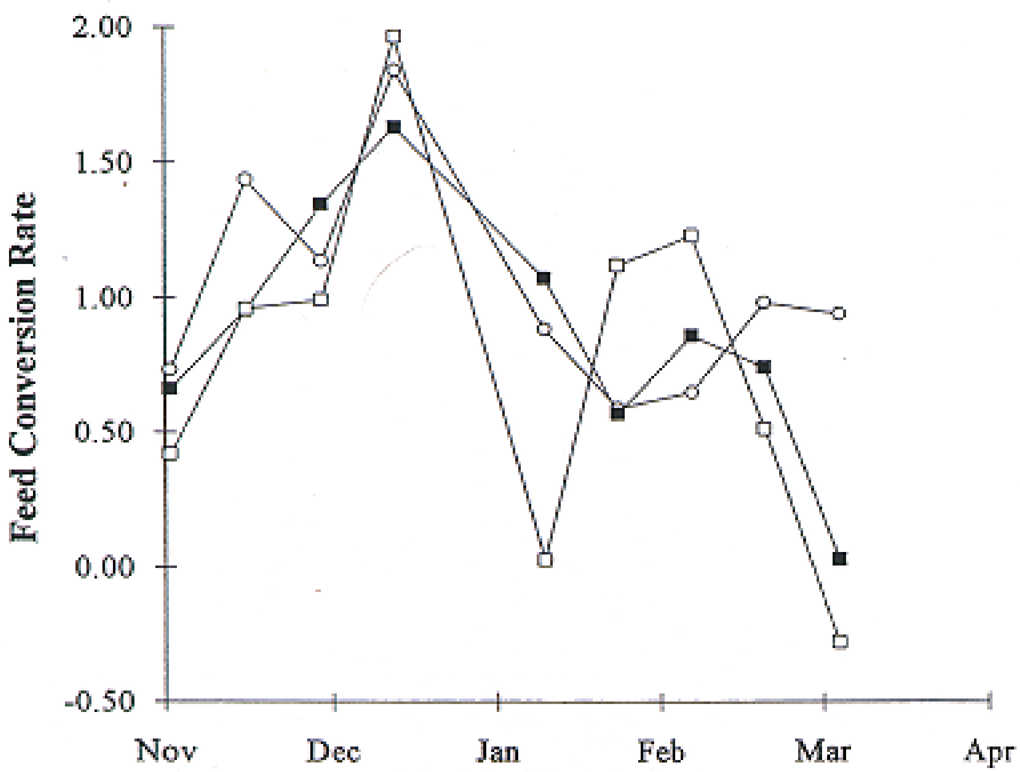


Figure 2. Changes in feeding rate and feed conversion rate during culture for ponds in each treatment.


Feeding Rate (%BW/d)
7
6
5
4
3
2
1
0
A
B
C
Nov
Dec
Jan
Feb
Mar
Apr


Feed Conversion Rate
2.00
1.50
1.00
0.50
0.00
-0.50
Nov
Dec
Jan
Feb
Mar
Apr

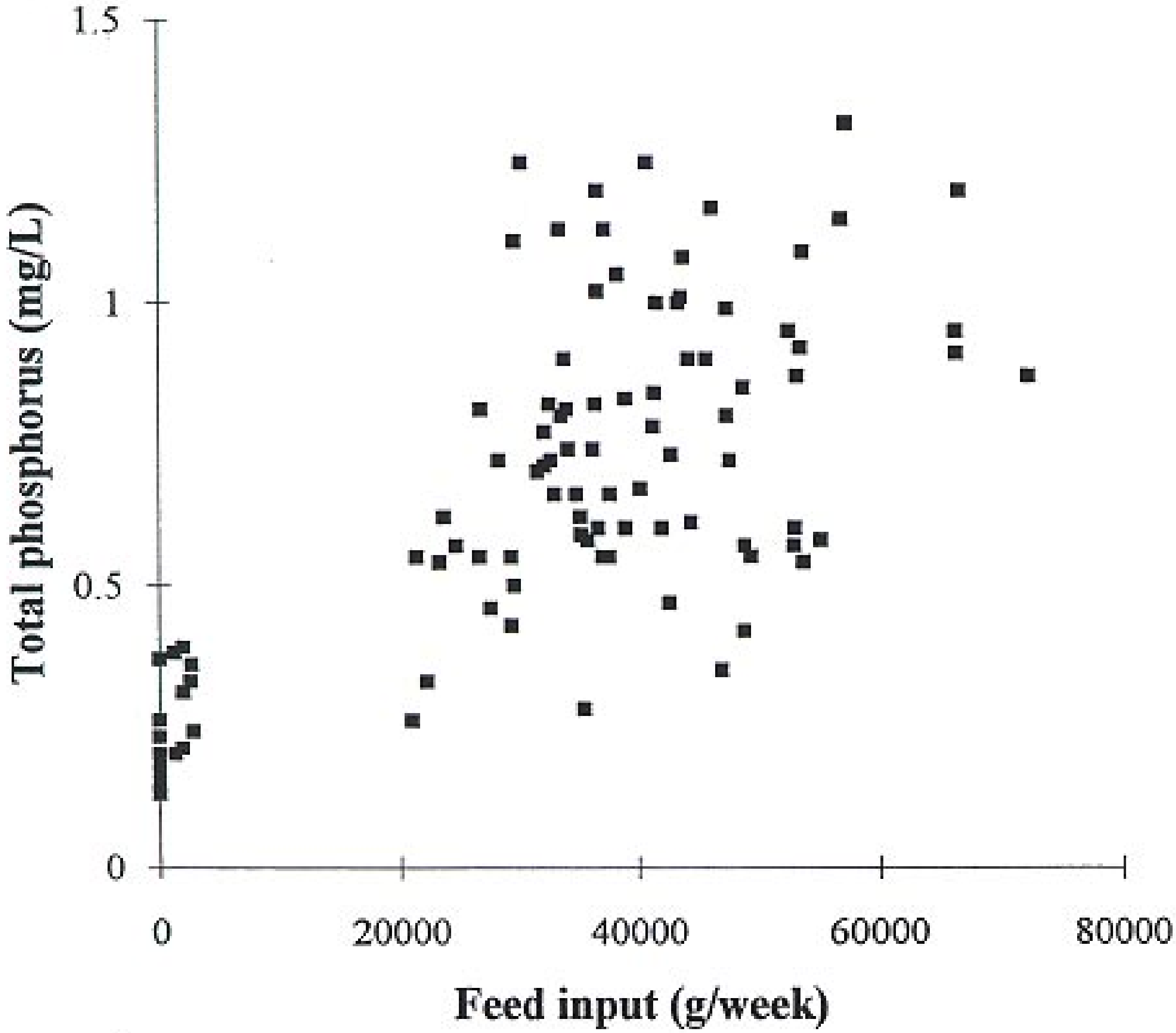


Figure 5. Relationship between total phosphorus and feed input in ponds of all treatments.

Discussion

Growth and survival of tilapia differed as expected among treatments, with best growth and survival at lowest density. Trends in growth rate among treatments were clearly differentiated by the first month sample. Growth was rapid in all ponds, and reached rates near the maximum measured for tilapia. However, reductions in growth which occurred at high density did not appear to be due to poor water quality, because water quality did not differ significantly among treatments. 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. Supporting evidence was also obtained through statistical analysis, as the only variable that differed among treatments (chlorophyll-*a*) is a measure of natural food density, not poor 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 1.93, 1.78, and 1.87 %BW/d in the low, intermediate, and high density treatments, respectively. 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.

The application of this study to tilapia management is not entirely clear. Most rapid growth and highest survival occurred at 3 fish/m^2. Since increased densities required more feed to achieve the same yield, culture at these densities was inefficient. However, feed conversion values were not significantly different among treatments, contradicting the former statement. The optimal feeding system at present appears to be with tilapia at 3/m^2. The combined application of feed and fertilizer remains an important tool, as even at 9 fish/m^2 with intensive feeding, water quality remained high. However, the enhanced chlorophyll-*a* levels which occurred in heavily fed ponds appeared to result from surplus phosphorus in the water, and may indicate that further fine-tuning of fertilizer balance may be necessary at high feeding rates.

Literature Cited

American Public Health Association (APHA). 1980. Standard methods for the examination of water and waste water. Fifteenth Edition, Washington, D.C.,1134 pp.

Diana, J.S., D.D. Dettweiler, and C.K. Lin. 1991a. Effect of Nile tilapia (*Oreochromis niloticus*) on the ecosystem of aquaculture ponds, and its significance to the trophic cascade hypothesis. Canadian Journal of Fisheries and Aquatic Sciences 48:183-190.

Diana, J.S., C.K. Lin, and P.J. Schneeberger. 1991b. Relationships among nutrient inputs, water nutrient concentrations, primary production, and yield of *Oreochromis niloticus* in ponds. Aquaculture 92:323-341.

Diana, J.S., C.K. Lin, and K. Jaiyen. 1994. Supplemental feeding of tilapia in fertilized ponds. Journal of the World Aquaculture Society 25:497-506.

Diana, J.S., C. K. Lin, and Y. Yi. 1995. Timing of supplemental feeding for tilapia production. Journal of the World Aquaculture Society (submitted).

Egna, H.S., N. Brown, and M. Leslie. 1987. General reference: site descriptions, material and methods for the global experiment. Pond Dynamics/Aquaculture Collaborative Research Data Reports, Volume 1. Oregon State University, Corvallis, Oregon. 84 pp.

Green, B.W. 1992. Substitution of organic manure for pelleted feed in tilapia production. Aquaculture 101:213-222.

Knud-Hansen, C.F., C.D. McNabb, and T.R. Batterson. 1991. Application of limnology for efficient nutrient utilization in tropical pond aquaculture. Proceedings of the International Association of Theoretical and Applied Limnologists 24:2541-2543.

Piedrahita, R.H. 1988. Introduction to computer modeling of aquaculture pond ecosystems. Aquaculture and Fisheries Management 19:1-12.

Wilkinson, L. 1990. SYSTAT: The system for statistics. SYSTAT, Inc., Evanston, Illinois.