The Effects of Fertilization on Growth and Production of Nile Tilapia in Rain-Fed Ponds

Work Plan 7, Thailand Study 1

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(Printed as Submitted)

Introduction

Semi-intensive production of Nile tilapia *Oreochromis niloticus* commonly utilizes organic and inorganic fertilizers to increase primary production and fish yield. Most experiments on such systems are done at fish culture stations where water supplies are readily available, and water loss through evaporation or by seepage is replaced regularly, often weekly. Rainfall during such experiments may also flush the ponds, reducing nutrient concentrations and improving water quality. In such systems, regular fertilization at high input levels can result in yields approaching 3,500 kg / ha over 5 months, or extrapolated yields of up to 10,000 $kg \cdot ha^{-1} \cdot yr^{-1}$ (Knud-Hansen et al. 1993, Diana 1996). Optimal fertilization rates in Thailand determined to be 28 $kg\ N \cdot ha^{-1} \cdot wk^{-1}$ and an N:P ratio of 4:1 (Knud-Hansen et al., 1993). The fertilization schedule was weekly in these ponds, where combinations of chicken manure and urea or triple super phosphate were used for inputs. Knud-Hansen et al. (1993) believed that inorganic fertilizer produced higher yields than manures at the same loading rates. However, Diana et al. (1994) found reductions in alkalinity in some ponds fertilized with inorganic fertilizers alone which they believed were due to carbon extraction for photosynthesis. No declines in alkalinity were noted in ponds fertilized with manure and inorganic fertilizer or ponds receiving inorganic fertilizer and feed.

The effectiveness of fertilization in rain-fed ponds may differ considerably from ponds receiving water inputs. During the rainy season, these ponds fill and may flush, while during the dry season only evaporation and seepage occur. Rain-fed ponds are generally dug deeper to hold more water during the wet season, and water depth declines during the dry season. Thus, there are two characteristics of importance: increased pond depth and a stagnant water supply. Stagnant water may require less nutrients to maximize fish production, since flushing does not occur. The schedule of fertilization may also differ. However, Knud-Hansen and Batterson (1994) found that fertilization frequencies varying from daily to once every three weeks had no effect on primary production or fish yield in ponds with water inputs.

The purpose of this study was to evaluate fertilization strategies for rain-fed ponds based on strategies developed in ponds with regular water inputs. To accomplish this, four experimental treatments were utilized: (a) fertilization every two weeks with water replacement, (b) fertilization every two weeks without water replacement, (c) fertilization once at the start of culture without water replacement, and (d) fertilization irregularly (when water concentrations of nutrients declined) without water replacement.

Materials and Methods

Data for this study were collected at the Huay Luang Freshwater Fisheries Station located near Udorn (17˚ 27' N, 102˚48' E), approximately 160 km northeast of Bangkok, Thailand. Fifteen ponds used in the experiments were 1600 m^3 in volume, 800 m^2 in surface area, and originally filled to a depth of 2.5 m. All ponds were fertilized with chicken manure (assayed at 89% dry matter, 1.4% N, and 1.2 % P) and enough urea and triple super phosphate (TSP) to produce an N:P ratio of 4:1 and total N addition to the desired treatment level.

Table 1. The biomass (g), number, and mean weight (g) of tilapia stocked and harvested from each pond.

Pond	At Stocking			At Harvest		
	Mean Weight	Number	Biomass	Mean Weight	Number	Biomass
A1	18.8	1600	30	194.5	1508	308
A2	17.5	1600	28	178.2	1591	299
A3	15.1	1600	24	263.0	1301	333
B1	17.3	1600	28	220.5	1461	347
B2	19.0	1600	30	218.4	1599	368
B3	13.3	1600	21	232.8	1480	346
C1	12.2	1600	20	47.7	1194	55
C2	14.2	1600	23	30.0	1281	36
C3	14.1	1600	23	23.5	659	14
D1	13.3	1600	21	158.5	1467	240
D2	14.6	1600	23	153.5	1540	235
D3	15.6	1600	25	151.3	1068	173

Four fertilization treatments were used: a) weekly fertilization with water addition, b) weekly fertilization without water addition, c) one fertilization at the start without water addition, and d) fertilization at irregular intervals dependent on the nutrient concentrations of the pond water, without water addition. Treatments A, B, and D were fertilized with 22.5 kg chicken manure, 4.5 kg urea, and 1.4 kg TSP per pond at each dosing. These rates equaled 280 kg $\cdot$ ha^{-1} $\cdot$ wk^{-1} manure, 56 kg $\cdot$ ha^{-1} $\cdot$ wk^{-1} urea, and 17.5 kg $\cdot$ ha^{-1} $\cdot$ wk^{-1} TSP. Treatment C received 89 kg chicken manure, and 2.4 kg urea at the start of the experiment, with no further additions. Treatment D received a new dose of fertilizer when dissolved inorganic nitrogen (DIN) levels in the water declined below 0.5 mg/L.

Each fertilization treatment was done in triplicate. Sex-reversed Nile tilapia were stocked on 8 September 1994. Stocking density was 2 fish/m^2 (1600 fish per pond) and size at stocking averaged 15 g (Table 1). Every two weeks, 20 fish from each pond were sampled, individually weighed (to 1 g), and measured in length (to 1 mm). Growth rate was calculated as the increase in weight per day between sampling periods.

Physical and chemical data were collected in a similar manner to earlier experiments (Diana et al. 1991b, 1994). Meteorological data, including solar radiation, rainfall, and wind speed were collected daily. For most water analyses, combined 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, soluble-reactive phosphorus, 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 0530 hr, 1200 hr, 1800 hr, 2400 hr, and 0600 hr in each pond. These diel analyses were repeated about monthly on water from depths of 5 cm (top), 30 cm, 100 cm, 150 cm, and 180 cm (bottom). Maximum temperature and oxygen differentials were calculated as the difference between top and bottom measurements at 1800 hr.

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

Pond	Growth	Survival	Yield	Annual Yield
A1	0.75	94	3479.38	5427.23
A2	0.69	99	3386.90	5282.99
A3	1.06	81	3853.85	6011.35
B1	0.87	91	3988.13	6220.79
B2	0.85	100	4215.90	6576.08
B3	0.94	93	4059.15	6331.58
C1	0.15	75	446.08	695.80
C2	0.07	80	168.50	262.83
C3	0.04	41	-110.79	-172.82
D1	0.62	92	2734.13	4264.77
D2	0.59	96	2642.83	4122.36
D3	0.58	67	1851.30	2887.71

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.

One interest in this study was to determine the accumulation of nutrients and metabolites in pond waters. This accumulation was estimated by averaging values over the first two water sampling periods (8 and 22 September 1994) as estimates of initial water chemistry, then over the last two sampling periods (9 and 23 March 1995) as the final water chemistry.

Statistical analyses were conducted using SYSTAT (Wilkinson 1990). Overall growth (g / day) and net yield (kg) were calculated for each pond. Average overall values for physical and chemical parameters and total fertilizer input were also calculated. Multiple regressions between growth rate and design variables (fertilizer input, depth) 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. Significantly correlated variables were then examined for auto correlation, and acceptable variables input to the multiple regression to evaluate determinants of fish growth. 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. Accumulation or loss of materials in the water over time was estimated by comparing initial and final values with a t-test, using data for each treatment. All differences were considered significant at an alpha of 0.05.

Results

There were significant differences in growth rate among treatments, with treatments A and B having the highest growth rate, D with an intermediate growth, and C with no growth at all (Figure 1, Table 2). Growth rates in treatments A and B averaged 0.86 g / d. Survival was variable among ponds, but was not significantly different among treatments and averaged 84%. Yield showed similar trends to growth rate, with the highest yields occurring in Treatments A and B, the lowest in C, and statistically significant differences.

Table 3. Treatment-related values for physical and chemical variables measured throughout the experiment. Values with the same superscript are not significantly different. Variable names with superscripts had no significant differences among treatments.

Variables	A	B	C	D
Alkalinity[1]	93.4	92.5	96.8	89.4
Chlorophyll *a*	75.8[1]	59.3[1]	12.8	59.2[1]
Depth	248.9	207.8[1]	194.4[1]	205.7[1]
Ammonia	0.345[1]	0.405[1]	0.047[1]	0.314[1]
Nitrite	0.374[1]	0.410[1]	0.059[2]	0.107[2]
Nitrate	0.438[1]	0.461[1]	0.071[2]	0.189[2]
Soluble reactive P	0.448[1]	0.407[1]	0.141[2]	0.217[2]
Secchi disk depth[1]	34.7	34.4	34.6	34.4
DIN	1.16[1]	1.28[1]	0.177[2]	0.611[3]
Total P	0.533[1]	0.477[1]	0.113[2]	0.295[3]
Total suspended solids[1]	34.4	40.5	28.8	38.3
Total volatile solids	12.8[1]	11.7[1]	5.8	11.9[1]

Depth of water declined throughout the experiments in ponds without water replacement (Figure 2). There was no effect of fertilization on water depth. Depth averaged 242 cm upon initiation of experiments and declined to 158 cm at harvest in ponds without water replacement.

Several physical and chemical variables also varied by treatment. Nitrogen and phosphorus levels in water differed by treatment, with treatments A and B showing similar levels, which were often significantly higher than D, which in turn was often significantly higher than C (Table 3). This was true for ammonia, nitrite, nitrate, DIN, soluble-reactive phosphorus, and total phosphorus. Also, chlorophyll- *a* content differed significantly by treatment in the same manner.

Fish growth rates were strongly correlated to the treatment variable of manure input but not to water depth (Table 4). This correlation was very strong ($R^2 = 0.89$), and residuals were not correlated to any physical or chemical variables. Survival was not significantly correlated to the design variables. Yield was again strongly and significantly correlated to fertilizer input only ($R^2 = 0.94$), and the residuals were not correlated to any physical or chemical variables.

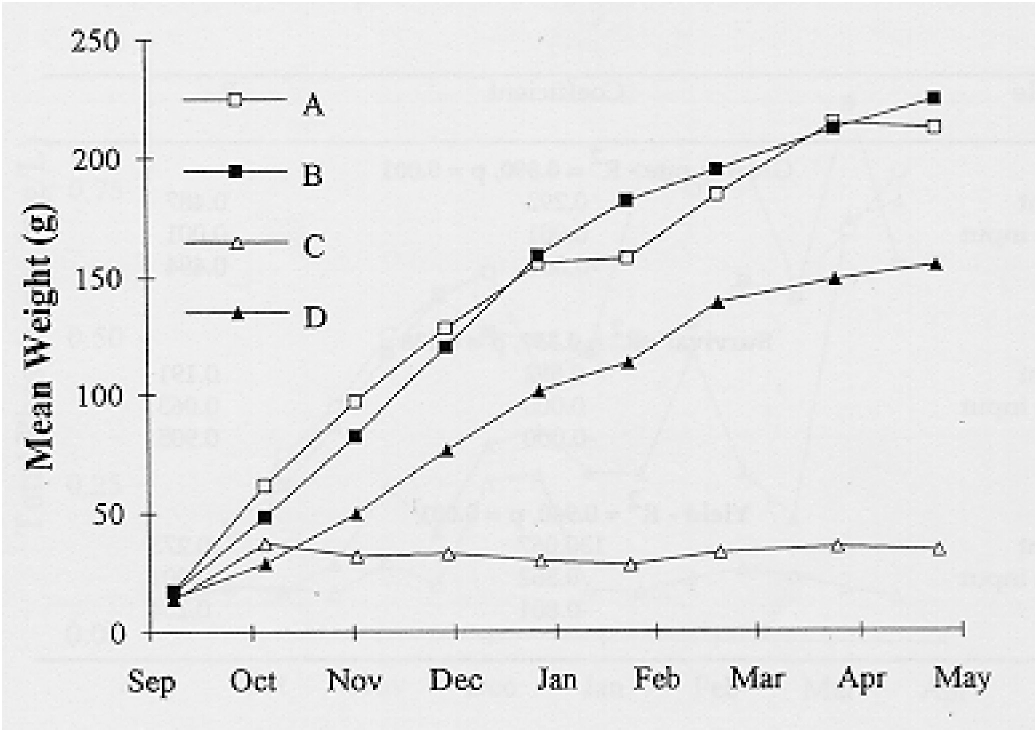

Figure 1. Changes in mean weight throughout the experiment for fish from each fertilization treatment.

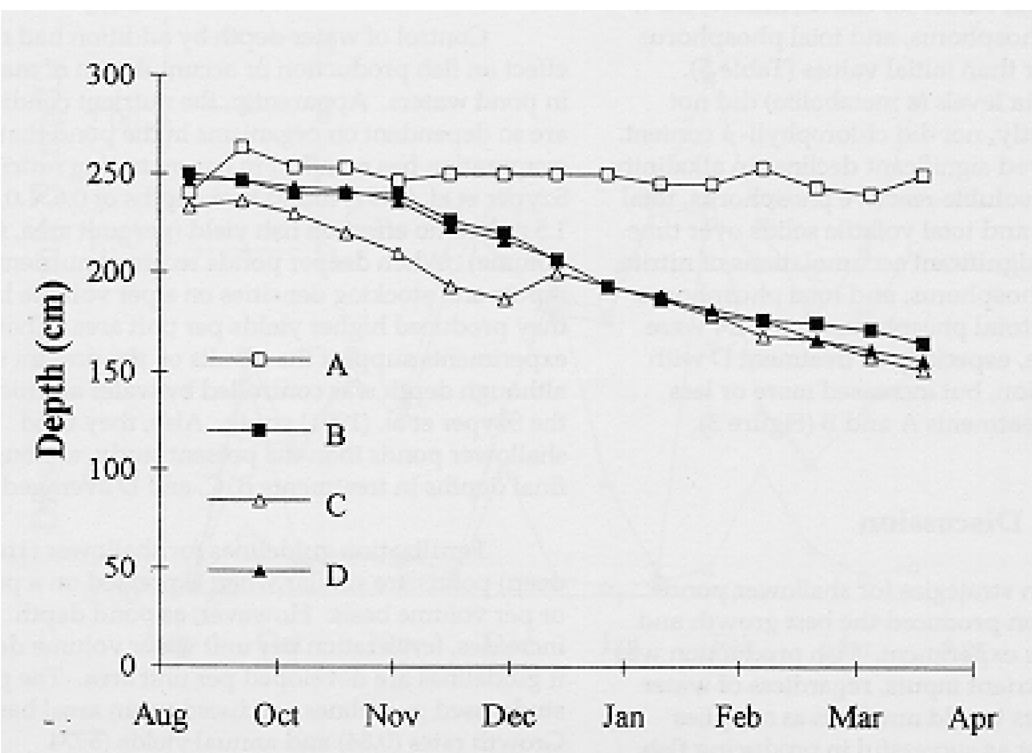

Figure 2. Changes in mean water depth throughout the experiment for ponds from each treatment.

Table 4. Results of multiple regression analyses for fish growth (g / d), survival (%), and yield (kg / pond).

Variable	Coefficient	P
	Growth rate - R^2 = 0.890, p = 0.001	
Constant	0.292	0.487
Manure input	0.001	0.001
Depth	-0.002	0.494
	Survival - R^2 = 0.337, p = 0.138	
Constant	0.692	0.191
Manure input	0.000	0.063
Depth	-0.000	0.905
	Yield - R^2 = 0.940, p = 0.001	
Constant	130.067	0.273
Manure input	0.562	0.001
Depth	-0.801	0.204

One concern in rain-fed ponds was that nutrients and metabolites might accumulate at deleterious levels as time progressed. Treatments A and B showed significant accumulation of nutrients over time, with final values for nitrite, nitrate, DIN, soluble-reactive phosphorus, and total phosphorus being much higher than initial values (Table 5). However, ammonia levels (a metabolite) did not increase significantly, nor did chlorophyll- *a* content. Treatment C showed significant declines in alkalinity, ammonia, nitrate, soluble-reactive phosphorus, total suspended solids, and total volatile solids over time. Treatment D had significant accumulations of nitrite, soluble-reactive phosphorus, and total phosphorus. Accumulations of total phosphorus and DIN were sporadic over time, especially in treatment D with irregular fertilization, but increased more or less continuously in treatments A and B (Figure 3).

Discussion

Fertilization strategies for shallower ponds with water addition produced the best growth and yield of fish in this experiment. Fish production was similar at high nutrient inputs, regardless of water addition. Attempts to add nutrients as supplies dwindled were not as successful in producing fish. These results all indicate that fertilization guidelines may be much more generally applicable than to ponds with similar depths and water management systems.

Control of water depth by addition had no effect on fish production or accumulation of materials in pond waters. Apparently, the nutrient conditions are so dependent on organisms in the pond that evaporation has no effect in concentrating nutrients. Szyper et al. (1991) found that depths of 0.6, 1.0, and 1.5 m had no effect on fish yield (per unit area, not volume). When deeper ponds received nutrient inputs and stocking densities on a per volume basis, they produced higher yields per unit area. These experiments support the results of the present study, although depth was controlled by water addition in the Szyper et al. (1991) study. Also, they used shallower ponds than the present study, although the final depths in treatments B, C, and D averaged 1.5 m.

Fertilization guidelines for shallower (1m deep) ponds are similar when expressed on a per area or per volume basis. However, as pond depth increases, fertilization per unit water volume declines if guidelines are developed per unit area. The present study used guidelines produced on an areal basis. Growth rates (0.84) and annual yields (5974 $kg \cdot ha^{-1} \cdot yr^{-1}$) were somewhat lower than found in

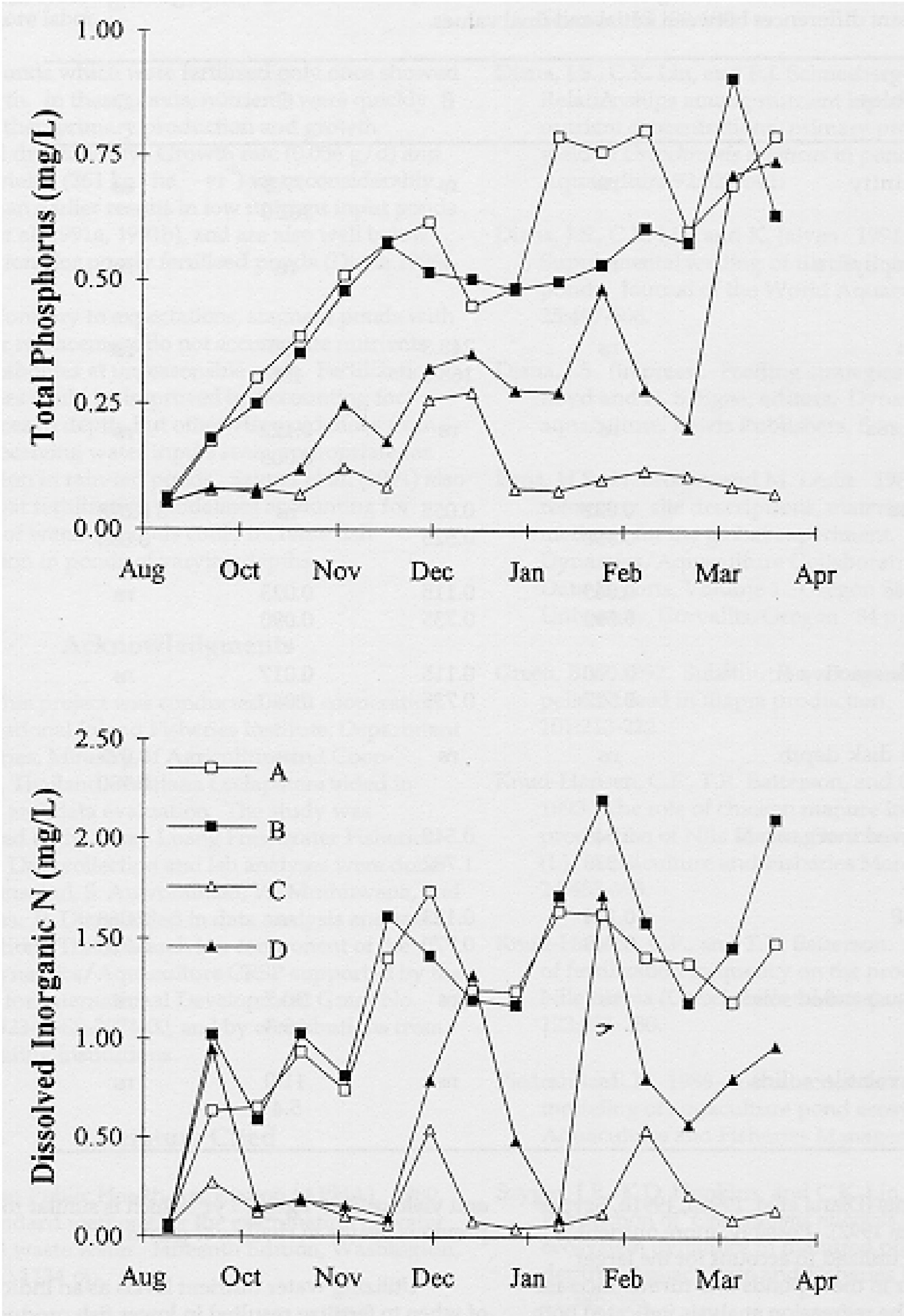

Figure 3. Changes in total phosphorus (top) and dissolved inorganic nitrogen (bottom) throughout the experiment in ponds from each treatment.

Table 5. Time-related values for physical and chemical variables measured throughout the experiment. Treatments with two values indicate significant time differences, and are listed with beginning values first; ns = no significant differences between initial and final values.

Variables	A	B	C	D
Alkalinity	ns	ns	77.3 102.0	ns
Chlorophyll *a*	ns	ns	ns	ns
Depth	ns	248.3 168.3	235 155	ns
Ammonia	ns	ns	0.122 0.005	ns
Nitrite	0.032 0.558	0.055 0.523	ns	0.028 0.095
Nitrate	0.065 0.592	0.115 0.735	0.023 0.090	ns
Soluble reactive P	0.030 0.527	0.115 0.735	0.017 0.040	ns
Secchi disk depth	ns	ns	ns	0.027 0.180
Dissolved inorganic N	0.343 1.333	0.540 1.782	ns	ns
Total P	0.114 0.743	0.123 0.770	ns	0.068 0.728
Total suspended solids	ns	ns	30.7 15.3	ns
Total volatile solids	ns	ns	11.0 5.4	ns

other experiments (Diana et al. 1991a, 1991b, Szyper et al. 1991, Green 1992). Possibly, more nutrient inputs could be utilized to account for the larger volume of water in these ponds and further increase productivity. The regression analysis indicated both growth and yield increased significantly with manure input. Using that regression, a manure input of 316 $kg \cdot ha^{-1} \cdot wk^{-1}$ would result in fish growth of 1 g/d and yield of 7039 $kg \cdot ha^{-1} \cdot yr^{-1}$ which is similar to the previous results in shallower ponds.

Utilizing water nutrient levels as an indicator of when to fertilize resulted in lower fish production. Since nutrient levels were only measured biweekly, the only adjustment which could be made was to reduce nutrient input. More frequent measures of nutrients might allow such a system to more efficiently utilize nutrients, although it would require much more labor.

Ponds which were fertilized only once showed no growth. In these ponds, nutrients were quickly utilized then primary production and growth declined dramatically. Growth rate (0.086 g / d) and annual yields (261 kg · ha^{-1} · yr^{-1}) were considerably lower than earlier results in low nutrient input ponds (Diana et al. 1991a, 1991b), and are also well below expectations for poorly fertilized ponds (Diana 1996).

Contrary to expectations, stagnant ponds with no water replacement do not accumulate nutrients and metabolites at unreasonable rates. Fertilization guidelines could be improved by accounting for differences in depth, but otherwise guidelines from ponds receiving water inputs seem appropriate for production in rain-fed ponds. Szyper et al. (1991) also found that fertilization guidelines accounting for volume of water in ponds could increase fish production in ponds of varying depths.

Acknowledgments

This project was conducted with cooperation of the National Inland Fisheries Institute, Department of Fisheries, Ministry of Agriculture and Cooperatives, Thailand. Wattana Leelapatera aided in logistics and data evaluation. The study was conducted at the Huay Luang Freshwater Fisheries Station. Data collection and lab analyses were done by V. Tansakul, S. Auworatham, W. Muthuwana, and assistants. B. Diana aided in data analysis and text preparation. This research is a component of the Pond Dynamics / Aquaculture CRSP supported by the Agency for International Development Grant No. DAN-4023-G-SS-2074-00, and by contributions from participating institutions.

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