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The Effects of Fertilization and Water Management on Growth and Production of Nile Tilapia in Deep Ponds During the Dry Season

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Abstract

Fertilization guidelines developed for shallow ponds (1 m) with controlled depths were tested in deeper (2.5 m) ponds to determine effectiveness of these guidelines for culture of Nile tilapia *Oreochromis niloticus*. Twelve ponds of 2.5-m depth were used in four treatments: (A) weekly fertilization with water addition; (B) weekly fertilization without water addition; (C) one early fertilization without water addition; and (D) fertilization frequency dependent on nutrient concentrations, without water addition. Sex-reversed Nile tilapia were stocked at 2 fish/m^2 with an initial weight of 15 g, and harvested after 234 d. Depth of water declined from 2.4 m to 1.6 m over the experiment in ponds without water addition. Fish growth rate was significantly higher in treatments A and B (0.86 g/d), than in other treatments, as was yield (3,830 kg/ha). Treatment C was lowest in growth (0.086 g/d) and yield (168 kg/ha), with treatment D intermediate. Fish growth rates and yields were strongly correlated to manure input (R^2 = 0.89 and 0.94, respectively), and residuals were not correlated to any physical or chemical variables. Growth and yield in these deep ponds were somewhat lower than those in previous experiments for shallow ponds with regular water inputs. However, stagnant ponds did not accumulate nutrients and metabolites at rates higher than ponds with controlled water depths.

Semi-intensive culture 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 altering water quality. In such systems, regular fertilization at high input levels can result in yields approaching 3,500 kg/ha over 5 mo, or extrapolated yields of up to 10,000 kg/ha per yr (Knud-Hansen et al. 1993; Diana 1997). Optimal fertilization rates in Thailand were determined to be 28 kg N/ha per wk and an N:P ratio of 4:1 by weight (Knud-Hansen et al. 1993). These ponds were fertilized weekly with combinations of chicken manure and urea or triple super phosphate. Knud-Hansen et al. (1993) believed that inorganic fertilizer produced higher yields than manures at the same N loading rates. However, Diana et al. (1994) found reductions in alkalinity in some ponds fertilized with inorganic fertilizers alone that were attributed 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 watershed ponds may differ considerably from ponds receiving regular water inputs. During the rainy season, water levels in these ponds increase and the ponds may flush, while during the dry season only evapora-

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tion and seepage occur. Such watershed ponds are generally constructed to hold more water during the wet season, so water depth and pond area decline 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 tilapia ponds with water inputs. Similarly Doyle and Boyd (1984) and Boyd (1990) showed limited effects of fertilization timing on primary production or fish yield in largemouth bass *Micropterus salmoides* and bluegill *Lepomis macrochirus* ponds.

The purpose of this study was to evaluate fertilization strategies for deep ponds based on strategies developed in shallow ponds with regular water inputs. To accomplish this, four experimental treatments were utilized: (A) weekly fertilization with water addition; (B) weekly fertilization without water addition; (C) fertilization once at the start of culture without water addition; and (D) fertilization irregularly (when water concentrations of nutrients declined) without water addition.

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 600 km northeast of Bangkok, Thailand. Twelve ponds used in the experiments were 1,600 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 (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 by weight and total N addition to the desired treatment level.

Four fertilization treatments were used: (A) weekly fertilization with regular water addition; (B) weekly fertilization without water addition; (C) one early fertilization without water addition; and (D) fertilization frequency dependent on nutrient concentrations, without water addition. Ponds in 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 application. These rates equaled 280 kg/ha per wk manure, 56.3 kg/ha per wk urea, and 17.5 kg/ha per wk TSP. Ponds in treatment C received 89-kg chicken manure and 2.4-kg urea at the start of the experiment, with no further additions. Ponds in treatment D received an application of fertilizer when dissolved inorganic nitrogen (DIN) levels in the water declined below 0.5 mg/L, which is near the threshold level of 0.25 mg/L that Diana et al. (1997) found was commonly maintained in tilapia ponds fertilized weekly. Each fertilization treatment was done in triplicate.

Sex-reversed Nile tilapia were stocked on 8 September 1994 at 2 fish/m^2 (1,600 fish per pond). Size at stocking averaged 15 g (Table 1). Every 2 wk, 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. Fish were harvested on 30 April 1995 after 234 d of culture.

Physical and chemical data were collected regularly. For most water analyses, integrated water column samples were taken from the end of walkways extending to the center of the ponds. Temperature, dissolved oxygen (both taken at four depths in the water column), ammonia, nitrate, nitrite, soluble-reactive phosphorus, total phosphorus, alkalinity, pH, Secchi-disk depth, and chlorophyll *a* content were measured biweekly using standard methods (APHA 1980; Egna et al. 1987). Monthly, vertical distribution of dissolved oxygen and temperature was determined at 0600, 1200, 1800, 2400, and 0600 h in each pond at depths of 30 cm, 100 cm, 150 cm, and 180

TABLE 1. *The biomass (kg), number and mean size (g) of tilapia stocked and harvested from each pond.*

	At stocking			At harvest		
Pond	Mean weight	Number	Biomass	Mean weight	Number	Biomass
A1	18.8	1,600	30	194.5	1,508	308
A2	17.5	1,600	28	178.2	1,591	299
A3	15.1	1,600	24	263.0	1,301	333
B1	17.3	1,600	28	220.5	1,461	347
B2	19.0	1,600	30	218.4	1,599	368
B3	13.3	1,600	21	232.8	1,480	346
C1	12.2	1,600	20	47.7	1,194	55
C2	14.2	1,600	23	30.0	1,281	36
C3	14.1	1,600	23	23.5	659	14
D1	13.3	1,600	21	158.5	1,467	240
D2	14.6	1,600	23	153.5	1,540	235
D3	15.6	1,600	25	151.3	1,068	173

cm. Maximum temperature and oxygen differentials were calculated as the difference between top (30 cm) and bottom (180 cm) measurements at 1800 h.

The accumulation of nutrients and metabolites in pond waters was estimated by calculating the difference between average values over the first two water sampling periods (8 and 22 September 1994) as estimates of initial water chemistry, and average values 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/d) 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 conducted to evaluate the relative importance of 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 autocorrelation, and variables which were not autocorrelated were then input to the multiple regression to evaluate determinants of fish growth. These variables were included in the regression if $P < 0.10$. Treatment effects on fish growth or chemical variables were tested with the biweekly data set by analysis of variance (ANOVA) and the least significant difference test. Accumulation or loss of materials in the water over time were 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 of Nile tilapia among treatments, with fish in treatments A and B having the highest growth rate (0.86 g/d), D with intermediate growth, and C with no growth at all (Fig. 1, Table 2). 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 (about 4,000 kg/ha) occurring in treatments A and B, the lowest in C, and statistically significant differences between treatments.

Water depth declined throughout the experiments in ponds without water replacement (Fig. 2). There was no effect of fertilization treatments (B, C, or D) on water depth in stagnant ponds. Depth averaged 242 cm upon initiation of experiments and declined to 158 cm at harvest in ponds without water addition.

Vertical stratification of oxygen and tem-

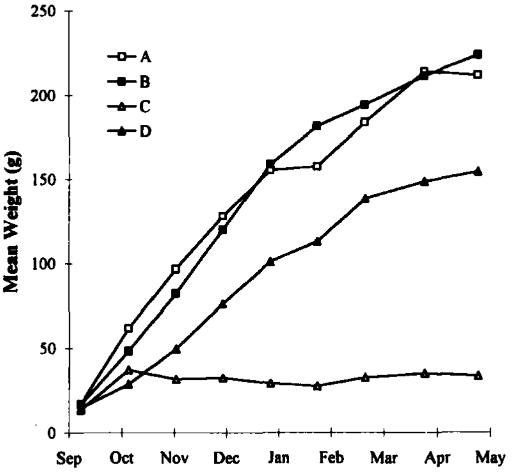

FIGURE 1. *Changes in mean weight throughout the experiment for fish from each fertilization treatment.*

TABLE 2. *Growth, survival, yield, and forecasted annual yield for tilapia from each pond.*

Pond	Growth (g/d)	Survival (%)	Yield (kg/ha)	Annual yield (kg/ha per yr)
A1	0.75	94	3,479	5,427
A2	0.69	99	3,387	5,283
A3	1.06	81	3,854	6,011
B1	0.87	91	3,988	6,221
B2	0.85	100	4,216	6,576
B3	0.94	93	4,059	6,332
C1	0.15	75	446	696
C2	0.07	80	169	263
C3	0.04	41	−111	−173
D1	0.62	92	2,734	4,265
D2	0.59	96	2,643	4,122
D3	0.58	67	1,851	2,888

perature was a regular feature of ponds in all treatments, and there were no significant differences in oxygen or temperature differentials among treatments. Peak stratification occurred at 1800 h, and the deeper pond water (≥180 cm) mixed on occasion but not every night sampled (Fig. 3).

Several physical and chemical variables also varied by treatment. Various nitrogen and phosphorus levels in water were similar between treatments A and B, which were significantly higher than treatment D, which in turn was 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 manure input but not to water depth (Table 4). This correlation was very strong (R^2 = 0.89), and residuals were not corre-

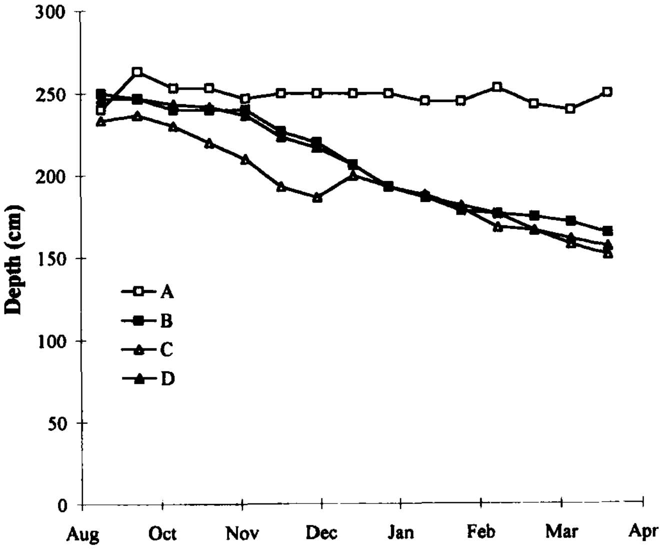

FIGURE 2. *Changes in mean water depth throughout the experiment for ponds from each treatment.*

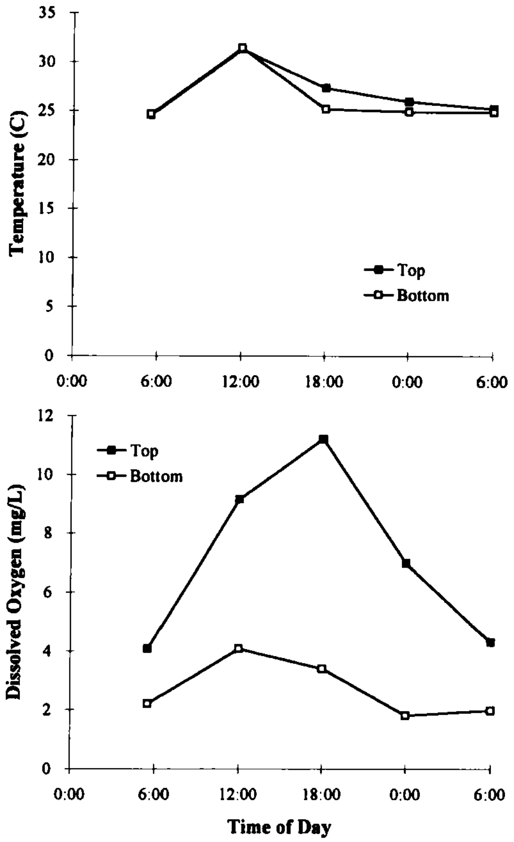

FIGURE 3. *Diel changes in temperature (upper) and oxygen (lower) conditions at the surface (30 cm) and bottom (180 cm) of experimental ponds from all treatments combined.*

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

lated to any physical or chemical variables. Survival was not significantly correlated to the design variables. Yield was strongly and significantly correlated to fertilizer input only ($R^2 = 0.94$), and the residuals were not correlated to any physical or chemical variables.

One concern in deeper ponds from treatments B, C, and D was that nutrients and metabolites might accumulate to deleterious levels as time progressed during the dry season. Treatments A and B had significant accumulation of nutrients over time, with final values for nitrate, nitrite, DIN, soluble-reactive phosphorus, and total phosphorus

TABLE 3. *Treatment-related values for physical and chemical variables measured throughout the experiment. Values with a similar superscript are not significantly different. Variable names followed by NSD had no significant differences among treatments.*

	Treatments			
Variables	A	B	C	D
Alkalinity$^{\mathrm{NSD}}$	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	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$^{\mathrm{NSD}}$	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$^{\mathrm{NSD}}$	34.4	40.5	28.8	38.3
Total volatile solids	12.8^1	11.7^1	5.8	11.9^1

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.*

	Treatment			
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	0.050 0.492	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

being much higher than initial values (Table 5). However, ammonia and chlorophyll *a* did not increase significantly. Alkalinity, ammonia, nitrate, nitrite, soluble-reactive phosphorus, total suspended solids, and total volatile solids in treatment C ponds decreased over time. Treatment D ponds 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 ponds with irregular fertilization, but increased more or less continuously in ponds from treatments A and B (Fig. 4).

Discussion

Control of pond depth by water addition had no effect on fish production or accumulation of materials in pond waters. Apparently, the nutrient regime was so regulated by organisms in the pond that evaporation had no strong effect in concentrating nutrients. Szyper et al. (1991) found that regulated pond depths of 0.6, 1.0, and 1.5 m had no effect on fish yield (per unit area, not volume). When deeper ponds (in that study) received nutrient inputs and stocking densities on a per volume basis, they produced higher yields per unit area. Those 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, where the final depths in treatments B, C, and D averaged 1.6 m.

Fertilization strategies originally developed for shallow ponds with regular water addition resulted in best growth and yield of fish in this experiment in deep ponds without water addition. Fish production was

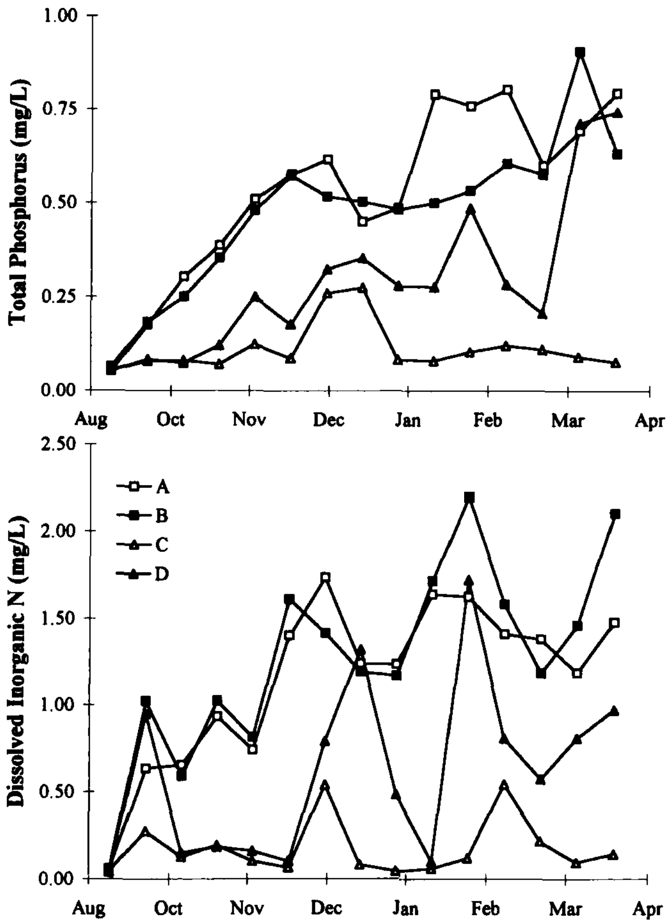

FIGURE 4. *Changes in total phosphorus (top) and dissolved inorganic nitrogen (bottom) throughout the experiment in ponds from each treatment.*

similar at high nutrient inputs whether or not water was added. The management strategy of adding fertilizers as nutrients in pond waters dwindled was not as successful in producing fish as regular fertilization addition. These results indicate that weekly fertilization is much more generally applicable than to ponds with constant depths and water addition.

Fertilization guidelines for shallow (1-m deep) ponds are similar when expressed on a per area or per volume basis. However, as pond depth increases, fertilization input per unit water volume declines if guidelines are developed per unit area. The present study used guidelines developed on an areal basis. Growth rates (0.86 g/d) and annual yields (5,974 kg/ha per yr) were somewhat lower than those measured in other experiments (Diana et al. 1991a, 1991b; Szyper et al. 1991; Green 1992). This may lead one to believe that higher fertilizer input could be utilized in deeper ponds to account for the larger volume of water in these ponds and further increase productivity. However, there was not a significant difference in growth and yield between treatment A (with a depth of 2.5 m) and treatment B (depth declining to 1.6 m) at similar input levels. This result indicates that higher inputs per unit volume would not increase yield in these ponds. It is clear from these and earlier results that water chemistry is a complicated result of nutrient inputs, use by plants, and conditioning by soils, atmosphere and other organisms.

Utilizing water nutrient levels (DIN) as an indicator of when to fertilize resulted in lower fish production. Since nutrient levels were only measured weekly, one could fertilize that week (the same as treatment B) or not fertilize, which would reduce nutrient input. More frequent measures of nutrients and addition of fertilizer might allow phytoplankton to more efficiently utilize nutrients, although it would require much labor.

Ponds that were fertilized only once showed no growth and yield of Nile tilapia. 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 per yr) were considerably lower than earlier results in low nutrient input ponds (Diana et al. 1991b), and were also well below expectations for poorly fertilized ponds (Diana 1997). Surprisingly, these ponds had similar Secchi disk depth to the other treatments, but much lower nutrient and chlorophyll *a* concentrations (Table 3). The water transparency may have been altered by increased clay turbidity in ponds without organic fertilization (Diana et al. 1991b; Teichert-Coddington et al. 1992; Lin et al. 1997), but there was no significant difference in suspended solids among treatments. This result again emphasizes the poor relationship between Secchi disk depth and algal concentration in tropical ponds, as was also noted by Diana et al. (1997).

Contrary to our expectations and to Boyd (1990), nutrients and metabolites did not accumulate by evaporation in stagnant ponds with no water replacement. Fertilization guidelines might be improved by accounting for differences in depth, but otherwise guidelines from ponds receiving water inputs are appropriate for production in deep ponds without regular water addition. Szyper et al. (1991) found that fertilization guidelines accounting for volume of water in ponds could increase fish production in ponds of varying depths.

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