Timing of Supplemental Feeding for Tilapia Production

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Abstract

The staged addition of feed to fertilized fish ponds was evaluated by adding fertilizers to 15 ponds stocked with Nile tilapia *Oreochromis niloticus*, then adding feed at half ad libitum rates once fish in the ponds reached a target weight. Each pond was stocked with 750 fish (3 fish/m²), and each treatment included three ponds with first feeding at (a) 50 g, (b) 100 g, (c) 150 g, (d) 200 g, and (e) 250 g. Ponds in Thailand (at the Ayutthaya Freshwater Fisheries Station, Royal Thai Department of Fisheries) were maintained for 236–328 d until the fish reached 500 g.

Growth was similar for all treatments under fertilizer alone (1.17 g/d) and was also similar when feed was applied (3.1 g/d). Feed application rates averaged 1.17% BW/d, indicating substantial use of natural food. Pond water quality did not deteriorate under supplemental feeding. Feed conversion rates averaged 1.03. Multiple regression indicated that 73.8% of the variance in growth was explained by design variables (feed input and days), while 86.2% of the variance in growth was explained by adding dissolved oxygen content and alkalinity into the equation.

The most efficient system was to grow fish to 100–150 g with fertilizers alone, then add feed. First adding feed (at 50% ad libitum) once fish reached 100 g produced the highest predicted annual revenues ($6,164 per hectare). Results of this experiment indicated that either critical standing crop occurred early (before the first fish sample) or did not occur at all in these ponds.

The culture of Nile tilapia *Oreochromis niloticus* is commonly done worldwide in semi-intensive systems with fertilization. Additionally, feed may be provided for part or all of a grow-out to increase carrying capacity and growth of fish. Earlier experiments indicated that supplemental feeding in fertilized ponds resulted in significantly higher growth rates and greater yields than fertilization alone (Green 1992; Diana et al. 1994). Diana et al. (1994) determined that feeding rates of 50 to 100% ad libitum, combined with fertilization under optimal levels (Knud-Hansen et al. 1991), resulted in similar growth rates and yields. Fish in such systems grew to near 500 g in 160 d,

and yields approached 10,000 kg/ha. Since larger fish often fetch a higher market price, these yields may even be more valuable than increased biomass alone. Early growth of tilapia differed significantly in these feeding treatments, and it was unclear whether critical standing crop was ever reached, or whether it occurred in the first month of grow-out.

Hepher (1978) proposed the concepts of critical standing crop (CSC) and carrying capacity as mechanisms to regulate and understand fish production in aquaculture ponds. According to his data from carp ponds, fish growth was similar in early grow-out stages regardless of inputs. Once the fish grew and reached critical standing crop, growth declined. This growth could

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then be stimulated by increasing inputs, such as moving from fertilization alone to supplemental feeding. Data collected so far are unclear as to the existence and timing of this decline in growth for tilapia (Zonneveld and Fadholi 1991; Green 1992; Diana et al. 1994). The timing and size of fish at CSC is important if management intensity is to be regulated by this concept (Hepher 1978).

The purpose of this experiment was to determine the optimal timing of supplementally feeding Nile tilapia in fertilized ponds, both as a technique to produce larger fish than fertilization alone and also as one means to further determine relationships between growth and critical standing crop. In particular, we hoped to determine appropriate times for initial application of supplemental feed in fertilized ponds.

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. Fifteen earthen ponds used in the experiments were 250 m² in surface area, and normally filled to a maximum depth of 1.0 m (mean depth 0.88 m). All ponds were fertilized weekly with 1.5 kg urea (60 kg/ha) and 0.85 kg triple super phosphate (34 kg/ha).

Five treatments were used to estimate optimal timing for first feed application. In all treatments, sex-reversed males were reared early on fertilizer alone at densities of 3 fish/m². They were ultimately reared until they reached about 500 g. Use of supplemental feed for each treatment was initiated when fish first reached a target weight. The five treatments varied in the size of fish at first feeding, with first feeding occurring when fish reached a mean weight of (a) 50 g, (b) 100 g, (c) 150 g, (d) 200 g, and (e) 250 g. These treatments resulted in different timing of first feeding and harvest for each treatment.

Each feeding treatment was done in trip-

licate. Sex-reversed Nile tilapia were stocked on 15 January 1993. Stocking density was 3 fish/m² and size at stocking averaged 15 g. Every two weeks, 40 fish from each pond were sampled, and individual weight (to 1 g), as well as length (to 1 mm) were determined. Growth rate was calculated as the increase in weight per day between sampling periods. Once the average size of fish in a treatment approximated the target weight, feeding commenced. Floating feed (30% crude protein) was provided to each pond in a treatment. Ad libitum feeding rates were determined for each pond by measuring the total amount of feed eaten from 0700–0900 h and from 1500–1700 h every Monday. Feed was applied sequentially to each pond until all feed was eaten. Feed application rates (50% ad libitum) were then calculated for each treatment, and this rate was applied from Tuesday through Sunday. Feeding was continued until the mean weight of fish in at least two ponds in each treatment was projected to exceed 500 g, then the ponds for that treatment were harvested.

Tilapia reproduction occurred to a limited extent in all ponds. Biomass of fry produced averaged 15.9 kg/pond, with a maximum of 34.3 kg. This was less than 10% of the adult fish biomass in any pond. Fry seined during biweekly sampling were discarded, and fry weights were not included in tilapia growth or yield calculations.

Meteorological data, including solar radiation, rainfall, and wind speed were collected daily. Pond water column samples were analyzed biweekly for ammonia, nitrate-nitrite, orthophosphate, total phosphorus, alkalinity, pH, Secchi-disk depth, and chlorophyll a content using standard methods (APHA 1980; Egna et al. 1987; Diana et al. 1991b). Dissolved oxygen and temperature were measured at the top, middle, and bottom of the water column in early morning. In addition, vertical distribution of dissolved oxygen, temperature, pH, alkalinity, and ammonia was determined at 0600, 0900, 1400, 1600, 1800, 2300, and

0600 h in each pond. These diurnal analyses were repeated monthly on water from the top (25 cm), middle, and 25 cm above the bottom of the water column. Maximum temperature and oxygen differentials were calculated as the difference between top and bottom measurements at 1600 h.

Primary production was determined by oxygen changes in the ponds, using methods described by Hall and Moll (1975) and Piedrahita (1988). Daily oxygen production was corrected for diffusion and nocturnal respiration. Gross primary production (oxygen basis) was then converted to carbon synthesis by relative molecular weights.

Statistical analyses were conducted using SYSTAT (Wilkinson 1990). Overall growth (g/d), net yield (kg), and daily yield (kg/d) were calculated for each pond. Feed conversion rates were calculated as the increase in fish biomass divided by feed applied over the entire experiment. Average overall values for physical and chemical parameters, total days of culture, total days of feeding, total food input, and total fertilizer input were also calculated. Analysis of variance was used to test for treatment differences in means; while analysis of covariance was used to test treatment differences in growth rates (slope of curve between mean size and time). Multiple regressions between growth rate and design variables (feed input, days of culture) were done to test main treatment 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 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. Differences were considered significant at an alpha of 0.05.

Preliminary economic evaluations of each grow-out were done using Pond 3.0 (Copyrighted to Oregon State University, Bolte et al. 1996). Facility costs and labor were not included in the analysis, because the intent was only to compare relative differences in efficiency among treatments, and we assumed the previous costs would be similar for all treatments. Local market prices were used to estimate costs and income, which were all converted into U.S. dollars. Feed prices were set at $0.50/kg, urea and triple super phosphate combined at $0.284/kg, and sex-reversed fry at $0.009 each. Market value of Nile tilapia varied with size: fish from 100–300 g sell at $0.48/kg, from 300–499 g at $0.60/kg, and above 500 g at $0.80/kg.

Results

Initial trajectories for growth rate were similar among all treatments. Once feeding commenced, growth rate of fish in that treatment increased dramatically (Fig. 1). All treatments showed parallel rates of growth under fertilization conditions, and also parallel rates of growth under feeding conditions.

The timing of harvest was problematic among treatments. We intended to project the date at which mean weight of at least two ponds reached 500 g, then harvest. However, we inadvertently let fish in grow-out treatments A through D continue for too long. Treatment A took 236 d to harvest, while it could have been harvested in 196 d. Comparable actual and possible dates were 236 (210) for treatment B, 265 (224) for treatment C, and 305 (266) for treatment D. Since growth rate continued linearly throughout the fed portion of the grow-out, this should not have affected annual yield estimation much.

For various treatments, first feeding occurred between one and eight months after stocking (Fig. 1). While fish were stocked at similar weights (Table 1), their sizes diverged early after initiation of supplemental feeding, and overall weight and growth rate varied with treatment (Tables 2, 3). First feeding occurred on days 38, 80, 153, 178,
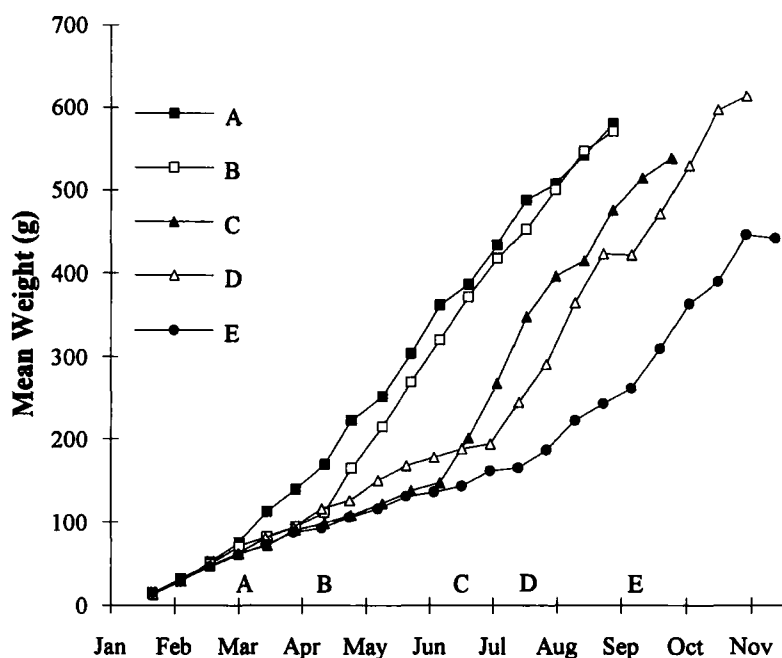
FIGURE 1. *Weekly mean weight for tilapia in each treatment. Treatments were first feeding at: A) 50 g, B) 100 g, C) 150 g, D) 200 g, and E) 250 g. The letters A to E on the x axis indicate dates when supplemental feeding was initiated for each treatment.*

and 234 in treatments A–E, respectively. Growth rates were significantly different during the feeding stage (3.10 g/d) and the fertilizer-only stage (1.17 g/d) of the experiments, but were not significantly different among treatments within a stage. The growth trajectories also did not differ significantly among treatments in the fed or unfed stages (ANCOVA). Ad libitum feeding rates varied from 0.07 to 3.71% body weight per day (%BW/d), and averaged 1.17% BW/d (Fig. 2). There were no significant differences among treatments in ad libitum feeding rates. Similarly, feed conversion rates averaged 1.03, and were not significantly different among treatments.

Fish parameters were sometimes correlated with treatments. Survival and biomass at harvest were not significantly different among treatments (ANOVA). One pond (D3) had extremely low survival and biomass at harvest (Table 2). Both overall growth and yield rates (g/d and kg/d, respectively) were significantly higher in the

two earliest fed treatments than in the latest fed treatment.

Multiple regression analyses indicated that growth rate (g/d) was significantly correlated with the main experimental variables of days and input of feed (Table 4). The regression explained 73.8% of the variation in growth rate. Residuals of the multiple regression for growth rate were significantly correlated with alkalinity ($r = 0.672$, $P = 0.006$), chlorophyll a content ($r = 0.734$, $P = 0.002$), gross primary productivity ($r = 0.700$, $P = 0.004$), total inorganic nitrogen ($r = -0.699$, $P = 0.004$) and dissolved oxygen ($r = 0.628$, $P = 0.012$). Significant positive correlations were found between alkalinity and chlorophyll a, alkalinity and total inorganic nitrogen, alkalinity and gross primary productivity, chlorophyll a and gross primary productivity, and dissolved oxygen and gross primary productivity. Significant negative correlations were found between alkalinity and total inorganic nitrogen, chlorophyll a

TABLE 1. *Weights (mean and SD) at stocking, first feeding, and harvest in each experimental pond, as well as the total amount of feed added to each pond.*

| | Weight (g) | | | | | | | |
| | Stocking | | First feeding | | Harvest | | Feed added (kg/ha) |
Pond	Mean	SD	Mean	SD	Mean	SD	
A1	14.0	5.9	64	18.3	547	86.4	15,923
A2	14.9	5.0	42	12.7	657	120.0	18,352
A3	15.1	5.1	50	10.6	574	72.8	18,268
A	14.7		52		593		17,514
B1	15.7	4.6	99	20.8	686	107.7	15,190
B2	15.3	4.6	140	21.6	523	88.1	13,807
B3	15.2	3.6	94	19.5	579	109.0	13,989
B	15.4		111		596		14,329
C1	15.9	4.5	140	20.1	534	96.1	13,403
C2	15.1	4.5	179	24.0	606	111.7	12,782
C3	14.3	6.9	124	17.1	462	91.7	13,276
C	15.1		148		534		13,154
D1	15.9	3.9	161	26.0	584	100.4	15,387
D2	14.0	5.0	202	24.3	640	119.7	16,939
D3	14.0	3.8	219	39.4	657	114.3	15,407
D	14.6		194		627		15,911
E1	14.8	5.1	273	58.3	502	95.0	11,474
E2	15.9	4.8	269	38.9	553	103.3	11,373
E3	14.0	4.7	187	34.1	410	69.7	10,885
E	14.9		243		488		11,244

TABLE 2. *The biomass, number, and mean size of tilapia harvested from each pond.*

Pond	Biomass (kg)	Number	Size (g)
A1	334.0	611	547
A2	427.4	651	657
A3	393.3	685	574
A	384.9	649	593
B1	455.7	664	686
B2	342.7	655	523
B3	354.4	612	579
B	384.3	644	596
C1	319.3	598	534
C2	371.2	613	606
C3	316.0	684	462
C	353.3	632	534
D1	373.3	639	584
D2	422.7	660	640
D3	223.9	341	657
D	340.0	547	627
E1	333.5	664	502
E2	377.2	682	553
E3	260.8	636	410
E	323.8	661	488

and total inorganic nitrogen, and dissolved oxygen and total inorganic nitrogen. Because of the strengths of correlations and the nature of the variables, the final regression was chosen utilizing alkalinity and dissolved oxygen, as well as the original design variables. This final regression with fish growth included feeding rate, dissolved oxygen and alkalinity and explained 86.2% of the variance in growth (Table 4).

Some chemical parameters varied among treatments in this experiment. Chlorophyll *a* content and alkalinity both differed significantly among treatments (ANOVA), with the latest fed treatment (E) being significantly lower in both values than the next to last fed treatment (D). Also, pH differed significantly, with the three earliest fed treatments having lower pH values than the last two fed treatments. Combined inputs of fertilizer and feed generally resulted in no change in water quality compared to fertil-

TABLE 3. *Growth (g/d), survival (%), change in biomass (kg/ha), and annual yield (kg/ha per yr) for tilapia from each pond.*

| | Growth | | | | | |
Pond	Pre-feeding	During feeding	Overall	Survival	Change in biomass	Annual yield
A1	1.76	2.63	2.32	81.5	12,940	20,535
A2	1.14	2.99	2.79	86.8	16,648	26,420
A3	1.43	2.72	2.43	91.3	15,280	24,249
B1	1.00	3.84	2.92	88.5	17,756	28,178
B2	1.49	2.78	2.21	87.3	13,248	21,024
B3	0.95	3.24	2.45	81.6	13,720	21,773
C1	1.18	3.51	2.00	79.7	12,296	17,328
C2	1.43	4.16	2.28	81.7	14,396	20,288
C3	1.01	2.78	1.73	91.2	12,212	17,210
D1	1.10	3.17	1.90	85.2	14,456	17,647
D2	1.24	3.36	2.10	88.0	16,488	20,127
D3	1.45	3.34	2.15	45.5	8,536	10,420
E1	1.15	2.70	1.51	88.5	12,896	14,618
E2	1.17	3.02	1.67	90.9	14,612	16,563
E3	0.78	2.56	1.23	84.8	10,012	11,349
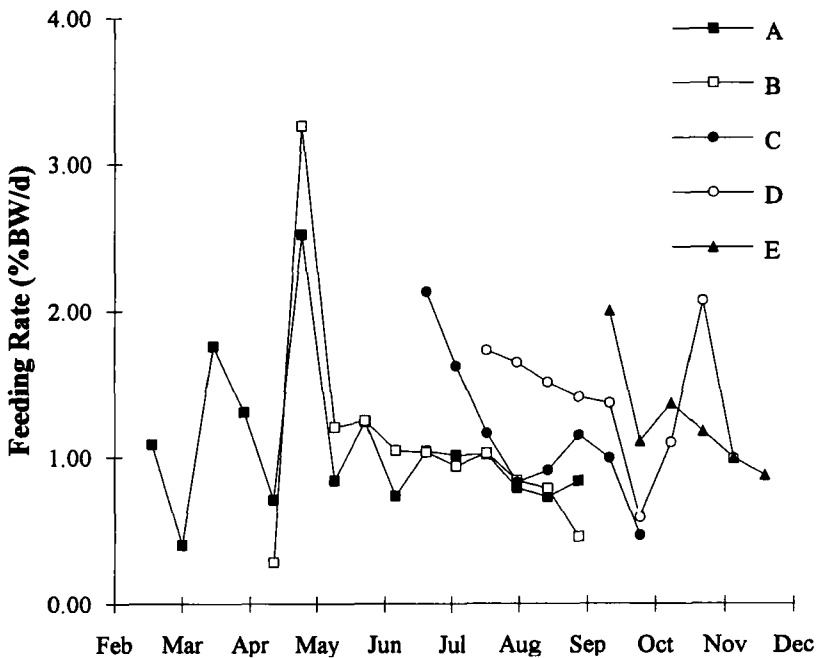
FIGURE 2. *Mean feeding rates (%BW/d) for tilapia in each treatment.*

ization alone, in spite of higher loading rates (Table 5). These feeding rates averaged 116 kg/ha per d (minimum 1.6, maximum 390) during the feeding period. Dissolved oxygen, ammonia, pH, total dissolved phosphorus, total inorganic nitrogen and Secchi disk depth showed no significant differences within a treatment before or after feeding, although they did vary sporadically over time. The only variables showing such an effect were related to strat-

TABLE 4. *Results of multiple regression analyses for fish growth (g/d).*

Variable	Coefficient	P
Main effects–R^2 = 0.738, P = 0.001		
Constant	2.799	0.008
Feed input	0.000	0.028
Days	−0.006	0.009
Overall effects–R^2 = 0.862, P = 0.001		
Constant	179.549	0.124
Feed input	0.001	0.002
Days	0.278	0.320
Dissolved oxygen	33.734	0.006
Alkalinity	1.593	0.002

ification, and included temperature differentials and oxygen differentials. Both of these variables were higher in ponds prior to feeding. Temperature differential was positively correlated to solar radiation, and negatively related to wind velocity and mean weight of fish (multiple regression, R^2 = 0.673, P < 0.001). Oxygen differential was negatively correlated to feed application rate and positively correlated to solar radiation (R^2 = 0.365, P < 0.001). Wind velocity, feed input and mean fish weight all increased significantly during the experiment (correlation, P < 0.05).

The economic analysis (Table 6) indicated that all of the treatments in this experiment would generate a profit, while first feeding at 100 g was most profitable. Inclusion of data from Diana et al. (1994) further clarified tilapia culture economics. Tilapia grown on fertilizer alone produced a reasonable profit, while feeding at full or 0.75 ad libitum was predicted to lose money. This loss of money occurred mainly because the fish were harvested at sizes less

TABLE 5. *Average values for physical and chemical parameters of pond water during the fertilized or fed stage as well as overall values. Most parameters in mg/L, except chlorophyll a (μg/L), gross primary productivity (gO₂/m³ per d), pH, rainfall (mm/d), Secchi disk depth (cm), solar radiation (Einsteins/m² per d) and temperature (C).*

Parameter	Fertilization stage		Fed stage		Overall	
	Mean	SD	Mean	SD	Mean	SD
Alkalinity	86.2	26.9	114.1	34.7	99.8	33.9
Chlorophyll *a*	172	142	415	265	291	243
DO	2.45	1.76	2.47	1.52	2.46	1.64
DO differential	12.6	4.6	7.3	4.4	10.0	5.2
Gross primary production	19.2	6.1	20.2	7.1	19.7	6.6
Ammonia	1.30	1.9	1.91	2.0	1.60	2.0
Orthophosphate	0.24	0.18	0.09	0.15	0.17	0.18
pH	8.01	0.59	7.54	0.32	7.78	0.53
Rainfall	1.79	6.1	5.89	9.3	3.52	7.9
Secchi disk depth	18.7	5.2	16.3	5.3	17.7	5.4
Solar radiation	18.5	1.9	18.5	1.9	18.5	1.8
Temperature	28.2	1.5	29.0	0.8	28.5	1.3
Temperature differential	2.67	1.19	0.98	0.89	1.96	1.36
Dissolved inorganic nitrogen	1.95	1.91	2.88	2.24	2.34	2.09
Total phosphorus	0.55	0.22	0.54	0.18	0.54	0.20
Total suspended solids	140.9	71.3	176.4	77.0	155.8	75.5
Total volatile solids	43.9	131.2	58.4	34.7	51.1	96.1

TABLE 6. *Calculation of profit for each fertilization and feeding scheme in this experiment and in Diana et al. (1994). Fish were stocked at 3 per m². Profit is also extrapolated to annual since durations of experiments varied. The final three sets of numbers are extrapolated from Diana et al. (1994) to include dates when the fish reached 500 g in size.*

Treatment	Fertilizer (kg)	Feed (kg)	Fish biomass	Fish size (g)	Days	Profit ($)	Annual profit ($/ha per yr)
Size at feeding							
50 g	77.6	438	384.9	593	236	60.13	3,720.01
100 g	77.6	358	384.3	596	236	99.65	6,164.89
150 g	87	328	353.3	534	265	87.18	4,803.23
200 g	101.1	398	340	627	305	37.54	1,796.88
250 g	108.1	281	323.8	488	328	81.09	3,609.48
Diana et al. (1994)							
Fertilizer (F) only	54.6	0	88.2	149	155	20.08	1,891.37
Feed (f) only	0	347	249.2	416	155	−30.73	−2,894.57
0.75f/1F	52.3	284	268.1	403	155	−2.74	−258.39
0.5f/1F	52.3	200	233.9	388	155	18.74	1,764.89
0.25f/1F	52.3	100	152.6	250	155	1.64	154.93
f[a]	0	428	299	500	185	18.45	1,456.05
0.75f[a]	64.2	357	333	500	190	62.92	4,834.69
0.5f[a]	66.6	270.4	301	500	199	79.94	5,864.62

[a] Extrapolated linearly from feeding and growth rates in Diana et al. (1994).

than 500 g, when the value of fish ($0.60 per kg) barely exceeded feed costs ($0.50 per kg). If the feeding and growth rates were extrapolated to continue linearly until the fish reached 500 g, then all feeding treatments in Diana et al. (1994) would also be profitable, with feeding at 0.5 ad libitum most profitable. Overall, the most efficient system was first feeding (at 50% ad libitum) at 100 g.

Discussion

The results of this experiment were much as expected, with a slower rate of growth in fertilized ponds than in fed ponds. Once ponds were fed, the growth rates of fish reached similar levels, regardless of time duration of prior fertilization. These results, along with earlier studies (Diana et al. 1994), indicate that CSC of tilapia in semi-intensive ponds must occur during the first month of culture. If critical standing crop had not occurred prior to the first initiation of feeding in this study, then the first fed fish should have maintained the same growth rate for some time after feeding. Since each treatment increased dramatically in growth upon application of feed, CSC either does not exist for tilapia or had already occurred. While several studies have been conducted to evaluate CSC for tilapia, density-dependent growth of tilapia has been demonstrated both in fed (Zonneveld and Fadholi 1991) and fertilized systems (Diana et al. 1991a), but in both studies the differences in growth rate were expressed by the first month of culture. Green (1992) found that feed or fertilizer alone produced similar growth rates of tilapia during the first 30 d. By day 60, fish in the fertilizer-alone treatment were significantly smaller than in feed-alone or combined fertilizer-feed treatments, indicating CSC in fertilizer-alone had been reached. Diana et al. (1994) found that higher growth occurred on feed than fertilizer alone, and higher rates of growth were measured by 30 d. All of these studies vary in stocking density, pond types, and fish stocks so that direct comparisons are difficult, but the majority of evidence suggests early achievement of CSC by tilapia.

Supplemental feeding of fish resulted in much more rapid growth than fertilization alone, and the timing of supplemental feeding affected overall growth rate. The first two treatments, fed after 38 and 80 d, respectively, ultimately resulted in the same size of tilapia at harvest. All subsequent feeding treatments required longer times to reach harvest size. Feed conversion rates averaged 1.03 for all treatments combined, and there were no significant differences among treatments in conversion efficiency. However, treatments fed earlier in the cycle had a larger portion of the fish growth occur under feeding regimes than under fertilization regimes, and reached harvest size sooner. The total amount of food applied did differ significantly among treatments (ANOVA), with treatment E requiring the least feed, then C, then B and D (which were not significantly different), and A requiring the most feed. In terms of overall efficiency including time, treatment B was most efficient and generated the largest profit. Thus, it appears from this analysis that supplementally feeding fish once they reached 100 g was the most effective means to reach larger size at limited costs.

The economic analysis of Nile tilapia ponds reflected the marginal profits for some systems in Thailand. While total costs (facilities, labor) were not included, some treatments were still predicted to lose money and others to profit only marginally. Semi-intensive production with urea and triple super phosphate was predicted to be reasonably profitable, which could possibly be improved by using less expensive organic fertilizers like chicken manure. Feeding would only realize its full potential if fish were grown to at least 500 g to achieve the highest market value. These analyses reflect common expectations for tilapia, which are most commonly grown for local consumption with limited market potential (Pillay 1993). Only large fish, with export markets

and higher market values can be efficiently grown with feeds, and best at less than maximum feeding rates.

Growth of tilapia averaged 1.17 g/d under optimal fertilization and 3.10 g/d under fertilization and feeding. Both of these rates were comparable to or higher than growth in other studies (Zonneveld and Fadholi 1991; Green 1992; Diana et al. 1994). Feed application rates averaged 1.17% BW/d, which is lower than maximum total consumption of pellets alone. Since growth was very high even at these low consumption rates, considerable consumption of natural foods must have also occurred. Diana et al. (1994) found similar growth rates and ad libitum consumption of supplemental feed by tilapia in ponds with both fertilizer and feed. Green (1992) combined fertilizer and feed (1.5% BW/d) in tilapia ponds in Honduras and increased growth but at a lower rate than recorded in this study (2.03 g/d). Temperature differences between Honduras and Thailand may well explain this difference in growth. Combining feed and fertilizer resulted in rapid growth of tilapia at reduced food inputs compared to supplying feed alone (Diana et al. 1994).

Combined fertilizer and feed application resulted in efficient use of nutrients, since pond water quality did not vary significantly in any treatment before or after feed application at rates up to 390 kg/ha per d. Green (1992) found changes in primary production when fertilization and feeding were done. His feeding rates (1.5% BW/d, averaging up to 60 kg/ha per d) may have resulted in overfeeding and nutrient accumulation, although his feed loading rates were lower than ours. Diana et al. (1994) found changes in water quality between feed only (averaging 100 kg/ha per d, maximum 190) and feed with fertilizer treatments (fed daily at up to 155 kg/ha per d), but no differences between combined treatments (feed and fertilizer) and fertilizer alone. Apparently the efficient use of supplemental feed at a limited rate, along with fertilizer and natural feeds does not ad-

versely affect water quality. From a pond management perspective, fertilization early in the grow-out, then adding supplemental feed once the fish reach 100–150 g, is probably the optimal system to grow large tilapia efficiently.

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