GLOBAL EXPERIMENT: OPTIMIZATION OF NITROGEN FERTILIZATION RATE IN FRESHWATER TILAPIA PRODUCTION PONDS (COOL-SEASON TRIAL)

Eighth Work Plan, Feeds and Fertilizers Research 1 (8FFR1Ph)
Final Report

Christopher L. Brown
Marine Biology Program
Florida International University
North Miami, Florida, USA

Remedios B. Bolivar
Eddie Boy T. Jimenez
Freshwater Aquaculture Center
Central Luzon State University
Nueva Ecija, Philippines

James P. Szyper
Sea Grant College Program
University of Hawaii at Manoa
Hilo, Hawaii, USA

ABSTRACT

An experiment was conducted, following a standardized experimental design, to determine optimum inputs of nitrogen to be used in pond cultivation of tilapia. Twelve 0.05-ha earthen research ponds were used at the Freshwater Aquaculture Center of the Central Luzon State University, Nueva Ecija, Philippines, from 14 December 1999 to 14 March 2000. A completely randomized design was employed, involving the use of three replicates per treatment of the following nitrogen fertilization rates: 0, 10, 20, and 30 kg N ha^{-1} wk^{-1} (termed Treatments 1, 2, 3, and 4, respectively). Productivity, water chemistry, and cost parameters were analyzed statistically. A trend in mean body weights favoring the ponds receiving supplemental nitrogen was detected, favoring higher mean body weights in Treatments 4, 2, 3, and 1 in that order, although the apparent difference was not statistically significant due in part to inherent variance in growth and also to the competition of unwanted tilapia recruits into the experimental ponds. Yields were improved in the fertilized ponds (Treatments 2, 3, and 4) relative to those receiving no nitrogen (Treatment 1), although only the presence or absence of fertilizer had a significant effect, and not the concentration that was applied. Some water chemistry differences were noted, specifically higher Secchi disk readings, alkalinity, and dissolved oxygen levels in ponds receiving less added nitrogen. The most cost-effective treatment was the addition of the lowest tested concentration of nitrogen (Treatment 2).

INTRODUCTION

Optimization of aquaculture production systems requires optimal use of inputs. Nitrogen, phosphorus, and carbon availability are important considerations in management of ponds for optimal fish production. PD/A CRSP research has addressed enhancement of primary productivity through inorganic and organic nutrient addition to ponds; however, previous findings on the optimum nitrogen, phosphorus, and carbon inputs required to improve fish yields at the PD/A CRSP sites appear inconsistent and demand clarification. Higher inputs have increased fish production at all PD/A CRSP sites, but optimum inputs of nitrogen, phosphorus, and carbon have not been defined.

Fertilization rates in PD/A CRSP experiments were higher than rates reported for earlier pond fertilization research. In an often-cited series of fertilization experiments conducted in Malaysia, Hickling (1962) never used more than 1.1 kg P and 1.1 kg N ha^{-1} wk^{-1}. In Israel, the standard fertilizer dose was 2.3 kg P and 6.5 kg N ha^{-1} wk^{-1} (Hepher, 1962a; 1962b). The highest rates of phosphorus and nitrogen used in most experiments at Auburn University were 1.26 and 3 kg ha^{-1} wk^{-1}, respectively (Swingle, 1947; Boyd, 1976; Boyd and Sowles, 1978; Murad and Boyd, 1987; Boyd, 1990). Rates in Europe seldom exceeded 1 kg ha^{-1} wk^{-1} for nitrogen and phosphorus (Mortimer, 1954). Rates used in Malaysia, USA, Israel, and Europe were adequate to give dense phytoplankton blooms and good fish production. Also, in all of the studies cited above, phosphorus was the most important limiting nutrient.

The objectives of this study were: 1) to determine optimal rates of nitrogen fertilizer to obtain tilapia yields with the greatest profit in ponds and 2) to develop a full-cost enterprise budget for the most profitable fertilization rate.

METHODS AND MATERIALS

The experiment was conducted in twelve 0.05-ha earthen research ponds at the Freshwater Aquaculture Center of the Central Luzon State University, Nueva Ecija, Philippines, from 14 December 1999 to 14 March 2000.

Table 1. Growth performance of Nile tilapia in ponds fertilized with different rates of nitrogen in the 90-day culture period. Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

Performance	Treatment			
	1	2	3	4
Initial Biomass (kg pond^{-1})	50 ± 0^{a}	50 ± 0^{a}	50 ± 0^{a}	50 ± 0^{a}
Initial Mean Weight (g fish^{-1})	13.7 ± 0.9^{a}	12.1 ± 0.3^{a}	12.4 ± 1.2^{a}	13.4 ± 0.3^{a}
Final Mean Weight (g fish^{-1})	23.2 ± 5.9^{a}	49.2 ± 11.4^{b}	43.9 ± 11.2^{b}	59.2 ± 1.4^{b}
Net Fish Yield (kg pond^{-1})	6.9 ± 2.3^{a}	82.1 ± 16.9^{b}	72.8 ± 25.8^{b}	83.6 ± 16.6^{b}
Extrapolated Net Fish Yield (kg ha^{-1})	137 ± 45^{a}	1,642 ± 338^{b}	1,456 ± 516^{b}	1,671 ± 332^{b}
Gross Fish Yield (kg pond^{-1})	56.9 ± 2.2^{a}	132.1 ± 16.9^{b}	122.8 ± 5.7^{b}	133.6 ± 16.6^{b}
Extrapolated Gross Fish Yield (kg ha^{-1})	1,138 ± 45^{a}	2,642 ± 338^{b}	2,456 ± 516^{b}	2,671 ± 332^{b}
Survival (%)	71 ± 16.5^{a}	68 ± 16.6^{a}	76.7 ± 23^{a}	60.7 ± 8.6^{a}

A completely randomized design with three replicates per treatment was used in this experiment. Four nitrogen fertilization rates served as treatments at 0, 10, 20, and 30 kg N ha^{-1} wk^{-1}, which correspond to Treatments 1, 2, 3, and 4, respectively. Urea and ammonium phosphate were the chemical fertilizer sources for nitrogen and phosphorus. Due to the unavailability of triple superphosphate, Treatment 1 did not receive any phosphorus fertilizer, but the rest of the treatments received 8 kg P ha^{-1} wk^{-1}.

Sex-reversed male Nile tilapia (*Oreochromis niloticus*) of the Genetically Improved Farmed Tilapia (GIFT) strain averaging 12.9 g were stocked at the rate of 1,000 kg ha^{-1}. This resulted in a stocking rate of about 78,000 fish ha^{-1}. The fish were sampled by seine net at biweekly intervals to measure growth. Approximately 10% of the initial stock was seined, counted, and weighed en masse from each pond during sampling. All fish were harvested by draining after 90 days of culture. Mean body weight of fish, fish yield (kg ha^{-1}), and survival rates were calculated.

Table 2. Mean (± SE) pond water quality parameters measured at the initial, midway, and final weeks in ponds fertilized with different rates of nitrogen fertilization. Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

Performance	Treatment			
	1	2	3	4
DO at Dawn (mg L^{-1})				
Initial	1.68 ±0.05^{a}	1.76 ±0.13^{a}	1.70 ±0.08^{a}	1.70 ±0.13^{a}
Midway	5.27 ±0.07^{a}	4.77 ±0.26^{a}	4.40 ±0.35^{a}	4.27 ±0.37^{a}
Final	7.35 ±0.40^{a}	4.76 ±0.74^{b}	4.69 ±0.13^{b}	4.27 ±0.26^{b}
pH				
Initial	8.26 ±0.13^{a}	7.96 ±0.46^{a}	8.33 ±0.09^{a}	8.67 ±0.19^{a}
Midway	8.47 ±0.08^{a}	8.56 ±0.11^{a}	8.46 ±0.06^{a}	8.62 ±0.14^{a}
Final	8.32 ±0.08^{b}	8.51 ±0.05^{ab}	8.43 ±0.03^{ab}	8.55 ±0.05^{a}
Temperature (°C)				
Initial	24.47 ±0.15^{ab}	24.60 ±0.06^{a}	24.20 ±0.06^{b}	24.33 ±0.12^{ab}
Midway	20.23 ±0.15^{a}	20.47 ±0.20^{a}	20.33 ±0.24^{a}	20.47 ±0.09^{a}
Final	24.28 ±0.14^{a}	24.47 ±0.11^{a}	24.23 ±0.28^{a}	24.42 ±0.15^{a}
Total Ammonia Nitrogen (mg L^{-1})				
Initial	0.03 ±0.01^{a}	0.04 ±0.02^{a}	0.04 ±0.01^{a}	0.05 ±0.01^{a}
Midway	0.07 ±0.02^{a}	0.08 ±0.01^{a}	0.20 ±0.09^{a}	0.24 ±0.06^{a}
Final	0.13 ±0.03^{b}	0.32 ±0.03^{a}	0.35 ±0.03^{a}	0.29 ±0.02^{a}
Total Phosphorus (mg L^{-1})				
Initial	0.23 ±0.06^{a}	0.32 ±0.04^{a}	0.26 ±0.03^{a}	0.32 ±0.06^{a}
Midway	0.24 ±0.06^{a}	0.23 ±0.03^{a}	0.21 ±0.04^{a}	0.24 ±0.06^{a}
Final	0.39 ±0.03^{a}	0.36 ±0.02^{a}	0.34 ±0.02^{a}	0.39 ±0.07^{a}
Total Alkalinity (mg L^{-1})				
Initial	238 ±17.5^{a}	214 ±7.5^{a}	220 ±20.5^{a}	198 ±3.5^{a}
Midway	240 ±14.8^{a}	199 ±9.2^{b}	178 ±15.3^{b}	167 ±1.8^{b}
Final	151 ±20.0^{a}	132 ±3.8^{a}	132 ±10.4^{a}	122 ±2.6^{a}
Primary Productivity (mg O_2 L^{-1} d^{-1})				
Initial	11.4 ±0.87^{a}	14.2 ±2.24^{a}	13.9 ±1.80^{a}	16.6 ±2.4^{a}
Midway	11.6 ±0.77^{a}	21.5 ±0.38^{a}	16.3 ±3.39^{a}	18.9 ±2.34^{a}
Final	8.0 ±0.17^{b}	19.6 ±3.11^{a}	20.9 ±2.29^{a}	18.7 ±0.80^{a}
Secchi Disk Depth (cm)				
Initial	31.7 ±4.1^{a}	29.0 ±5.7^{a}	23.7 ±4.7^{a}	28.3 ±3.5^{a}
Midway	35.7 ±5.2^{a}	19.0 ±4.0^{b}	18.7 ±4.2^{b}	18.7 ±1.2^{b}
Final	33.7 ±2.4^{a}	21.3 ±0.67^{b}	16.0 ±1.5^{b}	16.3 ±1.8^{b}

Table 3. Partial budget analysis for Nile tilapia cultured in ponds fertilized with different rates of nitrogen fertilization (budget items in Philippine Pesos; US$1 = P45).

Item	Treatment			
	1	2	3	4
Income (Selling Fish)	1,138.00	4,623.50	4,298.00	4,676.00
Added Income (A)	----	3,485.50	3,160.00	3,538.00
Cost for Urea	0	189.00	280.98	372.96
Added Cost from Urea (B1)	----	189.00	280.98	372.96
Cost for Ammonium Phosphate	0	118.58	118.58	118.58
Added Cost from Ammonium Phosphate (B2)	----	118.58	118.58	118.58
Ratio of Added Income to Added Cost	----	11.3	7.9	7.2
Profit (A – B1 – B2)	----	3,177.92	2,760.44	3,046.46
US$	----	70.62	61.34	67.70

Dissolved oxygen (DO), pH, temperature, total ammonia nitrogen (TAN), total phosphorus (TP), total alkalinity, primary productivity, and Secchi disk depth (SDD) were determined during the second week, midway through the experiment, and two weeks before the harvest of fish. Analyses of water quality were done according to methodologies detailed in the PD/A CRSP Handbook of Analytical Methods (PD/A CRSP Technical Committee, 1996). DO, temperature, and pH measurements were taken on the three sampling dates at 0600 h, 1000 h, 1600 h, 1800 h, and 0600 h the following morning at 5-cm, 25-cm, 50-cm, and 75-cm depths in the water column. Water level in the pond was maintained at 1 m throughout the culture period by occasionally adding water to the ponds.

Data from the experiment were analyzed statistically by regression analysis and analysis of variance using SAS System for Windows v6.12 statistical software (SAS Institute, 1996). Partial budget analysis was conducted to determine which fertilization rate yielded the greatest profitability (Shang, 1990). A full-cost enterprise analysis was developed for the fertilization rate that yielded the greatest profitability.

RESULTS

Mean values with their standard errors for initial and final body weights, gross and net yields, and survival of Nile tilapia are shown in Table 1. Mean initial body weights did not differ significantly among treatments ($P > 0.05$). Mean final body weights were significantly different, with Treatment 1 having the lowest mean body weight of fish at harvest ($P < 0.05$) among treatments. The highest mean weight of fish at harvest was observed in Treatment 4 (59.2 ± 1.4 g), followed by Treatments 2 (49.2 ± 11.4 g) and 3 (43.9 ± 11.2 g). However, there was no significant difference in the final mean body weights of fish in these treatments. Similar trends were observed in the gross and net fish yields and in extrapolated values. Yields were significantly higher in the fertilized ponds relative to the unfertilized ponds, but treatment-dependent differences among the ponds given different concentrations of fertilization were otherwise absent. The mean growth of the Nile tilapia in the different treatments is shown in Table 1.

The percent survival of Nile tilapia was highest in Treatment 3 (77%), followed by Treatment 1 (71%), Treatment 2 (68%), and Treatment 4 (61%). Survival rates of fish in this study did not vary significantly among treatments ($P > 0.05$).

Water Quality

Mean values for water quality parameters are shown in Table 2. Except for temperature, mean values for the initial analysis of water quality parameters did not differ significantly among treatments ($P > 0.05$).

Analysis of water quality midway through the experiment indicated significant differences in total alkalinity and SDD. Total alkalinity was significantly highest ($P < 0.05$) in Treatment 1 (240 ± 14.8 mg l^{-1}), followed by Treatment 2 (199 ± 9.2 mg l^{-1}), Treatment 3 (178 ± 15.3 mg l^{-1}), and Treatment 4 (167 ± 1.8 mg l^{-1}). There were significant differences among Treatments 2, 3, and 4 with respect to total alkalinity ($P < 0.05$).

SDD was also significantly different among treatments ($P < 0.05$). Treatment 1 had the highest SDD (35.7 ± 5.2 cm) as compared to the other three treatments, which had similar SDD (19 cm). This roughly indicated the condition of the water in terms of phytoplankton growth. Treatment 1 had the poorest phytoplankton growth compared to the treatments that received nitrogen fertilization.

Analyses of final water quality parameters showed five parameters that were significantly different among treatments. These were DO concentration at dawn, pH, TAN, primary productivity, and SDD. DO concentration and SDD were

Table 4. A full-cost enterprise budget for Nile tilapia cultured in a 0.05-ha pond fertilized with 10 kg N ha^{-1} wk^{-1} (budget items in Philippine Pesos; US$1 = P45).

Item	Price (P kg^{-1})	Quantity (kg $pond^{-1}$)	Value (P $pond^{-1}$)
Gross Revenue (A)			
Harvested Tilapia	35.00	132.00	4,623.50
Cost (B)			
Fingerlings	35.00	50.00	1,750.00
Urea	7.30	12.60	91.98
Ammonium Phosphate	7.70	28.00	215.60
Net Returns (A – B)			2,565.92
Break-Even Price		15.58	

significantly higher in Treatment 1 than in the treatments with nitrogen fertilization. However, no significant differences were observed among Treatments 2, 3, and 4 ($P > 0.05$) in terms of the final DO concentration at dawn and SDD. For pH, TAN, and primary productivity, significantly lower mean values were recorded in Treatment 1, while Treatments 2, 3, and 4 did not differ significantly with respect to these parameters.

Tilapia Recruits

Due to unsuccessful hormonal sex reversal, tilapia recruits were observed in the ponds. The recruits were bulk-weighed at harvest, and the highest average weight was observed in Treatment 4 (13.6 ± 6.7 kg), while Treatments 2 and 3 had an average of 5.3 ± 2.04 kg and 5.1 ± 0.70 kg of recruits, respectively. Treatment 1 had only one pond with observed reproduction (1.4 kg). Although there was no significant difference in the weight of recruits among treatments ($P > 0.05$), the presence of recruits affected the final growth of Nile tilapia in Treatment 4 because of possible fish competition for food and space.

Budget Analysis

Partial budget analysis indicated that Treatment 2 (10 kg N ha^{-1} wk^{-1}) gave slightly more profit than the treatments with higher nitrogen fertilization (Table 3). A full-cost enterprise budget was developed for this nitrogen fertilization rate (Table 4). A net return of P2,566 (US$57) can be obtained in the culture of Nile tilapia in a 0.05-ha pond for 90 days.

DISCUSSION

These results show the effects of adding exogenous nitrogen to tilapia culture ponds in the Philippines; the differences observed and the lack of differences among treatments may be considered equally instructive. Individual growth (mean body weight) was not significantly affected by fertilization, although a trend favoring the fertilized ponds was apparent. Additional replicates and the exclusion of competing recruits might show this effect to be biologically significant, but that remains to be seen. In general, tilapia production was enhanced by the addition of fertilizer relative to the lack of any fertilizer, but doubling or tripling the amount added had no effect on pond yields. Consequently we found that the addition of the minimal amount of fertilizer used in this study (10 kg ha^{-1} wk^{-1}) was most cost-effective.

ANTICIPATED BENEFITS

Although this experiment was not designed by those who carried it out, it fits with the majority of the research being done by our team at Central Luzon State University. Specifically, the theme of moderate intensification of fish farming technology, with attention to reduction of operating costs, is consistent with our feed studies. This study illustrates the point that low-level fertilization improves yields, but that doubling or tripling the application of fertilizers is not cost-effective. We anticipate that this approach will be readily accepted by farmers in the Luzon area, who have already demonstrated a willingness to adopt low-cost aquaculture methods, as opposed to methods that increase intensification but which also drive up production costs.

LITERATURE CITED

Boyd, C.E., 1976. Nitrogen fertilizer effects on production of Tilapia in ponds fertilized with phosphorus and potassium. Aquaculture, 7:385–390.

Boyd, C.E., 1990. Water Quality in Ponds for Aquaculture. Alabama Agriculture Experiment Station, Auburn University, Alabama, 482 pp.

Boyd, C.E. and J.W. Sowles, 1978. Nitrogen fertilization of ponds. Trans. Amer. Fish. Soc., 107:737–741.

Hepher, B., 1962a. Primary production in fish ponds and its application to fertilization experiments. Limnol. Oceanogr., 7:131–135.

Hepher, B., 1962b. Ten years of research in fish ponds and its application to fertilization experiments. Bamidgeh, 14:29–38.

Hickling, C.F., 1962. Fish Culture. Faber and Faber, London, 295 pp.

Mortimer, C.F., 1954. Fertilization in Fish Ponds. Fish Pub., Her Majesty's Stationery Office, London, 155 pp.

Murad, A. and C.E. Boyd, 1987. Experiments on fertilization of sportfish ponds. Prog. Fish-Cult., 49:100–107.

PD/A CRSP Technical Committee, 1992. Handbook of Analytical Methods. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon.

SAS Institute, 1996. SAS System for Windows v6.12 Statistical Software. SAS Institute Inc., Cary, North Carolina.

Shang, Y.C., 1990. Aquaculture Economic Analysis: An Introduction. World Aquaculture Society, Baton Rouge, Louisiana, 211 pp.

Swingle, H.S., 1947. Experiments on Pond Fertilization. Alabama Agriculture Experiment Station Bull. 264, Auburn, Alabama, 36 pp.

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