GLOBAL EXPERIMENT: OPTIMIZATION OF NITROGEN FERTILIZATION RATE IN FRESHWATER TILAPIA PRODUCTION PONDS

Eighth Work Plan, Honduras Feeds and Fertilizers Research 1 (FFR1H)
Final Report

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ABSTRACT

Results of previous research at PD/A CRSP sites have demonstrated that increased fertilization rates have increased fish production, but optimum inputs of nitrogen, phosphorus, and carbon have not been defined. These experiments, the first of a series to identify optimum nutrient input levels at PD/A CRSP sites, addressed identification of the optimal nitrogen fertilization rate in freshwater tilapia production ponds. This research was conducted at the El Carao National Fish Culture Research Center, Comayagua, Honduras, using 0.1-ha earthen ponds. Nitrogen was added to ponds weekly at rates of 0, 10, 20, and 30 kg N ha^{-1}. Phosphorus was added to all ponds weekly at 8 kg P ha^{-1}, and sodium bicarbonate was added to ponds as needed to maintain total alkalinity $\geq$ 75 mg l^{-1}. Sex-reversed *Oreochromis niloticus* fingerlings (average weight 46 g) were stocked into ponds. The experiment was repeated during the rainy season and the dry season. During the rainy season trial, tilapia yield varied curvilinearly in response to increased weekly nitrogen inputs. Gross tilapia yields varied from 1,128 to 2,490 kg ha^{-1} per 128 d in the 0 and 20 kg N ha^{-1} wk^{-1} treatments, respectively. No significant differences in tilapia yield among treatments were detected during the dry season experiment because of increased variability, although the data appeared to show a quadratic tendency when plotted. Gross yields varied from 1,360 to 1,729 kg ha^{-1} per 107 d in the 30 and 20 kg N ha^{-1} wk^{-1} treatments, respectively. Chlorophyll *a* and primary production increased with increasing fertilizer application, as did total net tilapia yield. Total input costs ranged from $1,072 ha^{-1} for the 0 kg ha^{-1} treatment to $2,020 ha^{-1} for the 30 kg ha^{-1} treatment and from $1,173 ha^{-1} for the 0 kg ha^{-1} treatment to $1,894 ha^{-1} for the 30 kg ha^{-1} treatment during the rainy and dry season experiments, respectively. Highest total revenues were observed for the 20 kg N ha^{-1} wk^{-1} fertilization rate during both seasons. Partial budget analysis demonstrated that weekly pond fertilization at 20 kg N ha^{-1} was the economically optimal rate for Honduras under current economic conditions. The full-cost enterprise budget developed for this fertilization rate indicated that income above variable costs was $991 ha^{-1} per five-month production cycle.

INTRODUCTION

Optimization of aquacultural production systems requires optimal use of inputs. Nitrogen, phosphorus, and carbon availability are important considerations in the management of ponds for optimum fish production. PD/A CRSP research has addressed enhancement of primary productivity through inorganic and organic nutrient additions to ponds; however, our 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 nutrient inputs have increased fish production at all PD/A CRSP sites, but optimum inputs of nitrogen, phosphorus, and carbon have not been defined (see reports in Egna et al., 1990, 1991; Egna et al., 1992; Egna et al., 1993; Egna et al., 1994, 1995).

Fertilization rates in PD/A CRSP experiments were greater 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, b). The highest rates of phosphorus and nitrogen used in most experiments in the USA were 1.26 and 3 kg ha^{-1} wk^{-1}, respectively (Swingle, 1947; Boyd, l976, l990; Boyd and Sowles, 1978; Murad and Boyd, 1987). 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 the research reported herein were:

1) To determine the optimal rate of nitrogen fertilization (in the presence of adequate phosphorus and carbon) to obtain optimum primary productivity and optimum yields of tilapia in freshwater production ponds;
2) To determine which of the nitrogen fertilization rates evaluated had the greatest profitability; and
3) To develop a full-cost enterprise budget for the fertilization level that resulted in the greatest profitability.

METHODS AND MATERIALS

Research was conducted using 12 earthen ponds located at the Centro Nacional de Investigación Piscícola El Carao, Dirección

General de Pesca y Acuacultura, Secretaría de Agricultura y Ganadería, Comayagua, Honduras. A general description of the site is given in Egna et al. (1987). Ponds averaged 1,045 ± 24.4 m^2 in area and 82 ± 5.9 cm in depth. Water was added to ponds to replace losses due to evaporation and seepage.

Nitrogen was added to ponds at 0, 10, 20, and 30 kg N ha^{-1} wk^{-1}. A completely randomized design with three replicates per treatment was used. Treatment allocation to ponds was re-randomized for the second experiment. Nitrogen sources were urea and diammonium phosphate (DAP) fertilizers. Phosphorus, as triple superphosphate (TSP), was added to all ponds at 8 kg P ha^{-1} wk^{-1}. Sodium bicarbonate was added weekly as needed to maintain pond total alkalinity ≥ 75 mg l^{-1} as $CaCO_3$. All fertilizer was dissolved in buckets containing pond water and the fertilizer solution splashed over the pond surface. Fertilization was initiated two weeks prior to pond stocking. Agricultural limestone was spread over pond bottoms prior to initial inundation. Quantities of all inputs used during each experiment are given in Table 1.

Two experiments were conducted, corresponding to the rainy and dry seasons. Rainy season experiment ponds were stocked on 30 September 1997 with 1,165 ± 26.4 kg ha^{-1} of tilapia

Table 1. Total quantities of inputs used during the rainy season (121-day duration) and dry season (107-day duration) Global Experiments at Comayagua, Honduras.

Weekly Nitrogen Application	DAP[1] (kg ha^{-1})	Urea[2] (kg ha^{-1})	TSP[3] (kg ha^{-1})	Lime[4] (kg ha^{-1})	Sodium Bicarbonate (kg ha^{-1})
RAINY SEASON					
0 kg ha^{-1}	0	0	797	1,000	577
10 kg ha^{-1}	797	123	0	1,000	1,333
20 kg ha^{-1}	797	558	0	1,000	1,511
30 kg ha^{-1}	797	993	0	1,000	1,545
DRY SEASON					
0 kg ha^{-1}	0	0	717	1,000	388
10 kg ha^{-1}	717	111	0	1,000	1,112
20 kg ha^{-1}	717	502	0	1,000	1,085
30 kg ha^{-1}	717	893	0	1,000	1,057

1 Diammonium phosphate (18-46-0)
2 Urea (46-0-0)
3 Triple superphosphate (0-46-0)
4 Calcium carbonate

Table 2. Mean (± SD) tilapia yields, individual weight, survival, and amount of reproduction removed from 0.1-ha ponds during the rainy season (121-day duration) and dry season (107-day duration) Global Experiments at Comayagua, Honduras.

Weekly Nitrogen Application	Yield (kg ha^{-1})			Average Weight of Males (g)	Reproduction (kg ha^{-1})	Survival (%)
	Male Fish	*Gross*[1]	*Net*			
RAINY SEASON						
0 kg ha^{-1}	1,094 ± 127.1	1,128 ± 130.7	-38 ± 154.8	49.3 ± 4.88	113 ± 16.2	83.3 ± 0.81
10 kg ha^{-1}	1,843 ± 228.4	1,891 ± 229.3	751 ± 202.3	73.5 ± 8.06	251 ± 65.3	96.8 ± 0.12
20 kg ha^{-1}	2,438 ± 459.1	2,490 ± 459.6	1,308 ± 138.8	94.0 ± 10.16	391 ± 240.1	96.7 ± 2.52
30 kg ha^{-1}	1,825 ± 780.9	1,914 ± 742.3	741 ± 734.6	88.1 ± 20.04	86 ± 118.1	78.1 ± 3.36
Orthogonal Contrast	Quadratic *	Quadratic *	Quadratic *	0 < (10=20=30) *	ns	Quadratic **
DRY SEASON						
0 kg ha^{-1}	1,488 ± 552.9	1,501 ± 547.2	571 ± 530.9	91.1 ± 34.25	214 ± 254.8	97.6 ± 0.52
10 kg ha^{-1}	1,604 ± 112.7	1,611 ± 111.5	657 ± 95.1	96.0 ± 9.75	213 ± 71.7	97.6 ± 1.85
20 kg ha^{-1}	1,715 ± 693.9	1,729 ± 694.5	758 ± 707.6	107.2 ± 50.66	159 ± 149.1	92.5 ± 0.58
30 kg ha^{-1}	1,297 ± 907.4	1,360 ± 850.2	405 ± 843.1	96.6 ± 35.69	40 ± 36.5	74.4 ± 17.05
Orthogonal Contrast	ns	ns	ns	ns	ns	ns

1 Gross yield includes female fish removed at harvest and dead fish from harvest and samples.
* Significant ($P < 0.05$)
** Highly significant ($P < 0.01$)
ns Not significant ($P > 0.05$)

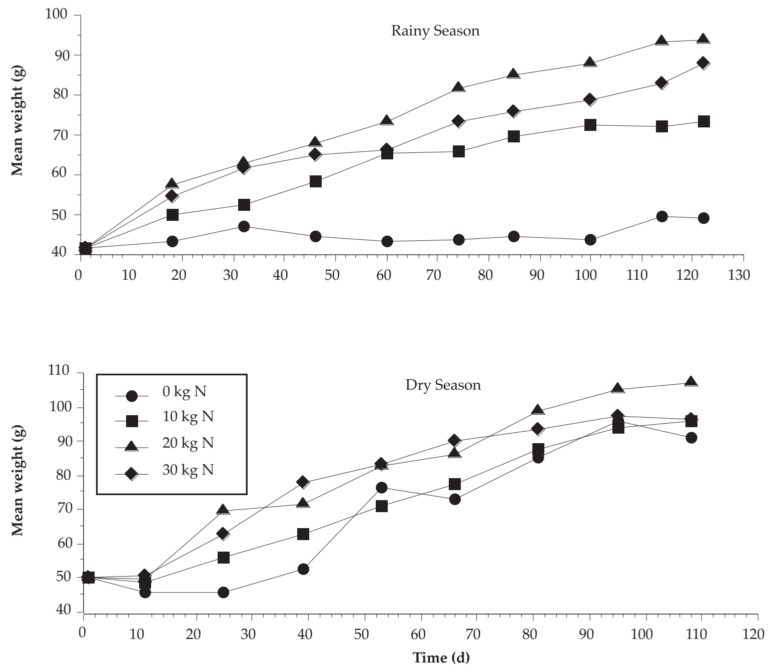

Figure 1. Growth of *Oreochromis niloticus* in earthen ponds fertilized with different rates of nitrogen during the rainy and dry season Global Experiments in Comayagua, Honduras.

fingerlings (average weight 41.8 g) and harvested on 29 January 1998. Dry season experiment ponds were stocked on 24 February 1998 with 952 ± 21.9 kg ha^{-1} of tilapia fingerlings (average weight 50.3 g) and harvested on 11 June 1998. Sex-reversed Nile tilapia (*Oreochromis niloticus*) were used in both experiments. 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. Ponds were harvested by draining. At harvest, fish were counted and weighed en masse.

Pond water was analyzed weekly during both experiments for total alkalinity by titration to pH 4.8 endpoint, pH, and chlorophyll *a* according to methodologies detailed in APHA (1985). Soluble reactive phosphate (SRP), ammonia-nitrogen, nitrate-nitrite-nitrogen by cadmium reduction to nitrite, and nitrite-nitrogen were determined weekly during the dry season experiment according to methods given in APHA (1985). Total nitrogen and total phosphorus were determined by nitrate and phosphate analysis, respectively, after simultaneous persulfate oxidation in a strong base (Grasshoff et al., 1983). Total nitrogen was determined on four and seven occasions and total phosphorus on four and five occasions during the rainy and dry season experiments, respectively. Primary productivity was measured on three dates during the rainy season experiment and on four dates during the dry season experiment using the free-water diurnal curve method as described in the PD/A CRSP Materials and Methods Handbook (1987). Dissolved oxygen concentrations were not corrected for diffusion because wind data were not available.

Partial budget analyses were performed to determine which fertilization rate yielded the greatest profitability (Kay, 1981). A full-cost enterprise budget was prepared for that fertilization rate (Kay, 1981).

Data were computer analyzed using ANOVA with treatment difference determined by orthogonal contrasts, regression analysis, and covariance analysis using the StatView 5.0 (SAS, 1998) and SuperANOVA (Abacus Concepts, 1991) software packages. Differences were declared significant at alpha level 0.05.

RESULTS

A significant quadratic relationship was observed for rainy season experiment tilapia yield in response to increased weekly nitrogen inputs (Table 2). Gross tilapia yields in the 121-day rainy season experiment ranged from 1,128 kg ha^{-1} in ponds that did not receive nitrogen fertilization to 2,490 kg ha^{-1} in ponds fertilized with 20 kg N ha^{-1} wk^{-1} (Table 2). Growth of fish was similar among treatments fertilized with nitrogen during the rainy season experiment (Table 2; Figure 1). No statistically significant differences in tilapia yield were detected among treatments during the 107-day dry season experiment (Table 2) nor were any differences among treatments observed for dry season experiment fish growth (Table 2; Figure 1).

Water quality variable treatment means are presented in Table 3. Application of sodium bicarbonate was effective in maintaining total alkalinity concentrations ≥ 75 mg l^{-1} during both experiments (Table 3; Figure 2). Total alkalinity concentrations shown in Table 3 represented initial weekly samples; sodium bicarbonate was added to ponds as required to increase total alkalinity to 75 mg l^{-1}. Total hardness and calcium hardness concentrations decreased quadratically in response to increased levels of nitrogen fertilization (Table 3). Chlorophyll *a* concentrations during both seasons increased linearly with increased nitrogen fertilization (Table 3; Figure 3). Chlorophyll *a* concentrations tended to increase throughout the experiment in the two highest nitrogen fertilization treatments (Figure 4). No differences were detected among treatments in either

Table 3. Means (± SD) of pond water quality variables by treatment during the rainy and dry season Global Experiments at Comayagua, Honduras at Comayagua, Honduras.

Weekly Nitrogen Application	Total Alkalinity (mg l^{-1} as $CaCO_3$)	Total Hardness (mg l^{-1} as $CaCO_3$)	Calcium Hardness (mg l^{-1} as $CaCO_3$)	Chlorophyll *a* (mg m^{-3})	Total Phosphorus (mg l^{-1})	Soluble Reactive Phosphate (mg l^{-1})
RAINY SEASON						
0 kg ha^{-1}	103.1 ± 12.25	73.6 ± 21.05	50.7 ± 14.12	121.7 ± 30.55	3.7 ± 0.54	3.4 ± 0.41
10 kg ha^{-1}	73.6 ± 3.90	31.5 ± 2.8	22.3 ± 4.03	450.4 ± 59.11	3.8 ± 0.51	3.1 ± 0.40
20 kg ha^{-1}	71.2 ± 2.84	24.1 ± 11.65	16.7 ± 9.51	854.4 ± 221.69	3.6 ± 0.70	2.6 ± 0.41
30 kg ha^{-1}	71.5 ± 1.86	24.5 ± 8.42	19.0 ± 5.93	812.7 ± 307.75	3.1 ± 1.04	2.3 ± 0.97
Orthogonal Contrast	Quadratic **	Quadratic *	Quadratic *	Linear **	ns	ns
DRY SEASON						
0 kg ha^{-1}	90.8 ± 4.85	57.3 ± 3.45	44.9 ± 2.07	215.6 ± 48.63	1.9 ± 0.36	1.8 ± 0.53
10 kg ha^{-1}	71.3 ± 5.54	39.9 ± 2.75	31.3 ± 0.91	331.3 ± 76.92	1.8 ± 0.34	1.6 ± 0.41
20 kg ha^{-1}	71.9 ± 1.16	28.1 ± 9.21	21.1 ± 2.28	882.3 ± 303.60	2.3 ± 0.44	1.3 ± 0.10
30 kg ha^{-1}	70.5 ± 1.30	22.0 ± 6.45	19.3 ± 6.14	936.1 ± 209.12	2.3 ± 0.39	1.3 ± 0.41
Orthogonal contrast	Quadratic **	Linear **	Quadratic *	Linear *	ns	ns

Weekly Nitrogen Application	pH	Total Nitrogen (mg l^{-1})	Ammonia-Nitrogen (mg l^{-1})	NO_3-NO_2-Nitrogen (mg l^{-1})	Nitrite-Nitrogen (mg l^{-1})	Sodium Bicarbonate Added to Ponds (kg ha^{-1})
RAINY SEASON						
0 kg ha^{-1}	8.2 ± 9.24	0.8 ± 0.13	0.07 ± 0.007	-	-	577 ± 254.5
10 kg ha^{-1}	8.7 ± 9.32	1.6 ± 0.04	0.35 ± 0.423	-	-	1,333 ± 357.5
20 kg ha^{-1}	8.6 ± 8.62	2.7 ± 0.60	0.12 ± 0.024	-	-	1,511 ± 475.1
30 kg ha^{-1}	9.0 ± 9.00	2.9 ± 0.29	0.15 ± 0.037	-	-	1,545 ± 281.9
Orthogonal Contrast	Cubic *	Linear **	ns			Linear **
DRY SEASON						
0 kg ha^{-1}	8.4 ± 8.62	0.2 ± 0.06	0.08 ± 0.023	0.01 ± 0.000	0.01 ± 0.006	388 ± 141.2
10 kg ha^{-1}	8.7 ± 8.76	0.2 ± 0.08	0.10 ± 0.049	0.03 ± 0.029	0.01 ± 0.010	1,112 ± 165.4
20 kg ha^{-1}	9.3 ± 9.95	0.5 ± 0.11	0.11 ± 0.029	0.11 ± 0.089	0.04 ± 0.026	1,085 ± 748.0
30 kg ha^{-1}	9.3 ± 9.89	0.7 ± 0.06	0.19 ± 0.070	0.26 ± 0.101	0.11 ± 0.021	1,057 ± 129.9
Orthogonal contrast	ns	Linear **	Linear *	Linear **	Quadratic *	ns

* Significant ($P < 0.05$)
** Highly significant ($P < 0.01$)
ns Not significant ($P > 0.05$)

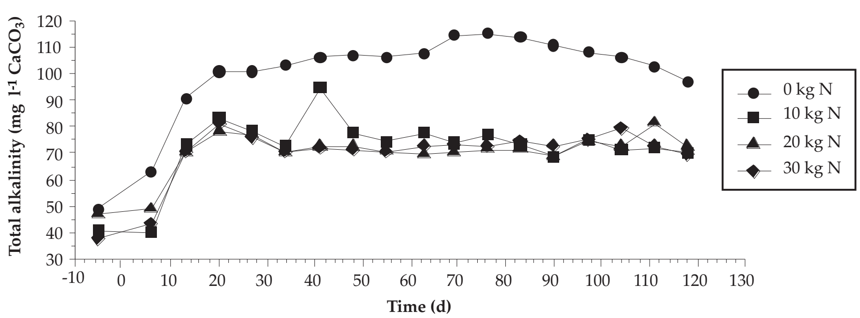

Figure 2. Mean total alkalinity concentrations in ponds fertilized with different rates of nitrogen during the rainy season Global Experiment, Comayagua, Honduras. Data for the dry season experiment were similar.

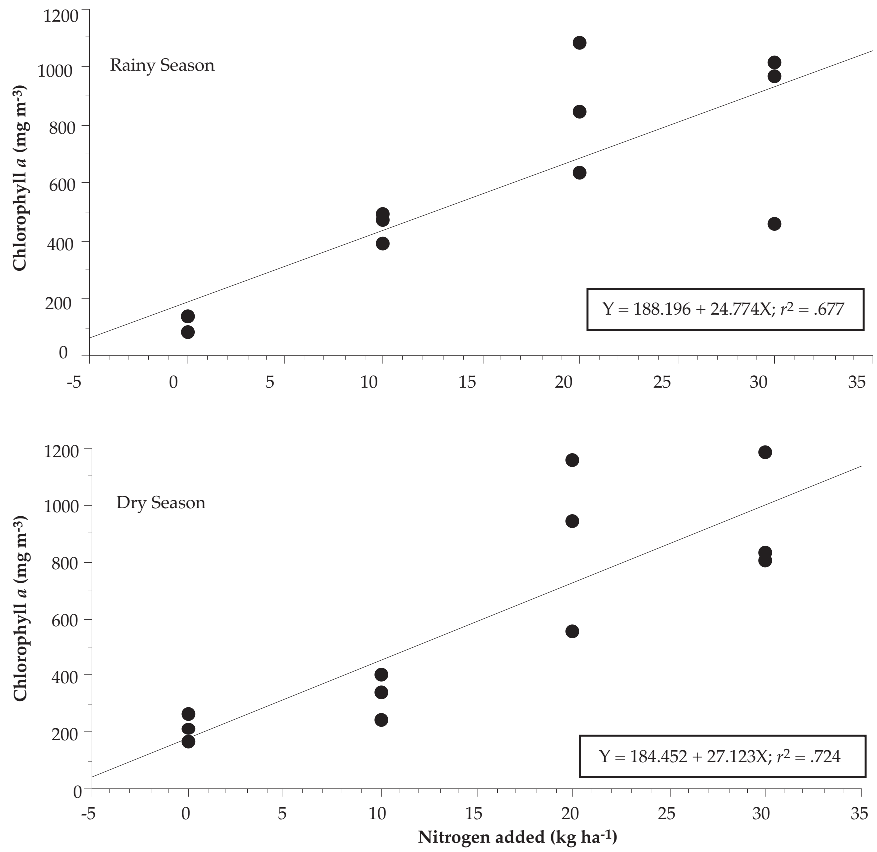

Figure 3. Relationship between weekly pond fertilization with different rates of nitrogen and chlorophyll *a* concentration during the rainy and dry season Global Experiments, Comayagua, Honduras.

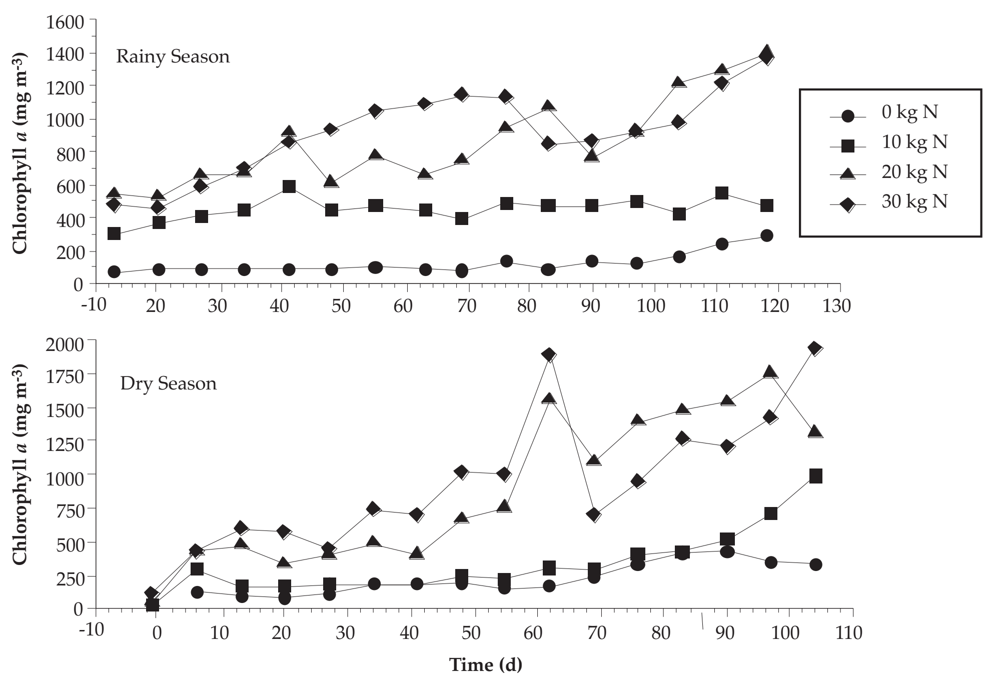

Figure 4. Mean weekly chlorophyll *a* concentrations in ponds fertilized with different rates of nitrogen.

Table 4. Mean (± SD) primary production and community respiration in ponds fertilized weekly with nitrogen at different rates during the rainy and dry season Global Experiments.

Weekly Nitrogen Application	Primary Production		Community Respiration ($g\ O_2\ m^{-3}$ per day)
	Net ($g\ O_2\ m^{-3}$ per day)	*Gross* ($g\ O_2\ m^{-3}$ per day)	
RAINY SEASON			
0 kg ha^{-1}	3.2 ± 0.67	4.5 ± 0.93	2.6 ± 0.52
10 kg ha^{-1}	5.9 ± 0.64	8.7 ± 0.84	5.7 ± 0.43
20 kg ha^{-1}	7.7 ± 0.85	11.5 ± 1.09	7.5 ± 0.79
30 kg ha^{-1}	7.3 ± 0.75	10.8 ± 1.10	7.0 ± 0.68
Orthogonal Contrast	Quadratic **	Quadratic **	Quadratic **
DRY SEASON			
0 kg ha^{-1}	5.5 ± 2.43	8.4 ± 3.60	5.9 ± 2.34
10 kg ha^{-1}	5.5 ± 1.18	8.6 ± 2.24	6.1 ± 2.15
20 kg ha^{-1}	6.3 ± 1.09	9.7 ± 1.78	6.8 ± 1.39
30 kg ha^{-1}	7.7 ± 1.85	11.7 ± 2.76	8.1 ± 1.83
Orthogonal Contrast	ns	ns	ns

ns Not significant ($P > 0.05$)
** Highly significant ($P < 0.01$)

experiment for total phosphorus and soluble reactive phosphate concentrations (Table 3). Total nitrogen increased linearly in response to nitrogen input during both experiments (Table 3). While no significant differences were detected among treatments for ammonia-nitrogen concentrations during the rainy season experiment, ammonia-nitrogen concentrations were linearly correlated with nitrogen input during the dry season experiment (Table 3). Nitrate-nitrite-nitrogen and nitrite-nitrogen concentrations increased with nitrogen fertilization level during the dry season (Table 3).

Net and gross primary production and community respiration exhibited a significant quadratic relationship to nitrogen fertilization rate during the rainy season (Table 4). Mean net primary production during the rainy season experiment ranged from 3.2 to 7.7 g $O_2\ m^{-3}\ d^{-1}$ in the 0 kg ha^{-1} wk^{-1} and 20 kg ha^{-1} wk^{-1} treatments, respectively. No significant differences in any measure of primary production were detected among treatments during the dry season experiment (Table 4).

Increased nitrogen fertilization increased chlorophyll *a* concentrations during both experiments and increased primary production during the rainy season experiment. Chlorophyll *a*, however, was not a good indicator of total net fish yield. No significant relationship was observed between total net tilapia yield and mean chlorophyll *a* concentration during either experiment (Figure 5). However, total net tilapia yield increased significantly with increased net primary production during both experiments (Figure 6).

Total costs of inputs consumed during each experiment increased with nitrogen fertilization rate (Table 5). Total input costs ranged from $1,072 ha^{-1} to $2,020 ha^{-1} and from $1,173 ha^{-1} to $1,894 ha^{-1} for the 0 kg ha^{-1} to 30 kg ha^{-1} treatments during the rainy and dry season experiments, respectively. Highest total revenues were observed for the 20 kg N ha^{-1} wk^{-1} fertilization rate during both seasons (Table 5). Gross profit was affected by the cost of sodium bicarbonate (Table 5). Results of partial budget analyses demonstrated that the most profitable fertilization level was 20 kg N ha^{-1} wk^{-1} (Table 6). Average net change in profit was +$190 ha^{-1} per cycle when fertilizing with 10 kg N ha^{-1} wk^{-1} compared to no nitrogen fertilization. Increasing weekly nitrogen fertilization from 10 kg ha^{-1} to 20 kg ha^{-1} resulted in an average net change in profit of +$441 ha^{-1} per cycle. Average net change in profit was -$1,027 ha^{-1} per cycle when nitrogen fertilization rate was increased from 20 kg ha^{-1} to 30 kg ha^{-1}. The full-cost enterprise budget developed for the 20 kg N ha^{-1} wk^{-1} treatment was based on a five-month production cycle that includes two weeks down-time before and after the 120-day production cycle, and indicated that income above variable costs was $991 per hectare per five-month cycle (Table 7).

DISCUSSION

The significant quadratic relationship detected between tilapia yield and nitrogen fertilization rate demonstrated that in Honduras fish yield was not increased by fertilizing with rates above 20 kg N ha^{-1} wk^{-1}. Although no significant relationship was detected for dry season experiment tilapia yields, the data appeared to show a quadratic tendency when plotted. In an earlier experiment at El Carao that tested weekly nitrogen applications of 0, 7, 14, and 28 kg ha^{-1} with phosphorus in excess (8 kg P ha^{-1} wk^{-1}) tilapia yields were similar to yields in the current experiments (Teichert-Coddington and Claros, 1996). These authors also noted a decrease in gross yield at the highest nitrogen fertilization rate.

The absence of significant differences in tilapia yields among treatments during the dry season may be caused by some residual treatment effect from the rainy season experiment. Treatment assignments to ponds were re-randomized prior to initiation of the dry season study, and given the one-month turnaround time between harvest of the rainy season

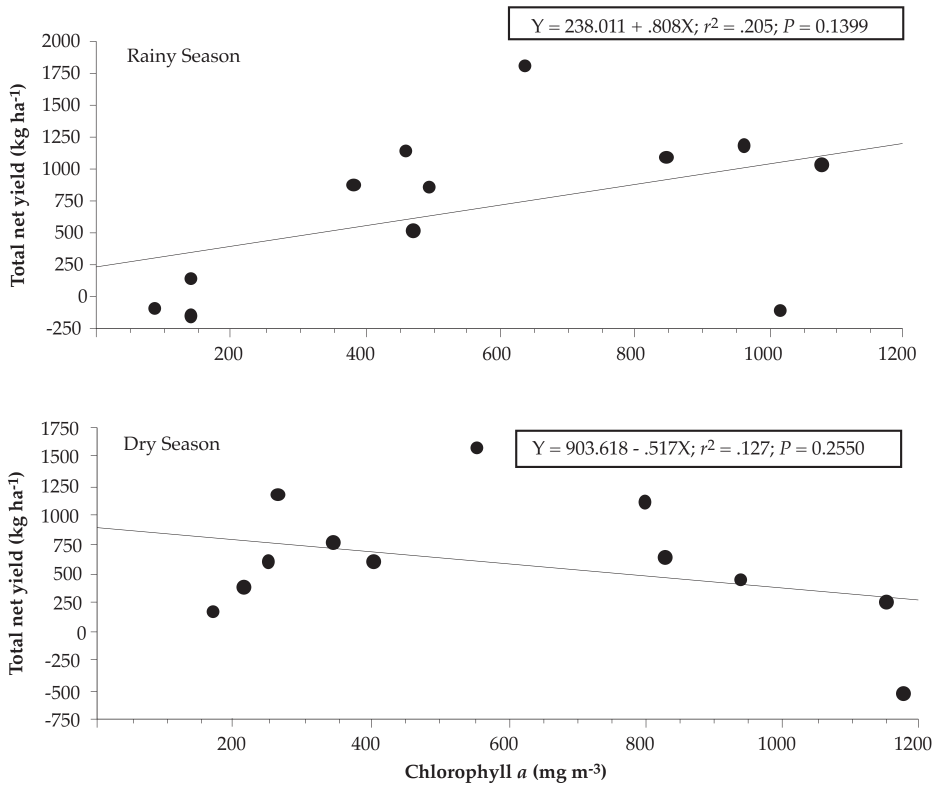

Figure 5. Relationship between total net tilapia yield and chlorophyll *a* concentration in earthen ponds at Comayagua, Honduras, during the rainy and dry season Global Experiments.

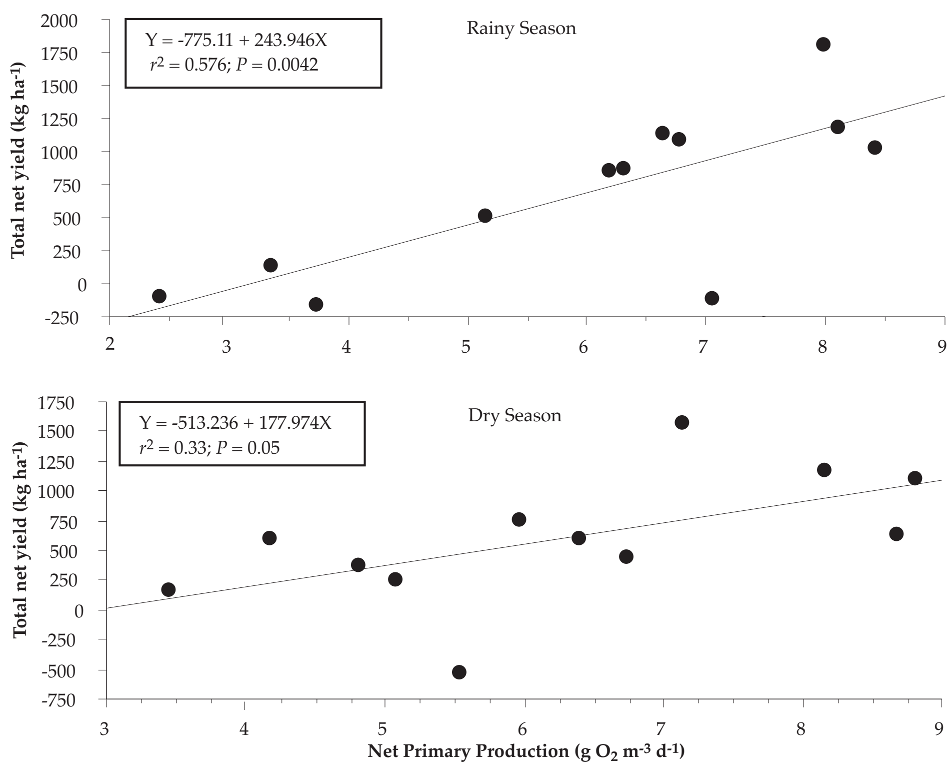

Figure 6. Relationship between total net yield of tilapia and mean net primary productivity in earthen ponds at Comayagua, Honduras, during the rainy and dry season Global Experiments.

Table 5. Costs per hectare of inputs consumed, total revenues, and gross profits during the rainy season (121-day duration) and dry season (107-day duration) Global Experiments at Comayagua, Honduras.

Weekly Nitrogen Application	**DAP**[1] ($ ha^{-1})	**Urea**[2] ($ ha^{-1})	**TSP**[3] ($ ha^{-1})	**Lime**[4] ($ ha^{-1})	**Sodium Bicarbonate**[5] ($ ha^{-1})	**Fingerlings**[6] ($ ha^{-1})	**Total Cost** ($ ha^{-1})	**Adult Fish**[7] ($ ha^{-1})	**Reproduction**[8] ($ ha^{-1})	**Total Revenue** ($ ha^{-1})	**Gross Profit** ($ ha^{-1})
RAINY SEASON											
0 kg ha^{-1}	$0	$0	$188	$65	$378	$441	$1,072	$1,859	$26	$1,885	$813
10 kg ha^{-1}	$223	$34	$0	$65	$874	$441	$1,637	$3,127	$57	$3,184	$1,547
20 kg ha^{-1}	$223	$156	$0	$65	$991	$441	$1,876	$4,137	$89	$4,226	$2,350
30 kg ha^{-1}	$223	$278	$0	$65	$1,013	$441	$2,020	$3,097	$20	$3,117	$1,097
DRY SEASON											
0 kg ha^{-1}	$0	$0	$169	$65	$254	$685	$1,173	$2,486	$49	$2,535	$1,362
10 kg ha^{-1}	$201	$31	$0	$65	$729	$685	$1,711	$2,669	$48	$2,717	$1,006
20 kg ha^{-1}	$201	$141	$0	$65	$712	$685	$1,804	$2,854	$36	$2,890	$1,086
30 kg ha^{-1}	$201	$250	$0	$65	$693	$685	$1,894	$2,172	$9	$2,181	$287

1 Diammonium phosphate (18-46-0); cost: $13.99 (50 kg)$^{-1}$
2 Urea (46-0-0); cost: $11.15 (50 kg)$^{-1}$
3 Triple superphosphate (0-46-0); cost: $13.99 (50 kg)$^{-1}$
4 Calcium carbonate; cost: $3.23 (50 kg)$^{-1}$
5 Cost: $32.79 (50 kg)$^{-1}$
6 Sex-reversed (≈ 50-gram each); cost: $0.038 each
7 Farm gate price: $1.68 kg^{-1} live weight; includes only live fish at harvest
8 Sale price: $0.22 kg^{-1}

Table 6. Partial budget analysis for increasing nitrogen pond fertilization rate in Honduras. Values are in US dollars per hectare per cycle.

Increase Weekly Nitrogen Fertilization From 0 kg ha^{-1} to 10 kg ha^{-1}

	Rainy Season	*Dry Season*		*Rainy Season*	*Dry Season*
ADDITIONAL COSTS			ADDITIONAL INCOME		
DAP Fertilizer	223	201	Adult Fish	3,184	2,718
Urea Fertilizer	34	31			
Sodium Bicarb.	874	729			
REDUCED INCOME			REDUCED COSTS		
Adult Fish	1,884	2,535	TSP Fertilizer	188	169
			Sodium Bicarb.	378	254
TOTAL ADDITIONAL COSTS AND REDUCED INCOME	3,015	3,496	TOTAL ADDITIONAL INCOME AND REDUCED COSTS	3,750	3,141
			NET CHANGES IN PROFIT	735	- 355
			AVERAGE NET CHANGE IN PROFIT	190	

Increase Weekly Nitrogen Fertilization From 10 kg ha^{-1} to 20 kg ha^{-1}

	Rainy Season	*Dry Season*		*Rainy Season*	*Dry Season*
ADDITIONAL COSTS			ADDITIONAL INCOME		
Urea Fertilizer	156	141	Adult Fish	4,226	2,890
Sodium Bicarb.	991	712			
REDUCED INCOME			REDUCED COSTS		
Adult Fish	3,184	2,718	Urea Fertilizer	34	31
			Sodium Bicarb.	874	729
TOTAL ADDITIONAL COSTS AND REDUCED INCOME	4,331	3,571	TOTAL ADDITIONAL INCOME AND REDUCED COSTS	5,134	3,650
			NET CHANGES IN PROFIT	803	79
			AVERAGE NET CHANGE IN PROFIT	441	

Increase Weekly Nitrogen Fertilization From 20 kg ha^{-1} to 30 kg ha^{-1}

	Rainy Season	*Dry Season*		*Rainy Season*	*Dry Season*
ADDITIONAL COSTS			ADDITIONAL INCOME		
Urea Fertilizer	278	250	Adult Fish	3,116	2,181
Sodium Bicarb.	1,013	693			
REDUCED INCOME			REDUCED COSTS		
Adult Fish	4,226	2,890	Urea Fertilizer	156	141
			Sodium Bicarb.	991	712
TOTAL ADDITIONAL COSTS AND REDUCED INCOME	5,517	3,833	TOTAL ADDITIONAL INCOME AND REDUCED COSTS	4,263	3,034
			NET CHANGES IN PROFIT	- 1,254	- 799
			AVERAGE NET CHANGE IN PROFIT	- 1027	

Table 7. Full-cost enterprise budget for the 20 kg N ha^{-1} wk^{-1} fertilization treatment in Honduras, based on a five-month production cycle. Values are in US dollars per hectare per cycle.

Description	Unit Cost or Price	Quantity	Cash
CASH RECEIPTS			
Adult Tilapia	\$1.68 kg^{-1}	2,077 kg	\$3,489
Reproduction	\$0.22 kg^{-1}	275 kg	\$61
Total Cash Receipts			\$3,550
VARIABLE COSTS			
Fingerling Tilapia	\$0.038 each	10,000 fingerlings	\$380
Plastic Bags	\$1.00 each	40 bags	\$40
Urea Fertilizer	\$11.15 $(50\ kg)^{-1}$	12 sacks	\$134
DAP Fertilizer	\$13.99 $(50\ kg)^{-1}$	16 sacks	\$224
Lime	\$3.23 $(50\ kg)^{-1}$	20 sacks	\$65
Sodium Bicarbonate	\$32.79 50 $kg)^{-1}$	31 sacks	\$1,016
Fingerling Transport	\$60		\$60
Fertilizer Transport	\$75		\$75
Field Labor	\$4.48 d^{-1}	38 d	\$170
Irrigation Water	\$5	1	\$5
Interest on Variable Capital	0.36		\$390
TOTAL VARIABLE COSTS			\$2,559
INCOME ABOVE VARIABLE COSTS			\$991

experiment and stocking of the dry season experiment, the presence of some carryover effect is plausible. Nitrogen input rate was the only variable in these experiments; both phosphorus and carbon were provided in excess. Thus, residual nitrogen from fertilization during the rainy season experiment was suspected to have influenced tilapia yield in the dry season experiment. However, no significant relationship ($P = 0.9233$, $r^2 = 0.001$) was detected when residuals of total net fish yield for the dry season experiment were regressed against total nitrogen added during the rainy season experiment. Similarly, when total nitrogen added during the rainy season experiment was included as a covariate in the analysis of variance of the dry season experiment total net fish yield, it was shown not to have a significant effect ($P = 0.9706$) nor to result in a significant reduction of the residual. Knud-Hansen (1992) found a maximum reduction in ANOVA residual for net fish yield when the total accumulated P or chicken manure from four previous experiments was included as a covariate. Knud-Hansen (1992) reasoned that the positive effect of previous pond management on net fish yields was because of increased availability of phosphorus for primary and secondary productivity. Phosphorus availability in the current experiments probably was not an important factor given the high phosphorus fertilization rate (8 kg P ha^{-1} wk^{-1}) and high soluble reactive phosphate concentrations (see Table 3). Perhaps the previous pond treatments acted to reduce the amount of very small clay particles in suspension in the water column, thereby allowing for increased primary production.

Increased nitrogen application rates resulted in increased plankton biomass as indicated by chlorophyll *a* concentrations. Yet gross and net primary production exhibited a quadratic relationship during the rainy season in response to increased nitrogen fertilization. No significant differences in primary production were detected during the dry season because of increased variability in the data, although a linear tendency was apparent when the data were plotted. Thus, results of these experiments did not indicate where nitrogen limitation of primary production ceased. In a similar experiment testing four levels of nitrogen fertilization, Teichert-Coddington and Claros (1996) also were not able to demonstrate a point where nitrogen no longer limited primary production.

Input costs increased with increasing nitrogen fertilization rate as would be expected. In all cases total revenue from the sale of adult fish and reproduction exceeded total costs. Gross profit during the rainy season was highest for the 20 kg N ha^{-1} wk^{-1} fertilization rate. However, during the dry season highest gross profit was observed for ponds not fertilized with nitrogen. Sodium bicarbonate was added to ponds as a carbon source for primary production. The cost of sodium bicarbonate represented from 22 to 53% of total costs. Identification of a less expensive carbon source would result in increased gross profit.

Fish yield data indicated that optimal production was attained with weekly applications of 20 kg N ha^{-1}. Primary production data did not clearly indicate an optimal nitrogen fertilization rate, nor a rate where nitrogen no longer limited primary production. However, the goal was optimal tilapia production and not necessarily optimal primary production. The final step in verifying the optimal nitrogen fertilization rate for tilapia production required a partial budget analysis. Results of the partial budget analysis showed positive net changes in profit as nitrogen fertilization rate was increased from 0 to 20 kg ha^{-1} wk^{-1}. Increasing nitrogen fertilization rate from 20 to 30 kg ha^{-1} wk^{-1} resulted in large negative net changes in profit. Therefore, nitrogen fertilization at 20 ha^{-1} wk^{-1} appeared to be the economically optimal rate for Honduras given current economic conditions.

ANTICIPATED BENEFITS

Results of these experiments have demonstrated an economically optimal nitrogen fertilization rate for tilapia production in Honduras. Tilapia farmers in other Central American countries could benefit from this information if an economic analysis demonstrates local, economic feasibility. Cost, revenue, and gross profit data and the enterprise budget will assist host country and international economists and planners in their evaluation of fish culture systems. Aquacultural scientists and students will benefit from this research through an improved understanding of the role of nutrients in optimizing tilapia production in the tropics.

LITERATURE CITED

Abacus Concepts, 1991. SuperANOVA. Abacus Concepts, Berkeley, California, 322 pp.

American Public Health Association (APHA), 1985. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, D.C., 1268 pp.

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. Ala. Agr. Exp. Sta., Auburn University, Alabama, 482 pp.

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

Egna, H.S., J. Bowman, and M. McNamara (Editors), 1990. Seventh Annual Administrative Report 1989. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, 114 pp.

Egna, H.S., J. Bowman, and M. McNamara (Editors), 1991. Eighth Annual Administrative Report 1990. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, 166 pp.

Egna, H.S., N. Brown, and M. Leslie (Editors), 1987. Pond Dynamics/Aquaculture Collaborative Research Data Reports, Volume 1: General Reference: Site Descriptions, Materials and Methods for the Global Experiment. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, 84 pp.

Egna, H. S., M. McNamara, and N. Weidner (Editors). 1992. Ninth Annual Administrative Report 1991. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, 172 pp.

Egna, H.S., J. Bowman, B. Goetze, and N. Weidner (Editors), 1994. Eleventh Annual Technical Report 1993. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, 178 pp.

Egna, H.S., J. Bowman, B. Goetze, and N. Weidner (Editors), 1995. Twelfth Annual Technical Report 1994. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, 209 pp.

Egna, H.S., M. McNamara, J. Bowman and N. Astin (Editors), 1993. Tenth Annual Administrative Report 1992. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, 275 pp.

Grasshoff, K., M. Ehrnhardt, and K. Kremling (Editors), 1983. Methods of Seawater Analysis. Verlag Chemie, Weinheim, Germany, 419 pp.

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

Hepher, B., 1962b. Ten years of research in fish pond fertilization in Israel. I. The effect of fertilization on fish yields. Bamidgeh, 14:29-38.

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

Kay, R.D., 1981. Farm Management: Planning, Control and Implementation. McGraw-Hill Book Company, New York, 370 pp.

Knud-Hansen, C.F., 1992. Pond history as a source of error in fish culture experiments: A quantitative assessment using covariate analysis. Aquaculture, 105:21-36.

Mortimer, C.H., 1954. Fertilizers in Fish Ponds. Fish Publ. No. 5. 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.

SAS Institute Inc. (SAS), 1998. StatView 5. SAS Institute Inc., Cary, North Carolina, 288 pp.

Swingle, H.S., 1947. Experiments on pond fertilization. Bull. 264. Agr. Exp. Sta. of the Ala. Polytech. Inst., Auburn, Alabama, 36 pp.

Teichert-Coddington, D.R. and N. Claros, 1996. Nitrogen fertilization in the presence of adequate phosphorus. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report 1995. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, pp. 18-26.

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