PD/A CRSP SEVENTEENTH ANNUAL TECHNICAL REPORT

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

Eighth Work Plan, Feeds and Fertilizers Research 1 (8FFR1K)
Progress Report

Karen L. Veverica
Department of Fisheries and Allied Aquacultures
Auburn University, Alabama, USA

Jim Bowman
Department of Fisheries and Wildlife
Oregon State University
Corvallis, Oregon, USA

Tom Popma
Department of Fisheries and Allied Aquacultures
Auburn University, Alabama, USA

ABSTRACT

Two experiments to determine the optimum nitrogen fertilization rates for freshwater tilapia production ponds at Sagana Fish Farm, Sagana, Kenya, were conducted during 1998 and 1999. Twelve 800-m^2 earthen research ponds managed by the PD/A CRSP at Sagana were used for the experiments. Diammonium phosphate and urea were used to apply nitrogen to the ponds at rates of 0, 10, 20, and 30 kg N ha^{-1} wk^{-1}. Triple superphosphate or diammonium phosphate (DAP) and sodium carbonate were applied to ponds to assure that phosphorus and carbon were not limiting. A completely randomized design was used, with three replicates for each of the four treatments. The experiment was conducted once during the 1998 cool season (May to October) and again during the warm season of 1998-1999 (November to March). In the cool-season experiment, ponds were stocked with sex-reversed Nile tilapia, *Oreochromis niloticus*, averaging 16.9 g at a rate of 1,000 kg ha^{-1} and with *Clarias gariepinus* fingerlings averaging 37 g at a rate of 37 kg ha^{-1}. In the warm-season experiment, all ponds were stocked with sex-reversed *O. niloticus* averaging 90 g at 1,000 kg ha^{-1} and with *C. gariepinus* juveniles averaging 166 g at 125 kg ha^{-1}. Pond assignments were re-randomized prior to the second experiment. Ponds were drained when fish growth appeared to have stopped in all treatments. In both experiments, a highly significant ($P < 0.01$) quadratic relationship best described gross (as well as net) fish yield as related to weekly N input. Presence of *Clarias* had little impact on the relationship but it appeared the high nitrogen input rates had no negative effect on *Clarias* production. Increasing nitrogen input from 20 kg N ha^{-1} wk^{-1} did not result in increased tilapia yield. Total nitrogen and all mineral forms of nitrogen increased with increasing nitrogen input, as did chlorophyll *a*. Partial budget analysis indicated that greatest marginal returns were at the calculated rates of 19.9 and 16.0 kg N ha^{-1} wk^{-1} for the cool- and warm-season experiments, respectively. A carryover effect of the first experiment is suggested. Results from this experiment are similar to those obtained at the CRSP site at El Carao, Honduras.

INTRODUCTION

Nitrogen, phosphorus, and carbon availability are important considerations in the management of ponds for optimum fish production. Previous PD/A CRSP research has addressed increasing primary productivity through inorganic and organic nutrient additions to ponds, but findings on the optimum nitrogen, phosphorus, and carbon inputs required to improve fish yields at the PD/A CRSP sites appeared inconsistent and called for clarification. Higher nutrient inputs had resulted in increased fish production at all PD/A CRSP sites, but optimum inputs of nitrogen, phosphorus, and carbon had 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 at Auburn University were 1.26 and 3 kg ha^{-1} wk^{-1}, respectively (Swingle, 1947; Boyd, 1976, 1990; 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.

This set of experiments was designed to determine the optimal application rates of nitrogen to attain the most profitable tilapia yields in tropical freshwater ponds at the PD/A CRSP site at Sagana, Kenya, and to provide data for the development of a full-cost enterprise budget for the most profitable fertilization rate. Trials were conducted during both the warm and cool seasons to determine seasonal effects.

METHODS AND MATERIALS

Cool-Season Experiment

These experiments were conducted in twelve CRSP-managed 800-m^2 earthen research ponds at Sagana Fish Farm, Sagana, Kenya. The cool-season experiment was conducted between May and October 1998. Triple superphosphate (TSP) was applied to each pond at a rate of 250 kg P ha^{-1} prior to filling. Each pond was also limed at a rate of 2.5 t ha^{-1}. The lime and TSP were raked into the bottom of the pond. Inorganic fertilizer, either as TSP or as diammonium phosphate (DAP) and urea, was applied weekly beginning two weeks prior to stocking (first application on 29 April 1998). Soda ash (97% sodium carbonate), obtained from Magadi Soda (the world's largest soda mine), was applied weekly to ponds with total alkalinity less than 75 mg l^{-1} as $CaCO_3$.

DAP and urea were used to apply nitrogen to the ponds at rates of 0, 10, 20, and 30 kg N ha^{-1} wk^{-1}. A completely randomized design was used, with three replicates for each of the four treatments. The final fertilizer and soda ash applications were on 6 October 1998. The total quantities of inputs used are shown in Table 1.

All ponds were stocked with sex-reversed tilapia averaging 16.9 g at a rate of 1,000 kg ha^{-1} on 13 May 1998. This resulted in a stocking rate of approximately 60,000 fish ha^{-1}. Each pond also received 80 *Clarias* averaging 37 g, resulting in an additional 37 kg ha^{-1}. Ponds were sampled at biweekly intervals by seining. All fish caught in the seine were separated by species, counted, and weighed. No attempt was made to obtain enough *Clarias* for a sample, so no *Clarias* were caught on some sampling dates, and growth curves were not made for this species. Ponds were drained on 16 October 1998 after it was determined that fish in all treatments had ceased to grow ("no growth" was defined as weight increases of less than 10% on two successive sampling occasions). Fish were separated by species, counted, and weighed. Of the fish harvested, 25,000 tilapia were sold to a cage culture operation for 120 KSh kg^{-1}, 10,640 tilapia and 720 *Clarias* were used to restock ponds for the next experiment, and 4,000 tilapia and the remaining *Clarias* were used to stock ponds in a supplementary carrying-capacity experiment.

Temperature and dissolved oxygen (DO) were measured weekly at four depths (5, 25, 50, and 75 cm below surface) at the pier near the drain in the morning and the afternoon. Total alkalinity (TA) and pH were measured weekly using column samples collected at three places in each pond. Chlorophyll *a* (corrected and uncorrected), TAN, nitrite, nitrate, and soluble reactive-P were measured biweekly (a total of 11 measurements for each parameter). Total N, total P, and total hardness (TH) were measured every four weeks, with a total of eight total N and total P measurements made during the experiment. Methods used were as indicated in the CRSP Handbook of Analytical Methods (PD/A CRSP Technical Committee, 1992), with the exception of nitrate analysis, which was performed using the NAS method. Diurnal oxygen and temperature readings were also made on these occasions to calculate primary productivity using the whole-pond method. Water sampling and analysis was done on Mondays (all were usually finished the same day or by Tuesday), and fertilizers and soda ash were applied on Tuesdays. Fish sampling was done on Wednesdays.

Ponds' water levels were recorded daily. Ponds were topped off to replace evaporation and seepage losses weekly (Mondays or Tuesdays). Night watchmen occasionally added water to some ponds when fish deaths occurred, but these ponds never overflowed, so effects on water quality are thought to have been negligible.

On occasions of fish death, dissolved oxygen, TAN, and nitrites were measured as soon as possible after fish deaths were reported. Most fish die-offs occurred on weekends (about four days after fertilization). Dead fish were counted and weighed. Only the ponds receiving the highest nitrogen input were affected.

Warm-Season Experiment

The warm-season experiment was conducted in the same 12 ponds between November 1998 and March 1999. At the end of the first (cool-season) experiment, residual lime and TSP could be seen on the bottoms of most ponds. Prior to refilling, ponds that had had TH less than 75 mg l^{-1} at the end of the cool-season experiment were relimed. Liming rates varied according to TH at the end of the first experiment. No further

Table 1. Total quantities of inputs used during cool season (147-day duration) and warm season (133-day duration) Global Experiment on optimum nitrogen fertilization at Sagana, Kenya.

Weekly N Input (kg ha^{-1})	DAP (kg ha^{-1})	Urea (kg ha^{-1})	TSP (kg ha^{-1})	Lime (kg ha^{-1})	Soda Ash (kg ha^{-1})
COOL SEASON					
0	0	0	1,585	2,500	283
10	960	146	625	2,500	492
20	960	668	625	2,500	229
30	960	1,190	625	2,500	254
WARM SEASON					
0	0	0	840	1,875	75
10	840	128	0	417	258
20	840	584	0	625	321
30	840	1,041	0	2,083	704

additions of TSP were deemed necessary because soluble phosphate levels in all ponds had remained high in the first experiment. Treatments for the warm-season experiment were the same as those for the cool-season experiment: DAP and urea were again used to add nitrogen at rates of 0, 10, 20, and 30 kg N ha^{-1} wk^{-1}.

Ponds were re-randomized and the first fertilizer application was made on 4 November 1998. Male tilapia averaging 90 g were used (left from the previous experiment) to stock all ponds at 1 t ha^{-1} on 18 November. Sixty *Clarias* averaging 166 g were added to each pond (125 kg ha^{-1}) on 23 November. This resulted in a stocking density of 11,000 tilapia and 750 *Clarias* ha^{-1}. Two tilapia and two *Clarias* were removed from each pond once a month to examine stomach contents. The removed fish were counted as live when survival was calculated but their weight was not used in calculating gross fish yield, on the assumption that the fish remaining in the pond increased in weight to compensate for those that had been removed. Ponds were drained on 29 March 1999 after it was concluded that all treatments had less than 5% weight gain on two successive samplings. Fish were separated by species, counted, and weighed. Tilapia were separated by sex, and fingerling weight was noted. The tilapia and *Clarias* were sold at 120 KSh kg^{-1} to a Nairobi fish-out operator.

Water quality parameters were measured at the same frequency as in the cool-season experiment. Fertilizers and soda ash were applied on Tuesdays. Some ponds in the experiment exhibited very high morning pH and their hardness was beginning to diminish, so soda ash applications were suspended for ponds that had a morning column pH greater than 8.5. These ponds typically increased in pH to more than 10 before noon, so any additional carbonate would not have been available for photosynthesis. Chlorophyll *a* (corrected and uncorrected), TAN, nitrite, nitrate, and soluble reactive-P (a total of 9 measures for each parameter) were measured biweekly. Total N, total P, and TH were measured every four weeks. A total of five total N and total P measurements were made during the experiment.

Data for each experiment were analyzed statistically by regression analysis using Statgraphics Plus for Windows software (Statistical Graphics Corp. 1997). Models that resulted in the lowest P values (not necessarily the highest r^2 values) were used.

RESULTS

Preliminary observations are outlined in this progress report. A complete, final report will be submitted after completion of the data analysis for these experiments.

Site Observations

The Sagana site has very cool surface waters (usually 19 to 21°C) with low alkalinity and hardness compared to the El Carao station in Honduras and the AIT station in Thailand. TA runs about 16 to 28, and TH is 13 to 28, with higher values in dry months. There is not much difference in average air temperature in the so-called cool season. Minimum air temperatures tend to be the same but maximum temperatures are lower in the cool season due to increased cloud cover. Solar radiation during the cool season is much lower than during the warm season. Average solar radiation during the first experiment was 24.64 Einsteins m^{-2} (7.56 MJ m^{-2}), whereas it was 41.91 Einsteins m^{-2} (12.34 MJ m^{-2}) during the warm-season experiment. The beginning and end of the cool-season experiment actually fell into warm-season months. There was a slight difference in pond water temperatures between the cool- and the warm-season experiments.

Another seasonal difference has to do with winds. In the cool season, wind is less and the ponds mix only in the night to early morning. In the warm season, especially December through February, high winds occur every afternoon and the ponds mix twice, once in the evening and once in the early morning.

During the cool season, ponds in the 20 and 30 kg N treatments had dense blooms of euglenophytes (*Trachelomonas*, *Euglena*, and *Phacus* spp.) These blooms did not occur in the warm-season experiment. The lower solar radiation tends to favor the euglenophytes during the cool season (these blooms have occurred each cool season since the CRSP began work at Sagana). Surface blooms of any kind cannot resist the intense solar radiation experienced at Sagana from December through February.

Fish Growth

Figures 1 and 2 show average fish weight by nitrogen input rate for each experiment. In the cool season, the high nitrogen input rate showed high growth after about 25% of the fish died in two of the ponds.

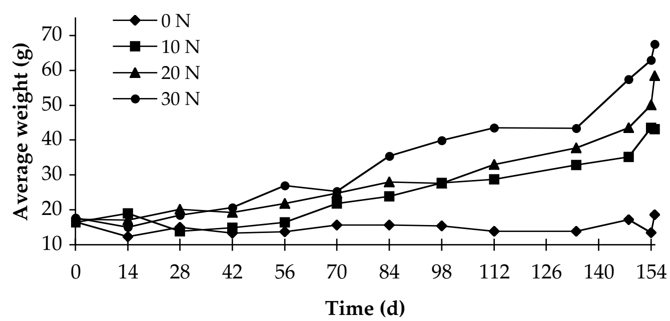

Figure 1. Growth of tilapia under four different nitrogen input rates during the cool-season trial of the PD/A CRSP Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya.

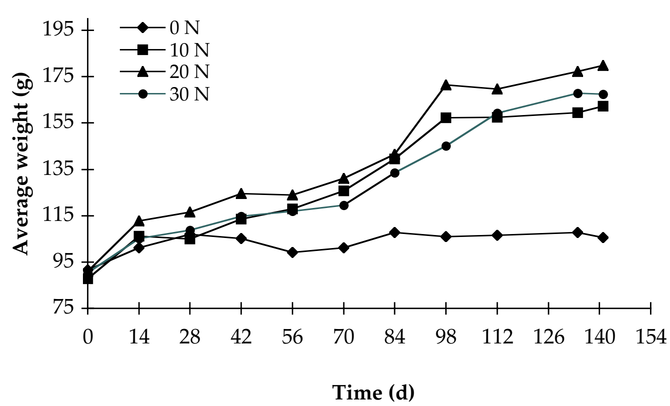

Figure 2. Growth of tilapia under four different nitrogen input rates during the warm-season trial of the PD/A CRSP Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya.

Table 2. Mean (± SE) tilapia yields, *Clarias* yields, average weights by species, and survival for cool and warm season of the Global Experiment on optimum nitrogen fertilization at Sagana Fish Farm, Sagana, Kenya.

Weekly N Input (kg ha^{-1})	**Yield** (kg ha^{-1})				**Average Weight** (g)		**Tilapia Reproduction** (kg ha^{-1})
	Tilapia	*Clarias*	*Gross*	*Net*	*Tilapia*	*Clarias*	
COOL SEASON							
0	1,015 ± 113	208 ± 34	1,297 ± 116	251 ± 117	23.1 ± 1.6	156.1 ± 2.9	74 ±20.6
10	2,602 ± 107	270 ± 59	2,949 ± 120	1,908 ± 120	48.1 ± 1.9	263.2 ± 40.6	7 ±19.3
20	2,953 ± 296	250 ± 22	3,229 ± 278	2,191 ± 280	60.4 ± 3.8	275.1 ± 28.2	30 ±3.5
30	2,510 ± 348	495 ± 24	3,043 ± 371	2,004 ± 371	70.5 ± 5.9	375.7 ± 45.3	37 ±4.8
Best Fit Model	quadratic	linear	quadratic	quadratic	sq. root x	reciprocal-y	linear
r^2	82%**	57%*	82%**	82%**	92%**	78%**	43%*
WARM SEASON							
0	1,119 ± 115	154 ± 23	1,272 ± 137	296 ± 162	106 ± 8.3	251.3 ± 29.5	43 ±7.4
10	1,672 ± 156	164 ± 6	1,837 ± 161	883 ± 169	162 ± 12.4	262.9 ± 3.8	29 ±2.3
20	1,720 ± 100	181 ± 89	1,901 ± 95	957 ± 91	181 ± 4.3	283.2 ± 6.7	34 ±11.5
30	1,520 ± 160	183 ± 16	1,703 ± 45	761 ± 28	168 ± 6.5	283.1 ± 16.4	17.5 ±0.9
Best Fit Model	quadratic	NS	quadratic	quadratic	quadratic	NS	exponential
r^2	68%**		67%**	67%**	86%**		41%*

** highly significant ($P < 0.01$)
* significant ($P < 0.05$)

models used in Tables 2 and 4:
linear: $y = a + bx$
exponential: $y = \exp(a + bx)$
sq. root y: $y = (a + bx)^2$
sq. root x: $y = a + bx^{1/2}$
reciprocal-y: $y = (a + bx)^{-1}$
quadratic: $y = a + bx + cx^2$

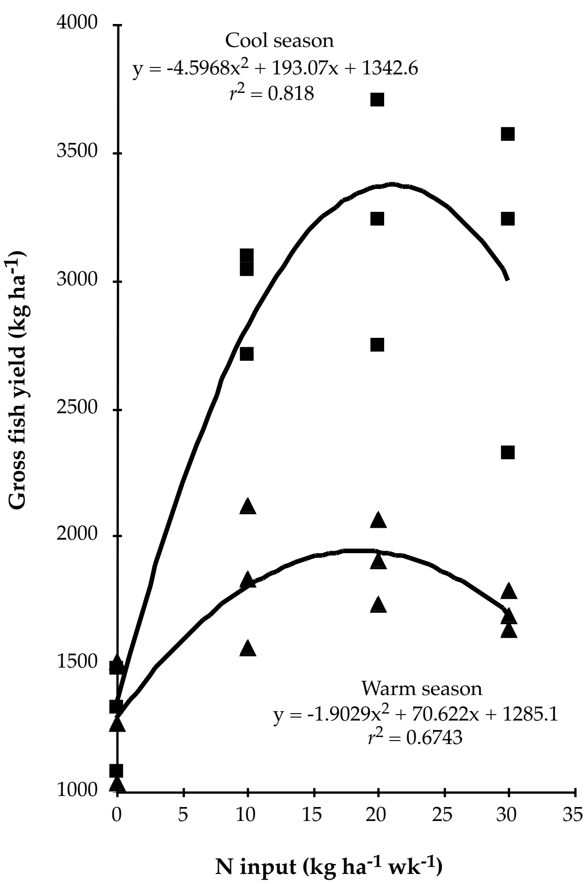

Figure 3. Gross fish yield (GFY) as a function of nitrogen (N) input for the cool- and warm-season trials of the PD/A CRSP Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya.

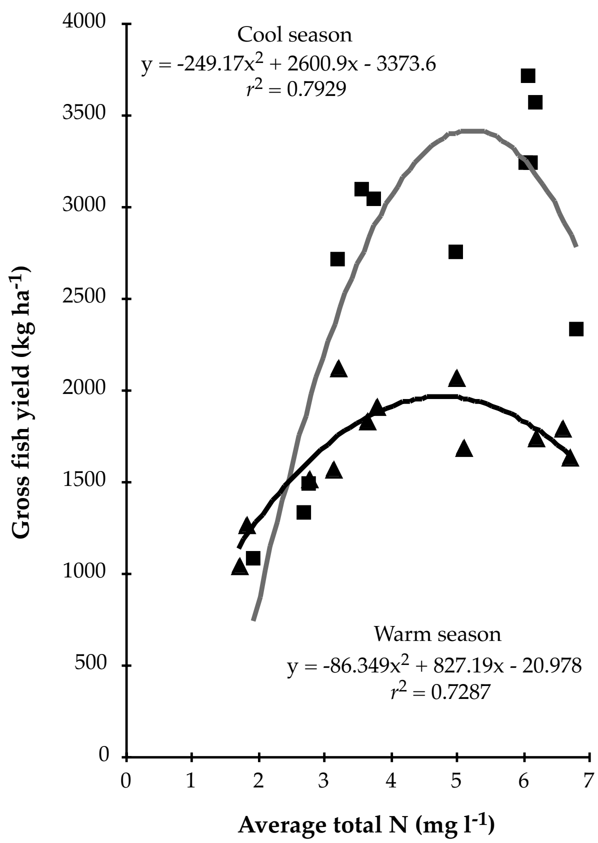

Figure 4. Relationship between gross fish yield (GFY) and average total nitrogen (N) content in pond waters during the cool- and warm-season trials of the PD/A CRSP Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya.

The relationship between gross fish yield (GFY) and nitrogen input rate was best described by a quadratic model. It was highly significant ($P < 0.01$) in both experiments but better correlated in the cool-season experiment (Table 2 and Figure 3). Fish deaths occurred in the treatment with the highest nitrogen application rate on at least two occasions during the cool-season experiment, on 12–13 June in pond E09 and on 22 June in pond D04. Dead tilapia were picked up occasionally during the warm-season experiment but they never totaled more than two or three on any day. No *Clarias* died on these occasions. In fact, the relationship between *Clarias* yield and nitrogen input rate was linear, suggesting that they are less affected by the high nitrogen.

Taking the first derivative of the regression equation gives the nitrogen input rate at which maximum GFY would be obtained: 21.0 kg N ha^{-1} wk^{-1} for the cool-season experiment and 18.6 kg N ha^{-1} wk^{-1} for the warm-season experiment. A highly significant relationship exists between GFY and average total N in ponds as well (Figure 4). Differences in initial fish size and density do not permit a valid comparison of growth and productivity as a function of season.

At draining of the cool-season experiment, every pond had at least two large *Clarias* (> 1 kg). These fish were probably left over from the previous experiment. Some ponds contained many more *Clarias* than were stocked, and these extra fish may have entered with the tilapia fingerlings. It was easier to separate out *Clarias* during stocking in the second experiment because fish were fewer in number and larger.

The weight of tilapia reproduction decreased with increasing nitrogen input (Table 2). Size of tilapia females, *Clarias* size, or adverse water quality due to high nitrogen input rate could have been causes.

Water Quality

During the warm season the ponds did have higher water temperatures and lower morning dissolved oxygen concentrations than they did during the cool season (Table 3). If the difference between afternoon and morning dissolved oxygen is used as an indicator of net primary production, then primary production was a bit higher in

Table 3. Dissolved oxygen (DO) and temperature observations in ponds during the cool- and warm-season trials of the Global Experiment on optimum nitrogen fertilization conducted at Sagana Fish Farm, Sagana, Kenya.

Ponds	Weekly N Input ($kg\ ha^{-1}$)	Dissolved Oxygen ($mg\ l^{-1}$)							
		Morning				*Afternoon*			
		5 cm	25 cm	50 cm	75 cm	5 cm	25 cm	50 cm	75 cm
COOL									
D7, D8, E6	0	4.6	4.5	4.3	3.7	12.1	10.6	5.3	2.9
D6, E4, E5	10	4.3	4.1	4.0	3.7	14.7	13.6	6.9	3.7
D5, E7, E8	20	3.5	3.3	3.2	2.8	16.5	15.3	7.2	3.1
D4, E3, E9	30	2.5	2.2	2.0	1.9	15.9	13.7	7.0	3.3
WARM									
D4, D8, E9	0	3.0	3.0	3.0	2.9	9.5	9.3	6.5	3.3
D7, E3, E6	10	2.1	2.0	2.0	1.9	10.9	10.1	7.4	3.1
E4, E5, E7	20	2.0	1.9	1.9	1.9	11.9	10.5	7.1	2.9
D5, D6, E8	30	1.8	1.8	1.8	1.7	13.4	12.7	8.7	3.9

Ponds	Weekly N Input ($kg\ ha^{-1}$)	Temperature (ºC)							
		Morning				*Afternoon*			
		5 cm	25 cm	50 cm	75 cm	5 cm	25 cm	50 cm	75 cm
COOL									
D7, D8, E6	0	22.5	22.5	22.5	22.5	26.4	25.9	24.0	23.4
D6, E4, E5	10	22.9	22.9	22.9	22.9	26.3	26.0	24.6	23.8
D5, E7, E8	20	22.8	22.8	22.8	22.8	26.4	26.0	24.5	23.8
D4, E3, E9	30	22.9	22.8	22.8	22.8	26.1	25.7	24.7	23.9
WARM									
D4, D8, E9	0	23.5	23.5	23.5	23.5	28.2	28.0	26.4	24.7
D7, E3, E6	10	23.5	23.5	23.5	23.5	27.8	27.6	26.5	25.1
E4, E5, E7	20	23.6	23.6	23.6	23.6	27.6	27.5	26.5	25.0
D5, D6, E8	30	23.6	23.3	23.3	23.3	28.0	27.9	26.6	24.7

the cool season than the warm season. This relationship will be examined in more detail in the final report for this experiment.

Observations for TH, TA, corrected and uncorrected chlorophyll *a*, soluble reactive phosphorus, pH, total N, ammonia-N, nitrite-N, and nitrate-N for both the cool- and warm-season experiments are shown in Table 4. In both experiments, it can be concluded that phosphate was not limiting in any way. Attempts to keep TA high were successful in the first experiment but not in the second. Decreasing total hardness meant that there was less buffering capacity, which probably kept pH high in ponds receiving large amounts of sodium carbonate. Although TA averaged less than 60 mg l^{-1}, chlorophyll *a* levels were higher in the highest nitrogen input treatment.

Table 4. Mean (± SE) pond water quality observations during the cool- and warm-season Global Experiments on optimum nitrogen fertilization at Sagana Fish Farm, Sagana, Kenya.

Weekly N Input (kg ha^{-1})	**Total Alkalinity** (mg l^{-1} as $CaCO_3$)	**Total Hardness** (mg l^{-1} as $CaCO_3$)	**Corrected Chlorophyll *a*** (mg m^{-3})	**Uncorrected Chlorophyll *a*** (mg m^{-3})	**Total Phosphorus** (mg l^{-1})	**Soluble Reactive Phosphorus** (mg l^{-1})
COOL SEASON						
0	89.7 ± 15.9	75.5 ± 18.3	60.2 ± 2.7	107.5 ± 10.6	2.0 ± 0.72	1.0 ± 0.46
10	73.8 ± 5.5	60.0 ± 7.2	85.0 ± 8.3	171.5 ± 14.5	1.9 ± 0.29	1.1 ± 0.20
20	74.8 ± 8.5	52.1 ± 5.4	156.5 ± 43.8	233.0 ± 52.3	2.4 ± 0.12	1.2 ± 0.06
30	77.9 ± 3.6	60.0 ± 8.0	185.4 ± 15.5	277.6 ± 20.2	1.3 ± 0.24	0.6 ± 0.14
Best Fit Model			reciprocal-y	exponential		
Correlation	NS	NS	-.86**	.84**	NS	NS
Std. Error Est.			0.00277	0.243		
WARM SEASON						
0	84.8 ± 6.3	80.2 ± 7.2	89.5 ± 37.6	89.9 ± 23.5	1.5 ± 0.06	0.7 ± 0.14
10	69.6 ± 0.9	59.2 ± 3.4	109.3 ± 8.8	147.3 ± 7.0	3.0 ± 1.88	1.4 ± 0.39
20	64.0 ± 1.6	47.5 ± 4.3	182.2 ± 78.4	252.3 ± 97.8	2.6 ± 0.47	1.3 ± 0.08
30	55.3 ± 0.8	30.8 ± 3.6	198.5 ± 16.9	271.0 ± 25.7	3.7 ± 0.42	1.5 ± 0.23
Best Fit Model	reciprocal	sq. root-y	exponential	exponential	reciprocal	exponential
Correlation	.95**	-.94**	.63*	.76**	-.75**	-.65*
Std. Error Est.	0.0008	0.511	0.514	0.412	0.129	0.357

Weekly N Input (kg ha^{-1})	**pH**	**Total Nitrogen** (mg l^{-1})	**Ammonia-N** (mg l^{-1})	**NO_2-N** (mg l^{-1})	**NO_3-N** (mg l^{-1})	**Soda Ash Added to Ponds** (kg ha^{-1})
COOL SEASON						
0	7.5 ± 0.13	2.5 ± 0.27	0.8 ± 0.06	0.0 ± 0.00	0.0 ± 0.01	254 ± 242
10	7.8 ± 0.16	3.5 ± 0.16	0.9 ± 0.12	0.0 ± 0.02	0.1 ± 0.02	229 ± 67
20	8.0 ± 0.25	5.7 ± 0.35	1.1 ± 0.07	0.3 ± 0.08	0.3 ± 0.14	491 ± 256
30	7.5 ± 0.07	6.4 ± 0.75	1.3 ± 0.09	0.7 ± 0.20	0.3 ± 0.06	283 ± 136
Best Fit Model		linear	linear	linear	sq. root-y	
Correlation	NS	.96**	.82**	.83**	.79**	NS
Std. Error Est.		0.529	0.140	0.196	0.143	
WARM SEASON						
0	7.7 ± 0.31	2.1 ± 0.33	0.5 ± 0.05	0.0 ± 0.00	0.0 ± 0.03	75 ± 38
10	8.4 ± 0.13	3.3 ± 0.16	0.5 ± 0.10	0.0 ± 0.01	0.1 ± 0.03	258 ± 33
20	8.8 ± 0.30	5.0 ± 0.69	0.6 ± 0.09	0.1 ± 0.05	0.2 ± 0.08	321 ± 17
30	8.8 ± 0.20	6.1 ± 0.52	0.8 ± 0.08	0.3 ± 0.11	0.3 ± 0.01	704 ± 115
Best Fit Model	sq. root-x	sq. root-y	linear	sq. root-y	linear	sq. root-y
Correlation	.77**	.92**	.67*	.90**	.77**	.89**
Std. Error Est.	0.388	0.179	0.144	0.101	0.119	1.05

** highly significant ($P < 0.01$)
* significant ($P < 0.05$)

Table 5. Cost of inputs and revenue per hectare for the optimum nitrogen fertilization experiments (Global Experiment) conducted at Sagana Fish Farm, Sagana, Kenya, during 1998 and 1999. Costs include initial phosphorus-saturation inputs of TSP applied to ponds for the cool-season experiment. (US$1 = 60 KSh)

Treatment	Weekly N Input ($kg\ ha^{-1}$)							
	Cool Season				*Warm Season*			
	0	10	20	30	0	10	20	30
COSTS ($KSh\ ha^{-1}$)								
DAP	-	24,000	24,000	24,000	-	21,000	21,000	21,000
Urea	-	2,776	12,688	22,601	-	2,429	11,102	19,775
TSP	39,625	15,625	15,625	15,625	36,625	-	-	-
Lime	10,000	10,000	10,000	10,000	7,500	1,667	2,500	8,333
Soda Ash	2,796	2,521	5,408	2,521	825	2,842	3,529	7,746
Stockers	124,440	124,440	124,440	124,440	135,000	135,000	135,000	135,000
Total Cost	176,861	179,362	192,161	199,186	179,950	162,937	173,131	191,855
REVENUES (Ksh)								
Tilapia Revenue	121,800	312,240	354,360	301,200	134,280	200,640	206,400	182,400
Clarias Revenue	24,960	32,400	30,000	59,400	18,480	19,680	22,080	21,960
Total Revenue	146,760	344,640	384,360	360,600	152,760	220,320	228,480	204,360
GROSS PROFIT								
KSh	-30,101	165,278	192,199	161,414	-27,190	57,383	55,349	12,505
$US	-502	2,755	3,203	2,690	-453	956	922	208

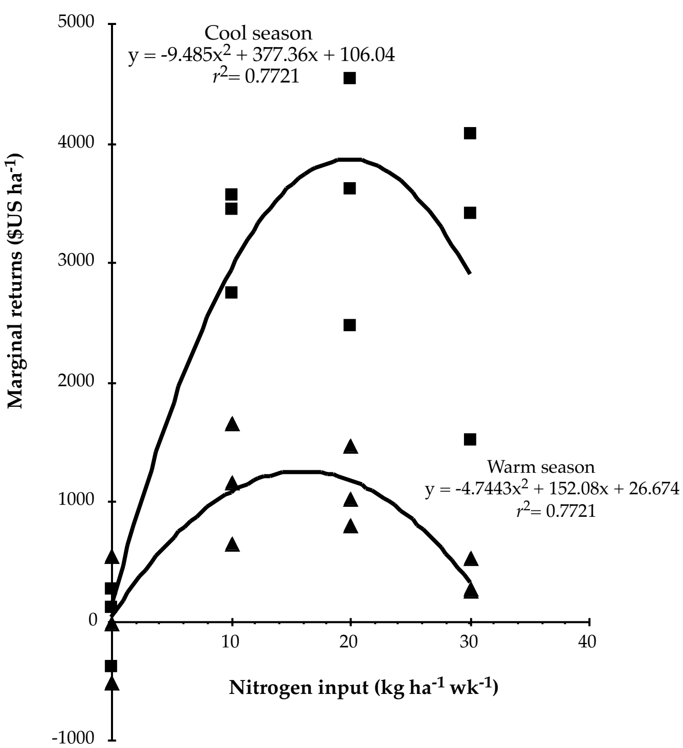

Figure 5. Marginal returns (increased revenues less increased costs) as a function of nitrogen input rates for the cool- and warm-season trials of the Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya. Cost of capital was estimated at 12%.

Economic Analysis

The costs of inputs and revenues per hectare for these experiments are shown in Table 5. The highest marginal return (increase in revenues less increased costs) was obtained at the 20 $kg\ N\ ha^{-1}\ wk^{-1}$ rate in both experiments. Maximum marginal returns were calculated at input rates of 19.9 and 16.0 $kg\ N\ ha^{-1}\ wk^{-1}$ for the cool- and warm-season experiments, respectively (Figure 5).

Carry-Over Effect

Table 6 was assembled to examine the possible effects of previous treatments on the outcome of the second experiment.

Table 6. Performance of ponds in the second trial in relation to the nitrogen input level received in the first trial of the Global Experiment on optimum nitrogen fertilization, Sagana, Kenya.

Weekly N Input in Second Expt. ($kg\ ha^{-1}$)	Performance in Second Expt.	Weekly N Input in First Expt. ($kg\ ha^{-1}$)
0	Best pond: D04	30
	Worst pond: D08	0
10	Best pond: E03	30
	Worst pond: E06	0
20	Best pond: E05	10
	Worst pond: E07	20
30	Best pond: D06	10
	Worst pond: E08	20

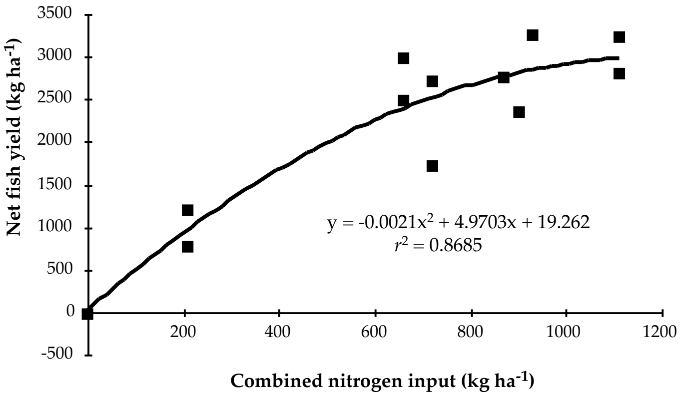

Figure 6. Combined net fish yield in relation to total nitrogen input for the cool- and warm-season trials of the Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya.

Ponds that received no nitrogen during the first experiment were the worst performers in the lower nitrogen input rates of the second experiment and the best performers in the high-N treatments of the second experiment. Ponds that received high nitrogen inputs were better performers (in terms of fish yields) in the no nitrogen input treatments of the second experiment and the worst performers in the high nitrogen input treatments. It therefore appears that overall production over the two experiments was related to cumulative nitrogen input. Figure 6 shows this relationship. Combined net fish yields for the cool- and warm-season experiments were highly correlated to combined nitrogen inputs over the two experiments. Unfortunately, no pond received two consecutive highest nitrogen input rates. The calculated maximum net fish yield would occur at 1,183.5 kg ha^{-1} N input over 45 weeks or 26.3 kg N ha^{-1} wk^{-1}. This relationship was the most highly correlated of any fish yield relationship examined.

Discussion

The observations of water quality parameters (chlorophyll *a* and total N), which usually correlate well with high tilapia production, were very similar in both experiments. They definitely do not explain why fish production was so low in the warm-season experiment. Production was lower in the second experiment at the El Carao site as well but no explanation was given (Green et al., 1999). A lack of significant differences in fish yields in the second experiment at El Carao was attributed to carry-over effects of the nitrogen from the preceding experiment. The results from Sagana also suggest some carry-over effect or possibly the effect of differences in initial stocking size and density.

In addition to conducting the first round of the Global Experiment on optimum nitrogen, researchers at the Asian Institute of Technology (AIT) in Thailand conducted a complementary study, in which they compared production from ponds that had been stocked with three different sizes of tilapia. They concluded that stocking with medium-sized fish (averaging 10 g in size) resulted in greater production than stocking with either small tilapia (averaging 4.6 g in size) or larger fingerlings (averaging 21 g in size). The fish used to stock ponds in the first round of the Sagana experiment were in between the medium and large sizes used in the AIT study.

The results obtained at Sagana are more similar to those obtained at the El Carao site than to those from the AIT site. Increasing nitrogen input rates to 30 kg ha^{-1} wk^{-1} did not result in increased fish yields at either El Carao or Sagana. The high water temperatures that are typical at the AIT site (29 to 37°C) are a plausible explanation for a higher optimum nitrogen input rate there. Hatchery technicians who work with recirculating systems know that the capacity of a biofilter to process nitrogen is affected by temperature, with maximum nitrogen loading rates being higher at higher temperatures.

The two experiments conducted at Sagana took much longer than at the other two CRSP sites. The experiment was terminated after 91 days at AIT and after 121 and 107 days at El Carao. In contrast, the cool-season experiment at Sagana lasted 147 days and the warm-season experiment lasted 133 days.

These results and questions led us to qualify our recommendations for farmers. A chemical fertilizer-only treatment will probably not form part of the extension recommendations to farmers in Kenya because of problems in controlling alkalinity. Organic matter inputs seem to stabilize the pond system and maintain total alkalinity. However, the optimum nitrogen input rate will be used in setting input recommendations and in estimating carrying capacity for certain input combinations. Farmers in cooler areas will be cautioned to not exceed 16 kg ha^{-1} wk^{-1} of chemical nitrogen.

Anticipated Benefits

The results from this experiment were valuable additions to the formulation of extension recommendations for tilapia culture in the East Africa region. Combining the discussions from the three PD/A CRSP sites that conducted the Global Experiment can lead to some additional research topics as well: Fish size as a variable in carrying capacity estimates and temperature as the main reason for different optimum N input rates. The temperature question has been answered for the most part but the question of fish size versus carrying capacity merits further work, especially for systems using filter feeders and relying on natural production.

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The work of Mr. James Karuri, lab technician, and Thomas Ndegwa, lab assistant, was invaluable. Paul Wamwea Wabitah helped out in keeping data for the pond sampling. Our super seine crew demonstrated that 12 ponds can indeed be sampled in under two hours—a feat never thought possible at Sagana. Mr. John Kogi was a highly reliable pond manager and recordkeeper.

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