Global Experiment: Optimization of Nitrogen Fertilization Rate in Freshwater Tilapia Production Ponds

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

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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 800m^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 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 grams 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 1000 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 fish yield (as well as net) as related to weekly nitrogen 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 beyond 20 kg N ha^{-1} wk^{-1} did not result in increased tilapia yields. 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 from the first experiment is suggested. Results from this experiment are similar to those obtained at the CRSP site at El Carao, Honduras.

Introduction

Nitrogen (N), phosphorus (P), and carbon (C) 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 N, P, and C 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 input rates for N, P, and C 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 per week. In Israel, the standard fertilizer dose was 2.3 kg P and 6.5 kg N/ha per week (Hepher 1962a, b). The highest rates of P and N used in most experiments at Auburn University were 1.26 and 3 kg/ha per week, respectively (Swingle 1947; Boyd l976, l990; Boyd and Sowles 1978; Murad and Boyd 1987). Rates in Europe seldom exceeded 1 kg/ha per week for N and P (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, P was the most important limiting nutrient.

This set of experiments was designed to determine the optimal application rates of N 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.

MATERIALS AND METHODS

Cool Season Experiment

These experiments were conducted in twelve CRSP-managed 800m^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 tons 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 as $CaCO_3$.

Dap and urea were used to apply N 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 16.9g at a rate of 1,000 kg ha^{-1} on 13 May 1998. This resulted in a stocking rate of about 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 bi-weekly intervals by seining. All fish caught in the seine were separated by species and counted and weighed. No attempt was made to obtain enough *Clarias* for a sample, so on some sampling dates no *Clarias* were caught, 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, 10,640 tilapia and 720 *Clarias* were used to re-stock 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 measures 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 measures being made during the experiment. Diurnal oxygen and temperature readings were also made to calculate primary productivity using the whole pond method. Gross and net primary production were calculated on three occasions: two weeks after stocking the ponds, six weeks after stocking, and during the week prior to pond draining. Methods used were as described in the CRSP Handbook of Analytical Methods (PD/A CRSP 1992), with the exception of nitrate analysis, which was performed using the NAS 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 N input were affected.

Soil samples were taken from each pond two weeks after stocking and again during the week prior to pond draining. Nine cores of 2-cm depth (from the soil surface) were combined to make the soil sample for each pond at the beginning of the experiment; the core depth taken at the end of the experiment was 5 cm.

Warm Season Experiment

The warm-season experiment was conducted in the same twelve ponds between November 1998 and March 1999. At the

Table 1. Total quantities of inputs used during the cool-season (156 day duration) and warm-season (131 day duration) trials of the experiment on optimum nitrogen fertilization (CRSP global experiment) at Sagana Fish Farm (Sagana, Kenya).

Weekly Nitrogen Application	DAP (kg ha^{-1})	Urea (kg ha-1)	TSP (kg ha-1)	Lime (kg ha-1)	Soda Ash (kg ha-1)
Cool Season					
0 kg ha^{-1}	0	0	1585	2500	283
10 kg ha^{-1}	960	146	625	2500	492
20 kg ha^{-1}	960	668	625	2500	229
30 kg ha^{-1}	960	1190	625	2500	254
Warm Season					
0 kg ha^{-1}	0	0	840	1875	75
10 kg ha^{-1}	840	128	0	417	258
20 kg ha^{-1}	840	584	0	625	321
30 kg ha^{-1}	840	1041	0	2083	704

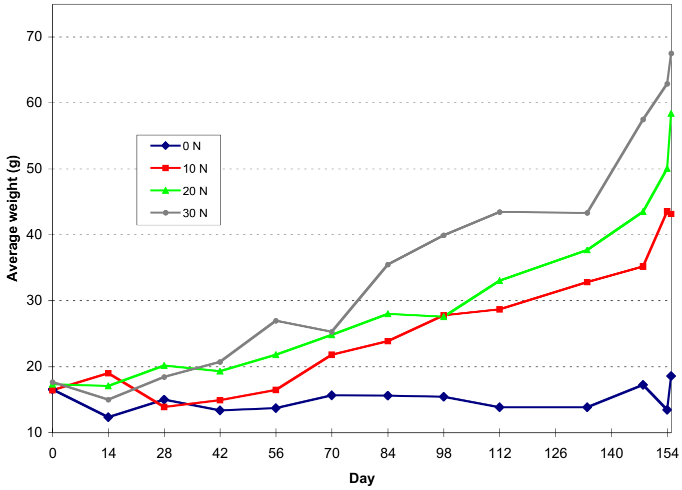

Figure 1. Growth of tilapia under four different nitrogen input rates during the cool season trial of the PD/A CRSP Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya.

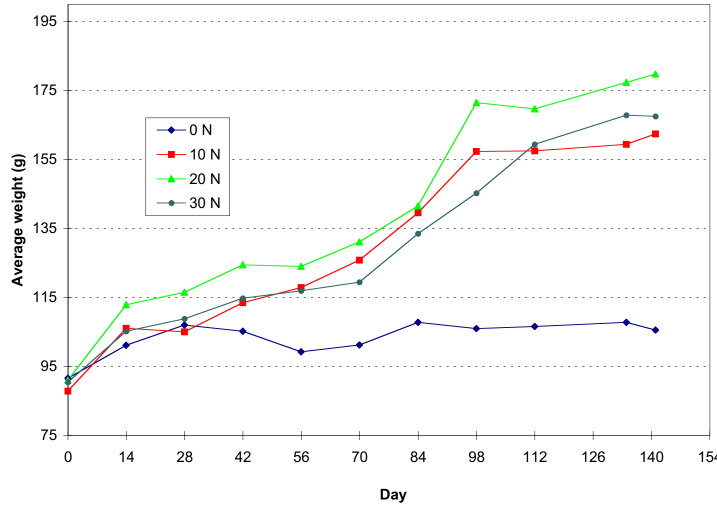

Figure 2. Growth of tilapia under four different nitrogen input rates during the warm season trial of the PD/A CRSP Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya.

end of the first (cool-season) experiment, residual lime and TSP could be seen on the bottoms of most ponds. Prior to re-filling, ponds that had had TH less than 75 mg/l at the end of the cool season experiment were re-limed. Liming rates varied according to TH at the end of the first experiment. No further additions of TSP were deemed necessary because soluble P 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 N 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 ton ha^{-1} on 18 November. Sixty *Clarias* averaging 166g 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* per hectare. 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

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

Weekly Nitrogen Application	Yield ($kg\ ha^{-1}$)				Average Weight (g)		Tilapia Reprod ($kg\ ha^{-1}$)
	Tilapia	Clarias	Gross	Net	Tilapia	Clarias	
Cool							
0 kg ha^{-1}	1015 ±113	208 ±34	1297 ±116	251 ±117	23.1 ±1.6	156.1 ±2.9	74±20.6
10 kg ha^{-1}	2602 ±107	270 ±59	2949 ±120	1908 ±120	48.1 ±1.9	263.2 ±40.6	77±19.3
20 kg ha^{-1}	2953 ±296	250 ±22	3229 ±278	2191 ±280	60.4 ±3.8	275.1 ±28.2	30±3.5
30 kg ha^{-1}	2510 ±348	495 ±24	3043 ±371	2004 ±371	70.5 ±5.9	375.7 ±45.3	37±4.8
Best fit model	quadratic	linear	quadratic	quadratic	sq. root x	reciproc.-y	linear
R-squared	82%**	57%*	82%**	82%**	92%**	78%**	43%*
Warm							
0 kg ha^{-1}	1119 ±115	154 ±23	1272 ±137	296 ± 162	106 ± 8.3	251.3 ±29.5	43 ±7.4
10 kg ha^{-1}	1672 ±156	164 ± 6	1837 ±161	883 ± 169	162 ±12.4	262.9 ± 3.8	29 ±2.3
20 kg ha^{-1}	1720 ±100	181 ±89	1901 ±95	957 ± 91	181 ± 4.3	283.2 ± 6.7	34 ±11.5
30 kg ha^{-1}	1520 ±160	183 ±16	1703 ±45	761 ± 28	168 ± 6.5	283.1 ±16.4	17.5 ±0.9
Best fit model	quadratic	NS	quadratic	quadratic	quadratic	NS	exponen.
R-squared	68%**		67%**	67%**	86%**		41%*

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

<u>models used in Tables 2 and 3:</u>
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: $y=a+bx+cx^2$

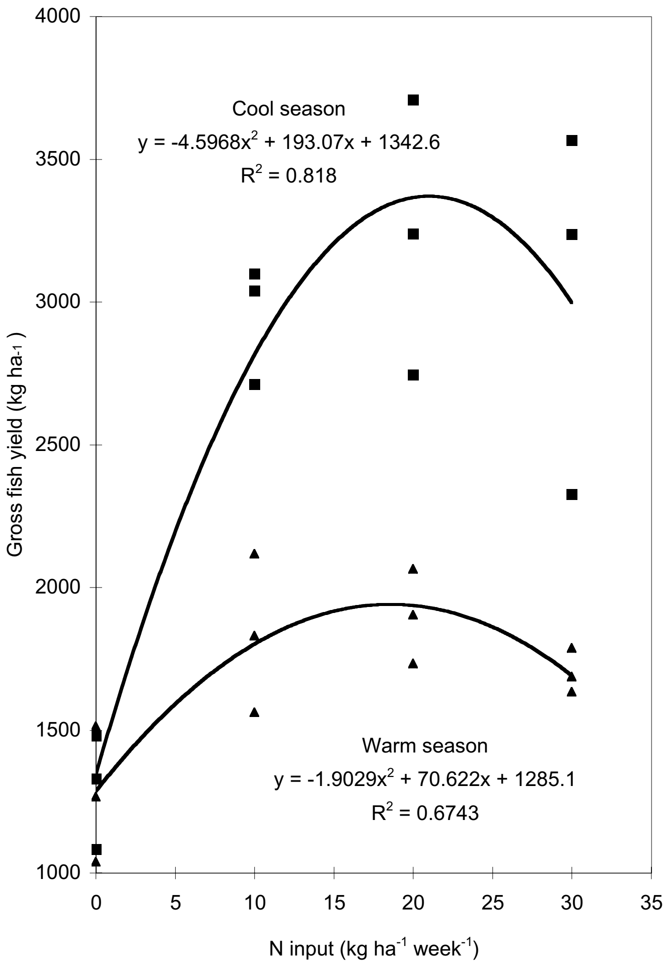

Figure 3. Gross fish yield (GFY) as a function of nitrogen (N) input for the cool and warm season trials of the PD/A CRSP Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya.

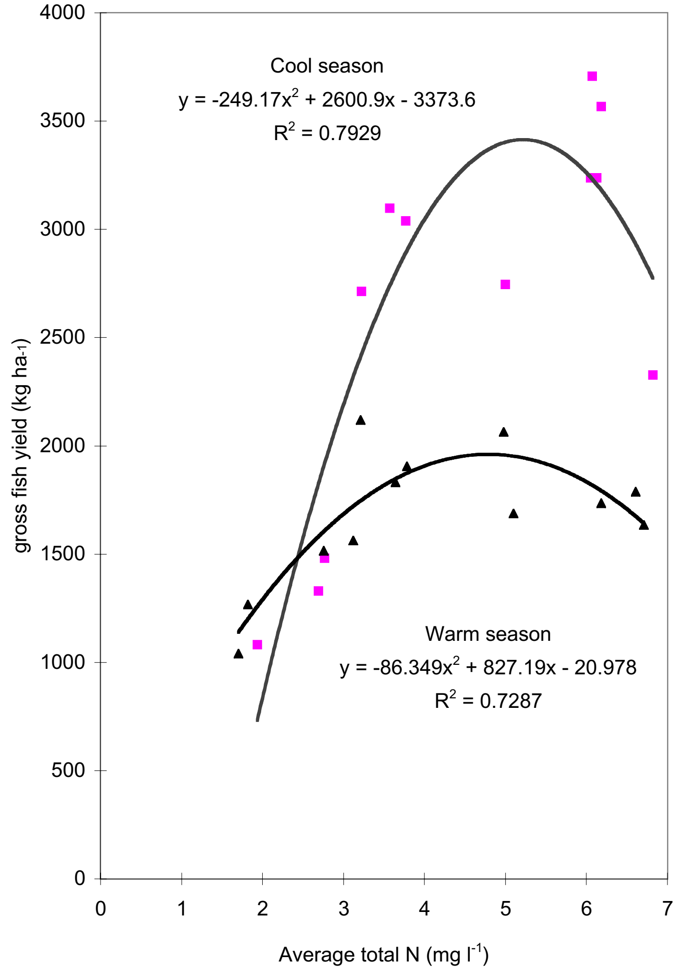

Figure 4. Relationship between gross fish yield (GFY) and average total nitrogen (N) content in pond waters during the cool and warm season trials of the PD/A CRSP Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya.

species, counted and weighed. Tilapia were separated by sex and fingerling weight was noted. The tilapia and *Clarias* were sold at 120 KSh per kg to a Nairobi fish-out operator.

Water quality parameters were measured on the same frequencies 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 measures were made during the experiment. Gross and net primary production were calculated by the whole pond method (PD/A CRSP 1992) on four occasions during the experiment, once at the beginning of the experiment (December 1998) and once each in January, February, and March of 1999.

Soil samples were taken from each pond two weeks after stocking and again during the week prior to pond draining. On each sampling occasion, nine cores of 2-cm depth from the soil surface were combined to make the soil sample for each pond.

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

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 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 cool season (these blooms have occurred each cool season since the CRSP began work at Sagana). Surface blooms of any kind cannot withstand the intense solar radiation experienced at Sagana from December through February.

Fish Growth

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

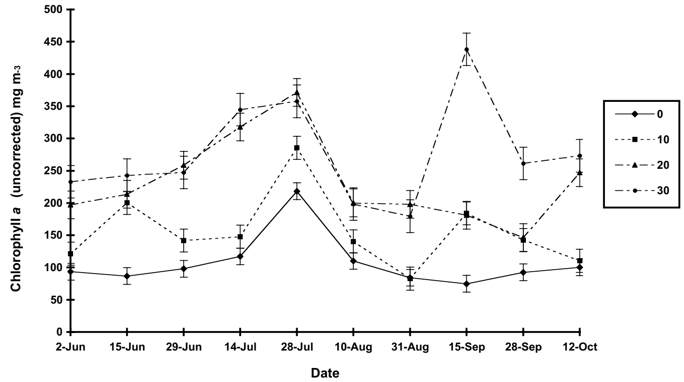

Figure 5. Trends in chlorophyll *a* (uncorrected) concentrations (treatment means and standard errors) during the cool season trial of the Global Experiment at Sagana Fish Farm, Sagana, Kenya.

The relationship between gross fish yield (GFY) and N 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 highest N 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

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.

		Dissolved oxygen (mg/l)							
	Weekly N	Morning				Afternoon			
Pond	**Input (kg)**	**5cm**	**25cm**	**50cm**	**75cm**	**5cm**	**25cm**	**50cm**	**75cm**
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

		Temperature							
	Weekly N	Morning				Afternoon			
Pond	**input (kg)**	5cm	25cm	50cm	75cm	5cm	25cm	50cm	75cm
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

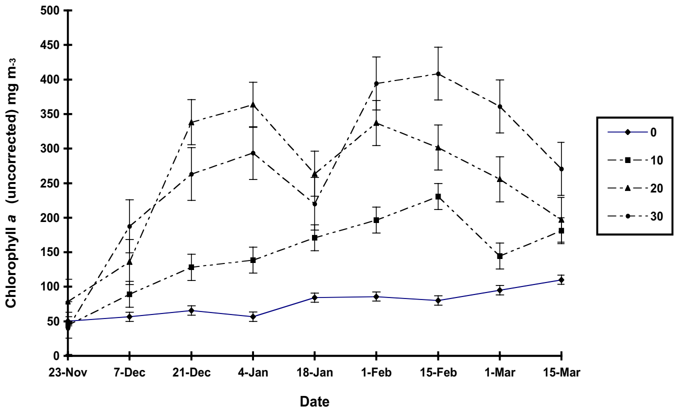

Figure 6. Trends in chlorophyll *a* (uncorrected) concentrations (treatment means and standard errors) during the warm season trial of the Global Experiment at Sagana Fish Farm, Sagana, Kenya.

picked up occasionally during the warm season experiment but they never totaled more than 2 or 3 on any day. No C*larias* died on these occasions. In fact, the relationship between C*larias* yield and N input rate was linear; suggesting that they are less affected by high N.

Taking the first derivative of the regression equation gives the N input rate at which maximum GFY would be obtained: 21.0 kg N ha^{-1} $week^{-1}$ for the cool season experiment and 18.6 kg N ha^{-1} $week^{-1}$ 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 C*larias* (> 1 kg). These fish were probably left over from the previous experiment. Some ponds contained many more C*larias* than were stocked, and these extra fish may have entered with the tilapia fingerlings. It was easier to separate out C*larias* during stocking in the second experiment because fish were fewer in number and larger.

The weight of tilapia reproduction decreased with increasing N input (Table 2). Size of tilapia females, C*larias* size, or adverse water quality due to high N 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). Chlorophyll *a* levels tended to be slightly higher during the warm season experiment than during the cool season experiment, so the warm season's lower fish production could not have been a result of low phytoplankton densities. Figures 5 and 6 illustrate the generally increasing trends in chlorophyll *a* levels that were observed during the experiment. In both seasons, chlorophyll *a* was significantly correlated to N input rates (P<0.01); the exponential model best described the relationship. In the first experiment (cool season), net tilapia yield was significantly correlated with both uncorrected chlorophyll *a* levels (r^2=60.6% using reciprocal × model) and chlorophyll *a* corrected for phaeophytin (r^2=54.4% using reciprocal × model). However, net tilapia yield was not significantly correlated with chlorophyll *a* levels (neither corrected for phaeophytin nor uncorrected) in the warm season experiment. Nitrogen input levels, gross primary production (GPP), and net primary production (NPP) for the cool- and warm-season experiments are shown in Table 4. NPP was not a good predictor of fish yields; nor was it related to N input rates. GPP was significantly correlated with net tilapia yield in the cool season experiment (r^2=81%, p=0.0001 using a log × model) and less well correlated in the warm season experiment (r^2=68% using multiplicative model). GPP was also a good indicator of N input rates in both experiments; for the cool season the relationship was quadratic, whereas for warm season the relationship was multiplicative, thereby indicating that GPP either did not increase much or actually decreased at the highest input rate of 30kg ha^{-1} wk^{-1}.

Observations for TH, TH, 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 5. In both experiments, it can be concluded that P was not limiting in any way. Attempts to keep TA high were successful in the first experiment but not so 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 N input treatment.

Table 4. Nitrogen input rates and corresponding mean gross (GPP) and net (NPP) primary productivity observations during the cool and warm season trials of the PD/A CRSP's optimum nitrogen input experiment, conducted at Sagana Fish Farm (Sagana, Kenya) during 1998 and 1999.

Pond	N input rate ($kg\ ha^{-1} wk^{-1}$)	Mean GPP ($mg\ O_2\ L^{-1}$)	Mean NPP ($mg\ O_2\ L^{-1}$)
Cool Season			
D07	0	5.46	0.38
D08	0	6.62	0.54
E06	0	7.13	0.67
D06	10	10.04	0.98
E04	10	12.88	0.78
E05	10	12.69	1.72
D05	20	11.55	1.80
E07	20	16.51	1.90
E08	20	18.81	2.91
D04	30	13.17	4.85
E03	30	16.12	0.92
E09	30	11.22	0.59
Warm Season			
D04	0	11.31	1.79
D08	0	6.68	0.44
E09	0	8.44	-0.07
D07	10	17.18	0.94
E03	10	13.37	0.04
E06	10	10.38	0.27
E04	20	13.19	0.89
E05	20	14.04	0.84
E07	20	17.45	2.34
D05	30	16.64	1.78
D06	30	14.64	0.90
E08	30	16.31	2.47

Soils

Because the soil was sampled to a depth of 5 cm at the end of the cool season experiment, comparison at beginning and end of the experiment is difficult. Although P input rates were high for all treatments (8 kg P $ha^{-1}wk^{-1}$) and the pond soils were supposedly saturated with P at the beginning of the experiment, soil P still tended to decrease over time and to decrease more as N inputs increased. In the warm season experiment, soil P at the end of the experiment was significantly negatively correlated to N input rate ($r = -0.69$; $p = 0.013$). There was however no relationship between N input rates and soil N or soil C.

Economic Analysis

The costs of inputs and revenues per hectare for these experiments are shown in Table 6. 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 first and second season experiments, respectively, (Figure 7).

Carry-over Effect

Table 7 was assembled to examine the possible effects of previous treatments on the outcome of the second experiment. Ponds that received no N during the first experiment were the worst performers in the lower N input rates of the second experiment and the best performers in the high-N treatments of the second experiment. Ponds that received high N inputs were better performers (in terms of fish yields) in the no-N input treatments of the second experiment and the worst performers in the high-N input treatments. It therefore appears that overall production

Table 5. Mean (±SE) pond water quality observations during the cool- and warm-season experiments on optimum nitrogen fertilization at Sagana Fish Farm, Sagana, Kenya.

Weekly Nitrogen Application	Total Alkalinity (mg L^{-1} as $CaCO_3$)	Total Hardness (mg L^{-1} as $CaCO_3$)	Corrected Chlorophyl *a* (mg m^3)	Uncorrected Chlorophyll *a* (mg m^3)	Total Phosphorus (mg L^{-1})	Soluble Reactive Phosphorus (mg L^{-1})
Cool Season						
0 kg ha^{-1}	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 kg ha^{-1}	73.8 ±5.5	60.0 ±7.2	85.0 ±8.3	155.6 ±2.9	1.9 ±0.29	1.1 ±0.20
20 kg ha^{-1}	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 kg ha^{-1}	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**	.866**	NS	NS
std error est.			0.00277	0.23		
Warm Season						
0 kg ha^{-1}	84.8 ±6.3	80.2 ±7.2	56.6 ±15.6	75.9 ±19.3	1.5 ±0.06	0.7 ±0.14
10 kg ha^{-1}	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 kg ha^{-1}	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 kg ha^{-1}	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**	.77*	.80**	-.75**	-.65*
std error est.	0.0008	0.511	0.44	0.40	0.129	0.357

Weekly Nitrogen Application	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 kg ha^{-1}	7.5 ±0.13	2.5 ±0.27	0.8 ±0.06	0.0 ±0.00	0.0 ±0.01	254 ±242
10 kg ha^{-1}	7.8 ±0.16	3.5 ±0.16	0.9 ±0.12	0.0 ±0.02	0.1 ±0.02	229 ±67
20 kg ha^{-1}	8.0 ±0.25	5.7 ±0.35	1.1 ±0.07	0.3 ±0.08	0.3 ±0.14	491 ±256
30 kg ha^{-1}	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 kg ha^{-1}	7.7 ±0.31	2.1 ±0.33	0.5 ±0.05	0.0 ±0.00	0.0 ±0.03	75 ±38
10 kg ha^{-1}	8.4 ±0.13	3.3 ±0.16	0.5 ±0.10	0.0 ±0.01	0.1 ±0.03	258 ±33
20 kg ha^{-1}	8.8 ±0.30	5.0 ±0.69	0.6 ±0.09	0.1 ±0.05	0.2 ±0.08	321 ±17
30 kg ha^{-1}	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

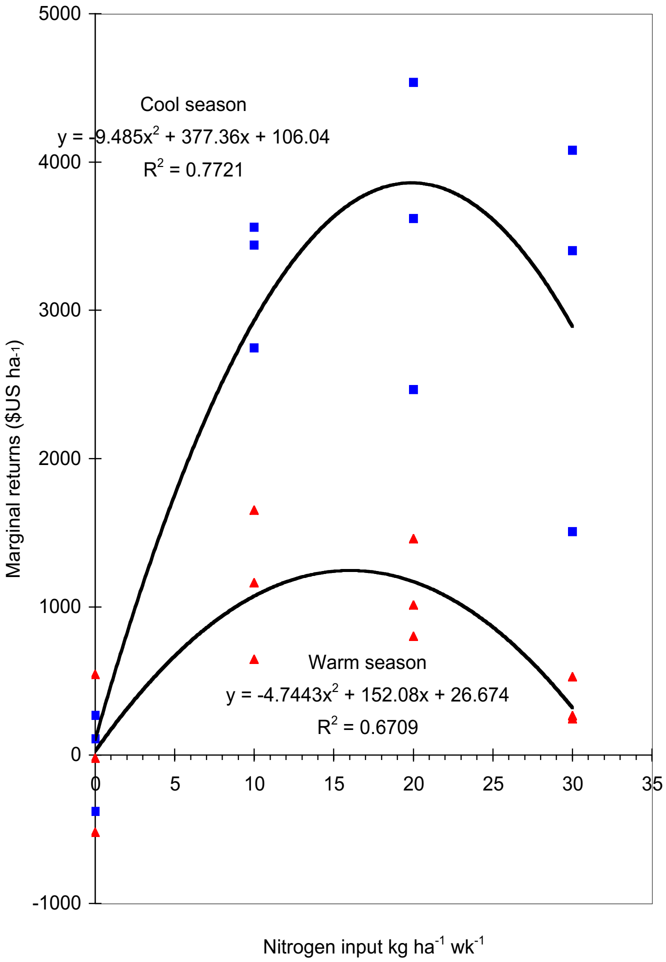

Figure 7. Marginal returns (increased revenues less increased costs) as a function of N input rates for the cool and warm season trials of the Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya. Cost of capital was estimated at 12%.

over the two experiments was related to cumulative N input. Figure 8 shows this relationship. Combined net fish yields for the cool- and warm-season experiments were highly correlated to combined N inputs over the two experiments. Unfortunately, no pond received two consecutive highest N input rates. The calculated maximum net fish yield would occur at 1183.5 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

Our observations on water quality parameters that usually correlate well with high tilapia production (chlorophyll *a*, total N) were very similar in both experiments. They definitely don't 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 carryover effects of the N from the preceding experiment. The results from Sagana also suggest some carryover 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 N, 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 fo 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 N input rates to 30 kg ha^{-1} week^{-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 N input rate there. Hatchery technicians who work with recirculating systems know that the capacity of a biofilter to process N is affected by temperature, with maximum N 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 lead 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

Table 6. Cost of inputs and revenue per hectare for the optimum nitrogen fertilization experiments (Global N Experiment) conducted at Sagana Fish Farm, Sagana, Kenya, during 1998 and 1999. Costs include initial P-saturation inputs of TSP applied to ponds for the cool-season experiment.

Nitrogen input in the 2nd experiment	Performance in the 2nd Experiment	Nitrogen Input in the 1st Experiment
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

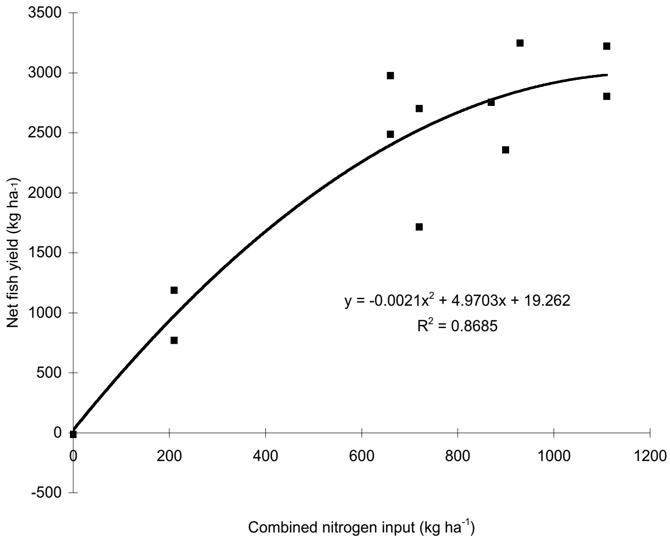

Figure 8. Combined net fish yield in relation to total nitrogen input for the cool and warm season trials of the Global Experiment conducted at Sagana Fish Farm, Sagana, Kenya.

(see carrying capacity test report) However, the optimum N 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 not to exceed 16 kg ha^{-1} wk^{-1} of chemical N.

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 questions 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 helper, was invaluable. Paul Wamwea Wabitah helped out in keeping data for the pond sampling. Our super seine crew demonstrated that twelve 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 record-keeper.

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Table 7. Performance of ponds in the second trial in relation to the N input level received in the first trial of the Global Experiment on optimum nitrogen fertilization.

N rate	DAP (KSh)	Urea (KSh)	TSP (KSh)	Lime (KSh)	Soda Ash KSh	Stockers (KSh)	Total Cost (KSh)	Total Cost ($US)	Tilapia Revenue (KSh)	*Clarias* Revenue (KSh)	Total Revenue (KSh)	Gross Profit (KSh)	Gross Profit ($US)
Cool													
0	-	-	39,625	10,000	2,796	124,440	176,861	2,948	121,800	24,960	146,760	(30,101)	(502)
10	24,000	2,776	15,625	10,000	2,521	124,440	179,362	2,989	312,240	32,400	344,640	165,278	2,755
20	24,000	12,688	15,625	10,000	5,408	124,440	192,161	3,203	354,360	30,000	384,360	192,199	3,203
30	24,000	22,601	15,625	10,000	2,521	124,440	199,186	3,320	301,200	59,400	360,600	161,414	2,690
Warm													
0	-	-	36,625	7,500	825	135,000	179,950	2,999	134,280	18,480	152,760	(27,190)	(453)
10	21,000	2,429	-	1,667	2,842	135,000	162,937	2,716	200,640	19,680	220,320	57,383	956
20	21,000	11,102	-	2,500	3,529	135,000	173,131	2,886	206,400	22,080	228,480	55,349	922
30	21,000	19,775	-	8,333	7,746	135,000	191,855	3,198	182,400	21,960	204,360	12,505	208

Prices	Per bag	Per kg (KSh)	Per kg ($US)
Diammonium phosphate (18-46-0) costs 1250 KSh/50kg bag	1250	25	0.42
Urea (46-0-0) cost 950 KSh/bag 50 kg	950	19	0.32
Triple superphosphate (0-46-0) cost 1250KSh/bag	1250	25	0.42
Lime: diatomite (Magmax) cost 200KSh/50 kg bag	200	4	0.07
Sodium carbonate (Na2CO3) cost 9KSh/kg+VAT=11KSh/kg	11	11	0.18
Fish priced at 120 KSh/kg (price for live fish), both for stocking and harvesting.	120	120	2.00

Fingerlings not attributed a value. We do not use fingerlings from S/R brooders.

Exchange rate is currently 70KSh/$ but was about 60 at the time of the experiment. Rate of 60 was used.

Prices of inputs have not increased, probably because we are finding cheaper suppliers all the time. For example, we can now get any of these fertilizers delivered to Sagana for equal to or less than the price in KSh.

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