Pond Dynamics/Aquaculture Collaborative Research Support Program

Sixteenth Annual Technical Report

1 August 1997 to 31 July 1998

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PD/A CRSP SIXTEENTH ANNUAL TECHNICAL REPORT

CONTENTS

Since the PD/A CRSPs inception in 1982, the annual report has presented, among many standard features (program overview, research background, staff and fiscal summaries, networking activities, report abstracts, and others), the full text of the technical reports that correspond to studies funded within the particular reporting period. Beginning in 1993, the sheer quantity of information generated by program research necessitated a two-volume annual report format—an administrative and a technical report. This year, however, owing to a combination of new technologies and fiscal constraints, we are not publishing technical reports in a bound hard-copy volume. Technical reports will be available at the program Internet website (www.orst.edu/dept/crsp/homepage.html). In addition, recognizing that many people do not have access to electronic information, hard copies of individual technical reports are available on request to the Information Management and Networking Component, Oregon State University, 400 Snell Hall, Corvallis OR 97330, USA.

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POND SOIL CHARACTERISTICS AND DYNAMICS OF SOIL ORGANIC MATTER AND NUTRIENTS

Eighth Work Plan, Pond Dynamics Research 1 (PDR1)
Progress Report

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ABSTRACT

Soil cores were collected from ponds at the Sagana Fish Culture Farm, Kenya. The pond bottoms had well-developed S horizons of 6 cm depth, but M and T horizons were weakly developed. Recent renovation of ponds with sediment removal explains the weak M and T horizons. The soils were near neutral in pH, with carbon concentrations between 2 and 5%. Carbon:nitrogen ratios were between 10 and 20. Total sulfur concentrations were around 0.5%, and soil phosphorous concentrations were low. The soils had high concentrations of exchangeable bases, and micronutrient concentrations were within normal ranges. Soil incubation studies on pond soils from Thailand, Honduras, and Kenya revealed relatively low microbial respiration rates as compared to typical terrestrial soils, and there was net negative nitrogen mineralization (nitrogen was immobilized). Equilibrium phosphorus concentrations in soil-water mesocosms were: AIT, new ponds, 0.17 mg l^{-1}; AIT, old ponds, 0.12 mg l^{-1}; Honduras, freshwater ponds, 0.22 mg l^{-1}; Honduras, brackishwater ponds, 0.23 mg l^{-1}; Kenya, 0.06 mg l^{-1}. At all sites, pond soils will be sinks for phosphorus added in fertilizer. Pond soils appear to develop distinct profiles within a few years, in contrast to terrestrial soils where soil development takes much longer.

INTRODUCTION

This study focuses on collection of data on basic characteristics of pond soil from the Pond Dynamics/Aquaculture CRSP research sites. These data are needed both to provide basic information on the pond ecosystems used in fish and shrimp production at the different CRSP sites and to develop a theory of pond soil development and a systemic method of pond soil classification.

This report contains data on soil characteristics for the CRSP ponds in Kenya, results of ammonia and carbon dioxide dynamics in soils incubated under aerobic conditions, ammonia dynamics in soil incubated under anaerobic conditions, phosphorus equilibrium concentrations in laboratory soil-water mesocosms, and a summary of some of our initial ideas related to the theory of pond soil development.

METHODS AND MATERIALS

Ponds

The ponds for the Africa CRSP site are located at the Sagana Fish Culture Farm, Kenya. The ponds were renovated between March and July 1997. The renovation included removing soil from parts of the bottoms to ensure that depths and bottom contours were uniform among the ponds (Bowman et al., 1997). The experimental ponds have a surface area of 800 m^2, and the maximum water depth is about 1 m. The ponds had been stocked with tilapia for about two months at time of sampling on 4 and 5 September 1997.

Sampling

Soil cores were taken with a hand-operated, 5-cm-diameter core sampler (Wildlife Supply Company, Saginaw, Michigan, USA, Model No. 242A15). Procedures for separating the cores into successive 2-cm-long core segments were described by Munsiri et al. (1995). Core segments were dried at 102°C (moisture content and dry bulk density) or 60°C (other analyses) and transported to Auburn University for analyses.

Physical and Chemical Analyses

Samples were analyzed for moisture content (gravimetry), dry bulk density (gravimetry), color (Munsell color chart), wet soil pH (direct, glass electrode), dry soil pH (1:1 slurry of dry soil and distilled water, glass electrode), exchangeable acidity (Adams-Evans buffer method), total carbon and nitrogen (Leco CHN Analyzer), total phosphorus (perchloric acid oxidation), total sulfur (Leco Sulfur Analyzer), and acid-extractable phosphorus and metal ions (extraction in a 0.075 N acid solution of 0.05 N HCl plus 0.025 N H_2SO_4) followed by plasma spectrophotometry. Particle size analyses were made by the pipette method. All methods followed details provided by Munsiri et al. (1995).

Soil Incubation Studies

Aerobic and anaerobic incubation methods were used to estimate potentially mineralizable N and C (aerobic incubation only) in soils sampled from 0-to-10-cm and 10-to-20-cm layers of pond bottoms. Soil samples were refrigerated at 5°C until incubation. Aerobic incubations were done following methods of Wood and Edwards (1992), while anaerobic incubations were done according to methods outlined by Keeney (1982). In aerobic incubations, respired CO_2 was trapped in a vial containing 8 ml of 1 M NaOH (Anderson, 1982).

Soil organic C and N, and inorganic N (NO_3-N plus NO_2-N [aerobic incubation only], and NH_4-N) were measured before incubations were initiated. Soil inorganic N and respired CO_2-C were measured upon termination of incubation. Soil organic C and N were determined via dry combustion with a LECO CHN-600 analyzer. Inorganic N was extracted with 2 M KCl, and analyzed via the microplate method (Sims et al., 1995). Carbon dioxide in NaOH traps was determined by titrating excess base with 1 M HCl in the presence of $BaCl_2$ (Anderson, 1982).

Soil potential N mineralization was calculated as the difference between final and initial contents of inorganic N for each incubation. Potential C mineralization was calculated as the difference between the incubation base trap and the mean of four blanks.

Phosphorus Equilibrium Studies

Water-extractable phosphorus was determined by shaking 1-g samples in 100 ml distilled water for 24 h, filtering the mixture, and measuring phosphorus in filtrates by the ascorbic acid technique (Boyd and Tucker, 1992).

RESULTS AND DISCUSSION

Pond Soils at Sagana, Kenya

The moisture content of the soil in ponds at the Sagana site decreased rapidly with depth, and the dry bulk density increased with depth (Table 1). The soils had a well-developed S horizon that extended to a depth of 6 cm. The M, T, and P horizons were poorly developed in these soils. Also, soil color did not change markedly with depth. Ponds at other CRSP sites and at the Auburn University Fisheries Research Unit (Boyd et al., 1997; Munsiri et al., 1995) had much better profile development than observed at the Sagana site. This suggests that the pond renovation activities greatly altered any profile that had developed in the ponds during previous years.

Table 1. Profiles for moisture content, dry bulk density, and color in soil cores from bottoms of freshwater aquaculture ponds in Kenya. Moisture content averages and standard errors are given as percentages of dry weight. Dry bulk density averages and standard errors are given as grams dry soil per cubic centimeter (g cm^{-3}). Color values are given as standard Munsell Color Chart Units (7.5YR 2.5/1—Black; 7.5YR 2.5/2—Very dark brown). Each entry is the average of three ponds.

Depth (cm)	Moisture content (%)	Dry bulk density (g cm^{-3})	Color
0 - 2	418.8 ± 30.5	0.20 ± 0.02	7.5YR 2.5/2
2 - 4	255.4 ± 17.5	0.31 ± 0.03	7.5YR 2.5/2
4 - 6	203.8 ± 25.1	0.37 ± 0.04	7.5YR 2.5/2
6 - 8	137.1 ± 21.6	0.59 ± 0.07	7.5YR 2.5/1
8 - 10	91.6 ± 6.5	0.71 ± 0.03	7.5YR 2.5/1
10 - 12	86.0 ± 6.4	0.76 ± 0.04	7.5YR 2.5/1
12 - 14	86.5 ± 28.5	0.80 ± 0.04	7.5YR 2.5/1
14 - 16	84.9 ± 9.9	0.80 ± 0.06	7.5YR 2.5/1
16 - 18	82.3 ± 9.0	0.81 ± 0.06	7.5YR 2.5/1
18 - 20	71.0 ± 3.9	0.87 ± 0.03	7.5YR 2.5/1

Soil pH was near neutral, with dry soil values ranging from 6.97 at the surface to 7.63 at 18 to 20 cm depth (Table 2). The wet soil pH was slightly lower than the dry soil pH, as was observed in earlier work (Boyd et al., 1997). This apparently is a result of the near neutral pH, because in acidic soils, the pH of dry pond soils usually is somewhat higher than that of wet soils (Munsiri et al., 1995). Because soils had a near neutral pH, exchange acidity values were only 3.47 to 4.80 meq/100 g (Table 2). Neither pH nor exchange acidity exhibited clear patterns of change with soil depth.

Table 2. Profiles for wet soil pH, dry soil pH, and exchangeable acidity in soil cores from bottoms of freshwater aquaculture ponds in Kenya. The wet soil pH is directly measured in soil cores and the dry soil pH is measured in 1:1 slurries of dry soil and distilled water. Exchangeable acidity averages and standard errors are given as milliequivalents per 100 grams dry soil (meq 100 g^{-1}). Each entry is the average of three ponds.

Depth (cm)	Wet soil pH	Dry soil pH	Exchangeable acidity (meq 100 g^{-1})
0 - 2	6.73 ± 0.05	6.97 ± 0.10	3.47 ± 0.15
2 - 4	7.17 ± 0.04	6.90 ± 0.03	3.73 ± 0.41
4 - 6	7.13 ± 0.15	6.83 ± 0.17	4.27 ± 0.41
6 - 8	7.07 ± 0.04	6.83 ± 0.20	4.80 ± 0.27
8 - 10	6.73 ± 0.22	6.80 ± 0.24	4.27 ± 0.67
10 - 12	6.73 ± 0.19	6.90 ± 0.27	4.53 ± 0.62
12 - 14	6.73 ± 0.18	7.13 ± 0.28	3.73 ± 0.41
14 - 16	6.67 ± 0.16	7.37 ± 0.17	3.47 ± 0.41
16 - 18	6.67 ± 0.15	7.40 ± 0.12	3.47 ± 0.15
18 - 20	7.13 ± 0.13	7.63 ± 0.08	3.47 ± 0.15

All other pond soil profiles that have been examined by the authors in Alabama, Mississippi, Honduras, Thailand, and Egypt had the highest concentrations of total carbon and total nitrogen at the soil surface, and concentrations of these two elements then declined with depth. Lowest soil carbon concentrations were observed in the original soil (P horizon). However, at the Sagana site, the carbon concentration exceeded 2% at all depths (Table 3), and the highest concentrations were below 10 cm depth. Nitrogen concentrations were greatest in the surface layer at Sagana, but there was no clear pattern of

Table 3. Profiles for total carbon and total nitrogen in soil cores from bottoms of freshwater aquaculture ponds in Kenya. Each entry is the average of three ponds.

Depth (cm)	Total carbon (%)	Total nitrogen (%)
0 - 2	2.60 ± 0.45	0.24 ± 0.06
2 - 4	3.73 ± 0.27	0.17 ± 0.02
4 - 6	3.19 ± 0.29	0.19 ± 0.01
6 - 8	2.95 ± 0.26	0.20 ± 0.04
8 - 10	2.20 ± 0.40	0.15 ± 0.04
10 - 12	4.01 ± 0.69	0.18 ± 0.02
12 - 14	2.04 ± 0.18	0.13 ± 0.03
14 - 16	4.51 ± 0.55	0.16 ± 0.02
16 - 18	2.58 ± 0.04	0.14 ± 0.01
18 - 20	2.15 ± 0.13	0.12 ± 0.01

nitrogen decrease with depth. As with the other CRSP sites, soil carbon concentrations are not high at the Sagana site, with all values being below 5% total carbon. The C/N ratios were usually between 10 and 20. These C/N ratios are generally greater than other CRSP sites where C/N ratios were between 7 and 15 (Boyd et al., 1997), and much higher than the C/N ratios of 5 to 7 found in pond soils at the Auburn University Fisheries Research Unit in Alabama (Munsiri et al., 1995).

The total sulfur concentrations tended to decline with depth (Table 4). Values decreased from 0.50 to 0.59% in the upper 0-to-8-cm layer to 0.17% in the 18-to-20-cm layer. Total phosphorus (Table 4) was at higher concentrations in the surface layers (S and M horizons) than in deeper layers. However, the acid-extractable phosphorus concentrations were low and relatively uniform with soil depth. The 0-to-2-cm layer contained 0.07%, or 700 ppm, while the dilute acid-extractable phosphorus was 14.2 ppm. At 18 to 20 cm depth, total phosphorus was 300 ppm (0.03%) and extractable phosphorus was 16.1 ppm. It seems that additions of fertilizers, manures, and feeds to the ponds over the years has caused considerable elevation of total phosphorus. However, this phosphorus has been fixed in a mineral form that is insoluble in dilute acid and therefore quite insoluble in water (Boyd and Munsiri, 1996). These soils will strongly adsorb phosphorus applied to ponds in aquacultural management.

The soils at the Sagana site had high concentrations of calcium, magnesium, sodium, and potassium (Table 5). Magnesium and calcium concentrations did not change with depth. Thus, we assume that liming has not been routinely practiced at the site, and, of course, that the soils are near neutral and liming is not required. Sodium concentrations also were similar at all depths, but potassium declined with depth. The high concentrations of potassium near the surface suggest inputs of this element to ponds in fertilizers and manures.

Concentrations of iron, manganese, zinc, and copper are provided in Table 6. Iron concentrations were greater in S and M horizons than in the P horizon. Iron concentrations are higher than those recorded for ponds at CRSP sites in Honduras, but lower than those recorded for Thailand. Manganese concentrations also were highest in S and M horizons. The surface layer contained 415 ppm as compared to 100 ppm for the deepest layer. Manganese concentrations at the Sagana site are greater than those observed in ponds at the other CRSP sites. Zinc concentrations decreased from 1.73 ppm at the surface to 0.42 ppm at 18 to 20 cm depth. The concentrations of zinc are similar to those of ponds at the brackishwater site in Honduras, but lower than zinc concentrations in soil of the other freshwater CRSP ponds. Copper concentrations did not change appreciably with soil depth at the Sagana site, and concentrations were similar to those found at other CRSP sites (Boyd et al., 1997).

The soil texture data for Honduras and Thailand were not provided in the 1997 annual report, so they are included here (Tables 7 and 8) for comparison with the Sagana site data (Table 9). Soils at all CRSP sites contain large percentages of clay. In Thailand and Kenya, clay concentrations tend to increase with depth in the soil profile. In Honduras, clay concentrations tend to increase in the M horizon and then decrease at greater depths. The textures for soil from different depths is named in Table 10. Notice that clay appears in all of the names.

Soil Incubation Studies

Total organic C and N concentrations in 0 to 10 and 10 to 20 cm soil depths beneath aquaculture ponds (Tables 11 and 12) were relatively high in comparison to typical terrestrial soils (Wood and Edwards, 1992), reflecting addition of organic materials and perhaps retarded decomposition beneath ponds. Data in Tables 11 and 12 indicate that C:N ratios were in the 10:1 range, suggesting N net mineralization should occur. However, when these soils were incubated aerobically (Table 13) net N mineral-

Table 4. Profiles for total phosphorus, dilute acid extractable phosphorus, and total sulfur in soil cores from bottoms of freshwater aquaculture ponds in Kenya. Each entry is the average of three ponds.

Depth (cm)	Total phosphorus (%)	Dilute acid extractable phosphorus (ppm)	Total sulfur (ppm)
0 - 2	0.07 ± 0.01	14.23 ± 0.94	0.50 ± 0.08
2 - 4	0.07 ± 0.01	14.64 ± 1.07	0.55 ± 0.08
4 - 6	0.06 ± 0.01	13.39 ± 1.17	0.54 ± 0.08
6 - 8	0.04 ± 0.00	13.82 ± 1.06	0.59 ± 0.09
8 - 10	0.05 ± 0.00	14.76 ± 1.09	0.41 ± 0.08
10 - 12	0.05 ± 0.01	14.92 ± 0.59	0.36 ± 0.08
12 - 14	0.04 ± 0.01	15.37 ± 0.90	0.32 ± 0.08
14 - 16	0.03 ± 0.00	15.28 ± 0.60	0.30 ± 0.07
16 - 18	0.03 ± 0.00	17.34 ± 0.93	0.23 ± 0.05
18 - 20	0.03 ± 0.01	16.06 ± 0.73	0.17 ± 0.02

Table 5. Profiles for calcium, magnesium, potassium, and sodium in soil cores from bottoms of freshwater aquaculture ponds in Kenya. Each entry is the average of three ponds.

Depth (cm)	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)
0 - 2	2,657 ± 72	1,743 ± 60	84 ± 7	145 ± 14
2 - 4	2,680 ± 86	1,739 ± 70	80 ± 9	121 ± 13
4 - 6	2,639 ± 78	1,765 ± 80	70 ± 8	121 ± 15
6 - 8	2,630 ± 65	1,818 ± 85	60 ± 8	116 ± 17
8 - 10	2,541 ± 56	1,873 ± 84	53 ± 6	136 ± 19
10 - 12	2,641 ± 40	1,888 ± 92	37 ± 5	145 ± 21
12 - 14	2,584 ± 45	1,966 ± 100	33 ± 2	142 ± 25
14 - 16	2,575 ± 74	2,062 ± 90	27 ± 3	166 ± 31
16 - 18	2,595 ± 79	2,124 ± 75	28 ± 2	170 ± 33
18 - 20	2,811 ± 103	1,996 ± 88	24 ± 2	179 ± 37

Table 6. Profiles for iron, manganese, zinc, and copper in soil cores from bottoms of freshwater aquaculture ponds in Kenya. Each entry is the average of three ponds.

Depth (cm)	Iron (ppm)	Manganese (ppm)	Zinc (ppm)	Copper (ppm)
0 - 2	37 ± 5	415 ± 24	1.73 ± 0.09	0.31 ± 0.05
2 - 4	50 ± 7	390 ± 14	1.67 ± 0.14	0.33 ± 0.04
4 - 6	33 ± 6	327 ± 14	1.51 ± 0.16	0.21 ± 0.03
6 - 8	36 ± 9	331 ± 22	1.39 ± 0.21	0.33 ± 0.06
8 - 10	31 ± 9	294 ± 36	1.35 ± 0.27	0.35 ± 0.08
10 - 12	38 ± 14	259 ± 45	1.23 ± 0.40	0.26 ± 0.04
12 - 14	37 ± 12	204 ± 45	1.08 ± 0.31	0.48 ± 0.05
14 - 16	45 ± 16	163 ± 35	0.75 ± 0.16	0.33 ± 0.02
16 - 18	27 ± 4	130 ± 37	0.55 ± 0.04	0.48 ± 0.05
18 - 20	19 ± 0	100 ± 26	0.42 ± 0.03	0.33 ± 0.03

ization was negative and microbial respiration (Table 14) was low in comparison to typical terrestrial soils (Wood and Edwards, 1992). Two possibilities exist for explanation of negative net N mineralization in these aerobically incubated soils:

1) Organic N compounds in these soils were recalcitrant and relatively unavailable to heterotrophic microorganisms, which created a N limitation; or
2) N in these soils was denitrified after mineralization resulting in a net loss of inorganic N.

Of these explanations, the former is most likely. This conclusion is supported by data in Table 15 regarding net N mineralization under anaerobic conditions, which in large part indicated net negative N mineralization. Because anaerobic incubations should not result in production of nitrate that could be denitrified and lost, the most likely explanation for net negative N mineralization in these soils is N limitation and subsequent immobilization of N by heterotrophic microbes. These data suggest that these pond soils would not contribute N to the water column, but would likely act as sinks for any available N in overlying waters.

Phosphorus Equilibrium

The surface 0-to-4-cm layer of bottom soil for the five series of three ponds each had the following concentrations and standard deviations of distilled-water-extractable phosphorus

Table 7. Profiles for soil texture in cores from bottoms of aquaculture ponds in Thailand, Honduras, and Kenya. Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras		Kenya
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackishwater ponds*	*Freshwater ponds*
0 - 2	Silty clay	Silty clay	Silty clay	Silty clay	Silty clay
2 - 4	Silty clay	Clay	Silty clay	Silty clay	Silty clay
4 - 6	Silty clay	Silty clay	Silty clay	Silty clay	Clay
6 - 8	Silty clay	Clay	Silty clay	Silty clay	Clay
8 - 10	Clay	Clay	Silty clay	Silty clay	Clay
10 - 12	Clay	Clay	Silty clay	Silty clay	Clay
12 - 14	Clay	Clay	Silty clay	Silty clay	Clay
14 - 16	Clay	Clay	Silty clay	Silty clay	Clay
16 - 18	Clay	Clay	Silty clay	Silty clay	Clay
18 - 20	Clay	Clay	Silty clay	Clay	Clay
20 - 22		Clay	Silty clay	Clay	
22 - 24		Clay	Silty clay loam	Clay	
24 - 26		Clay	Silty clay loam	Clay loam	
26 - 28		Clay		Clay loam	
28 - 30		Clay			
30 - 32		Clay			
32 - 34		Clay			
34 - 36		Clay			

Table 8. Profiles for particle size distribution in soil cores from bottoms of aquaculture ponds in Thailand. Averages and standard errors are given as percentages of dry weight. Each entry is the average of three ponds.

Depth (cm)	New ponds			Old ponds		
	Sand	*Silt*	*Clay*	*Sand*	*Silt*	*Clay*
0 - 2	5.82 ± 0.48	44.67 ± 2.99	49.52 ± 1.75	2.74 ± 0.36	48.13 ± 2.80	49.13 ± 3.13
2 - 4	3.85 ± 0.73	40.83 ± 1.31	55.32 ± 1.75	1.87 ± 0.12	35.60 ± 1.87	62.53 ± 1.91
4 - 6	3.21 ± 0.64	40.30 ± 1.03	56.49 ± 1.56	2.47 ± 0.41	39.59 ± 1.06	57.95 ± 1.47
6 - 8	3.80 ± 0.36	40.21 ± 0.67	55.99 ± 1.04	1.80 ± 0.29	33.68 ± 1.54	64.52 ± 1.50
8 - 10	4.26 ± 0.51	38.84 ± 0.84	56.91 ± 0.07	1.73 ± 0.17	35.99 ± 0.63	62.28 ± 0.73
10 - 12	4.88 ± 0.53	36.86 ± 1.25	58.25 ± 0.48	2.02 ± 0.57	36.54 ± 0.28	61.44 ± 0.45
12 - 14	3.96 ± 0.25	36.34 ± 1.37	59.69 ± 0.61	1.85 ± 0.39	40.74 ± 0.93	57.41 ± 0.57
14 - 16	3.70 ± 0.32	35.29 ± 1.10	61.01 ± 0.81	1.59 ± 0.28	39.27 ± 1.09	59.13 ± 0.81
16 - 18	3.95 ± 0.51	35.10 ± 1.04	60.95 ± 0.61	1.91 ± 0.32	38.69 ± 1.00	59.40 ± 0.71
18 - 20	3.72 ± 0.64	35.41 ± 1.27	60.87 ± 0.78	2.27 ± 1.02	37.86 ± 1.01	59.87 ± 0.70
20 - 22				2.90 ± 0.34	37.57 ± 1.68	59.53 ± 1.35
22 - 24				3.09 ± 0.38	37.06 ± 1.81	59.85 ± 1.53
24 - 26				3.56 ± 0.36	35.00 ± 0.92	61.44 ± 0.59
26 - 28				3.60 ± 0.07	34.49 ± 0.33	61.91 ± 0.26
28 - 30				4.21 ± 0.49	34.56 ± 0.61	61.23 ± 0.26
30 - 32				5.50 ± 0.87	34.64 ± 0.27	59.87 ± 0.76
32 - 34				5.42 ± 1.12	34.86 ± 0.19	59.72 ± 1.04
34 - 36				4.39 ± 0.67	35.82 ± 0.38	59.79 ± 0.31

(equilibrium phosphorus): AIT, new ponds, 0.167 ± 0.099 mg l^{-1}; AIT old ponds, 0.123 ± 0.094 mg l^{-1}; Honduras, freshwater site, 0.221 ± 0.09 mg l^{-1}; Honduras, brackishwater site, 0.278 ± 0.075 mg l^{-1}; Kenya, 0.058 ± 0.023 mg l^{-1}. A series of 20 soil samples from potential aquaculture sites in Thailand which represented 10 soil suborders and a wide range in soil properties had water-extractable phosphorus concentrations of 0.0 to 0.16 mg l^{-1} (Boyd and Munsiri, 1996). None of these soils had been fertilized. Thus, with the exception of the Kenya site, the phosphorus equilibrium concentrations in surface layers of pond soil were higher than native phosphorus equilibrium concentrations found in the series of samples from Thailand.

The phosphorus equilibrium concentrations for profiles from a single pond from each site (Table 16) revealed that phosphorus concentrations generally declined with increasing soil profile depth at the two Thailand (AIT) sites and the site in Kenya. Thus, at these sites, aquacultural inputs apparently caused the increase in phosphorus. The phosphorus equilibrium

Table 9. Profiles for particle size distribution in soil cores from bottoms of aquaculture ponds in Honduras. Averages and standard errors are given as percentages of dry weight. Each entry is the average of three ponds.

Depth (cm)	Brackishwater ponds			Freshwater ponds		
	Sand	*Silt*	*Clay*	*Sand*	*Silt*	*Clay*
0 - 2	5.60 ± 0.77	50.62 ± 1.53	43.77 ± 1.42	2.30 ± 0.13	45.22 ± 1.16	52.48 ± 1.26
2 - 4	4.55 ± 1.94	46.58 ± 2.00	48.87 ± 0.18	1.92 ± 0.21	42.65 ± 0.39	55.43 ± 0.42
4 - 6	2.21 ± 0.87	50.87 ± 0.64	46.92 ± 0.39	2.39 ± 0.21	42.64 ± 0.73	54.97 ± 0.80
6 - 8	1.83 ± 0.59	50.95 ± 1.82	47.21 ± 1.40	2.07 ± 0.10	41.14 ± 23.14	56.80 ± 0.81
8 - 10	1.07 ± 0.21	51.71 ± 0.53	47.23 ± 0.61	2.44 ± 0.25	48.32 ± 4.50	49.24 ± 4.74
10 - 12	2.26 ± 0.45	50.48 ± 1.46	47.27 ± 1.10	2.65 ± 0.19	42.14 ± 0.82	55.21 ± 1.00
12 - 14	2.59 ± 0.87	49.55 ± 1.87	47.87 ± 1.38	2.59 ± 0.32	42.13 ± 0.93	55.28 ± 1.18
14 - 16	3.60 ± 1.22	47.27 ± 1.90	49.13 ± 0.92	3.93 ± 0.52	41.23 ± 0.35	54.84 ± 0.75
16 - 18	6.79 ± 1.96	42.05 ± 2.25	51.16 ± 0.83	6.31 ± 0.75	44.84 ± 0.43	48.85 ± 1.07
18 - 20	11.90 ± 1.61	36.36 ± 0.2	51.73 ± 1.82	8.55 ± 1.20	46.47 ± 1.46	44.99 ± 1.97
20 - 22	17.06 ± 3.60	35.57 ± 1.80	47.37 ± 1.81	8.58 ± 1.05	50.72 ± 2.58	40.71 ± 2.34
22 - 24	26.84 ± 8.29	32.42 ± 3.36	40.73 ± 4.93	10.73 ± 1.63	52.04 ± 3.89	37.24 ± 3.88
24 - 26	28.85 ± 10.24	32.19 ± 4.43	38.96 ± 5.81			
26 - 28	28.66 ± 11.28	32.76 ± 4.95	38.59 ± 6.38			

Table 10. Profiles for particle size distribution in soil cores from bottoms of freshwater aquaculture ponds in Kenya. Averages and standard errors are given as percentages of dry weight. Each entry is the average of three ponds.

Depth (cm)	Sand	Silt	Clay
0 - 2	5.9 ± 0.8	45.86 ± 3.93	48.24 ± 4.75
2 - 4	4.6 ± 0.4	41.33 ± 2.30	54.07 ± 2.10
4 - 6	5.2 ± 0.7	35.34 ± 3.94	59.43 ± 4.13
6 - 8	6.2 ± 0.8	32.21 ± 3.99	61.63 ± 3.87
8 - 10	6.9 ± 0.7	31.21 ± 4.75	61.92 ± 4.36
10 - 12	7.8 ± 0.7	26.50 ± 4.66	65.67 ± 4.52
12 - 14	14.6 ± 2.8	17.30 ± 0.24	68.13 ± 2.63
14 - 16	12.6 ± 2.3	17.59 ± 0.14	69.64 ± 2.27
16 - 18	9.5 ± 1.4	21.05 ± 1.65	69.45 ± 0.42
18 - 20	11.2 ± 1.5	18.15 ± 0.68	70.68 ± 1.05

Table 11. Profiles for total carbon in wet soils from bottoms of aquaculture ponds. Each entry is the average of three ponds.

	Total carbon (%)	
	0 - 10 cm depth	*10 - 20 cm depth*
Thailand - New ponds	2.20 ± 0.09	1.47 ± 0.18
Honduras - Freshwater ponds	2.01 ± 0.10	1.21 ± 0.14
Honduras - Brackishwater ponds	1.41 ± 0.07	0.96 ± 0.14
Kenya - Freshwater ponds	2.90 ± 0.23	2.28 ± 0.26

Table 12. Profiles for total nitrogen in wet soils from bottoms of aquaculture ponds. Each entry is the average of three ponds.

	Total nitrogen (%)	
	0 - 10 cm depth	*10 - 20 cm depth*
Thailand - New ponds	0.25 ± 4.55	0.11 ± 0.02
Honduras - Freshwater ponds	0.26 ± 0.01	0.13 ± 0.02
Honduras - Brackishwater ponds	0.20 ± 0.01	0.14 ± 0.02
Kenya - Freshwater ponds	0.25 ± 0.02	0.04 ± 0.02

Table 13. Profiles for net aerobic nitrogen mineralization (30 days incubation) of soil cores from bottoms of aquaculture ponds. Each entry is the average of three ponds.

	Net aerobic nitrogen mineralization (mg NH_4-N kg^{-1}soil)	
	0 - 10 cm depth	*10 - 20 cm depth*
Thailand - New ponds	-119.70 ± 45.15	-67.35 ± 85.50
Honduras - Freshwater ponds	-67.27 ± 56.10	-11.93 ± 11.68
Honduras - Brackishwater ponds	-33.05 ± 22.24	-12.46 ± 17.49
Kenya - Freshwater ponds	-134.61 ± 5.00	-30.52 ± 39.42

concentrations tended to increase with greater soil profile depth in Honduras. This suggests that the native soils in Honduras are extremely high in soluble phosphorus, and aquacultural activities have probably resulted in dissolution and loss of soluble phosphorus from surface layers. In Kenya, removal of surface soil in pond renovation was probably the reason for the relatively low phosphorus concentrations in the upper part of the profile.

Table 14. Profiles for CO_2 respiration for 7 days aerobic incubation of soil cores from bottoms of aquaculture ponds. Each entry is the average of three ponds.

	CO_2 respiration (mg CO_2 kg^{-1} soil)	
	0 - 10 cm depth	*10 - 20 cm depth*
Thailand - New ponds	42.46 ±13.28	20.27 ± 8.57
Honduras - Freshwater ponds	27.16 ± 3.97	8.68 ± 4.79
Honduras - Brackishwater ponds	33.66 ± 12.88	20.36 ± 17.38
Kenya - Freshwater ponds	14.63 ± 3.55	10.17 ± 0.51

Table 15. Profiles for NH_4-N anaerobic incubation for 7 days of soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as milligrams NH_4-N per kilogram of soil (mg kg^{-1}). Each entry is the average of three ponds.

	NH_4-N anaerobic incubation (mg NH_4-N kg^{-1} soil)	
	0 - 10 cm depth	*10 - 20 cm depth*
Thailand - New ponds	-16.60 ± 25.15	-21.97 ± 4.12
Honduras - Freshwater ponds	-18.65 ± 12.29	-6.73 ± 1.72
Honduras - Brackishwater ponds	10.47 ± 1.85	-2.67 ± 4.84
Kenya - Freshwater ponds	-44.33 ± 17.92	-20.50 ± 6.07

Soil Development

The factors influencing pond soil development are illustrated in Figure 1. This depiction of soil development is modified from the theory of terrestrial soil development which holds that soil development is a function of parent material, climate, activity of organisms, topography, and time. The same factors influence pond soil formation, but in the case of pond soils, ponds are built on existing soils and the parent material for pond soils is the pond bottom provided by the construction process. Usually, the O and A horizons are removed in the construction process, and the initial pond bottom consists of the B horizon. (These horizons are per terrestrial soil classification.) Of course, in some cases, additional soil material enters the pond as suspended particles in the water supply which settle onto the original pond bottom. If sediment input from outside is large, it may influence soil formation to a great extent. The internal ("within pond") processes of pond soil formation can be classified as additions, removals, transfers, and transformations.

Additions of organic materials include uneaten feed, feces, dead algae, manure, etc. Mineral materials also are added to deeper areas of ponds via sedimentation of mineral particles eroded from pond embankments and shallow areas by wave action and water currents generated by mechanical aeration. The organic material becomes mixed with the mineral particles and melanization (darkening of light-colored mineral matter by organic matter) occurs. Organic matter also settles onto the surface of the sediment resulting in a flocculent layer that is similar to the organic litter on the surface of terrestrial soils.

Removal of material from surface layers of pond soils occurs when ponds are drained. The outflowing water currents suspend the surface organic layer and mineral soil, and it is removed from the ponds in effluents. Ponds do not have high rates of infiltration (seepage), so leaching of materials from the soil profile is not as significant a factor as in terrestrial soils.

Transfers of material in pond bottoms result from a number of factors, such as bioturbation, erosion and resedimentation, leucinization, and salinization. Bioturbation is restricted to

Table 16. Water-extractable phosphorus concentrations in mg l^{-1} at 2-cm depth intervals in single ponds.

Depth in profile (cm)	**Thailand**		**Honduras**		**Kenya**
	New Pond	*Old Pond*	*Freshwater*	*Brackishwater*	
0–2	0.305	0.099	Lost	0.255	0.041
2–4	0.112	0.055	0.063	0.188	0.034
4–6	0.052	0.062	0.080	0.239	0.022
6–8	0.024	0.050	0.062	0.209	0.012
8–10	0.016	0.065	0.099	0.433	0.010
10–12	0.008	0.109	0.127	0.665	0.006
12–14	0.006	0.105	0.144	0.672	0.006
14–16	0.005	0.114	0.278	0.799	0.005
16–18	0.005	0.085	0.607	0.831	0.008
18–20	0.010	0.054	0.708	0.811	0.005
20–22		0.036	0.561	0.847	
22–24		0.022	0.515	0.617	
24–26		0.014		0.552	
26–28		0.006		0.563	
28–30		0.008			
30-32		0.003			
32-34		0.003			
34-36		0.003			

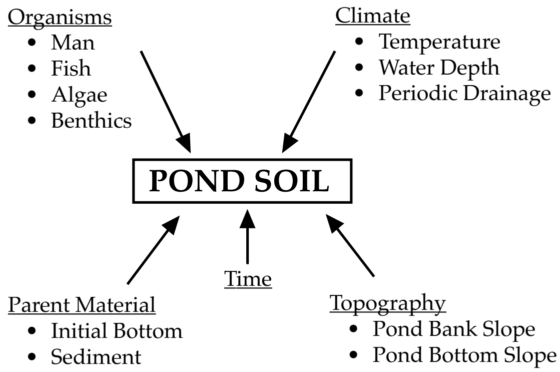

Figure 1. External factors of pond soil development.

activity of fish, benthic animals, and other organisms that suspend sediment, but for a discussion of pond soil formation, it is better to speak of pedoturbation to include physical processes such as erosion and resedimentation and wetting and drying between crops. Thus, pedoturbation includes all factors that result in gross redistribution of soil particles in the pond bottom. Two other processes that can be considered transfers of material are leucinization (the paling of pond soil by disappearance of dark organic material through drainage and respiration) and salinization. Salinization is probably only important in brackishwater ponds.

Transformations include aerobic and anaerobic decomposition, formation of organic matter through photosynthesis, humification (conversion of raw organic matter to humus), ripening (chemical, physical, and biological changes that occur when sediment is exposed to air when ponds are drained between crops), and gleization (darkening of soils when iron and manganese are reduced under anaerobic conditions).

Pond soils appear to develop distinct profiles within a few years in contrast to terrestrial soil, where soil development takes much longer. The major factors influencing pond soil development appear to be sedimentation, organic matter input, and wetting and drying processes between crops.

ANTICIPATED BENEFITS

This research will be useful in explaining various water quality phenomena observed during normal PD/A CRSP investigations which utilize these ponds. The data further confirm that the system of delineating soil horizons suggested by Munsiri, Boyd, and Hajek of Auburn University are applicable to ponds in general. Adoption of this system or some other system of delineating pond soil profiles is essential to developing a pond bottom soil taxonomy. The study suggests that pond soil organic matter decomposes rather slowly, and this will be useful in attempts to explain why pond soils tend to contain more organic matter than terrestrial soils. These findings also will be useful in developing a theory of pond soil development and explaining why pond bottoms quickly form distinct profiles.

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NEW SITE DEVELOPMENT AND CHARACTERIZATION—PERU

Eighth Work Plan, Peru Research 2 (PR2)
Final Report

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ABSTRACT

This report is a descriptive overview of the South American PD/A CRSP site located at the Instituto de Investigaciones de la Amazonia Peruana research facility in Iquitos, Peru, and contains information pertaining to the physical, geological, meteorological, and hydrological characteristics of the region. The facility is located in a densely populated region that has undergone significant commercialization, industrialization, and subsequent deforestation. The region surrounding the facility ranges from an elevation of 100 to 120 m above sea level and the soil is composed of sand in a mixture with clay and a slight amount of silt. The regional climate is tropical; the average temperature is 26.5°C; annual precipitation of the region is greater than 2,500 mm; and maximum sunshine hours range from 11 h 36 min to 12 h 38 min. The Amazon River levels fluctuate between 107 and 118 m, flooding nearly 10 m. The research facility is located at an elevation high enough to avoid the flooding common to the region. As a result of precipitation there are three categorizations of water chemistry in the Amazon region: white, clear, and black. White water is turbid with silt particles, ochre-colored, has transparencies (Secchi disk depth of 0.10 to 0.50 m), and pH ranges from 6.2 to 7.2; clear water is more transparent (Secchi disk depth) of 1.10 to 4.30 m green to olive-green in color, and pH ranges from 4.5 to 7.8; black water is mostly transparent (Secchi disk depth of 1.30 to 2.90 m, olive-brown to coffee-brown in color, and pH ranges from 3.8 to 4.9. The research ponds exhibited chemical properties characteristic of white and black water categorizations and their water was classified as soft and slightly acidic. Water temperature ranged from 29.3 to 31.7°C; DO averaged in excess of 4.0 mg l^{-1}; total ammonia nitrogen was < 1 mg l^{-1}; carbon dioxide reached as high as 22 mg l^{-1}; and average transparency ranged between 29 and 125 cm. Additionally, the report describes the research facility's flow-through system, research ponds, and additional infrastructure.

INTRODUCTION

The Eighth Work Plan in Peru has been in effect since 1996. The project has taken place at the Instituto de Investigaciones de la Amazonia Peruana (IIAP) research facility. The facility is established within a natural area, and has remained simple in nature, consisting of a few small one-story buildings and 25 irregularly shaped research/culture ponds. Since the beginning of this project, the facility has undergone major renovations for the improvement of aquaculture studies. The facility is still under renovation and in the process of acquiring new research equipment, but will soon be capable of recording all data necessary to complete project requirements. A descriptive overview of the facility and the area of Iquitos, Peru, including physical and geological descriptions, hatchery and ponds descriptions, and meteorological and hydrological descriptions, has been developed for this Eighth Work Plan report based on data collected or obtained from references from accredited sources.

Legend to the physical layout of IIAP CRI-Loreto research facility at Iquitos, Peru, 1997

1. 3,100-m^2 pond
2. 650- m^2 pond
3. 1,347-m^2; 1,368-m^3 pond
4. 1,198-m^2; 1,532-m^3 pond
5. 1,158-m^2; 1,278-m^3 pond
6. 1,015-m^2; 900-m^3 pond
7. 600-m^2 pond
8. 600-m^2 pond
9. 600-m^2 pond
10. 2,443-m^2 pond
11. 1,408-m^2 pond
12. 2,642-m^2 pond
13. 5,320-m^2; 4,490-m^3 pond
14. 2,940-m^2 pond
15. 1,000-m^2 pond
16. 1,000-m^2 pond
17. 60-m^2 ponds (nine)
18. Offices/housing
19. Water tower (well)
20. Laboratory
21. Administration
22. Service Building (storage)/feed lab
23. Supply and tool house
24. 45- and 50-m^3 cisterns
25. Fish hatchery

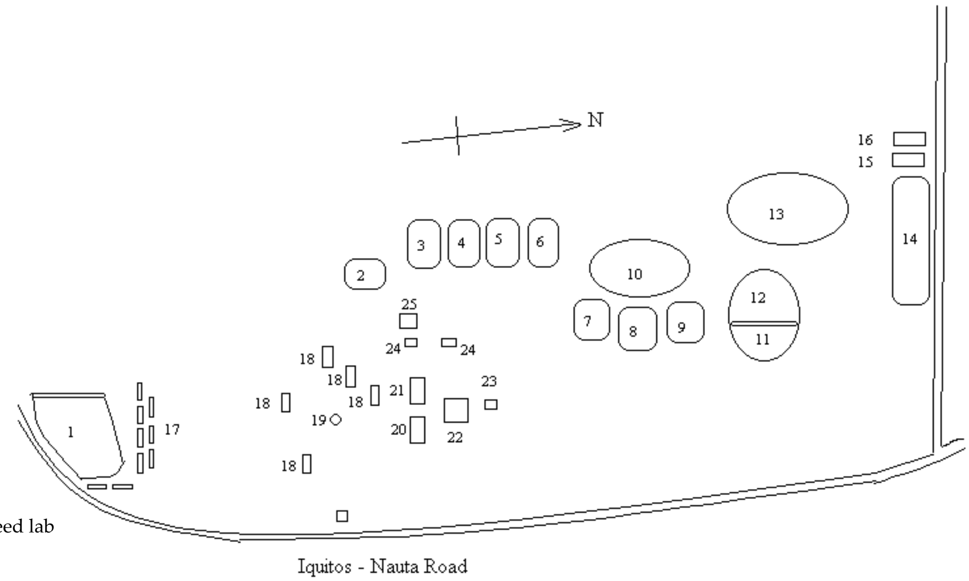

Figure 1. Physical layout of the IIAP CRI-Loreto research facility at Iquitos, Peru, 1997.

PHYSICAL AND GEOLOGICAL DESCRIPTION

The Eighth Work Plan study site is located at the Instituto de Investigaciones de la Amazonia Peruana (IIAP) Centro Regional de Investigaciones-Loreto (CRI-Loreto), a regional research site. This facility is located 7 to 10 km southeast of Iquitos, Peru (-3°45′10″ latitude and -7.3°11′29″ longitude). The local time, during fall and winter, matches the United States Eastern Time Zone and during spring and summer matches the Central Time Zone. The region is heavily populated relative to the rest of the lowland forest region, with an estimated human population of approximately 300,000 inhabitants. Consequently, commercialization and industrialization in the area have led to significant deforestation. Secondary succession tropical forests are predominant in this region. Natural undisturbed rainforest is sustained approximately 20 to 30 km from Iquitos. The IIAP CRI-Loreto facility is located in the outskirts of Iquitos. This region is sloping and full of hills, ranging in altitude from 100 to 120 meters above sea level. Most of this area is declared floodplain since it divides the Itaya and Nanay tributaries to the Amazon River. It is built within a densely vegetated area on a land gradient suitable for gravity-fed ponds. The facility consists of several buildings serving different purposes (e.g., offices, labs, storage, and hatchery) and irregularly shaped ponds fed by rainwater contained in two cisterns and an artesian well-fed water tower used as an auxiliary source (Figure 1). Soil samples were collected in March 1997 and were sent to be analyzed at Auburn University. Dr. Wes Wood will be collecting more soil samples in August 1998 for additional analyses. Soil composition is predominantly sand in a mixture with clay and a little silt. Soil and terrain suitability for aquaculture ponds in this region was diagnosed by Kapetsky and Nath (1997) as moderately suitable (slope = 2 to 8%; effective soil depth 75 to 150 cm; gravel and stones 40 to 80%; soil and texture loamy or clayey without swell-shrink, and not organic; salinity 4 to 8 dS m^{-1}; pH 5.5 to 7.2; catclays not present; gypsum not present).

HATCHERY FACILITY AND PONDS

The hatchery facility at CRI-Loreto is approximately 65 m^2 and is equipped with a sand-based mechanical filter, six 200-US-gallon concrete brood tanks, twelve 30-l jar incubating system with a 40-US-gallon fry receptacle, a laboratory table, cabinets, and counter top with sinks for prep work.

Water is gravity fed throughout the facility. Water is fed into the hatchery from two cisterns (45 and 50 m^3) and then down through a custom built mechanical sand filter that removes large particles from the water. Water then flows through the six brood tanks and egg incubating system out the hatchery via grooved concrete ground channels into the ponds at lower elevation. The entire facility is a flow-through system with water being most abundant during rainy seasons. The incubator has a European design which allows water to flow from beneath the jars out through an upper lip. Adjusted pressure allows the eggs to remain revolving in the water column until the hatching period. Free-swimming fry eventually swim out the lip into the fry receptacle, where they are collected and stocked into grow-out ponds. Ponds throughout the facility are irregularly shaped and vary in size. They are filled primarily by rain and water from the cisterns, but the construction of an artesian well and elevated water tank will soon aid in pond filling during drier seasons. There are nine 60-m^2 rectangular fry ponds and sixteen grow-out and brood ponds, ranging from 600m^2 to 5,320 m^2. The area surrounding the ponds is sandy, covered with well-trimmed grass, palm trees, almond trees, and fruit trees around the levies, and with secondary succession forest bordering the whole facility. The water is predominantly black (some ponds may turn muddy or turbulent due to clay and silt in the substrate), slightly acidic, and soft. Irregular shapes of some ponds lead to high concentrations of macrophytes resulting from flat banks with mild slopes. Substrate composition varies among the ponds. During dry seasons, evaporation and infiltration through sandy sediment become an important issue

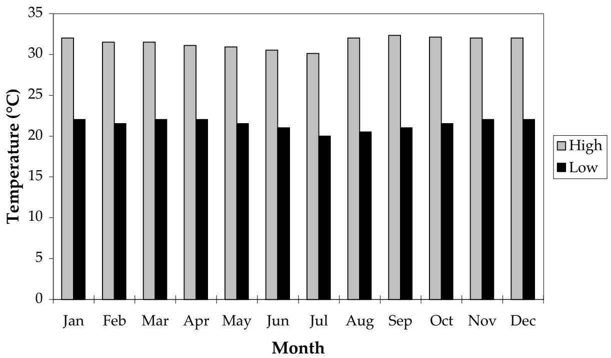

Figure 2. Average monthly ambient temperature range of Iquitos, Peru.

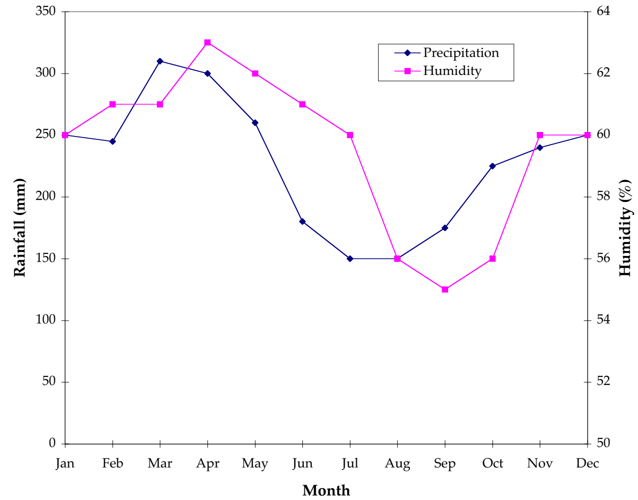

Figure 3. Average monthly precipitation and humidity at Iquitos, Peru.

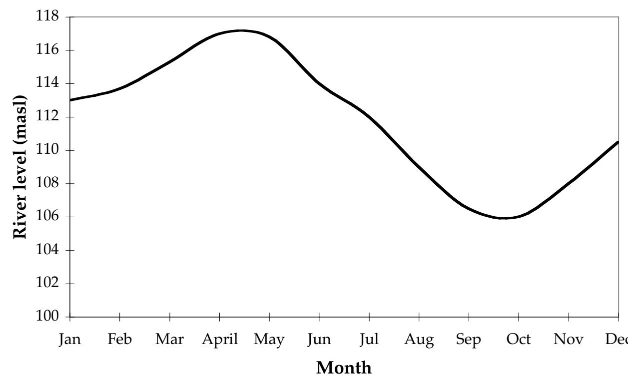

Figure 4. Amazon River annual hydrological cycle at Iquitos, Peru. Level fluctuation is directly related to rainfall. Information provided by the Amazon Hydrography and Navigation Service.

due to reliance upon rain to maintain water levels in the ponds. When the well becomes operational, this situation will be improved. Feed for the fish is prepared from raw ingredients at the feed lab. The ingredients are stored in the storage facility under cooled conditions to prevent denaturing. The prep room is equipped with weighing balances and an industrial custom-built pelletizer. After measuring, the ingredients are mixed in a wheelcart, then pelleted through the pelletizer. Finally, the feed is sun-dried until ready for use.

METEOROLOGY

The regional climate is tropical. It is hot and humid most of the year with an average temperature near 26.5°C (Figure 2). Average wind speed at the research facility was 1.6 km hr^{-1} this year. Maximum sunshine hours in the Amazon region are constant, ranging from 11 h 36 min to 12 h 38 min, although sunshine hours at the surface are lower due to high humidity leading to cloud formation, which also decreases solar radiation at the surface by 50%. (Salati and Marques, 1984). Average surface sunshine hours were calculated to be 3.0 h d^{-1} at the research facility. Annual precipitation in the Iquitos region, as well as the continuous western Amazon, surpasses 2,500 mm (Dumont and Garcia, 1992). In Iquitos most of this rain occurs between January and June (Figure 3).

HYDROLOGICAL CYCLE AND WATER TYPES

Changes in seasonal precipitation have an immense impact on river level fluctuations throughout the year. The Amazon River levels at Iquitos fluctuate between 107 and 118 m above sea level throughout the year (Amazon Hydrography and Navigation Service, 1997; see Figure 4). The region floods nearly 10 m during flood season. The CRI-Loreto facility is located on ground sufficiently high to prevent the frequent flooding common to the region. At the research facility, the rainy season triggers the time to fill the culture ponds and when certain species such as *Piaractus brachypomus* and *Colossoma macropomum* prepare to spawn. This precipitation increment also affects the water chemistry in rivers and ponds. Three types of water are described in the Amazon region: white, clear, and black waters (Sioli, 1984). Each type exhibits different chemical and physical properties. White water is turbid with silt particles, ochre-colored, and has transparency (Secchi disk depth) of 0.10 to 0.50 m, and pH ranging from 6.2 to 7.2. Clear water is more transparent

Table 1. Early morning water quality levels[a] of ponds used in the Eighth Work Plan at the IIAP CRI-Loreto research facility Iquitos, Peru, 1997 to present.

	Temperature	O_2	CO_2	pH	TAN[b]	Chloride	Conductivity	Alkalinity	Hardness	Transparency
Mean	29.2	4.9	7.2	6.7	< 1	8.6	96.0	20.0	20.0	104.3
High	28.8	0.5	22.0	7.6	< 1	40.0	200.0	20.0	20.0	125.0
Low	31.8	10.5	2.0	6.0	< 1	4.0	10.0	20.0	20.0	29.0

[a] Values in mg l^{-1} except temperature (°C), pH, conductivity (µ ohms cm^{-2}), and transparency (cm).
[b] TAN = total ammonia nitrogen.

(1.10 to 4.30 m), green to olive-green, and has pH ranging from 4.5 to 7.8. Black water also is more or less transparent (1.30 to 2.90 m), with olive-brown to coffee-brown coloration and pH ranging from 3.8 to 4.9. All three types are found in the Iquitos region.

WATER QUALITY

The ponds at CRI-Loreto exhibited a mixture between white and black water properties during the Eighth Work Plan study (Table 1). Mean maximum and minimum temperatures were 31.7 and 29.3°C, respectively. Minimum dissolved oxygen levels generally remained above 1.0 mg l^{-1}, and usually averaged in excess of 4.0 mg l^{-1}. Total ammonia nitrogen (TAN) remained below 1.0 mg l^{-1} while carbon dioxide levels reached a high of 22 mg l^{-1}. These waters can be classified as soft (hardness = 20 mg l^{-1}; alkalinity = 20 mg l^{-1}; conductivity = 96 µohms cm^{-2}) and slightly acidic (morning pH ranging from 6.3 to 7.1). Average transparency ranged between 29 and 125 cm.

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NEW SITE DEVELOPMENT AND CHARACTERIZATION—KENYA

Eighth Work Plan, Kenya Research 1 (KR1)
Abstract

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ABSTRACT

Site development and characterization activities for the new prime site at Sagana, Kenya, began immediately upon arrival of the Africa Project's resident researcher, Karen Veverica, on 31 March 1997. Major undertakings that were required to make the site suitable for CRSP research included modification of the existing ponds, refurbishment of the water quality laboratory, acquisition of suitable laboratory and farm supplies and equipment, installation of a weather monitoring and recording (datalogger) system, and acquisition of a new computer system and an appropriate four-wheel-drive vehicle. Pond and laboratory renovations proceeded rapidly, and the major portions of these tasks were complete by the end of September 1987. Four existing 4000-m^2 production ponds were modified to create twelve 800-m^2 ponds of uniform size and shape for CRSP research. Extra soil from the pond renovation was used to make seven additional ponds, ranging from 800 m^2 to 1500 m^2, which will be used as holding ponds, for fry production, or for activities requiring the use of hapas. Three of the extra ponds have dimensions appropriate for experimental work. Farm and laboratory supplies and equipment, including a new desktop computer, laboratory instruments, and seines, were shipped from the US on 30 June and arrived at Sagana on 3 September. A Land Rover was purchased from the United Kingdom and shipped to Kenya on 1 July, becoming available for project use in mid-September. Installation of the weather monitoring system was begun at the end of November and weather data were recorded beginning the first week of December. In addition, observations on pond soil and source water chemistry and annual weather patterns were begun to allow complete characterization of the new site. Initial pond soil samples were collected in October 1997, and water samples for source water characterization were collected starting in October 1997. Weather data recording was begun in December 1997. Solar radiation, photosynthetic active radiation (PAR), precipitation, relative humidity, wind speed, and air temperature were recorded hourly. Four temperature probes were suspended in one pond (D6) to record pond temperature at 5, 25, 50, and 75 cm depth as of April 1998. Preliminary analyses of pond soil samples indicate that they are mainly of the "black cotton soils" variety, high in 2:1 type clay minerals (70 to 90% clay), with cation exchange capacities typical for that type of soil (30 to 55 meq 100 g^{-1}), and pH values ranging from 5.4 to 7.5. Lime will be required to ensure that carbon is not limiting in fertilization experiments or during production cycles. Lime requirements of 5 to 10 tons ha^{-1} have been calculated. The phosphorus adsorption capacity of these soils is expected to be quite high. Total alkalinity and total hardness levels of water provided to the Sagana ponds through the 2-km canal system are typically 10 to 20 mg l^{-1} as $CaCO_3$. Conductivity was measured at 0.05 mmho cm^{-1}. Detailed characterization of the pond soils and source waters for the Sagana station, as well as a summary of the first year's weather, will be included in the final report for this activity.

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EFFECT OF MUD TURBIDITY ON FERTILIZATION, AND AN ANALYSIS OF TECHNIQUES TO MITIGATE TURBIDITY PROBLEMS

Eighth Work Plan, Thailand Research (TR1)
Final Report

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ABSTRACT

This experiment was designed to 1) assess effects of different turbidity reduction techniques on fish growth and water quality and 2) find a suitable approach for turbidity mitigation. It was conducted in 15 earthen ponds at the Asian Institute of Technology, Thailand, during October 1997 through April 1998. The five different treatments were: (A) control; (B) covering 50 cm of the pond edges starting from the top of pond dikes with black plastic to prevent turbidity from run-off; (C) covering pond bottoms with green manure (terrestrial weeds) to alter texture; (D) covering pond bottoms with netting material to prevent turbidity from fish disturbance; and (E) liming ponds biweekly with quick lime at a rate of 200 kg ha^{-1}. All ponds were fertilized weekly with chicken manure at a rate of 225 kg ha^{-1} (dry matter basis) supplemented with urea and triple super phosphorous (TSP) to provide 28 kg N ha^{-1} wk^{-1} and 7 kg P ha^{-1} wk^{-1}. Sex-reversed male Nile tilapia (*Oreochromis niloticus*) were stocked at 2 fish m^{-2} at a size of 15.0 ± 1.0 g. The liming treatment led to the best growth performance except for survival. The lowest survival and net fish yield occurred in the weed-covered treatment. With the exception of the weed-covered treatment, the different mitigation techniques did not result in significantly increased fish yield in the experiment conducted in the dry season. The significantly higher fish mortality in the weed-covered treatment was probably attributable to the low dissolved oxygen concentration due to decomposition of terrestrial weeds during the first month of the experiment. The bottoms covered by netting material prevented turbidity from fish disturbance, resulting in reduced phosphorus regeneration from pond muds but no reduced fish production. Compared with the control, the edge-covered treatment was not significantly different in fish growth performance. This treatment is expected to be more effective during the wet season. A similar experiment should be done during the wet season to further assess the proposed techniques for mitigating turbidity problems.

INTRODUCTION

Mud turbidity is a global problem in aquaculture using ponds with heavy clay dikes and bottoms. Colloidal clay particles from the dikes and bottom (as well as from runoff and source water) become suspended in the water column and inhibit plankton growth by binding with mineral nutrients from water as well as with plankton cells (Avinimelech et al., 1981). High mud turbidity usually causes acidity, low nutrient levels, and limited light penetration for photosynthesis (Boyd, 1990) and thus results in reduced primary production (Diana et al., 1991). With only fertilizer inputs, turbidity often limits production and growth of fish (Banarjea and Ghosh, 1963; Buck, 1956). From these points of view, mitigation of mud turbidity is essential to enhance and allow normal phytoplankton growth in response to fertilization.

The purpose of this study was to evaluate several mud turbidity mitigation techniques in order to: 1) assess effects of different mitigation techniques on fish growth; and 2) find a suitable approach for turbidity mitigation.

METHODS AND MATERIALS

The experiment was conducted in fifteen 200-m^2 earthen ponds with an average depth of 1.0 m at the Asian Institute of Technology, Thailand. All ponds were fertilized weekly with chicken manure at a rate of 225 kg ha^{-1} (dry matter basis) supplemented with urea and triple superphosphate (TSP) to provide 28 kg N ha^{-1} wk^{-1} and 7 kg P ha^{-1} wk^{-1}. Sex-reversed all-male Nile tilapia (*Oreochromis niloticus*) were stocked at 2 fish m^{-2} at a size of 15.0 ± 1.0 g (mean ± SE) on 24 October 1997.

The ponds were divided randomly into five treatments, with triplicate ponds for each treatment. The five treatments were: (A) control; (B) covering 50 cm of the pond edge starting from the top of dikes with black plastic to prevent turbidity from runoff (edge-covered); (C) covering pond bottoms with green manure (terrestrial weeds) to alter texture (weed-covered); (D) covering pond bottoms with netting material to prevent turbidity from fish disturbance (bottom-covered); and (E) liming ponds biweekly with quick lime at a rate of 200 kg ha^{-1}.

For analyses of most water quality parameters, combined water samples encompassing the entire water column were taken from walkways extending to the center of the ponds. Pondwater analyses—including DO, temperature, pH, alkalinity, total ammonium nitrogen (TAN), nitrite nitrogen, nitrate-nitrite nitrogen, total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), chlorophyll *a*, total suspended solids (TSS), and total volatile solids (TVS)—were conducted biweekly at 0900 h using standard methods

Table 1. Growth performance of Nile tilapia in the 180-day experiment.

Performance	Treatment				
	Control	*Edge-covered*	*Weed-covered*	*Bottom-covered*	*Limed*
Initial Biomass (kg pond^{-1})	6.0 ± 0.2	6.1 ± 0.1	6.1 ± 0.2	6.1 ± 0.1	6.0 ± 0.2
Initial Mean Wt. (g fish^{-1})	15.0 ± 0.5	15.3 ± 0.3	16.3 ± 0.5	15.3 ± 0.3	15.0 ± 0.5
Final Biomass (kg pond^{-1})	21.9 ± 1.6	23.6 ± 2.5	18.0 ± 0.2	21.9 ± 2.7	26.6 ± 1.0
Final Mean Wt. (g fish^{-1})	74.7 ± 2.3	71.1 ± 8.5	77.0 ± 5.4	69.1 ± 4.0	91.7 ± 1.1
Mean Wt. Gain (g fish^{-1})	59.7 ± 2.7	55.8 ± 8.6	61.6 ± 5.9	53.7 ± 4.0	76.7 ± 1.5
Mean Daily Wt. Gain (g fish^{-1} d^{-1})	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.4 ± 0.0
Net Fish Yield (kg pond^{-1})	15.9 ± 1.7	17.5 ± 2.5	11.8 ± 0.4	15.8 ± 2.7	20.6 ± 0.8
Extrapolated Fish Yield (t ha^{-1} yr^{-1})	1.6 ± 0.2	1.8 ± 0.3	1.2 ± 0.3	1.6 ± 0.3	2.1 ± 0.1
Survival (%)	73.2 ± 3.4	83.6 ± 1.8	59.3 ± 4.4	78.5 ± 5.8	72.8 ± 3.6

Table 2. Water quality variables at the end of the experiment.

Variable	Treatment				
	Control	*Edge-covered*	*Weed-covered*	*Bottom-covered*	*Limed*
DO (mg l^{-1})	2.9 ± 1.0	3.2 ± 0.3	3.3 ± 0.7	3.2 ± 0.4	2.4 ± 0.6
Temperature (°C)	30.9 ± 0.2	30.9 ± 0.1	30.7 ± 0.3	30.8 ± 0.3	30.5 ± 0.3
Alkalinity (mg $CaCO_3$ l^{-1})	174.7 ± 11.0	168.0 ± 13.9	123.3 ± 3.1	157.3 ± 15.0	179.3 ± 9.0
pH	7.7 ± 0.2	7.8 ± 0.2	7.4 ± 0.2	7.6 ± 0.1	7.7 ± 0.1
TKN (mg l^{-1})	0.51 ± 0.09	1.24 ± 0.11	0.46 ± 0.14	1.89 ± 1.57	2.13 ± 1.63
TAN (mg l^{-1})	0.44 ± 0.44	0.11 ± 0.20	0.07 ± 0.13	0.02 ± 0.03	0.04 ± 0.08
Nitrite Nitrogen (mg l^{-1})	0.023 ± 0.025	0.033 ± 0.023	0.010 ± 0.010	0.070 ± 0.035	0.030 ± 0.026
Nitrate-Nitrite Nitrogen (mg l^{-1})	0.10 ± 0.08	0.20 ± 0.17	0.10 ± 0.03	0.39 ± 0.19	0.16 ± 0.06
Total Phosphorus (mg l^{-1})	0.35 ± 0.08	0.32 ± 0.06	0.31 ± 0.07	0.27 ± 0.01	0.32 ± 0.04
SRP (mg l^{-1})	0.04 ± 0.02	0.04 ± 0.02	0.02 ± 0.02	0.04 ± 0.03	0.03 ± 0.01
Secchi Disk Depth (cm)	16.0 ± 4.6	14.7 ± 2.1	15.3 ± 1.5	18.3 ± 2.3	14.0 ± 1.0
Chlorophyll *a* (mg l^{-1})	37.6 ± 25.0	48.2 ± 14.1	37.2 ± 12.2	30.4 ± 6.7	44.4 ± 23.8
TSS (mg l^{-1})	138.3 ± 48.2	157.0 ± 27.7	135.0 ± 20.3	85.3 ± 17.0	172.3 ± 48.0
TVS (mg l^{-1})	42.0 ± 8.7	41.0 ± 18.5	32.0 ± 19.7	20.3 ± 11.7	39.0 ± 20.8

(APHA, 1980; Egna et al. 1987). Secchi disk depth was measured at 0900 h daily in all the ponds throughout the experimental period. Monthly diel measurements for temperature, DO, and pH were determined in each pond at 0600, 0900, 1400, 1600, 1800, 2300, and 0600 h, and those for alkalinity and TAN were determined at 0900, 1600, and 0600 h.

Prior to stocking, dissolved oxygen (DO) at 0600 h in ponds receiving the weed-covered treatment was monitored for two weeks to check the changes in dissolved oxygen concentration. Major species of terrestrial weeds grown in pond bottoms of the weed-covered treatment were identified. The emergent macrophyte (*Typha* sp.) was uprooted, and all other weeds were trimmed to 10 to 20 cm high. The total biomass of terrestrial weeds except *Typha* sp. was determined by random sampling. Nutrient composition (nitrogen, phosphorus, and organic matter) of the weeds was determined to estimate nutrient content in the terrestrial weeds.

Bottom soil samples from nine different locations were collected in each pond, air-dried, and thoroughly mixed. A representative subsample was taken from the homogenized sample for each pond. Nitrogen, phosphorus, and organic matter of the bottom soil were measured at the beginning and end of the experiment.

Fish were not sampled during the experimental period. Ponds were harvested on 22 April 1998, after 180 days of culture. Final biomass and numbers were determined. Daily weight gain (g fish^{-1} d^{-1}), net yield (kg pond^{-1}), and extrapolated yield (t ha^{-1} yr^{-1}) were calculated.

Data were analyzed statistically by analysis of variance (ANOVA) using the SPSS 7.0 statistical software package. Differences were considered significant at an alpha level of 0.05. All means are reported with ± 1 standard error (SE).

RESULTS

Growth performance of Nile tilapia indicates that all parameters except survival were highest in the liming treatment (Table 1). Final mean weight and net fish yield in the liming treatment were significantly ($P < 0.05$) higher than those in the edge- and bottom-covered treatments, but not significantly ($P > 0.05$) different from those in the weed-covered treatment or control. However, highest survival was achieved in the edge- and bottom-covered treatments, which had significantly ($P < 0.05$) higher survival than the weed-covered treatment, but not significantly higher survival than the liming treatment and control. Net fish yield in the weed-covered treatment was significantly ($P < 0.05$) lower than the net fish yield of the liming treatment, which was not significantly higher than the net fish yield of the other three treatments.

The final and overall mean water quality parameters are listed in Tables 2 and 3. Water temperature ranged from 26.9 to

39.4°C and pH from 6.0 to 9.6. The final mean and overall mean pH was significantly ($P < 0.05$) lower in the weed-covered treatment. The measured DO concentrations at dawn fluctuated between 1.0 and 4.0 mg l^{-1} over the entire culture period (Figure 1), with the liming treatment having the lowest final value. The weed-covered treatment had the lowest overall mean DO at dawn, but there were not significant differences among treatments in DO at dawn. Low DO at dawn was initially observed in the weed-covered treatment, but this treatment reached levels similar to other treatments after two months (Figure 1). Un-ionized ammonia nitrogen concentrations in all treatments were generally low with the control having the highest value (Figure 1) and with no significant differences among treatments. Overall alkalinity concentration in the liming treatment and control was significantly higher than the alkalinity concentrations in the edge- and bottom-covered treatments, which was also significantly ($P < 0.05$) higher than the alkalinity concentration in the weed-covered treatment (Table 3). No significant differences in SRP were found among treatments. Final nitrite nitrogen concentration was significantly ($P < 0.05$) higher in the bottom-covered treatment, while overall nitrite nitrogen concentration was significantly lower in the control. Chlorophyll *a* concentrations were very low throughout the experimental period (Figure 1), but did not differ significantly among treatments. However, overall TSS and TVS concentration in the weed- and bottom-covered treatments was significantly ($P < 0.05$) lower than the overall TSS and TVS concentrations in other treatments (Table 3). The bottom-covered treatment had the lowest final TSS level, which was significantly ($P < 0.05$) lower than the final TSS level of the liming and edge-covered treatments but not significantly different from the final TSS level of the weed-covered treatment and control (Figure 2). Secchi disk depth declined over the experimental period (Figure 3). Secchi disk depth in the weed-covered treatment was significantly ($P < 0.05$) higher than the Secchi disk depth of the other treatments, among which there were no significant differences.

DISCUSSION

With the exception of the weed-covered treatment, the different mitigation techniques did not result in significantly

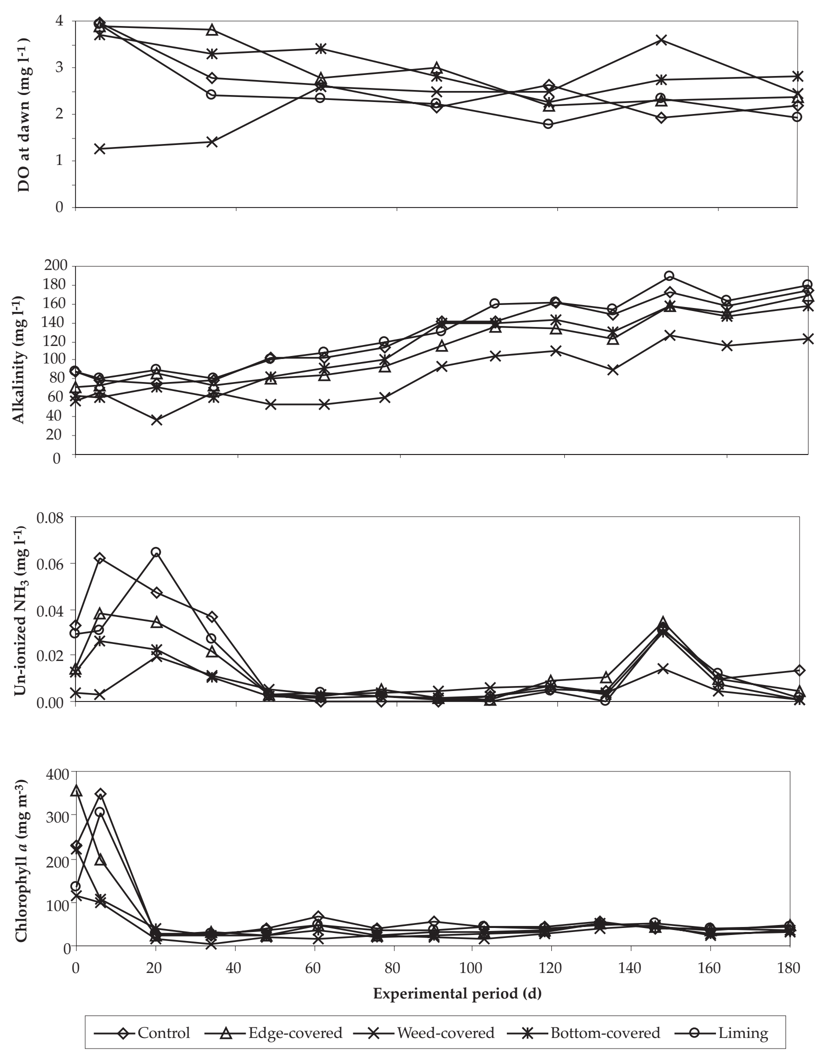

Figure 1. Changes in concentrations of dissolved oxygen at dawn, un-ionized ammonia nitrogen, alkalinity, and chlorophyll *a* in pond water during the 180-day experiment.

Table 3. Mean water quality variables throughout the experiment.

Variable	Treatment				
	Control	*Edge-covered*	*Weed-covered*	*Bottom-covered*	*Limed*
DO at Dawn (mg l^{-1})	2.6 ± 0.2	2.9 ± 0.3	2.3 ± 0.2	3.0 ± 0.6	2.4 ± 0.1
Temperature (°C)	29.1 ± 0.1	29.2 ± 0.2	29.2 ± 0.1	29.2 ± 0.1	28.9 ± 0.2
Alkalinity (mg $CaCO_3$ l^{-1})	124.4 ± 4.9	110.60 ± 6.4	82.5 ± 10.7	110.5 ± 3.8	128.9 ± 3.8
pH	7.8 ± 0.1	7.6 ± 0.0	7.3 ± 0.2	7.6 ± 0.0	7.7 ± 0.1
TKN (mg l^{-1})	2.43 ± 0.39	2.00 ± 0.10	2.17 ± 0.12	2.42 ± 0.19	2.38 ± 0.24
TAN (mg l^{-1})	0.32 ± 0.07	0.32 ± 0.06	0.44 ± 0.15	0.22 ± 0.04	0.25 ± 0.05
Nitrite Nitrogen (mg l^{-1})	0.04 ± 0.01	0.06 ± 0.02	0.07 ± 0.01	0.05 ± 0.01	0.04 ± 0.01
Nitrate-Nitrite Nitrogen (mg l^{-1})	0.16 ± 0.03	0.28 ± 0.08	0.54 ± 0.51	0.21 ± 0.02	0.20 ± 0.04
Total Phosphorus (mg l^{-1})	0.25 ± 0.04	0.20 ± 0.04	0.15 ± 0.02	0.19 ± 0.05	0.26 ± 0.01
SRP (mg l^{-1})	0.04 ± 0.01	0.03 ± 0.02	0.03 ± 0.01	0.04 ± 0.02	0.04 ± 0.01
Secchi Disk Depth (cm)	21.5 ± 0.9	24.6 ± 1.9	34.4 ± 5.2	25.4 ± 1.0	20.2 ± 1.4
Chlorophyll *a* (mg l^{-1})	77.9 ± 3.4	70.4 ± 32.5	36.1 ± 1.5	50.6 ± 20.8	65.2 ± 4.6
TSS (mg l^{-1})	102.0 ± 13.6	90.0 ± 18.0	64.3 ± 7.1	65.1 ± 9.4	102.6 ± 6.6
TVS (mg l^{-1})	27.8 ± 1.1	26.6 ± 1.0	22.4 ± 2.2	20.3 ± 2.7	26.0 ± 0.5

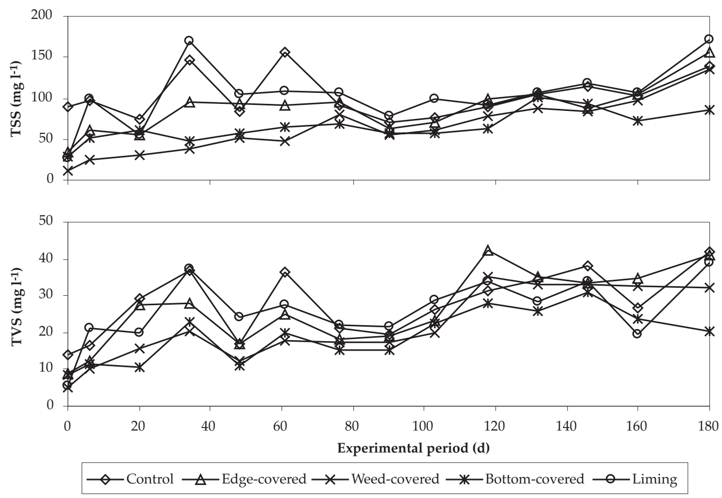

Figure 2. Changes in total suspended solids and total volatile solids in pond water during the 180-day experiment.

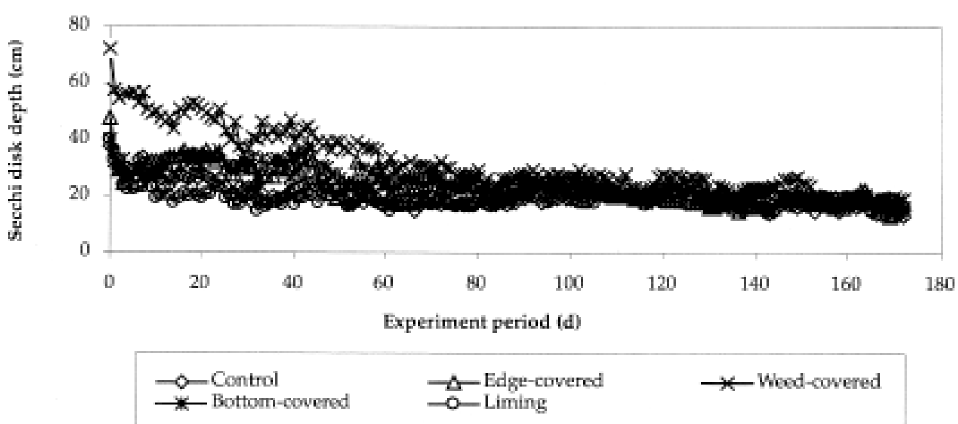

Figure 3. Daily changes in Secchi disk depth during the 180-day experiment

increased fish yield compared to the control ponds. The weed-covered treatment showed a significant reduction in fish yield.

In the weed-covered treatment, the decomposition of the terrestrial weeds in ponds consumed oxygen, causing the significantly low concentration of dissolved oxygen during the first month of the experiment. The highest fish mortality in the weed-covered treatment was probably due to the low dissolved oxygen. Significantly higher Secchi disk visibility and low total suspended solids concentration were observed in the weed-covered treatment during the first month. Ponds containing macrophytes usually had clearer water, and upon decay, dead vegetation increased the concentration of carbon dioxide, decreased pH, and resulted in the precipitation of colloidal clay (Irwin and Stevenson, 1951). However, better timing of stocking fish in the weed-covered ponds is needed to prevent mortality due to depletion of dissolved oxygen.

In the bottom-covered treatment, pond bottoms were covered with netting material to prevent turbidity from fish disturbance on pond bottoms. However, this may also reduce the nutrient regeneration from pond mud. A low level of total phosphorus and chlorophyll *a* was observed in the bottom-covered treatment, which was probably due mainly to the low rate of phosphorus release from pond mud. According to Boyd (1990), plankton growth is regulated to some extent by concentration of phosphorus in the mud of natural waters. However, compared with the control, the covered bottom did not result in significant reduction in fish growth, implying that Nile tilapia feed mainly on phytoplankton in the water column rather than graze on the pond bottom.

There were no significant differences in most water quality parameters and fish growth performance between the control and the edge-covered treatment, indicating that this treatment was not effective in mitigating turbidity problems. However, the edge-covered treatment was designed to prevent turbidity from runoff. It is not surprising that this treatment was not effective during our experiment in the dry season. It might be the most effective technique to mitigate turbidity problems during the wet season. The results also indicated that grazing on pond edges by Nile tilapia was less important than feeding on phytoplankton in the water column.

Lowest Secchi disk visibility and highest concentrations of chlorophyll *a*, resulting in the best growth performance of Nile tilapia, were observed in the liming treatment. The laboratory experiment by Vuthana (1995) indicates that quick lime is the best material to remove turbidity in fish ponds, which is consistent with results of the present experiment. However, fish growth even in this treatment was considerably below normal growth rates for well-fertilized ponds in Thailand (1 g d^{-1}; Diana, 1997), indicating that the technique was not very successful. Biswal and Roy (1991, cited by Vuthana, 1995) reported that the application of lime to remove turbidity in fish ponds turned water alkaline and was unsuitable for fish culture. However, the alkalinity concentration of the liming treatment in the present experiment conducted in earthen ponds was similar to that of the control, confirming the results of Vuthana's (1995) laboratory experiment. This experiment should be repeated in a wet season to compare the dry season results of the present experiment.

ANTICIPATED BENEFITS

The results generated in this study, in addition to similar studies in turbidity control at the other CRSP sites, will link bottom soil characteristics and water quality management for semi-intensive fish ponds. Turbidity problems prevail in many rain-fed ponds in Thailand, Cambodia, and Laos, where the effectiveness of available fertilizer input is reduced by turbidity, resulting in poor fish yields and lack of interest in managing such ponds. The topic of turbidity control has been considered a priority by the Royal Thai Government Department of Fisheries and by the Asian Institute of Technology outreach project.

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MANAGEMENT OF ORGANIC MATTER AND NUTRIENT REGENERATION IN POND BOTTOMS

Eighth Work Plan, Thailand Research 2 (TR2)
Final Report

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ABSTRACT

This report presents the results of two experiments, which were conducted in 12 earthen ponds at the Asian Institute of Technology, Thailand, from November 1997 through April 1998. The first experiment was conducted for 149 days to assess the effect of aerobic and anaerobic conditions of pond bottoms on organic matter decomposition and nutrient release and the effectiveness of common carp in removing organic matter from pond sediments and recycling nutrients for tilapia ponds. The experiment consisted of four treatments: (A) tilapia monoculture with water mixing; (B) tilapia monoculture without water mixing; (C) tilapia/carp polyculture with water mixing; and (D) tilapia/carp polyculture without water mixing. Sex-reversed male Nile tilapia were stocked at 2 fish m^{-2} at a size of 8 to 12 g in all ponds, and common carp fingerlings were stocked at 0.3 fish m^{-2} at a size of 13 to 17 g. All ponds were fertilized with chicken manure at the rate 1000 kg ha^{-1} wk^{-1} (dry matter basis) to create anaerobic pond bottoms. Aerobic pond bottoms in treatments A and C were created by fixing a submersible pump (0.5 kW) 30 cm above the bottom of each pond to mix surface and bottom water. The second experiment was conducted for 30 days in the same ponds used for experiment 1 to assess physical and chemical conditions during microbial decomposition of organic matter and the resultant nutrient release during pond drying. Six of the 12 ponds were refilled immediately after fish harvest and soil sampling, while the other six ponds were dried over a period of one month and then refilled. The polyculture of common carp and Nile tilapia was effective in recycling nutrients and might be effective in removal of organic matter if more common carp are added. Water mixing in the experiments caused greatly reduced phytoplankton growth in both mono- and polyculture ponds. Water mixing did not affect the growth of Nile tilapia in monoculture ponds, but significantly ($P < 0.05$) reduced the growth of both Nile tilapia and common carp in polyculture ponds. Results also showed that pond drying did not result in significant microbial decomposition of organic matter.

INTRODUCTION

Accumulation of organic matter in pond soils during the grow-out cycle causes severe oxygen depletion at the sediment-water interface (Boyd, 1990). A small amount of organic matter in pond soils is beneficial. However, too much organic matter in pond soils can be detrimental because microbial decomposition can lead to the development of anaerobic conditions at the sediment-water interface, under which organic compounds are often decomposed to reduced substances such as NO_2, H_2S, NH_3, and CH_4, which are toxic to fish at relatively low concentrations (Boyd and Bowman, 1997). It is of primary importance to prevent such situations in fish ponds. Two methods commonly practiced by fish farmers are: 1) polyculture with detritivorous fish (Lin, 1982) and 2) pond drying between cycles of production (Boyd, 1990). Detritivores consume organic matter, but also disturb bottom sediment while feeding, which may increase turbidity and reduce water quality (Pillay, 1992). The drying process enhances oxidation of organic material as well as nutrient regeneration in pond soils, and also allows photo-oxidation and microbial decomposition of organic matter (Fast, 1986). All of these processes should enhance nutrient recycling in ponds.

Polyculture and pond drying are commonly practiced throughout Asia to mitigate the accumulation of organic matter on pond bottoms, but there are very few systematic studies carried out on these management practices. This study was conducted to understand the link between bottom soil characteristics and management techniques and the effect of polyculture and pond drying on organic matter accumulation. The study objectives were to assess:

1) The effect of aerobic and anaerobic conditions at the pond bottom on organic matter decomposition and nutrient release;
2) The effectiveness of common carp in removing organic matter from pond sediments and in recycling nutrients for tilapia ponds; and
3) The physical and chemical conditions during microbial decomposition of organic matter and the resultant nutrient release during pond drying.

METHODS AND MATERIALS

Two experiments were conducted at the Asian Institute of Technology, Thailand. The first experiment involved culture of

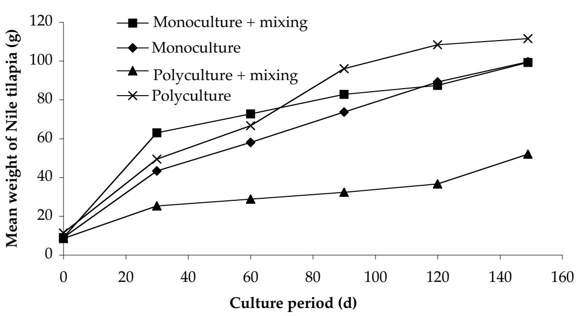
Nile tilapia (*Oreochromis niloticus*) and common carp (*Cyprinus carpio*) and tested four management strategies. The ponds after harvest were used to study the bottom soil characteristics in the second experiment.

Experiment 1: Culture of Nile Tilapia and Common Carp

The experiment was conducted in a 2x2 factorial design in 12 ponds. The ponds were divided randomly into four treatments, with triplicate ponds for each treatment. The treatment combinations were aerobic or anaerobic pond bottoms and monoculture of Nile tilapia or polyculture of Nile tilapia and common carp. Thus, the treatments were: (A) tilapia monoculture with water mixing; (B) tilapia monoculture without water mixing; (C) tilapia/carp polyculture with water mixing; and (D) tilapia/carp polyculture without water mixing.

Sex-reversed male Nile tilapia were stocked at 2 fish m^{-2} at a size of 8 to 12 g in all ponds, while common carp fingerlings were stocked at 0.3 fish m^{-2} at a size of 13 to 17 g on 4 November 1997. The water depth in all ponds was maintained at 1 m throughout the experiment. All ponds were fertilized with chicken manure at the rate 1000 kg ha^{-1} wk^{-1} (dry matter basis) to create anaerobic bottoms. Aerobic pond bottoms in treatments A and C were created by fixing a submersible pump (0.5 kW) 30 cm above the bottom of each pond to mix surface and bottom water. The pumps were modified to suck air above the water surface and release it along with the water jet. A 5x2-m polythene sheet was fixed on the pond bottom below each pump to prevent bottom disturbance by the water jet.

For analyses of most water quality parameters, combined water samples encompassing the entire water column were taken from walkways extending to the center of the ponds.



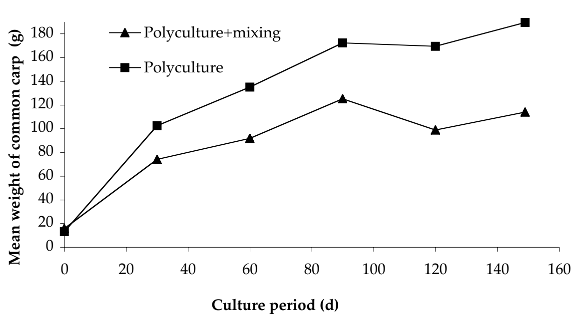


Figure 1. Changes in mean weight of Nile tilapia and common carp during experiment 1.

Pond water analyses including temperature, dissolved oxygen (DO), pH, Secchi disk depth, alkalinity, total ammonium nitrogen (TAN), nitrite nitrogen, nitrate-nitrite nitrogen, total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), chlorophyll *a*, total suspended solids (TSS), and total volatile solids (TVS) were conducted biweekly at 0900 h using standard methods (APHA, 1980; Egna et al., 1987). Monthly diel measurements for temperature, DO, and pH were determined in each pond at 0600, 0900, 1400, 1600, 1800, 2300, and 0600 h, and those for alkalinity and TAN were determined at 0900, 1600, and 0600 h.

Bottom soil samples from nine different locations in each pond were collected, air-dried, and thoroughly mixed one day prior to stocking and harvest. A representative subsample was taken from each homogenized sample for analyses of moisture, total nitrogen, total phosphorus, and organic matter.

During the experiment about 40 fish were seined from each pond and weighed monthly. All ponds were harvested on 2 April 1998 after a 149-day culture period. Final biomass and numbers were determined. Daily weight gain (g d^{-1}), net yield (kg $pond^{-1}$) and extrapolated net yield (kg ha^{-1} yr^{-1}) were calculated.

Experiment 2: Pond Drying

All 12 ponds from the previous experiment were used. Soil samples were taken immediately after draining from nine locations in each pond for the analyses of nitrogen, phosphorus, organic matter, moisture, and pH.

Six of the 12 ponds (Ponds #1, 3, 5, 7, 9, and 11) were refilled immediately after soil sampling. The water samples from the source and pond water were taken at the beginning and end of the experiment to determine dissolved inorganic nitrogen (DIN), TKN, SRP, and TP.

The other six ponds (Ponds #2, 4, 6, 8, 10, and 12) were dried over a period of one month. Soil samples from nine locations in each of the dried ponds were taken weekly to analyze moisture, organic carbon, temperature, and pH. After one month, the dried ponds were refilled, and water samples were taken from the source and pond water for analyses of DIN, TKN, SRP, and TP.

Data from both experiments were analyzed statistically by analysis of variance (ANOVA) using the SPSS 7.0 statistical software package. Differences were considered significant at an alpha level of 0.05. All means were given with ± one standard error (SE).

RESULTS

Experiment 1

Growth of Nile tilapia and common carp differed at the first sampling among all treatments (Figure 1; Table 1). Overall growth rate of Nile tilapia in the treatment of polyculture with water mixing was significantly lower ($P < 0.05$) than in the other three treatments. Survival of Nile tilapia in the two treatments without water mixing was significantly ($P < 0.05$) higher than in the two treatments with water mixing. There were no significant differences ($P > 0.05$) in extrapolated fish yield of Nile tilapia among the treatments of polyculture without water mixing (4.3 t ha^{-1} yr^{-1}), monoculture without

Table 1. Growth performance of Nile tilapia and common carp in experiment 1 after a 149-day culture period.

Performance measures	Nile tilapia				Common carp	
	Monoculture with water mixing	*Monoculture*	*Polyculture with water mixing*	*Polyculture*	*Polyculture with water mixing*	*Polyculture*
STOCKING						
Biomass (kg pond^{-1})	3.6 ± 0.3	3.6 ± 0.3	3.4 ± 0.0	4.5 ± 0.2	0.9 ± 0.0	0.8 ± 0.0
Mean wt. (g fish^{-1})	8.9 ± 0.6	9.0 ± 0.6	8.4 ± 0.1	11.3 ± 0.4	15.7 ± 0.8	13 ± 0.0
HARVEST						
Biomass (kg pond^{-1})	28.9 ± 1.6	32.6 ± 1.8	9.4 ± 5.1	39.8 ± 4.8	6.1 ± 0.6	11.5 ± 0.8
Mean wt. (g fish^{-1})	90.5 ± 7.5	99.5 ± 5.6	51.9 ± 11.2	111.5 ± 6.3	112.0 ± 8.9	189.5 ± 2.6
Weight gain (g fish^{-1})	81.6 ± 8.1	90.5 ± 6.3	43.4 ± 11.1	104.2 ± 6.0	96.4 ± 8.5	178.2 ± 6.0
Daily wt. gain (g fish^{-1} d^{-1})	0.6 ± 0.1	0.6 ± 0.0	0.3 ± 0.1	0.7 ± 0.1	0.6 ± 0.1	1.2 ± 0.1
Net fish yield (kg pond^{-1})	21.4 ± 0.5	29.7 ± 1.5	6.0 ± 5.1	35.0 ± 3.4	5.1 ± 0.6	10.6 ± 0.8
Extrapolated yield (t ha^{-1} yr^{-1})	2.6 ± 0.06	3.6 ± 0.18	0.74 ± 0.62	4.3 ± 0.42	0.63 ± 0.1	1.3 ± 0.1
Survival (%)	70.9 ± 7.4	84.2 ± 4.0	37.0 ± 13.1	88.1 ± 3.2	90 ± 1.6	100 ± 0.8

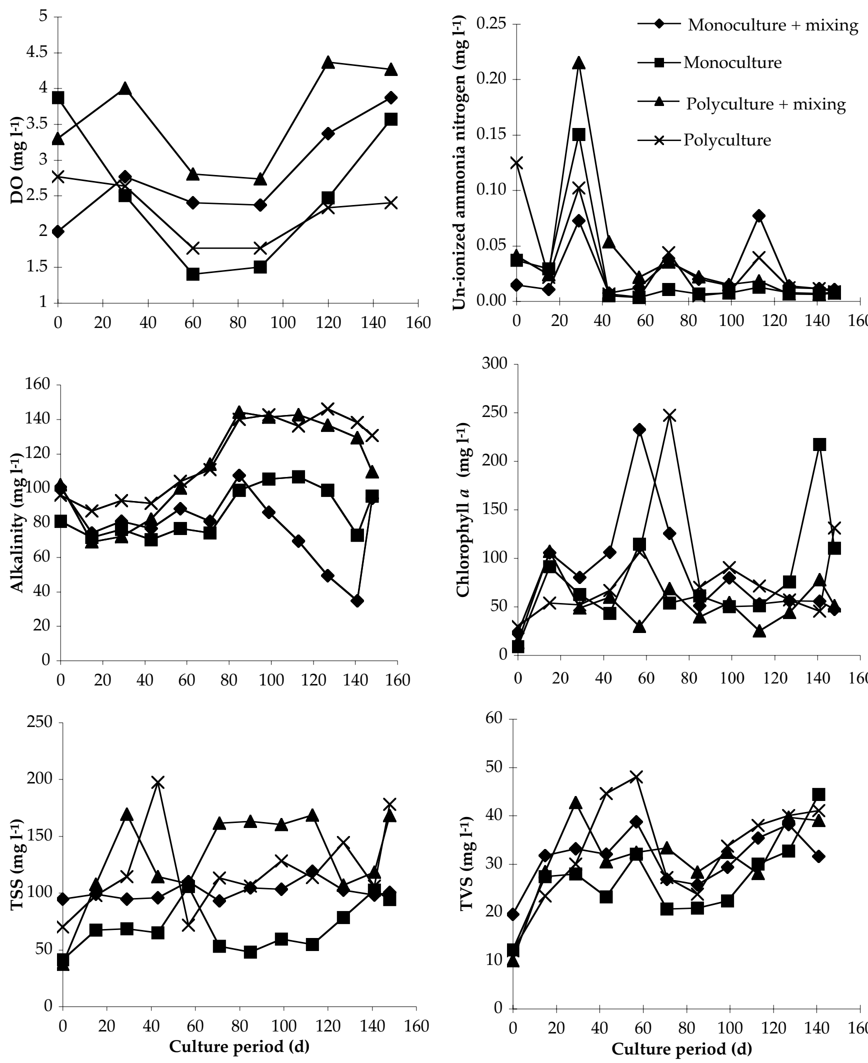


Figure 2. Changes in concentrations of dissolved oxygen (DO) at dawn, un-ionized ammonia nitrogen, alkalinity, chlorophyll *a*, total suspended solids (TSS), and total volatile solids (TVS) in pond water during experiment 1.

Table 2. Water quality parameters at the end of experiment 1.

Water quality	Treatment			
	Monoculture with water mixing	*Monoculture*	*Polyculture with water mixing*	*Polyculture*
DO (mg l^{-1})	5.4 ± 0.1	7.3 ± 0.5	7.0 ± 1.6	6.4 ± 0.1
Temperature (°C)	31.8 ± 0.2	31.8 ± 0.1	31.6 ± 0.1	31.7 ± 0.2
pH	7.2 ± 0.0	7.5 ± 0.1	7.6 ± 0.4	7.2 ± 0.1
Secchi disk depth (cm)	18.3 ± 3.0	21.3 ± 2.6	12.3 ± 1.5	11.0 ± 2.0
Alkalinity (mg l^{-1})	73 ± 20.1	95 ± 11.0	130 ± 15.1	131 ± 18.6
TAN (mg l^{-1})	1.04 ± 0.19	0.52 ± 0.24	0.48 ± 0.15	0.60 ± 0.14
TKN (mg l^{-1})	5.01 ± 3.41	12.26 ± 8.47	2.99 ± 0.78	5.44 ± 1.99
TP (mg l^{-1})	0.31 ± 0.08	0.68 ± 0.22	0.33 ± 0.07	0.39 ± 0.06
SRP (mg l^{-1})	0.17 ± 0.04	0.43 ± 0.13	0.11 ± 0.04	0.11 ± 0.02
Chlorophyll *a* (mg m^{-3})	47 ± 6.8	110 ± 112.2	51 ± 38.9	131 ± 68.0
TSS (mg l^{-1})	100 ± 20.1	94 ± 36.0	168 ± 32.1	178 ± 27.8
TVS (mg l^{-1})	21 ± 2.5	23 ± 10.1	33 ± 2.5	37 ± 13.8

Table 3. Initial and final concentrations and changes in concentrations and percent change for organic matter, total phosphorus, and total nitrogen in sediments of all treatments for experiment 1.

Treatment	Organic matter	Total phosphorus	Total nitrogen
(A) MONOCULTURE WITH WATER MIXING			
Initial level (mg g^{-1})	83.3 ± 18.4	2.1 ± 0.1	7.8 ± 1.0
Final level (mg g^{-1})	66.7 ± 1.0	2.1 ± 0.6	8.1 ± 0.9
Change (mg g^{-1})	-16.6 ± 17.5	-0.1 ± 0.7	0.3 ± 1.2
Change (%)	-17.7 ± 15.1	-2.7 ± 32.6	5.3 ± 16.4
(B) MONOCULTURE WITHOUT WATER MIXING			
Initial level (mg g^{-1})	71.1 ± 2.2	2.0 ± 0.8	6.9 ± 0.7
Final level (mg g^{-1})	64.3 ± 1.8	1.6 ± 0.1	8.3 ± 0.7
Changes (mg g^{-1})	-6.8 ± 3.7	-0.4 ± 0.7	1.4 ± 1.3
Change (%)	-9.4 ± 4.8	-13.3 ± 25.1	21.9 ± 20.4
(C) POLYCULTURE WITH WATER MIXING			
Initial level (mg g^{-1})	74.1 ± 9.2	2.5 ± 0.2	7.4 ± 0.9
Final level (mg g^{-1})	82.8 ± 21.0	3.2 ± 0.2	9.6 ± 0.8
Change (mg g^{-1})	8.7 ± 17.5	0.7 ± 0.3	2.1 ± 0.2
Change (%)	11.5 ± 21.9	29.1 ± 14.4	28.9 ± 6.0
(D) POLYCULTURE WITHOUT WATER MIXING			
Initial level (mg g^{-1})	80.2 ± 5.8	1.8 ± 0.1	8.1 ± 0.9
Final level (mg g^{-1})	73.3 ± 8.1	2.0 ± 0.5	8.7 ± 0.2
Change (mg g^{-1})	-6.8 ± 8.1	0.2 ± 0.6	0.6 ± 1.0
Change (%)	-8.4 ± 9.5	10.9 ± 33.9	7.7 ± 13.3

water mixing (3.6 t ha^{-1} yr^{-1}), and monoculture with water mixing (2.6 t ha^{-1} yr^{-1}), which were significantly higher ($P < 0.05$) than the extrapolated fish yield in the treatment of polyculture with water mixing (0.74 t ha^{-1} yr^{-1}). Growth of common carp was significantly higher ($P < 0.05$) in the treatment without water mixing than in the treatment with water mixing (Figure 1). Similarly, survival of common carp in the treatment without water mixing was significantly higher ($P < 0.05$) than in the treatment with water mixing.

The best growth performance of both Nile tilapia and common carp was achieved in the treatment of polyculture without water mixing. Adding common carp to Nile tilapia ponds had no significant ($P > 0.05$) effect on the growth of Nile tilapia. Water mixing did not significantly ($P > 0.05$) affect growth of Nile tilapia in the monoculture treatments, but significantly ($P < 0.05$) reduced growth of both Nile tilapia and common carp in the polyculture treatments.

Water quality parameters varied among treatments in the experiment (Figure 2; Table 2). Water temperature and pH throughout the experimental period in all ponds ranged from 27.0 to 35.1°C and 6.4 to 10.7, respectively. The measured DO concentrations at dawn fluctuated over the entire culture period, with the treatments with water mixing having significantly ($P < 0.05$) higher DO values than the treatments without water mixing. Un-ionized ammonia nitrogen concentrations in all treatments were generally low and had no significant ($P > 0.05$) differences among treatments. Alkalinity concentrations in the polyculture treatments were significantly ($P < 0.05$) higher than in the monoculture treatments. Both TSS and TVS concentrations were significantly ($P < 0.05$) higher in the polyculture treatments than in the monoculture treatments, implying that the difference in TSS was attributable at least partially to phytoplankton. However, chlorophyll *a* concentrations were not significantly different ($P > 0.05$) among all treatments, due probably to the extremely high level of chlorophyll *a* in a replication of the monoculture treatment without water mixing.

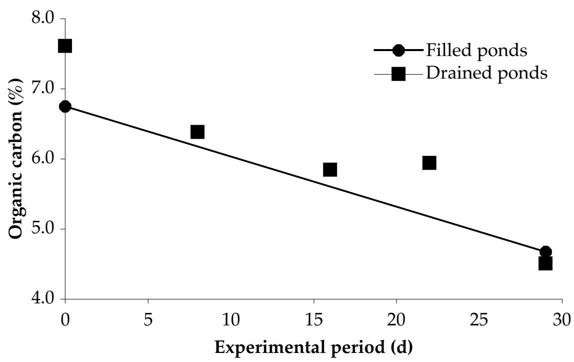


Figure 3. Changes in organic matter content in pond sediments during experiment 2.

The soil analyses showed that there were no significant ($P > 0.05$) differences for changes in organic matter, total nitrogen, and total phosphorus among all treatments (Table 3). While the organic matter content in the treatment of polyculture with water mixing increased by 8.7 mg g^{-1} soil or 11.5%, the reduction of organic matter in other three treatments ranged from 6.8 to 16.6 mg g^{-1} soil or from 8.4 to 17.7%. The content of total phosphorus decreased in the monoculture treatments, but increased in the polyculture treatments. However, nitrogen accumulated in sediments of all treatments after a 149-day culture period.

Experiment 2

The initial and final levels of organic matter, total nitrogen, and total phosphorus in the pond sediments were not significantly ($P > 0.05$) different between filled and drained treatments (Table 4). The organic matter content of the pond sediments of both treatments decreased over the one-month experimental period (Figure 3). However, pond draining for one month in the experiment did not result in the significant ($P > 0.05$) reduction of organic matter in pond sediments, as compared with ponds refilled immediately after harvest in experiment 1 (Table 4). In both experiments total nitrogen accumulated while total phosphorus content decreased in pond sediments (Table 4).

The measured water quality parameters (TKN, DIN, TP, and SRP) did not show any significant ($P > 0.05$) difference between the filled and drained treatments at the end of the experiment

Table 4. Initial and final concentrations and changes in concentrations and percent change for organic matter, total phosphorus, and total nitrogen in sediments of all treatments for experiment 2.

Treatment	Organic matter	Total phosphorus	Total nitrogen
FILLED PONDS			
Initial levels (mg g^{-1})	67.5 ± 2.5	2.2 ± 0.7	8.6 ± 0.8
Final levels (mg g^{-1})	46.7 ± 5.9	1.3 ± 0.4	13.0 ± 6.0
Changes (mg g^{-1})	-20.8 ± 6.1	-0.9 ± 0.6	4.4 ± 6.2
Changes (%)	-30.8 ± 9.0	-38.8 ± 18.7	53.0 ± 72.1
DRAINED PONDS			
Initial levels (mg g^{-1})	76.1 ± 16.6	2.2 ± 0.8	8.7 ± 0.8
Final levels (mg g^{-1})	45.0 ± 1.8	1.4 ± 0.2	13.9 ± 2.3
Changes (mg g^{-1})	-31.1 ± 18.0	-0.8 ± 0.9	5.2 ± 2.8
Changes (%)	-38.6 ± 12.8	-26.5 ± 30.6	61.0 ± 34.2

Table 5. Water quality parameters (mg l^{-1}) at the beginning and end of experiment 2.

Treatment	TKN	DIN	TP	SRP
FILLED PONDS				
Source water	0.80 ± 0.28	0.21 ± 0.18	0.15 ± 0.02	0.01 ± 0.00
Initial levels	0.96 ± 0.21	0.30 ± 0.37	0.12 ± 0.03	0.01 ± 0.00
Final levels	8.79 ± 1.18	1.08 ± 0.10	0.27 ± 0.18	0.07 ± 0.05
Net change	8.00 ± 1.18	0.87 ± 0.10	0.12 ± 0.18	0.06 ± 0.05
DRAINED PONDS				
Source water	5.06 ± 0.18	0.47 ± 0.00	0.06 ± 0.00	0.02 ± 0.01
Initial levels	------------	------------	------------	------------
Final levels	8.65 ± 0.64	1.12 ± 0.13	0.17 ± 0.05	0.07 ± 0.05
Net change	3.59 ± 0.64	0.65 ± 0.13	0.11 ± 0.05	0.06 ± 0.05

(Table 5). The net increase (final levels minus those in source water) of TKN and DIN in the filled treatments was significantly ($P < 0.05$) higher than that in the drained treatments (Table 5). However, there was no significant ($P > 0.05$) difference of the net increment of TP and SRP between these two treatments (Table 5).

DISCUSSION

The presence of common carp in polyculture ponds did not reduce the growth of Nile tilapia compared with Nile tilapia growth in monoculture ponds. Actually, the best growth of Nile tilapia was achieved in polyculture ponds, indicating that the stirring of bottom sediments into the water column by common carp oxygenates the pond bottom and recirculates nutrients into the water column (Cohen et al., 1983), thereby increasing phytoplankton production and food for Nile tilapia (Edirisinghe, 1990). The addition of a benthic detritivore such as the common carp produced extra fish and also resulted in higher system productivity because the unutilized benthic matter (characteristic of Nile tilapia monoculture ponds) was converted into fish flesh. However, soil analyses in the present experiment showed no significant removal of organic matter by common carp, implying that more common carp could be stocked in tilapia ponds.

Water mixing seemed to stimulate phytoplankton growth (Sanares et al., 1986), and continual water mixing, which resulted in the resuspension of the organic particles in ponds, led to high rates of microbial activity and the recycling of pond nutrients (Avnimelech et al., 1986). In the present experiment, however, water mixing largely reduced phytoplankton growth in both mono- and polyculture ponds. Water mixing did not affect the growth of Nile tilapia in monoculture ponds, but significantly reduced the growth of both Nile tilapia and common carp in polyculture ponds.

Pond drying is a common practice between grow-out periods in freshwater and brackishwater aquaculture ponds. Pond drying can greatly retard the rate of organic matter accumulation in pond bottom soil (Boyd and Bowman, 1997). This process is believed to improve the bottom soil conditions. When pond bottoms are dried and exposed to air—which contains 21% oxygen by volume compared to less than 0.001 to 0.002% in water—enhanced oxygen availability may permit greater rates of microbial decomposition of organic matter (Boyd and Bowman, 1997). However, pond drying in the present experiment did not result in significant oxidation of organic matter and releases of nutrients from pond sediments compared with the ponds filled immediately after harvest. One possible reason is that the ponds were not dried completely and deep cracks had not developed. The optimum soil moisture for microbial decomposition ranges from 12 to 20% (Boyd and Pippopinyo, 1994). However, the soil moisture concentration during drying in this study ranged from 50 to 68%, probably due to rain and leaching from the adjacent canal.

Results of the present experiment indicate that the inclusion of common carp in Nile tilapia ponds was effective in recycling nutrients, and might be effective in the removal of organic matter if more common carp are added. Water mixing together with stirring activities of common carp adversely affected the growth of both Nile tilapia and common carp in polyculture ponds. Results also showed that pond drying did not result in significant microbial decomposition of organic matter.

ANTICIPATED BENEFITS

The results generated in this study will link bottom soil characteristics and management techniques. The use of polyculture to mitigate the accumulation of organic material on pond bottoms is a common practice throughout Asia, but has been little studied. Pond drying is also a common practice. Both have strong likelihood of improving pond bottoms and therefore production of fish in ponds.

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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 ($P > 0.05$)

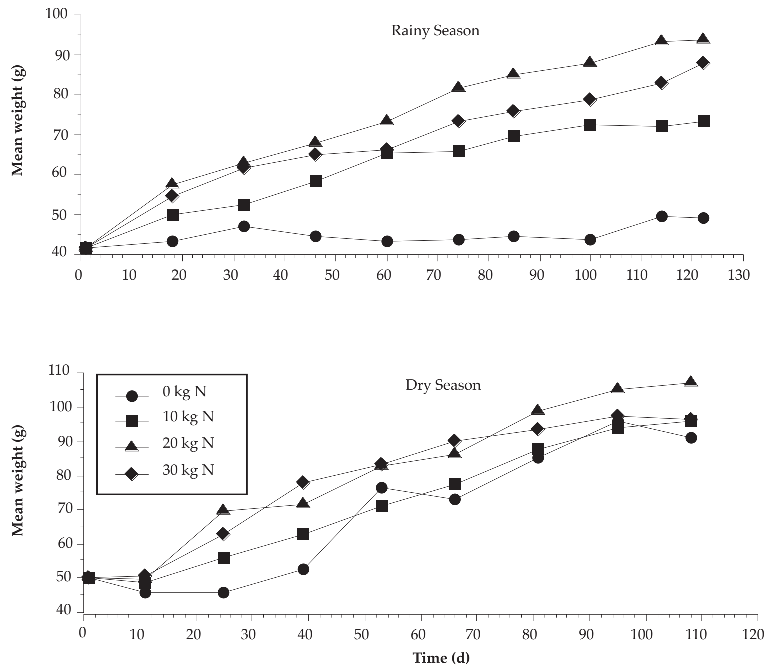

Figure 1. Growth of *Oreochromis niloticus* in earthen ponds fertilized with different rates of nitrogen during the rainy and dry season Global Experiments in Comayagua, Honduras.

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 ($P > 0.05$)

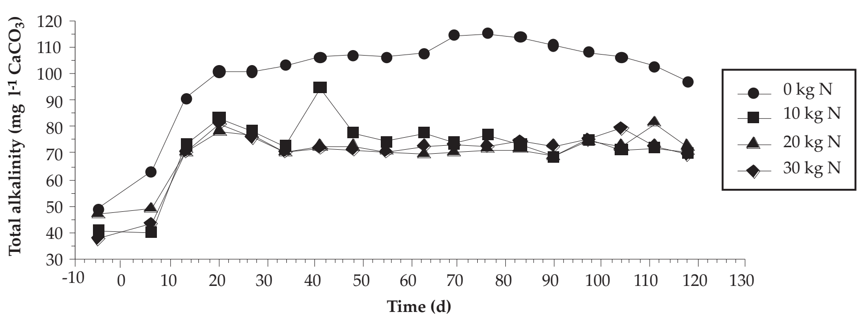

Figure 2. Mean total alkalinity concentrations in ponds fertilized with different rates of nitrogen during the rainy season Global Experiment, Comayagua, Honduras. Data for the dry season experiment were similar.

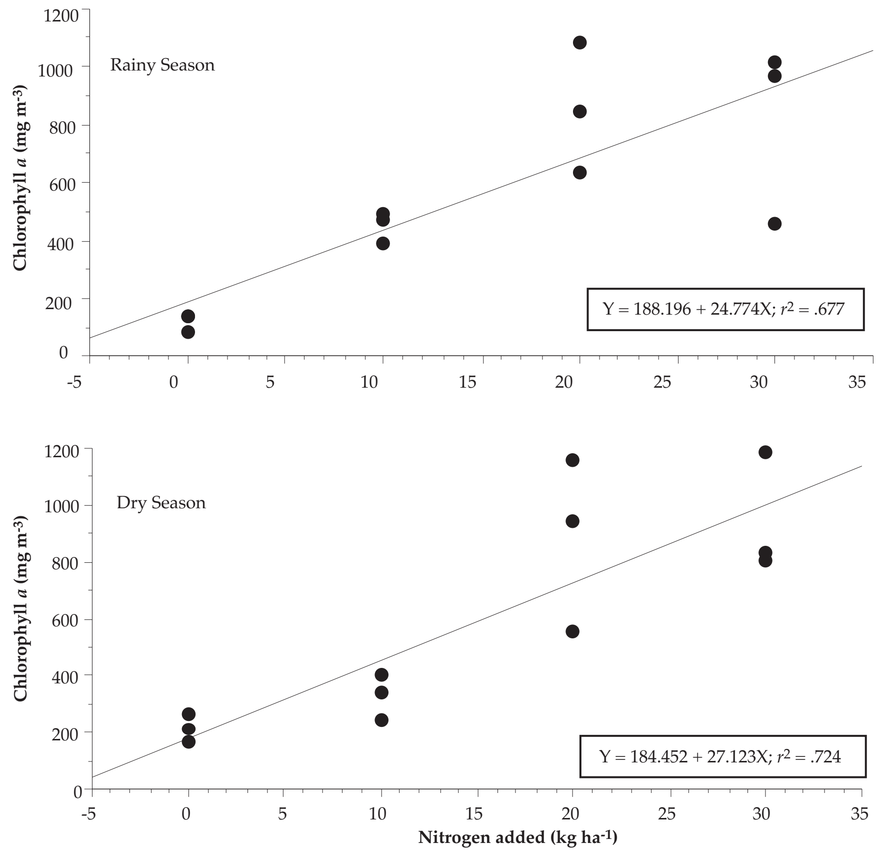

Figure 3. Relationship between weekly pond fertilization with different rates of nitrogen and chlorophyll *a* concentration during the rainy and dry season Global Experiments, Comayagua, Honduras.

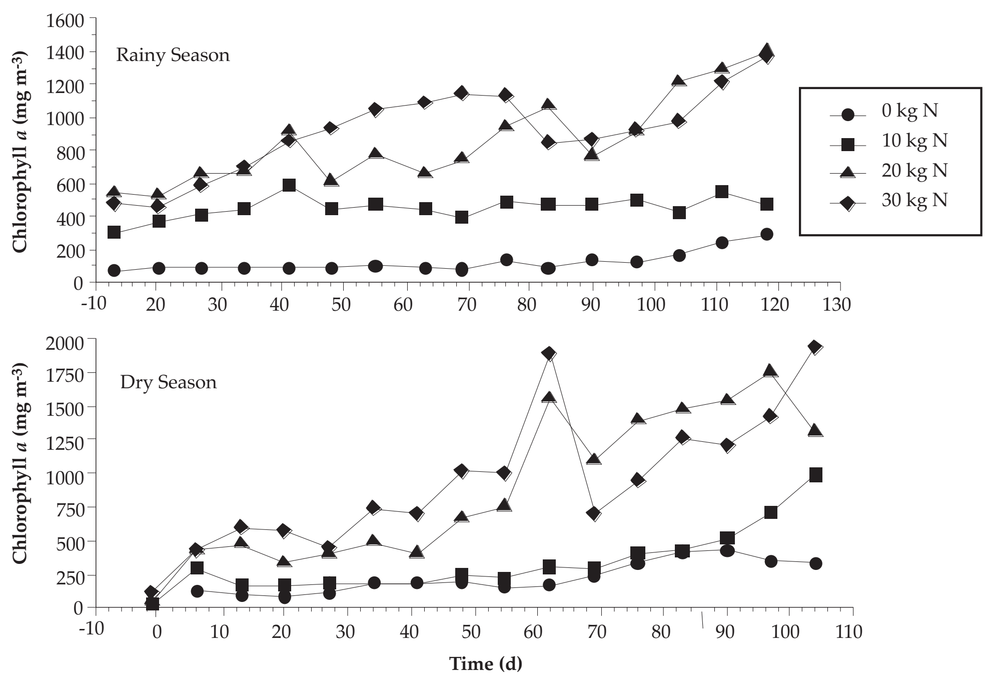

Figure 4. Mean weekly chlorophyll *a* concentrations in ponds fertilized with different rates of nitrogen.

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: *Net* (g O_2 m^{-3} per day)	Primary Production: *Gross* (g O_2 m^{-3} per day)	Community Respiration (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

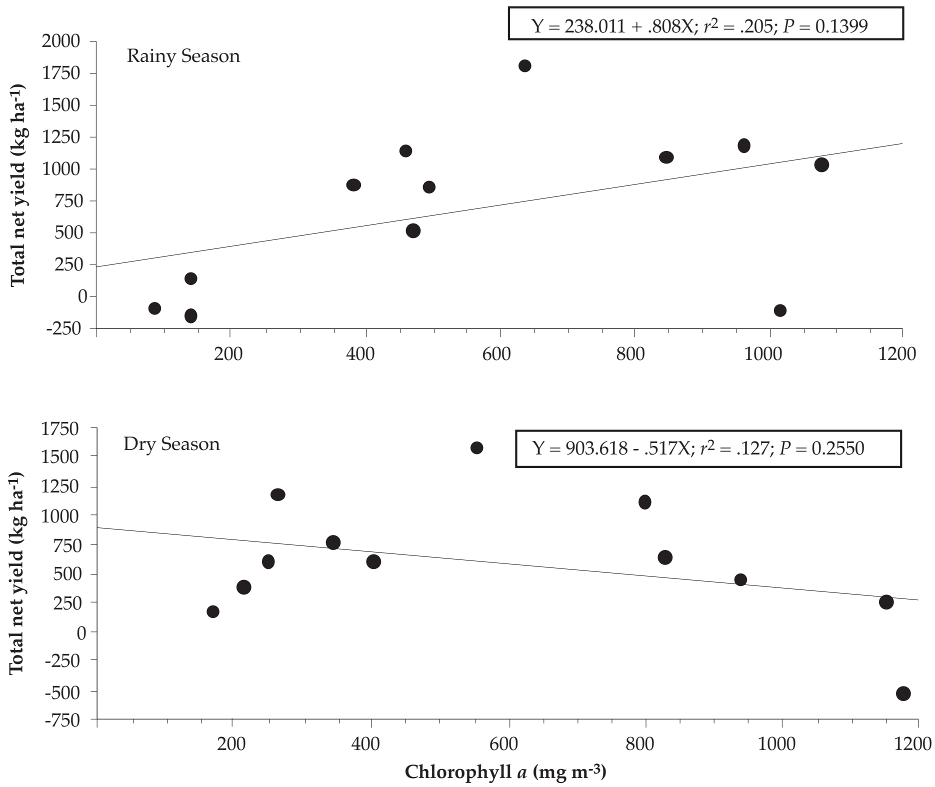

Figure 5. Relationship between total net tilapia yield and chlorophyll *a* concentration in earthen ponds at Comayagua, Honduras, during the rainy and dry season Global Experiments.

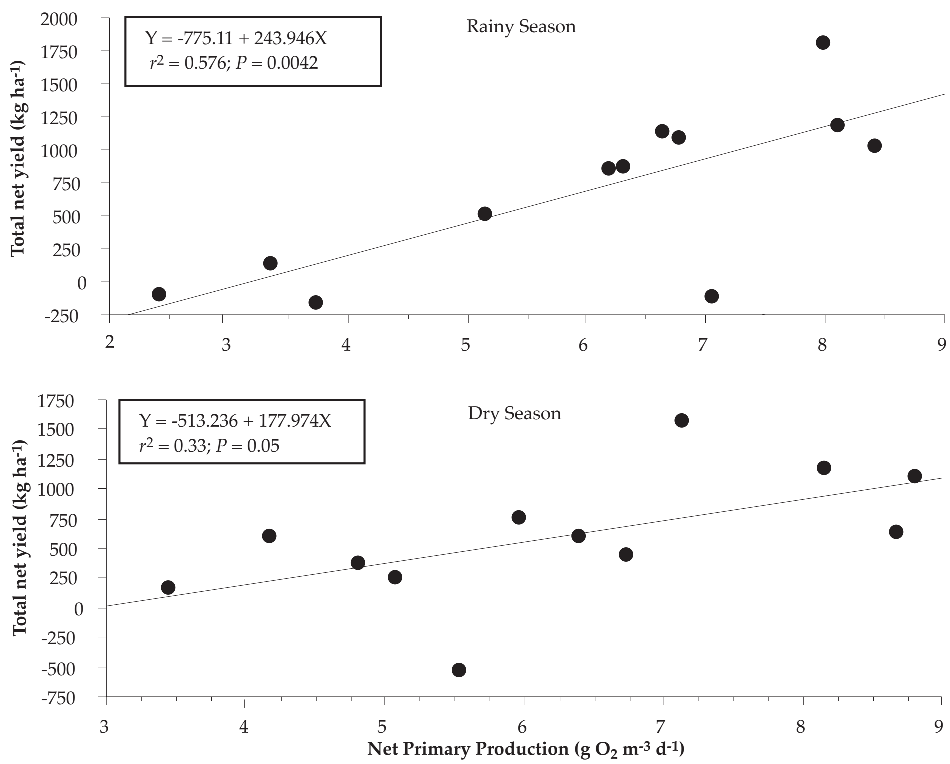

Figure 6. Relationship between total net yield of tilapia and mean net primary productivity in earthen ponds at Comayagua, Honduras, during the rainy and dry season Global Experiments.

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.

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RELATIVE CONTRIBUTION OF SUPPLEMENTAL FEED AND INORGANIC FERTILIZERS IN SEMI-INTENSIVE TILAPIA PRODUCTION

Eighth Work Plan, Kenya Research 3 (KR3)
Progress Report

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ABSTRACT

A 20-week experiment was conducted at Sagana Fish Farm, Kenya, to achieve the following: 1) characterize the productive capacity of ponds at this new CRSP research site; 2) evaluate the relative contributions of inorganic fertilizers and supplemental feeds to fish production; and 3) determine lowest-cost combinations of rice bran and inorganic fertilizer. Twelve 800-m^2 ponds were stocked with juvenile (32 g each) *Oreochromis niloticus* at 2 m^{-2} and *Clarias gariepinus* fingerlings (average weight 4.6 g) at 0.24 m^{-2}. Ponds contained about half sex-reversed and half mixed-sex tilapia, with an estimated ratio of approximately 75% males to 25% females at stocking. Four treatments were applied in triplicate as follows: 1) Urea and DAP to provide 16 kg N ha^{-1} wk^{-1} and 4 kg P ha^{-1} wk^{-1}; 2) Urea and DAP applied to give 8 kg N and 2 kg P ha^{-1} wk^{-1}, plus rice bran fed at 60 kg ha^{-1} d^{-1}; 3) Rice bran fed at 120 kg ha^{-1} d^{-1}; and 4) Rice bran as in Treatment 3 and fertilizer as in Treatment 2. Net fish yield averaged 1,127, 1,582, 1,607, and 2,098 kg ha^{-1} for Treatments 1 through 4, respectively. Fish in Treatments 2 through 4 were still growing rapidly at harvest time, but the growth rate of fish in Treatment 1 was beginning to decrease near the end of the experiment. Treatment 1 was the most cost-effective, but Treatments 1, 2, and 4 all resulted in fairly similar net profits. Input costs for Treatments 1 and 2 will be of interest to fish farmers, although it is possible that fish raised using only fertilizer at the rates in Treatment 1 may never reach market size at this stocking density, because of their reduced growth towards the end of the culture period and their resulting low final average weights, which were less than 100 g.

INTRODUCTION

Aquaculture development in Kenya has been hampered by a lack of complete feeds. The application of chemical fertilizers can enhance natural food production and indirectly provide protein to complement energy-rich rice bran. A 20-week experiment was conducted at Sagana Fish Farm, Kenya, to achieve the following:

1) Characterize the productive capacity of ponds at this new CRSP research site;
2) Evaluate the relative contributions of inorganic fertilizers and supplemental feeds to fish production; and
3) Determine lowest-cost combinations of rice bran and inorganic fertilizer.

This document is a report on progress to date, to be superseded by a final report when all data have been collected and analyzed.

METHODS AND MATERIALS

Lime was applied to all ponds at a rate of 5 t ha^{-1} prior to this experiment. The newest ponds received the lime treatment just prior to filling. Twelve 800-m^2 ponds were stocked with juvenile Nile tilapia *Oreochromis niloticus* (32 g each) at 2 m^{-2} and walking catfish fingerlings *Clarias gariepinus* (average weight 4.6 g) at 0.24 m^{-2}. Initially monosex tilapia were to be used for the study but the number of fingerlings available was insufficient to achieve the desired stocking density; mixed-sex fish were therefore added to complete the stocking. As a result, ponds contained about half sex-reversed and half mixed-sex fish, with an estimated ratio of approximately 75% males to 25% females at stocking.

Four treatments were applied in triplicate as follows:

1) Urea and DAP to provide 16 kg N ha^{-1} wk^{-1} and 4 kg P ha^{-1} wk^{-1};
2) Urea and DAP applied to give 8 kg N and 2 kg P ha^{-1} wk^{-1}, plus rice bran fed at 60 kg ha^{-1} d^{-1};
3) Rice bran fed at 120 kg ha^{-1} d^{-1}; and
4) Rice bran as in Treatment 3 and fertilizer as in Treatment 2.

Due to the relative newness of some ponds and a suspected high P adsorption capacity of newly exposed pond bottoms, the ponds were blocked according to the following criteria:

Block 1: New ponds, never before filled, that received lime just prior to filling.

Block 2: Ponds that had been limed and were in production for less than a month (These were drained and refilled prior to this experiment).

Block 3: Ponds that had been limed, filled, and in production (receiving feeds and fertilizers) for more than a month before the start of the present experiment.

Ponds were assigned randomly in a split block design (Table 1).

Dissolved oxygen, temperature, and pH were measured weekly in the morning and afternoon. Total alkalinity, chlorophyll *a*, Secchi disk visibility, and total ammonia nitrogen were measured every two weeks. Total N, mineral N, total P, and soluble reactive P were analyzed monthly. Samples for water chemistry were taken on Mondays, fertilizing was done on Tuesdays, and dissolved oxygen and temperature readings were done on Thursdays. Pond soils were sampled monthly for total N and P.

Ponds were sampled monthly to determine fish growth and drained completely after 20 weeks. Tilapia were separated by sex, counted, and weighed at draining. Tilapia reproduction was weighed and subsamples were counted. *Clarias* were also counted and weighed.

Table 1. Random pond assignment in split block design at Sagana Fish Farm, Kenya.

Treatment	Block 1	Block 2	Block 3
1	E05	D06	D05
2	E07	D07	E09
3	E04	D08	E03
4	E06	D04	E08

RESULTS

Although Treatments 1 through 3 were intended to be iso-nitrogenous, the rice bran contained less protein than expected. Total N and P inputs are summarized in Table 2. (The third batch of rice bran remains to be analyzed, so these numbers may vary slightly.)

Some of the ponds in Blocks 1 and 2 still had residual lime on their bottoms after draining; however, there were no significant differences in fish production between blocks. At harvest, the average weights of tilapia were 89, 106, 106, and 131 g and *Clarias* weights were 110, 217, 236, and 296 g for Treatments 1 through 4, respectively (Table 3). Male tilapia and *Clarias* showed significantly different average weights among treatments but differences among female tilapia were significant only for Treatments 1 and 4. Survival ranged from 67 to 88%; there were no significant differences by treatment. Males made up 65 to 71% of total tilapia numbers at draining, indicating that our estimate of 75% males at stocking was a bit high.

Fish began spawning during the first month of the experiment. However, due to the low number of females and the presence of *Clarias*, few fingerlings survived to harvest. Because it was somewhat difficult to distinguish initially stocked females from the larger fingerlings, some of the females may have been counted as fingerlings.

Net fish yield averaged 1,127, 1,582, 1,607, and 2,098 kg ha^{-1} for Treatments 1 through 4, respectively. Fish in Treatments 2 through 4 were still growing rapidly at harvest time, but the growth rate of fish in Treatment 1 was beginning to decrease near the end of the experiment (Figures 1 and 2).

Table 2. Preliminary data on nitrogen (N) and phosphorus (P) inputs for the experiment to evaluate the relative contributions of supplemental feeds and inorganic fertilizers in semi-intensive tilapia production.[a]

Treatment	Nitrogen Input		Total N (kg ha^{-1} wk^{-1})	Phosphorus Input		Total P (kg ha^{-1} wk^{-1})
	As Fertilizer	*As Feed*		*As Fertilizer*	*As Feed*	
1	16	0	16	4	0	4
2	8	6.5	14.5	2	3.64	5.64
3	0	13	13	0	7.28	7.28
4	8	13	21	2	7.28	9.28

[a] One of three rice bran lots has not yet been analyzed for N and P, so these figures may be slightly different after the final results are in.

Table 3. Final average fish weight, number of fingerlings, weight of tilapia reproduction, and average net fish yields by treatment. Numbers followed by the same letter are not significantly different at the 95% level (LSD).

Treatment	Tilapia					*Clarias*	Net Fish Yield (kg ha^{-1})
	Avg. Wt. Males (g)	*Avg. Wt. Females* (g)	*Avg. Wt. Mixed* (g)	*Number of Fingerlings*	*Weight of Reproduction* (kg)	*Avg. Wt.* (g)	
1	98 a	61 a	8 a	1,218 a	14.2 a	110 a	1,127 a
2	121 b	70 ab	106 b	837 a	12.5 a	217 b	1,582 ab
3	125 b	72 ab	106 b	1,230 a	15.7 a	236 b	1,607 ab
4	155 c	77 b	131 c	640 a	12.4 a	296	2,098 b

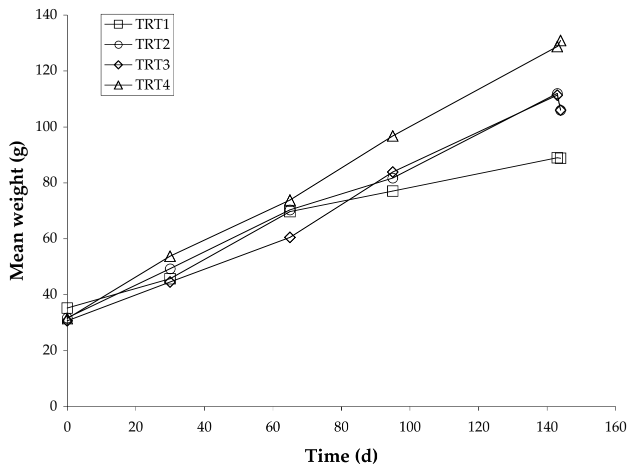

Figure 1. Tilapia growth for Treatments 1 through 4 during the 144-day experiment to evaluate the relative contributions of supplemental feed and inorganic fertilizer in semi-intensive tilapia production.

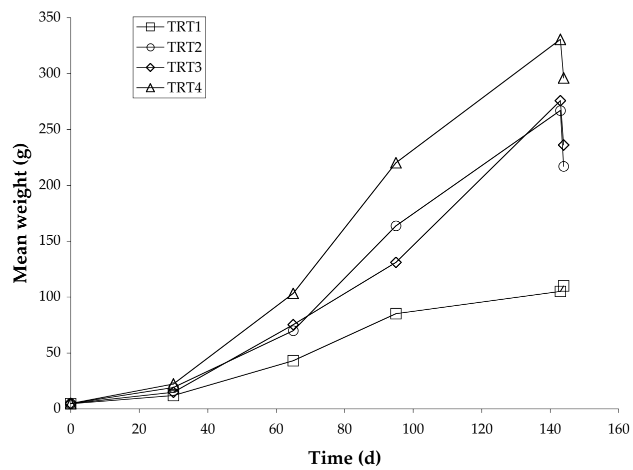

Figure 2. *Clarias* growth for Treatments 1 through 4.

Surface waters at Sagana have total alkalinity (TA) between 10 and 20 mg l^{-1} as $CaCO_3$. Total alkalinity in ponds receiving rice bran remained steady whereas TA for ponds receiving only chemical fertilizer declined after the first month (Figure 3).

Ponds in Treatment 1 had the highest average chlorophyll *a* concentrations. After December (month 2) the ponds in Treatment 3 (rice bran only) developed good algal blooms. Prior to December, however, they had little phytoplankton and dissolved oxygen levels were frequently less than 1 mg l^{-1} in the morning.

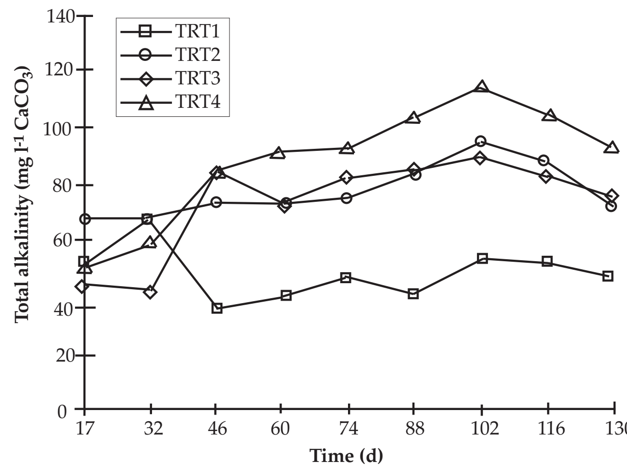

Figure 3. Average total alkalinity levels for ponds in Treatments 1 through 4 from Day 17 through Day 130 of the experiment.

Soluble reactive phosphorus concentrations were never higher than 0.05 mg l^{-1} in any pond. Total ammonia nitrogen never surpassed 0.5 mg l^{-1}. Nitrate and nitrite were low as well, except for a peak in nitrite (0.75 mg l^{-1} NO_2-N) on day 67 for pond E5 (Treatment 1). Ponds of all other treatments never surpassed 0.1 mg l^{-1} NO_2-N. "Black cotton" soils like the ones from which the Sagana ponds are built have notoriously high P adsorption rates. Assuming a clay content of 80% (ponds at Sagana are reported to have as much as 90% clay soils), a P adsorption capacity of 350 kg ha^{-1} was estimated using the formula proposed by Shrestha and Lin (1996). Only 80 kg P ha^{-1} was added to most ponds over the 20 weeks, so the P adsorption capacity was far from satisfied.

Nitrogen efficiency (kg net fish yield/kg N applied) averaged 3.52, 5.46, 6.18, and 5.0 for Treatments 1 through 4, respectively. The N:P ratio of the inputs was also lowest for Treatment 3.

Input costs for the different treatments are presented in Table 4. Treatment 1 was the most cost-effective, but Treatments 1, 2, and 4 resulted in fairly close net profits (Table 5). The higher production obtained in Treatment 4 more than compensated for the increased cost of adding fertilizer when compared with Treatment 3.

CONCLUSIONS

Cost of inputs for Treatments 1 and 2 will definitely be of interest to fish farmers. It is possible that fish raised using only fertilizer at the rates in Treatment 1 may never reach market size at this stocking density, as evidenced by their reduced growth towards the end of the experiment.

Table 4. Cost of inputs and labor per kg of fish harvested in Kenyan shillings (KSh). Numbers in parentheses denote costs if fingerlings harvested are subtracted from seed costs at 4 KSh each (60 KSh = US$1).

Treatment	Feed and Fertilizer	Labor	Fingerlings	Total Cost per kg Fish Produced
1	14.6	9.2	54.1 (17.5)	77.9 (41.3)
2	28.9	8.5	43.4 (23.2)	80.8 (60.6)
3	47.0	8.5	44.2 (14.0)	99.7 (69.5)
4	41.9	6.8	35.0 (22.5)	83.7 (71.2)

Table 5. Summary of costs and harvest revenues per pond, not counting fingerling costs, which were 200 KSh per pond, for all treatments. The price of adult fish is assumed to be 90 KSh per kg. No value is attributed to fingerlings harvested.

Treatment	Fertilizer (KSh)	Feed (KSh)	Input Labor (KSh)	Adults Harvested (kg)	Revenue (KSh)	Net Profit (KSh)
1	1,937	0	1,220	133	11,970	8,813
2	969	3,828	1,410	166	14,900	8,693
3	0	7,656	1,382	163	14,643	5,605
4	969	8,625	1,410	206	18,574	8,539

In order to further increase production over levels obtained using Treatment 2, applying additional fertilizer may be a better solution than increasing bran inputs. Diana et al. (1996) found that adding supplemental feed (floating pellets, 30% crude protein) after fish reached 150 g resulted in greater annual profit than either fertilization only or feeding right from the start. In this experiment, the bran was considered to function partly as feed and partly as organic fertilizer. At Rwasave Fish Station, Rwanda, an experiment was conducted in which fish were fed rice bran at 5 g fish^{-1} d^{-1} in ponds stocked at a density of 2 male tilapia m^{-2}. A mean net yield of 2,620 kg ha^{-1} and an apparent feed conversion of 7.6 were obtained after 192 days. No chemical fertilizers were applied, but small additions of chicken manure and grass were used as fertilizer (Verheust et al., 1992). The feed conversion ratios (FCRs) obtained in Treatments 3 and 4 of this experiment, in which rice bran was applied at 6 g tilapia^{-1} d^{-1}, are much higher (10.5 and 8 for Treatments 3 and 4, respectively) because the fish started out at a smaller size (32 g vs. 80 g in the Rwanda experiment) and they could not consume all the bran. Also, the ponds were harvested before market size was reached, thereby not allowing recovery from the overfeeding at the beginning of the experiment. A study that combined inorganic fertilization and feeding rice bran to tilapia (maximum application reached 46 kg ha^{-1} d^{-1}) obtained a mean net yield of 1,160 kg ha^{-1} after 159 days (Perschbacher and Lochmann, 1995). This yield is somewhat less than the net yield in Treatment 2 of this experiment (1,582 kg ha^{-1}).

Bran prices vary in Kenya. Rice bran can be purchased for as little as 3 KSh kg^{-1}, but 6 KSh kg^{-1} is more common for farmers buying retail. At the price of 6 KSh kg^{-1}, rice bran should be applied sparingly and not as a fertilizer. Wheat bran is available in greater quantities than rice bran and retails for 5 to 7 KSh kg^{-1}. Wheat bran may present a better alternative to farmers and should be tested in future PD/A CRSP experiments.

Fingerling prices as they currently stand at Sagana constitute a major portion of total costs. The current price for fingerlings is 4 KSh each for both mixed-sex tilapia and *Clarias*. It appears that farmers in Central Province are aware that seed contributes so much to their costs and therefore choose to use mixed-sex fingerling tilapia (even when offered monosex for no additional cost), so that they do not have to re-purchase fingerlings. Fingerlings in Western and Nyanza Provinces sell for 1 KSh each for mixed-sex and 3 KSh apiece for all-male tilapia. Interest in using monosex fingerlings is greater in those provinces (M. Wafula, pers. comm.). The Sagana station management is considering reducing the price of fingerlings, possibly to as low as 0.5 KSh each for fry that have just been sex-reversed and to 2 KSh each for both mixed-sex and all-male tilapia of 4 to 5 grams in size. Larger tilapia (e.g., 20 g) and *Clarias* fingerlings would remain at 4 KSh each.

ANTICIPATED BENEFITS

Characterization of pond production at the Africa site using high nutrient input levels provides data for comparison with other CRSP sites. Reliable data on the value of low-cost supplemental feeds and comparative benefits of fertilization for semi-intensive tilapia production can also provide a basis for the development of more efficient production strategies in Kenya and similar areas of Africa.

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Nutritional Contribution of Natural and Supplemental Foods for Nile Tilapia: Stable Carbon Isotope Analysis

Eighth Work Plan, Kenya Research 3A (KR3A)
Progress Report

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Abstract

Stable carbon isotope analysis is a useful technique to obtain quantitative estimates of the relative contributions of different food sources to the nutrition of aquatic animals in ponds. This technique is being used to obtain quantitative estimates of the contribution of natural and supplemental feeds to the nutrition of tilapia in ponds in Sagana, Kenya. Results can be used to adjust feeding/fertilization practices and minimize feed costs while maximizing fish production. Samples of *Oreochromis niloticus*, *Clarias*, chemical fertilizers (DAP and urea), rice bran, plankton, and mud taken from ponds in Sagana at three times during the study (initial, midpoint, final) have been submitted to a commercial lab for carbon isotope analysis. Results for initial and some of the midpoint samples are summarized and discussed in this report. The most distinct trend in the isotope data was the more positive values for plankton, *Clarias*, and *O. niloticus* found in Treatment 1 versus Treatments 2 through 4 for both initial and midpoint samples. Possible reasons for this trend are discussed in light of experimental and non-experimental variables. A more comprehensive discussion of the effects of various nutrient inputs on the production of *O. niloticus* and *Clarias* will be possible once the remaining isotope data are obtained.

Introduction

Stable carbon isotope analysis is a useful technique to obtain quantitative estimates of the relative contributions of different food sources to the nutrition of aquatic animals in ponds (e.g., Schroeder, 1983; Anderson et al., 1987; Lochmann and Phillips, 1996). Presumably, isotope ratios of the fish will resemble those of the food(s) they assimilate most. In the present study, stable carbon isotopic analysis is being used to obtain quantitative estimates of the contribution of natural and supplemental feeds to the nutrition of tilapia in ponds in Sagana, Kenya. Results can be used to adjust feeding/fertilization practices and minimize feed costs while maximizing fish production.

To date, selected samples of *Oreochromis*, *Clarias*, chemical fertilizers (diammonium phosphate (DAP) and urea), rice bran, plankton, and mud taken from ponds in Sagana at three times during the study (initial, midpoint, final) have been submitted to a commercial lab for carbon isotope analysis. Since not all data for midpoint and final samples have been received, this report is a summary and preliminary discussion of results for the initial and some midpoint samples.

Methods and Materials

Several months prior to collection of initial samples, *O. niloticus* and *Clarias* were fed a conditioning diet containing corn to increase the isotopic resemblance of the fish to corn (-14‰). Experimental treatments for the pond feeding trial were:

1) Urea and DAP to provide 16 kg N ha^{-1} wk^{-1} and 4 kg P ha^{-1} wk^{-1};
2) Urea and DAP applied to give 8 kg N and 2 kg P ha^{-1} wk^{-1}, plus rice bran fed at 60 kg ha^{-1} d^{-1};
3) Rice bran fed at 120 kg ha^{-1} d^{-1};
4) Rice bran as in treatment 3 and fertilizer as in treatment 2.

The major components of the pond system assumed to contribute to the nutritional status of *O. niloticus* and *Clarias* in this feeding study were sampled monthly throughout the study. Samples from three periods (initial, midpoint, and final) were processed and subjected to isotope analysis. Initially, a total of ten fish—five *O. niloticus* and five *Clarias*—were collected from a single pond at the Sagana research site, Sagana, Kenya. Initial fish samples were not pooled so that the variability of isotope ratios among individuals could be determined. Initial pooled samples of plankton and mud were collected from each of the 12 study ponds, as well as samples of chemical fertilizers (DAP, urea) and rice bran used as supplemental feed. All samples were processed as described previously (Lochmann and Phillips, 1996), except that carbonates were removed from mud samples prior to lyophilization, and DAP and urea samples were not processed prior to analysis. Samples collected from the midpoint and final periods were the same as described for initial samples except that a pooled sample of *O. niloticus* and a pooled sample of *Clarias* (each pooled sample consisting of two individuals) was collected from each pond. All samples were sent to a commercial laboratory (Coastal Science Laboratories, Inc., Austin, Texas) for stable carbon isotope analysis using a micromass isotope ratio mass spectrometer (Anderson et al., 1987).

Results

The mean isotope ratio ($\delta^{13}C$) of initial plankton samples in Treatment 1 was significantly more positive than the mean isotope ratios of plankton in Treatments 2 through 4 (Table 1). The mean $\delta^{13}C$ of initial mud samples did not differ among treatments (Table 1). The mean initial $\delta^{13}C$ of *Clarias* was more variable and approximately 3‰ more negative than that of *O. niloticus* (Table 1). The $\delta^{13}C$ of initial urea was -53.6‰ and

Table 1. Initial stable carbon isotope values ($\delta^{13}C$) of nutrient inputs and pond components in a feeding trial with *O. niloticus* and *Clarias* in Sagana, Kenya. Values are means of three replicates. The mean initial isotope values for fish (N = 5 individual fish) were: *O. niloticus* (-16.61 ± 0.70) and *Clarias* (-19.82 ± 1.19).

Treatment	$\delta^{13}C$ (‰) ± S.D.	
	Plankton	*Mud*
1. Chemical fertilizer: Urea (16 kg N ha^{-1} wk^{-1}) and DAP (4 kg P ha^{-1} wk^{-1})	-17.27 ± 0.47[a]	-13.53 ± 1.39
2. 1/2 of treatment 1	-23.50 ± 1.61[b]	-13.08 ± 0.63
3. Rice bran only (120 kg ha^{-1} d^{-1})	-26.27 ± 2.49[b]	-13.33 ± 0.72
4. Rice bran (as treatment 3) and Chemical fertilizer (as treatment 2)	-26.83 ± 2.49[b]	-12.30 ± 0.54

[a,b] Means in columns with different letters are significantly different ($P < 0.05$) according to Fisher's Least Significant Difference test.

Table 2. Midpoint stable carbon isotope values ($\delta^{13}C$) of nutrient inputs and pond components in a feeding trial with *O. niloticus* and *Clarias* in Sagana, Kenya. Values are means of three replicates.

Treatment	$\delta^{13}C$ (‰) ± S.D.			
	Tilapia	*Clarias*	*Plankton*	*Mud*
1. Chemical fertilizer: Urea (16 kg N ha^{-1} wk^{-1}) and DAP (4 kg P ha^{-1} wk^{-1})	-17.88 ± 0.86[a]	-22.40 ± 2.08[a]	-22.43 ± 1.79[a]	NA[c]
2. 1/2 of treatment 1	-22.83 ± 0.72[b]	-24.67 ± 1.27[ab]	-26.97 ± 1.16[b]	NA
3. Rice bran only (120 kg ha^{-1} d^{-1})	-22.93 ± 2.39[b]	-26.42 ± 1.23[b]	-29.55 ± 1.23[b]	NA
4. Rice bran (as treatment 3) and Chemical fertilizer (as treatment 2)	-24.03 ± 1.17[b]	-26.83 ± 0.61[b]	-27.83 ± 1.75[b]	NA

[a,b] Means in columns with different letters are significantly different ($P < 0.05$) according to Fisher's Least Significant Difference test.
[c] Isotope data for midpoint mud samples is currently not available.

the mean isotope ratios of DAP and rice bran were very similar: -26.8 and -27.8‰, respectively.

The mean $\delta^{13}C$ of midpoint plankton samples in Treatment 1 was significantly more positive than that of plankton in Treatments 2 through 4 (Table 2), as observed in the initial samples. The mean isotope ratios of *O. niloticus* and *Clarias* followed the same pattern as the plankton, although statistical differences were less pronounced for *Clarias* (Table 2).

The mean isotope ratios of plankton were significantly more negative (P = .0001) in all treatments in the midpoint than in the initial and samples (Tables 1 and 2). The mean isotope ratios of *O. niloticus* and *Clarias* followed the same trend (Tables 1 and 2).

Discussion

Corn, which was fed as the conditioning diet prior to collection of initial samples, is isotopically distinct from the rice bran (-27‰) that was used as a supplemental feed in Treatments 2, 3, and 4. The isotope technique is more effective in pinpointing nutritional inputs of an animal when the inputs are isotopically distinct from each other and from the animal itself (Anderson et al., 1987). However, the mean isotope ratios of initial *O. niloticus* (-16.6‰) and *Clarias* (-19.8‰) were not similar to that of corn (-14‰). It is possible that the amount of corn in the conditioning diet was too low to influence the isotope ratios of the fish, the corn was not assimilated well, or the diet was not fed long enough to elicit the desired isotopic effect in the fish.

The most distinct trend in the isotope data was the more positive values for plankton, *Clarias* and *O. niloticus* in Treatment 1 versus Treatments 2 through 4 for both initial and midpoint samples. Treatment 1 did not include rice bran, whereas Treatments 2 through 4 did. The rice bran was consumed directly by the fish, which may explain the increase in isotope values between initial and midpoint samples. However, the isotope values of the plankton in treatment 1 were more positive initially than those of the plankton in the other treatments. This suggests that the result may be due to an undefined pre-treatment effect. Karen Veverica also observed significantly higher chlorophyll *a* concentrations in Treatment 1 of this study vs. other treatments (see Veverica et al., 1999).

Some components other than the inputs identified earlier may have contributed to the isotope ratios of the plankton between initial and midpoint sampling periods. Rice bran was the only experimental input but apparently not the only factor influencing the isotope ratio of the plankton in Treatment 3, as was indicated by the more negative value of the midpoint plankton (-29.6‰) compared to the rice bran (-27.8‰). Also, the isotopic similarity of the DAP (-26.8‰) and the rice bran (-27.8‰) may confound interpretation of results for Treatments 2 and 4, which received both components as pond inputs.

A more comprehensive discussion of the effects of various nutrient inputs on the production of *O. niloticus* and *Clarias* will be possible once the remaining isotope data are obtained.

Anticipated Benefits

Production efficiency of *O. niloticus* and *Clarias* can be optimized once the quantitative importance of different nutrients under defined experimental conditions is established using the isotope technique in conjunction with comprehensive production data. Furthermore, the procedures used to define the importance of various components in this aquaculture production system may be modified and applied to other systems in other regions.

Acknowledgments

The authors wish to thank the staff at Sagana fish farm for collection and processing of samples prior to isotope analysis.

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

Eighth Work Plan, Kenya Feeds and Fertilizers Research 1 (FFR1K)
Abstract

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ABSTRACT

The Global Experiment for the prime Africa site (Sagana Fish Farm, Sagana, Kenya) was initiated by starting fertilization for the cool season experiment on 29 April 1998. Ponds were stocked on 13 May, and the experiment will continue through June, July, and August, which are the only three months of the year that can be considered "cool" at Sagana. Prior to filling, 100 kg of TSP (250 kg ha^{-1} P) was broadcast over the bottom of each pond. The ponds were stocked with all-male Nile tilapia at an initial density of 1 t fish ha^{-1}, and an average weight of 17 g. Nitrogen, as urea and DAP, is being added to ponds at rates of 0, 10, 20, and 30 kg N^{-1} ha^{-1} wk^{-1}. Phosphorus, as triple superphosphate, is being added to zero-N ponds at a rate of 8 kg P^{-1} ha^{-1} wk^{-1}, whereas DAP is used to provide phosphorus for all other treatments, also at a rate of 8 kg P^{-1} ha^{-1} wk^{-1}. Alkalinity is being maintained at or above 70 mg l^{-1} as $CaCO_3$, by adding sodium carbonate (soda ash). Preliminary observations after the first month of the experiment include very high nitrite levels (> 0.5 mg l^{-1}) in the highest-N treatment and a high mortality rate (almost 25%) in one pond of the high-N treatment. No mortalities have been observed in the other two ponds of this treatment. Morning and afternoon DO and temperature are measured weekly at four depths (5, 25, 50, and 75 cm), pH is measured weekly at 5 cm, and column total alkalinity is measured weekly; chlorophyll *a*, nitrates, nitrites, TAN, and soluble reactive P on column samples are measured biweekly, and total N, total P, total suspended solids, and total volatile solids will be measured on the days of the diurnal oxygen samplings (three times during the experiment). The sampling protocol is much more intensive than that called for in the work plan, but is necessary to be able to draw conclusions on the fate of N added to the ponds. It also serves to train the lab staff in intensive sampling and analysis of water quality parameters that is anticipated for the Global Experiment for the Ninth Work Plan. The warm season experiment was scheduled for the Spring of 1998, but is being postponed until the Fall of 1998 because of the late completion of the feed study ("Relative Contributions of Supplemental Feed and Inorganic Fertilizers in Semi-Intensive Tilapia Production," KR3, harvested the last week of March), which resulted in there being insufficient time to complete the warm-season experiment before the beginning of the cool-season phase of the Global Experiment. The cool-season phase must be conducted during the period from June through August, whereas the warm-season phase can be conducted almost any time during the remainder of the year, although December, November, and January are the most reliably warm months.

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

Eighth Work Plan, Thailand Feeds and Fertilizers Research 1 (FFR1T)
Progress Report

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Abstract

Two experiments were conducted in eighteen 200-m^2 earthen ponds at the Asian Institute of Technology, Thailand, for 91 days from 4 June to 3 September 1998. The first experiment was designed to: 1) determine the optimal rate of nitrogen fertilization; 2) determine which of the nitrogen fertilization rates evaluated to produce Nile tilapia (*Oreochromis niloticus*) had the greatest profitability; and 3) develop a full-cost enterprise budget for the fertilization level that resulted in the greatest profitability. Treatment ponds with triplicates each were fertilized with TSP at a rate of 8 kg P ha^{-1} wk^{-1} and with urea at 0, 10, 20, and 30 kg N ha^{-1} wk^{-1}. Sex-reversed male Nile tilapia, 10.1 to 10.9 g in size, were stocked at 1,000 kg ha^{-1} in all ponds (10 fish m^{-2}). For the second experiment, sex-reversed male Nile tilapia were also stocked at 1,000 kg ha^{-1}, but with respective fish sizes of 4.6 to 4.8 g, 10.1 to 10.5 g, and 21.3 to 21.8 g in each of the three treatments which were conducted in triplicate ponds. These various fish sizes resulted in stocking densities of 22, 10, and 5 fish m^{-2} for each of the three treatments, respectively. Ponds were fertilized with urea and TSP at a rate of 30 kg N and 8 kg P ha^{-1} wk^{-1}. All ponds for both experiments received sodium bicarbonate weekly to attain and maintain the minimum alkalinity (75 mg l^{-1} as $CaCO_3$) based on weekly measurements of alkalinity in pond water. The experiments showed that higher nitrogen inputs generally resulted in better growth performance of Nile tilapia. Growth in the treatment without N inputs ceased before day 50, which was earlier than growth ceased in the treatments with varied inputs of N (around day 70). During the entire culture period, the estimated fish biomass was highest in the treatment with 30 kg N ha^{-1} wk^{-1}, intermediate in the treatments with 10 and 20 kg N ha^{-1} wk^{-1}, and lowest in the treatment without N inputs. Nile tilapia yield was highest in the treatment with 30 kg N ha^{-1} wk^{-1} (2,409.6 ± 46.4 kg ha^{-1}), intermediate in the treatments with 10 and 20 kg N ha^{-1} wk^{-1} (2,172.8 ± 153.8 and 1,935.2 ± 165.9 kg ha^{-1}, respectively), and lowest in the treatment without N inputs (1,221.2 ± 44.0 kg ha^{-1}). The partial budget analysis indicated that the treatment with 30 kg N ha^{-1} wk^{-1} was most profitable. The full-cost enterprise budget showed that US$11.90 net return could be produced from a 200-m^2 pond in this treatment during a three-month culture period. All parameters of fish growth performance were significantly better in the treatments stocked with medium and large fish than in the treatment stocked with small fish. Survival rate was highest in the large-size treatment, intermediate in the medium-size treatment, and lowest in the small-size treatment. Individual fish growth rates were significantly higher in the treatment stocked with larger fish. However, the estimated fish biomass and yields were highest in the medium-size treatment, intermediate in the large-size treatment, and lowest in the small-size treatment.

Introduction

Nile tilapia (*Oreochromis niloticus*) are commonly grown in semi-intensive culture using fertilizers to increase primary production and fish food (Boyd, 1976; Diana et al., 1991). There is voluminous literature on pond fertilization, documenting many conflicting and inconsistent results based on various types of fertilizer, rates of input, and methods and frequency of application (Coleman and Edwards, 1987). Efficient production systems require optimal use of nutrient inputs. Among a large number of nutrients required to stimulate phytoplankton growth, nitrogen, phosphorus, and occasionally carbon are the most common limiting nutrients in natural water and fish ponds (Lin et al., 1997). The research of the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) has addressed enhancement of primary productivity through additions of inorganic and organic fertilizers to ponds. However, the findings on optimal nitrogen, phosphorus, and carbon inputs required to improve fish yields at the PD/A CRSP sites appear to be inconsistent, and further research is needed. Higher nutrient inputs increased fish production at all PD/A CRSP sites, but optimal inputs of nitrogen, phosphorus, and carbon were not well defined (Lin et al., 1997).

Fertilization rates in PD/A CRSP experiments were much greater than rates reported for earlier pond fertilization research (Lin et al., 1997). In an often-cited series of fertilization experiments conducted in Malaysia, Hickling (1962) used less than 1.1 kg P and 1.1 N ha^{-1} wk^{-1}. In Israel, the standard fertilizer dose was 2.3 kg P and 6.5 kg N ha^{-1} wk^{-1} (Hepher, 1962a; 1962b). The highest rates of phosphorus and nitrogen used in most experiments in the USA were 1.26 and 3 kg ha^{-1} wk^{-1}, respectively (Swingle, 1947; Boyd, 1976; Boyd and Sowles, 1978; Murad and Boyd, 1987; Boyd, 1990). Rates in Europe seldom exceeded 1 kg ha^{-1} wk^{-1} for nitrogen and phosphorus (Mortimer, 1954). However, rates used in Malaysia, USA, Israel, and Europe gave low fish production. Also, in all of the studies cited above, phosphorus was the most important limiting nutrient.

Therefore, the purposes of this study were to:

1) Determine the optimal rate of nitrogen fertilization (in the presence of adequate phosphorus and carbon) to obtain optimum primary productivity and optimum yields of Nile tilapia in freshwater production ponds;
2) Determine which of the nitrogen fertilization rates evaluated to produce Nile tilapia in freshwater production ponds had the greatest profitability;
3) Develop a full-cost enterprise budget for the fertilization level that resulted in the greatest profitability; and
4) Investigate the relationship between initial fish size and pond carrying capacity.

METHODS AND MATERIALS

Two experiments were conducted in a randomized complete block design in eighteen 200-m^2 ponds at the Asian Institute of Technology, Thailand. The first experiment involved culture of Nile tilapia using four nitrogen fertilization rates. The second experiment was to determine the relationship between initial fish size and pond carrying capacity with the same nitrogen and phosphorus input rates as those of experiment 1.

For the first experiment, all ponds were fertilized with triple superphosphate (TSP) at a rate of 8 kg phosphorus (P) ha^{-1} wk^{-1} and nitrogen (N) as urea at 0, 10, 20, and 30 kg N ha^{-1} wk^{-1}. All treatments were done in triplicate. Initial pond fertilization took place two weeks prior to stocking of fish. Sodium bicarbonate was added weekly to attain and maintain the minimum alkalinity (75 mg l^{-1} as $CaCO_3$) based on weekly measurements of alkalinity in pond water. Sex-reversed male Nile tilapia were stocked at 1,000 kg ha^{-1} at a size of 10.1 to 10.9 g in all ponds on 4 June 1998. The stocking density was 10 fish m^{-2} in all ponds.

For the second experiment, sex-reversed male Nile tilapia were also stocked on 4 June 1998 at 1,000 kg ha^{-1}, but with respective fish sizes of 4.6 to 4.8 g, 10.1 to 10.5 g, and 21.3 to 21.8 g in each of the three treatments which were conducted in triplicate ponds. These various fish sizes resulted in stocking densities of 22, 10, and 5 fish m^{-2} for each of the three treatments, respectively. All ponds were fertilized with urea and TSP at a rate of 30 kg N and 8 kg P ha^{-1} wk^{-1} and treated with sodium bicarbonate in the same way as experiment 1.

Water depth in all ponds was maintained at 1 m throughout the experiment by adding water weekly to replace evaporation and seepage losses.

Most parameters of pond water quality were analyzed with water column samples taken from the center of each pond from a walkway. Parameters of pond water quality, including total nitrogen (TN), total ammonium nitrogen (TAN), total phosphorus (TP), Secchi disk visibility, total alkalinity, chlorophyll *a*, pH, and primary productivity (gross and net), were analyzed at 1000 h during the second week (11 June 1998), midway (23 July 1998), and final week (1 September 1998) of the experiment using standard methods (APHA, 1980) modified by Egna et al. (1987). Dissolved oxygen (DO), pH, and temperature measurements were made on these three sampling dates at 0600, 1000, 1600, 1800, and 0600 h the following morning at 5-cm, 25-cm, 50-cm, and 75-cm depths in the water column. Total alkalinity and total hardness were determined weekly at 1000 h for calculating the amount of sodium bicarbonate required to maintain the minimum alkalinity as defined above.

During the experiment, approximately 10% of the initial stock was seined, counted, and bulk-weighed biweekly for each pond. All fish were harvested on 3 September 1998 after 91 days of culture. Daily weight gain (g $fish^{-1}d^{-1}$), yield (kg $pond^{-1}$), and extrapolated yield (kg ha^{-1}) were calculated. Fish biomass on the sampling dates was estimated by the measured mean fish weight from sampling and the number of fish surviving. It was assumed that surviving fish number decreased linearly from the beginning to end of experiments.

Data from both experiments were analyzed statistically by regression analysis and analysis of variance (ANOVA) using the SPSS 7.0 statistical software package. Differences were considered significant at an alpha level of 0.05. All means were reported with ± 1 standard error (SE).

A partial budget analysis was conducted to determine which fertilization rate yielded the greatest profitability, and a full-cost enterprise budget was developed for the fertilization rate that yielded the greatest profitability (Shang, 1990). The economic analyses were based on the current local market prices expressed in US dollar (US$1 = 40 baht) in Thailand. Prices of urea and TSP were $0.200 and $0.325 kg^{-1}, respectively. Market value of Nile tilapia fingerlings around 30 g size was $1.50 kg^{-1}. To simplify the analyses, the prices for stocked and harvested fingerlings were fixed at $1.50 kg^{-1}. Total fixed costs in the full-cost enterprise budget were derived from a previous study (Engle and Skladany, 1992).

RESULTS

Experiment 1

Among the three experimental treatments, higher N inputs generally resulted in better growth performance of Nile tilapia (Table 1; Figures 1, 2, and 3). But survival rates were not significantly different among all treatments ($P > 0.05$). Differential growth of Nile tilapia among all treatments was observed at the first sampling (Figure 1). Growth in the treatment without N inputs ceased before day 50, which was earlier than in the treatments with N inputs (around day 70) (Figure 1). Final mean weight, mean daily weight gain, and gross and net fish yields were significantly higher ($P < 0.05$) in the treatments with N inputs than in the treatment without N inputs. There were no significant differences ($P > 0.05$) for

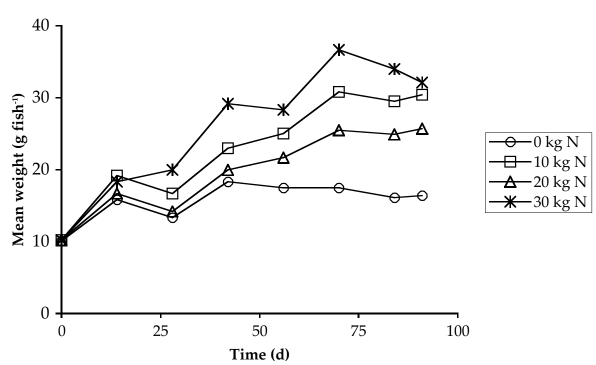

Figure 1. Growth of Nile tilapia in the treatments with 0, 10, 20, and 30 kg N ha^{-1} wk^{-1} during the 91-day experiment.

Table 1. Growth performance of Nile tilapia in ponds fertilized at different N application rates (kg ha^{-1} wk^{-1}) in the 91-day experiment.

Performance	Treatment			
	0	10	20	30
Initial Biomass (kg $pond^{-1}$)	20.3 ± 0.0 a	20.4 ± 0.1 a	20.4 ± 0.1 a	20.4 ± 0.2 a
Initial Mean Wt. (g $fish^{-1}$)	10.1 ± 0.0 a	10.2 ± 0.0 a	10.2 ± 0.0 a	10.2 ± 0.1 a
Final Biomass (kg $pond^{-1}$)	24.4 ± 0.9 a	43.5 ± 3.1 b	38.7 ± 3.3 b	48.2 ± 0.9 bc
Final Mean Wt. (g $fish^{-1}$)	16.4 ± 0.9 a	30.4 ± 1.3 bc	25.7 ± 1.1 b	32.1 ± 1.3 bc
Mean DWG (g $fish^{-1}$ d^{-1})	0.07 ± 0.01 a	0.22 ± 0.01 b	0.17 ± 0.01 b	0.24 ± 0.02 bc
Net Fish Yield (kg $pond^{-1}$)	4.2 ± 0.9 a	23.1 ± 3.2 b	18.3 ± 3.4 b	27.8 ± 1.0 bc
Extrapolated Net Fish Yield (kg ha^{-1})	207.8 ± 43.9 a	1,154.5 ± 157.7 b	915.2 ± 167.8 b	1,389.6 ± 49.3 bc
Gross Fish Yield (kg $pond^{-1}$)	24.4 ± 0.9 a	43.5 ± 3.1 b	38.7 ± 3.3 b	48.2 ± 0.9 bc
Extrapolated Gross Fish Yield (kg ha^{-1})	1,221.2 ± 44.0 a	2,172.8 ± 153.8 b	1,935.2 ± 165.9 b	2,409.6 ± 46.4 bc
Survival (%)	74.9 ± 4.0 a	71.5 ± 4.3 a	75.0 ± 3.7 a	75.2 ± 1.7 a

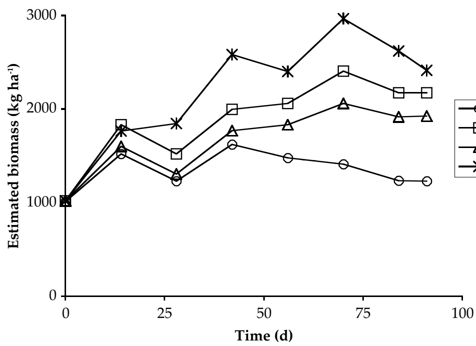

Figure 2. Estimated fish biomass in the treatments with 0, 10, 20, and 30 kg N ha^{-1} wk^{-1} during the 91-day experiment.

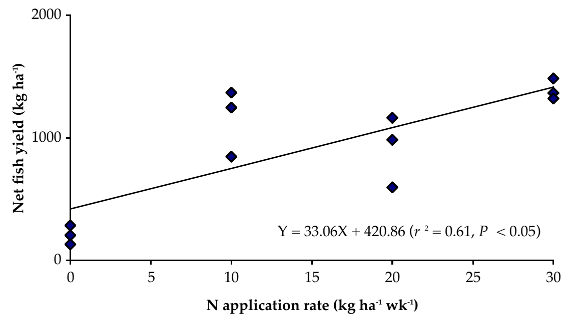

Figure 4. Relationship between net fish yield and nitrogen input rate in the first experiment.

those growth parameters among the treatments with N inputs. During the entire culture period, the estimated fish biomass was highest in the treatment with 30 kg N, intermediate in the treatments with 10 and 20 kg N, and lowest in the treatment without N inputs (Figure 2). The estimated fish biomass decreased earlier in the treatment without N inputs (around day 40) than in the treatments with various N inputs (around day 70) (Figure 2). The yield of Nile tilapia was highest in the treatment with 30 kg N ha^{-1} wk^{-1} (2,409.6 ± 46.4 kg ha^{-1}), intermediate in the treatments with 10 and 20 kg N ha^{-1} wk^{-1} (2,172.8 ± 153.8 and 1,935.2 ± 165.9 kg ha^{-1}, respectively), and lowest in the treatment without N inputs (1,221.2 ± 44.0 kg ha^{-1}) (Figure 3). The relationship between net fish yield and N inputs (Figure 4) can be expressed as:

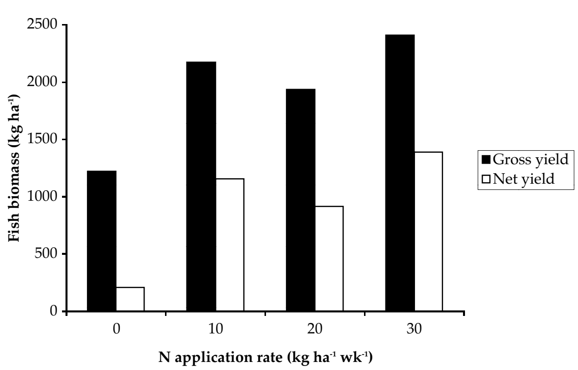

Figure 3. Gross and net fish yields in the treatments with 0, 10, 20, and 30 kg N ha^{-1} wk^{-1} in the 91-day experiment.

$$Y = 33.06X + 420.86 \ (r^2 = 0.61, P < 0.05)$$

where

Y = net fish yield and
X = N input

which shows that net fish yield generally increases with increasing N inputs.

Water quality parameters varied among treatments in the experiment (Table 2). There were no significant differences ($P > 0.05$) among any parameters during initial measurements. Water temperature and pH ranged from 29.3 to 37.0°C and 6.4 to 9.1, respectively, throughout the experimental period in all ponds. The DO concentration at dawn fluctuated over the entire culture period, but there were no significant differences ($P > 0.05$) among treatments. The final concentrations of TAN and TN increased with increasing N input and were significantly higher ($P < 0.05$) in the treatments with N inputs than in the treatment without N inputs. However, there were no significant differences ($P > 0.05$) in final concentrations of both TAN and TN among the treatments with various N inputs. TP concentration was not significantly different ($P > 0.05$) among all treatments during the entire experimental period. To maintain the minimal alkalinity, the total amount of sodium bicarbonate added to ponds was 22.1 ± 4.2, 28.5 ± 2.9, 26.0 ± 0.7, and 24.3 ± 9.7 kg for the treatments with 0, 10, 20, and 30 kg N, respectively. However, the alkalinity concentrations declined from approximately 150 to 50 mg l^{-1} during the first half of the culture period, and remained close to 50 mg l^{-1} during the second half (Figure 5). There were no significant differences ($P > 0.05$) in alkalinity concentrations among all treatments

Table 2. Mean values of water quality parameters measured at the initial, midway and final weeks in ponds fertilized with different N application rates (kg ha^{-1} wk^{-1}) in the 91-day experiment.

Parameter	Treatment			
	0	10	20	30
DO AT DAWN (mg l^{-1})				
Initial	1.57 ± 0.67 [a]	0.91 ± 0.50 [a]	1.63 ± 0.52 [a]	1.02 ± 0.18 [a]
Midway	1.99 ± 0.40 [a]	0.49 ± 0.10 [a]	1.52 ± 0.53 [a]	1.27 ± 0.62 [a]
Final	2.43 ± 0.28 [a]	1.52 ± 0.57 [a]	1.67 ± 0.77 [a]	1.12 ± 0.33 [a]
pH				
Initial	6.8–7.5	6.7–8.3	6.9–7.2	6.7–7.5
Midway	7.1–7.4	7.3–7.8	7.2–7.9	7.3–8.5
Final	7.1–7.7	6.4–8.0	7.1–8.2	7.1–9.1
TOTAL NITROGEN (mg l^{-1})				
Initial	1.95 ± 0.03 [a]	1.68 ± 0.28 [a]	3.00 ± 1.07 [a]	2.61 ± 0.83 [a]
Midway	4.42 ± 1.58 [a]	5.54 ± 1.49 [a]	3.95 ± 0.12 [a]	9.07 ± 3.57 [a]
Final	3.15 ± 0.38 [a]	5.58 ± 0.40 [b]	6.77 ± 0.31 [b]	7.85 ± 1.32 [b]
TAN (mg l^{-1})				
Initial	0.55 ± 0.24 [a]	0.11 ± 0.02 [a]	0.30 ± 0.13 [a]	0.46 ± 0.22 [a]
Midway	0.01 ± 0.01 [a]	0.09 ± 0.08 [a]	0.86 ± 0.26 [b]	0.91 ± 0.15 [b]
Final	0.45 ± 0.14 [a]	1.14 ± 0.14 [b]	1.75 ± 0.03 [b]	1.28 ± 0.33 [b]
TOTAL PHOSPHORUS (mg l^{-1})				
Initial	0.51 ± 0.06 [a]	0.77 ± 0.07 [a]	0.38 ± 0.04 [a]	0.74 ± 0.26 [a]
Midway	0.24 ± 0.04 [a]	0.67 ± 0.21 [a]	0.34 ± 0.10 [a]	0.64 ± 0.08 [a]
Final	0.42 ± 0.10 [a]	0.81 ± 0.22 [a]	0.59 ± 0.22 [a]	1.06 ± 0.11 [a]
TOTAL ALKALINITY (mg l^{-1} as $CaCO_3$)				
Initial	146 ± 8.7 [a]	159 ± 17.7 [a]	148 ± 11.4 [a]	137 ± 17.7 [a]
Midway	59 ± 2.4 [a]	37 ± 2.9 [a]	47 ± 2.9 [a]	61 ± 20.1 [a]
Final	55 ± 4.1 [a]	45 ± 10.3 [a]	65 ± 2.9 [a]	73 ± 14.3 [a]
CHLOROPHYLL *A* (mg m^{-3})				
Initial	72 ± 15.6 [a]	80 ± 13.4 [a]	39 ± 8.5 [a]	51 ± 6.1 [a]
Midway	31 ± 5.6 [a]	126 ± 37.2 [a]	67 ± 29.7 [a]	147 ± 75.2 [a]
Final	30 ± 8.1 [a]	84 ± 9.2 [b]	40 ± 16.3 [a]	205 ± 25.0 [c]

[a,b,c] Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

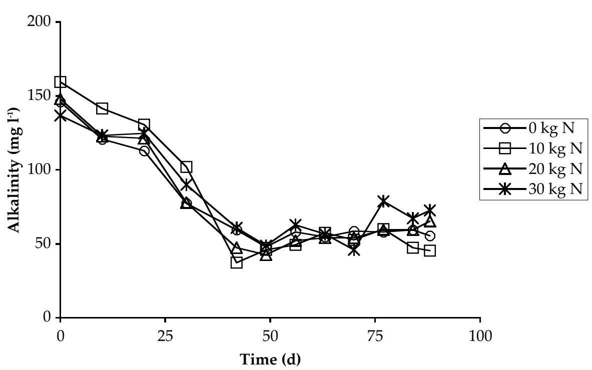

Figure 5. Change in alkalinity concentration in the treatments with 0, 10, 20, and 30 kg N ha^{-1} wk^{-1} over the 91-day experiment.

Table 3. Partial budget analysis for Nile tilapia cultured in ponds fertilized with different N application rates (kg ha^{-1} wk^{-1}) in the 91-day experiment (budget items in US$ pond^{-1}).

Item	Treatment			
	0	10	20	30
Income (selling fish)	36.60	65.25	58.05	72.30
Added Income (A)	----	28.65	21.45	35.70
Cost for Urea	0	1.30	2.60	3.90
Added Cost from Urea (B1)	----	1.30	2.60	3.90
Cost of $NaHCO_3$	17.13	22.10	20.15	18.83
Added Cost from $NaHCO_3$ (B2)	----	4.98	3.03	1.70
Ratio of Added Income to Added Cost	----	4.6	3.8	6.4
Profit (A - B1 - B2)	----	22.38	15.83	30.10

during the entire culture period. The final concentrations of chlorophyll *a*, from highest to lowest, were measured in ponds with treatments of 30, 10, 20, and 0 kg N ha^{-1} wk^{-1}. The final concentrations of chlorophyll *a* were significantly different ($P < 0.05$) by treatment; concentrations in treatments with 30 and 10 kg N ha^{-1} wk^{-1} were significantly higher ($P < 0.05$) than those in treatments with 20 and 0 kg N ha^{-1} wk^{-1}.

The partial budget analysis indicated that the treatment with 30 kg N ha^{-1} wk^{-1} was most profitable, giving the highest profit and ratio of added income to added cost (Table 3). The full-cost enterprise budget showed that $11.90 net return could be produced from a 200-m^2 pond in the treatment with 30 kg N ha^{-1} wk^{-1} during a three-month culture period (Table 4).

Table 4. A full-cost enterprise budget for Nile tilapia cultured in ponds fertilized with 30 kg N ha^{-1} wk^{-1} in the 91-day experiment.

Item	Unit	Price (US$)	Quantity (kg $pond^{-1}$)	Value (US$ $pond^{-1}$)
GROSS REVENUE (A)				
Harvested Tilapia	kg	1.50	48.2	72.30
COST				
Variable Cost				
Fingerlings	kg	1.50	20.4	30.60
Urea	kg	0.20	19.6	3.90
TSP	kg	0.33	12.0	3.90
$NaHCO_3$	kg	0.78	24.3	18.83
Interest on Operating Capital	year	12%	0.25	1.70
Total Variable Cost				58.93
Fixed cost				
Pond Depreciation and Equipment	ha*year	133.75	0.02*0.25	0.68
Interest on Fixed Capital	year	12%	0.25	0.80
Total Fixed Cost				1.48
TOTAL COST (B)				60.40
NET RETURNS (A - B)				11.90
BREAK-EVEN PRICE	kg	1.25		

Table 5. Growth performance of Nile tilapia stocked at different sizes in the 91-day experiment.

Performance	Treatment		
	Small Fish (4.6 g)	*Medium Fish* (10.2 g)	*Large Fish* (21.0 g)
Initial Biomass. (kg $pond^{-1}$)	20.5 ± 0.2 a	20.4 ± 0.2 a	20.4 ± 0.1 a
Initial Mean Wt. (g $fish^{-1}$)	4.6 ± 0.1	10.2 ± 0.1	21.0 ± 0.1
Final Biomass (kg $pond^{-1}$)	30.7 ± 2.0 a	48.2 ± 0.9 c	40.9 ± 0.5 b
Final Mean Wt. (g $fish^{-1}$)	13.8 ± 0.5	32.1 ± 1.3	48.7 ± 1.2
Mean DWG (g $fish^{-1}$ d^{-1})	0.10 ± 0.00 a	0.24 ± 0.02 b	0.30 ± 0.01 bc
Net Fish Yield (kg $pond^{-1}$)	10.2 ± 2.1 a	27.8 ± 1.0 bc	20.5 ± 0.5 b
Extrapolated Net Fish Yield (kg ha^{-1})	507.3 ± 106.3 a	13,89.6 ± 49.3 bc	1,024.2 ± 24.8 b
Gross Fish Yield (kg $pond^{-1}$)	30.7 ± 2.0 a	48.2 ± 0.9 bc	40.9 ± 0.5 b
Extrapolated Gross Fish Yield (kg ha^{-1})	1,532.3 ± 99.9 a	2,409.6 ± 46.4 bc	2,044.2 ± 26.4 b
Survival (%)	50.3 ± 4.8 a	75.2 ± 1.7 b	86.4 ± 1.6 c

a,b,c Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

Experiment 2

All parameters of fish growth performance were significantly better ($P < 0.05$) in the treatment stocked with medium and large fish than those stocked with small fish (Table 5). Survival rate was highest in the large-size treatment, intermediate in the medium-size treatment and lowest in the small-size treatment ($P < 0.05$). Individual fish growth rates were significantly higher ($P < 0.05$) in the treatment stocked with larger fish (Table 5; Figure 6). However, the estimated fish biomass was highest in the medium-size treatment, intermediate in the large-size treatment, and lowest in the small-size treatment (Figure 7). The highest gross and net fish yields were achieved in the medium-size treatment (Table 5; Figure 8).

Water temperature and pH ranged from 29.3 to 37.0°C and 6.7 to 9.1, respectively, throughout the experimental period in all ponds. There were no significant differences ($P < 0.05$) in water quality among all treatments during the entire culture period (Table 6).

The partial budget analysis indicated that stocking with medium-size fish was most profitable, giving the highest profit and ratio of added income to added cost (Table 7). The partial budget for experiment 1 (Table 3) shows that this same treatment was also the most profitable of all fertilization rate treatments.

DISCUSSION

Addition of nitrogen fertilizer significantly increased Nile tilapia yields. Higher N inputs generally resulted in higher phytoplankton standing crops, giving higher tilapia yields. The nitrogen inputs at rates of 10, 20, and 30 kg ha^{-1} wk^{-1} in ponds

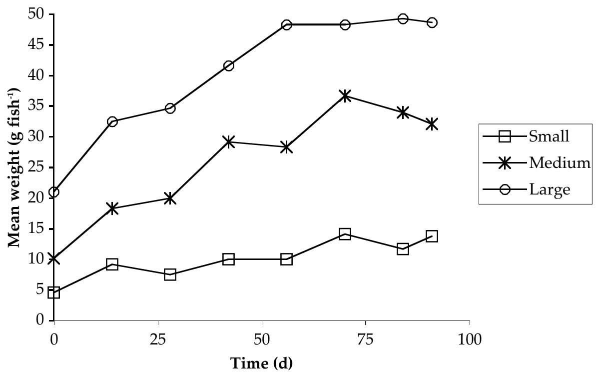

Figure 6. Growth of Nile tilapia in the small-, medium-, and large-size treatments during the 91-day experiment.

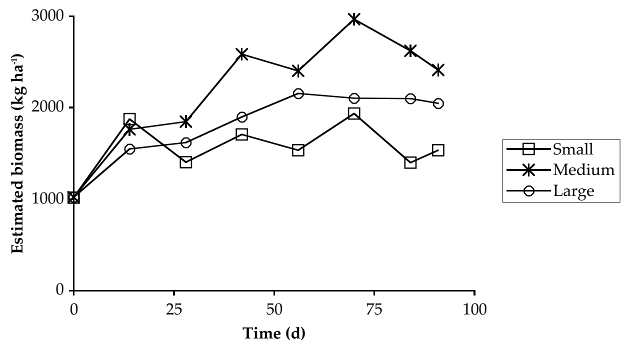

Figure 7. Estimated fish biomass in the small-, medium-, and large-size treatments during the 91-day experiment.

Table 6. Mean values of water quality parameters measured at the initial, midway, and final weeks in ponds stocked with Nile tilapia at different sizes in the 91-day experiment.

Parameter	Treatment		
	Small fish (4.6 g)	*Medium fish* (10.2 g)	*Large fish* (21.0 g)
DO AT DAWN (mg l^{-1})			
Initial	2.05 ± 0.22 [a]	1.02±0.18 [a]	2.09 ± 0.35 [a]
Midway	1.01 ± 0.06 [a]	1.27±0.62 [a]	0.69 ± 0.27 [a]
Final	1.60 ± 0.76 [a]	1.12±0.33 [a]	1.32 ± 0.40 [a]
pH			
Initial	6.9–7.3	6.7–7.5	6.7–7.3
Midway	7.1–7.8	7.3–8.5	7.2–7.5
Final	7.1–8.2	7.1–9.1	7.1–9.0
TOTAL NITROGEN (mg l^{-1})			
Initial	1.60 ± 0.14 [a]	2.61 ± 0.83 [a]	2.54 ± 0.85 [a]
Midway	5.40 ± 0.72 [a]	9.07 ± 3.57 [a]	5.93 ± 1.08 [a]
Final	8.16 ± 0.90 [a]	7.85 ± 1.32 [a]	9.37 ± 3.94 [a]
TAN (mg l^{-1})			
Initial	0.19 ± 0.07 [a]	0.46 ± 0.22 [a]	0.32 ± 0.23 [a]
Midway	0.70 ± 0.22 [a]	0.91 ± 0.15 [a]	0.68 ± 0.36 [a]
Final	2.00 ± 0.65 [a]	1.28 ± 0.33 [a]	1.19 ± 0.40 [a]
TOTAL PHOSPHORUS (mg l^{-1})			
Initial	0.41 ± 0.10 [a]	0.74 ± 0.26 [a]	0.48 ± 0.03 [a]
Midway	0.26 ± 0.02 [a]	0.64 ± 0.08 [a]	0.50 ± 0.06 [a]
Final	0.50 ± 0.14 [a]	1.06 ± 0.11 [a]	0.87 ± 0.15 [a]
TOTAL ALKALINITY (mg l^{-1} as $CaCO_3$)			
Initial	151 ± 7.7 [a]	137 ± 17.7 [a]	133 ± 7.4 [a]
Midway	48 ± 6.9 [a]	61 ± 20.1 [a]	40 ± 4.2 [a]
Final	55 ± 7.0 [a]	73 ± 14.3 [a]	55 ± 3.7 [a]
CHLOROPHYLL *A* (mg m^{-3})			
Initial	53 ± 17.7 [a]	51 ± 6.1 [a]	52 ± 3.8 [a]
Midway	48 ± 13.0 [a]	147 ± 75.2 [a]	86 ± 21.9 [a]
Final	68 ± 35.8 [a]	205 ± 25.0 [ab]	162 ± 52.4 [a]

[a,b,c] Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

fertilized with 8 kg P ha^{-1} wk^{-1} brought N:P ratios to 1.25:1, 2.5:1, and 3.75:1, respectively. The best fish growth performance was achieved in the treatment with the highest N input and N:P ratio. This finding confirms previous results of CRSP experiments which indicated optimal rates of 28 kg N ha^{-1} wk^{-1} and 7 kg P ha^{-1} wk^{-1}, giving a 4:1 N:P ratio (Knud-Hansen et al., 1991; Lin et al., 1997). Nile tilapia ceased to grow at around day 70 in all treatments with N inputs, indicating that the pond carrying capacity was around 2,000 to 2,500 kg ha^{-1}. With chemical fertilization alone, maximum fish production is about 15 kg ha^{-1} d^{-1} (Boyd, 1990), which is similar to the highest net fish yield (15.3 kg ha^{-1} d^{-1}) achieved in this 91-day experiment.

Table 7. Partial budget analysis for Nile tilapia stocked at small, medium, and large sizes in the 91-day experiment (budget items in US$ $pond^{-1}$).

Item	Treatment		
	Small fish (4.6 g)	*Medium fish* (10.2 g)	*Large fish* (21.0 g)
Income (selling fish)	46.05	72.30	61.35
Added Income (A)	----	26.25	15.30
Cost for $NaHCO_3$	15.28	18.83	19.53
Added Cost from $NaHCO_3$ (B)	----	3.55	4.25
Ratio of Added Income to Added Cost	----	7.4	3.6
Profit (A - B)	----	22.70	11.05

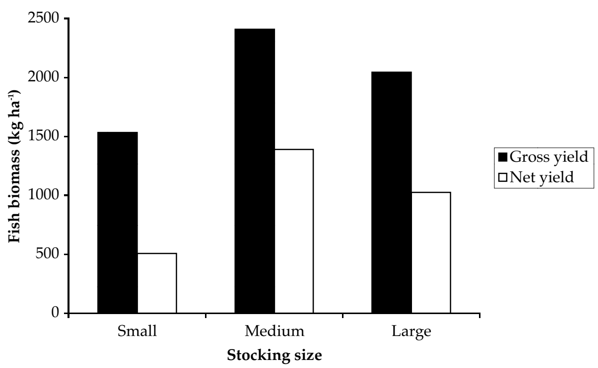

Figure 8. Gross and net fish yields in the small-, medium-, and large-size treatments in the 91-day experiment.

However, the net fish yield would have been 19.9 kg ha^{-1} d^{-1} and much higher profit could have been produced if tilapia had been harvested before growth ceased around day 70, suggesting the importance of timing for fish harvest in optimization of pond production systems.

The optimal N and P input rates determined in PD/A CRSP experiments are much higher than those used in most previous pond experiments, ranging from 1.0 to 6.5 kg N and 1.0 to 2.3 kg P ha^{-1} wk^{-1} (Swingle, 1947; Mortimer, 1954; Hickling, 1962; Hepher, 1962a, 1962b; Boyd, 1976; Boyd and Sowles, 1978; Murad and Boyd, 1987; Boyd, 1990). The annual fish yields in those studies were generally below 1,000 kg ha^{-1}. In addition to higher fertilizer inputs, the fish stocking rates were also much higher in most PD/A CRSP experiments (10,000 to 20,000 fish ha^{-1}) with extrapolated annual fish yields of 3,000 to 5,000 kg ha^{-1} (Lin et al., 1997). The highest extrapolated net yield obtained in the present study is around 5,500 kg ha^{-1} yr^{-1}, which could have reached 7,000 kg ha^{-1} yr^{-1} if fish had been harvested around day 70.

In the second experiment, there were no significant differences in all water quality parameters among treatments. It is not clear why fish yields were significantly different among treatments. The stocking densities were 5, 10, and 22 fish m^{-2} in the large-, medium-, and small-size treatments, respectively. With the same stocked biomass in all treatments, growth rates of individual fish were proportional to stocking size, but inversely proportional to stocking density. The latter indicated density-dependent growth occurred; however, fish yields were significantly different among treatments, with the highest fish yields achieved in the medium-size treatment.

With the development of Nile tilapia cage culture in rivers in northeast Thailand, there are strong demands for large fingerlings (30 to 50 g) to stock cages. Small-scale farmers nurse Nile tilapia fry to such sizes and sell them at around \$1.50 kg^{-1}, which is much higher than the price of marketable adult Nile tilapia. Farmers commonly nurse fry in fertilized ponds supplemented with artificial feed. In the present study, however, Nile tilapia were nursed at a very high density in ponds with fertilizer only, resulting in high yields. The results of this study imply that moving fish from high-density to low-density conditions when fish growth ceases or pond carrying capacity is reached could be a good strategy. Also, these results may provide small-scale farmers with a technically and economically effective strategy to optimize resource utilization and maximize profits.

ANTICIPATED BENEFITS

This is the first in a series of experiments to determine optimal rates of nitrogen, phosphorus, and carbon additions to ponds for fish production. Results of these trials will provide N, P, and C application rates to obtain fish yields with the greatest profit. Development of a full-cost enterprise budget for the fertilization rate that results in the greatest profitability will assist host country and international economists and planners in their evaluation of fish culture systems. Additionally, identification of optimal nutrient application rates would reduce the environmental impact of pond effluents.

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Development of Low-Cost Supplemental Feeds for Tilapia in Pond and Cage Culture

Eighth Work Plan, Philippines Research 1 (PHR1)
Progress Report

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Abstract

Two feeding trials were conducted at the Central Luzon State University Freshwater Aquaculture Center in the Philippines to determine the viability of using yeast and composted rice straw as alternative protein sources for tilapia diets. In the first phase, the experimental diets were prepared using a meat grinder to make pellets and fed to tilapia in ponds. In the second phase, the diets were fed to tilapia in cages in a common pond. In both experiments, the fish fed the diet incorporating the composted straw demonstrated the highest growth rate. In the pond study, 1.5-g tilapia were stocked in fertilized ponds, allowed to grow for seven months, and then fed the experimental feed for three months. The fish grew to an average of 141.3, 134.6, and 106 g in the compost, yeast, and un-fed control ponds, respectively. The ponds also yielded fingerlings with an average biomass of 124.3, 101.0, and 57.2 kg per pond in the compost, yeast, and un-fed controls, respectively. In the second phase, the fish were stocked into hapa cages at an average size of 73.9 g. In three months the fish grew to average sizes of 162.6, 155.6, 148.8, and 146.6 g when fed the compost diet prepared on a meat grinder, compost diet from a pellet mill, yeast diet from a grinder, and yeast diet from a pellet mill, respectively. Based on the results of these trials we conclude that these low-cost supplemental feeds would increase the yield from ponds and the composted rice straw would be the better protein source for the replacement of fishmeal compared to the variety of yeast used in the diet.

Introduction

Supplemental feeds providing additional quantities of nutrients are needed when the productivity of a water body cannot provide for the fish growth desired. Low-cost, high-quality feeds are needed in ponds when farmers wish to produce more fish than can be supported from fertilized systems (Diana et al., 1994) and in instances where cages are stocked with fish which do not have access to the entire water body for feeding. Many small-scale farmers have been encouraged to build and utilize cages to increase their household income and nutrition. After construction of the cage, cost of feed becomes the major input cost for fish production. Commercial feeds are widely used in the Philippines, mostly for cage farms which require a fairly complete diet. These diets contain a relatively complete set of nutrients, which may not be necessary for pond-reared fish.

Supplemental feeds, by definition, are not intended to provide complete nutrition. The goal is to provide nutrients that otherwise would be limiting the growth of the fish. In fertilized ponds, proteins are often that limiting factor. Providing protein in feeds can be cost-effective by increasing the growth rate of fish stocked in a pond and allowing more fish to be stocked in the same water volume. But dietary protein is often expensive to incorporate into a diet. The typical sources of proteins are fishmeal and soybean oil meal. These are relatively expensive ingredients that are useful in other animal feeds. With the recent financial problems in Asia and the devaluation of local currencies, fishmeal costs have risen to new highs. Providing less expensive sources of protein has been a goal of numerous other nutrition studies in the past, which have examined many ingredients including plants, agricultural processing wastes, and even brewery wastes. One source of protein that historically was prohibitively expensive is yeast. Brewer's and baker's yeast are known to be high in protein and readily digestible. New bioreactor technology has lowered the cost of yeast to the point that it now may be cost-effective to use as an ingredient. One common yeast used in feed studies that is commercially available in many areas is *Saccharomyces cereviseae*.

Rice bran is one of the agricultural by-products that have been used in supplemental diets in the past. Another material available from rice production is rice straw. However, the straw is not high in protein. One option is to compost the straw, which will allow microbial activity to use the straw as substrate and convert the straw from a material high in indigestible matter, with a high carbon-to-nitrogen ratio, to microbial biomass that is quite digestible for tilapia, with a low carbon-to-nitrogen ratio. In an effort to find a lower-cost ingredient as a fishmeal replacement we developed experimental diets that incorporated yeast and composted rice straw as replacements for fishmeal in a simple diet

Figure 1. Compression pellet mill used to make experimental tilapia diets.

Figure 2. Experimental pond receiving diet containing yeast.

formulation. Another aspect of the study was to determine if compression pelleting would make a difference in the performance of the diet. The experimental feeds developed at the Freshwater Aquaculture Center (FAC) in the past had been manufactured on a simple meat grinder. The strands were hand-dried and broken into small, pellet-size particles that could be consumed by the fish. A pellet mill was purchased in the US and delivered to the FAC (Figure 1). The mill was used to make compressed pellets using the same ingredient mix prepared on the meat grinder. The two forms were then tested in cages in a common pond.

A supporting study was conducted by an Arizona high school student. The student conducted the experiment as part of a science fair project. In this study the student used a composted rice diet prepared at the University of Arizona according to the formula used in the Philippines. This diet was compared to a commercially available tilapia diet used in the US.

METHODS AND MATERIALS

Phase 1

Twelve earthen ponds at the Freshwater Aquaculture Center at Central Luzon State University were used to test the experimental diets. The ponds were 0.05 ha each with a depth of one meter (Figure 2). Monosex (genetically male) *Oreochromis niloticus* from the Genetically Male Tilapia (GMT) program were stocked on 10 June 1997 at 3 fingerlings m^{-2} or 1,500 fish $pond^{-1}$.

Each of the 12 ponds was fertilized with nutrient inputs from urea (46-0-0) and ammonium phosphate (16-20-0) at the rate of 14 kg N and 2.8 kg P ha^{-1} wk^{-1}. To attain the desired input levels, 1.625 kg of 16-20-0 and 1.1 kg of urea (45-0-0) were added each week to each 500-m^2 pond. This assumes a moisture content of approximately 5% in the fertilizer. Dissolved fertilizer was broadcast across the entire pond surface. The application of nutrients was stopped once feeding of the experimental diets was begun, and continued in ponds that received fertilizers only (the control ponds). Feeding with the experimental diets started in February of 1998 at 5% of body weight for 2 months and 3% of body weight per day during April with harvest in early May of 1998. Four ponds were fed the yeast diet, four were fed the composted rice straw diet, and four ponds were un-fed, fertilized control ponds.

The yeast diet was composed of 60% rice bran, 15% yeast, and 25% meat and bone meal. Commercially available yeast was used to prepare the yeast diet. The rice diet was 60% rice bran, 15% rice straw, and 25% meat and bone meal. Two batches of rice straw were composted, one in January of 1997 and the other in June of 1997. These two batches were mixed together to provide the compost ingredient for the experimental diet. The rice compost preparation did not

Figure 3. Harvesting tilapia from pond receiving yeast diet.

Figure 4. Hapas used in feeding trial.

Table 1. Water parameters were analyzed (APHA, 1980; Boyd, 1979) at initial stocking and every two weeks thereafter at FAC, Philippines (Phase 2).

Parameter	Depth	Time	Analytical Methods
Temperature	Top, mid, bottom	AM & PM	YSI meter & probe
Dissolved O_2	Top, mid, bottom	AM & PM	YSI meter & probe
Alkalinity	Column sample	AM	Titration
pH	Top, mid, bottom	AM & PM	pH meter
Total NH_3-N	Column sample	AM	Indophenol method
Secchi Disk	Column sample	AM & PM	Visual
Sol. React. Phos.	Column sample	AM	Molybdate method

Table 2. Survival and average weight of *O. niloticus* reared in ponds fed compost and yeast diets. Values with similar letters are not significantly different; values with different letters are significantly different ($P = 0.05$).

Treatment	Average Mortality (%)	Final Average Weight ± s.d. (g)	Ave. Biomass of Fingerlings ± s.d. (kg)
Compost Diet	20.8 (a)	141.3 ± 5.3 (c)	124.3 ± 62.1 (e)
Yeast Diet	9.2 (a)	134.6 ± 2.9 (c)	101.0 ± 81.3 (e)
Control Ponds	44.8 (b)	106.1 ± 1.8 (d)	57.2 ± 43.5 (e)

involve any nutrient supplements nor any manure. The ingredients for the experimental diets were mixed as dry ingredients and then prepared on a meat grinder.

Sample weights were determined monthly. Fifty fish were sampled per pond by collection with a seine net (Figure 3). Feeding amount was adjusted according to the average weight of the fish sampled. At harvest, weights were determined for all of the large fish in each pond. The fingerlings were weighed in bulk, with no determination of number.

Phase 2

The second feeding trial was designed as a 2x2 factorial experiment (feed preparation by pellet mill or meat grinder, and compost or yeast diets). The same diet formulations were used as in Phase 1. Twenty cages, each 6 m^3, were placed into a 0.25-ha pond with a depth of 1.5 to 2 m (Figure 4). The cages were stocked with 120 *O. niloticus* fingerlings from the Genetically Improved Farmed Tilapia (GIFT) program which had already been sex-reversed using methyltestosterone feed per standard FAC protocols. The fish averaged 73.9 g each and were stocked 29 January 1998.

A compression style pelleting mill (CPM Master Series) was purchased and sent to the Philippines as a part of the project. The mill was used to pelletize a portion of the dry mix at the same time that the mix was prepared on the meat grinder. This provided equal portions of the compost and yeast diet feeds to be tested in their various forms.

The ponds receiving the rice compost and the yeast diets and the pond containing the hapa net feeding trial were monitored daily for water level. A comprehensive analysis of water quality was performed every two weeks including temperature, pH, alkalinity, dissolved oxygen, total available nitrogen, phosphate, and Secchi disk visibility (Table 1).

For Phases 1 and 2, the results were compared using one-way analysis of variance to determine differences and Duncan's Multiple Means test to determine differences between several treatments.

Chino Valley High School Study

The study was conducted at Chino Valley High in Chino, Arizona. Non-sex-reversed *O. niloticus* and hybrid red tilapia were used as the experimental animals. The fish were fed a composted rice diet (60% rice bran, 15% rice straw, and 25% meat and bone meal) prepared on a compression pellet mill (CPM) and a commercially available tilapia diet (Ace High Brand). Four perforated plastic buckets (20 l) were placed into a 1000-liter tank; two replicates of 21 fish each were used for each diet. The fish were fed twice daily at a feeding rate of 5% of the biomass. The trial lasted six weeks.

RESULTS

Phase 1

The twelve ponds were harvested in early May of 1998. Even though the fish were expected to be all males from the GMT program, only one pond did not have any reproduction. Most of the adult fish harvested appeared to be male. It appears that either there was contamination with females at some point or,

Figure 5. Fingerlings recovered from pond stocked with genetically male tilapia (GMT).

Table 3. Water quality sampling results in cage trials (hapas), FAC, Philippines (Phase 2).

Sampling Position	Date (MMDDYY)	Dissolved O_2 (mg l^{-1})						Temperature (°C)					
		Top AM	*Mid AM*	*Bottom AM*	*Top PM*	*Mid PM*	*Bottom PM*	*Top AM*	*Mid AM*	*Bottom AM*	*Top PM*	*Mid PM*	*Bottom PM*
7C.1	12998	1.4	1.3	1.2	4.0	4.0	4.0	25.2	25.2	25.2	29.3	29.3	29.3
7C.2	12998	1.4	1.3	1.2	3.9	3.9	3.9	25.1	25.1	25.1	29.0	29.0	28.8
7C.3	12998	1.4	1.2	1.2	3.9	3.9	3.9	25.2	25.2	25.2	29.1	29.1	29.1
7C.4	12998	1.3	1.3	1.1	4.0	4.0	4.0	25.2	25.2	25.2	29.0	29.0	29.0
7C.5	12998	1.4	1.3	1.2	4.0	4.0	4.0	25.2	25.2	25.2	29.0	29.0	29.0
7C.1	21398	2.9	2.8	2.7	5.4	5.4	5.5	27.5	27.5	27.5	32.0	31.9	31.6
7C.2	21398	2.9	2.7	2.7	5.4	5.6	5.6	27.5	27.5	27.5	31.8	31.6	31.5
7C.3	21398	2.8	2.8	2.6	5.6	5.6	5.5	27.5	27.5	27.5	31.8	31.6	31.5
7C.4	21398	2.9	2.7	2.7	5.5	5.5	5.6	27.5	27.5	27.5	32.0	31.9	31.7
7C.5	21398	2.7	2.6	2.5	5.5	5.4	5.4	27.5	27.5	27.5	31.9	31.8	31.6
7C.1	22698	2.3	2.2	2.0	10.2	9.2	8.8	25.8	25.8	25.8	32.8	31.8	31.3
7C.2	22698	2.1	2.0	1.9	10.1	9.0	8.9	25.8	25.8	25.8	32.8	32.0	31.3
7C.3	22698	2.3	2.1	2.0	10.2	9.1	8.8	25.9	25.9	25.9	32.9	31.9	31.3
7C.4	22698	2.3	2.1	2.0	10.2	9.1	8.9	25.8	25.8	25.8	32.8	31.9	31.2
7C.5	22698	2.4	2.3	2.1	10.2	9.2	8.8	25.9	25.9	25.9	32.8	31.8	31.2
7C.1	31298	2.4	2.3	2.2	10.4	9.4	5.9	28.5	28.5	28.5	32.1	31.6	31.0
7C.2	31298	2.4	2.3	2.2	10.8	9.5	6.2	28.5	28.5	28.5	32.5	31.5	31.2
7C.3	31298	2.3	2.3	2.2	10.5	9.5	6.2	28.4	28.4	28.4	32.4	31.5	31.2
7C.4	31298	2.4	2.3	2.2	10.6	9.5	6.3	28.5	28.5	28.5	32.2	31.4	31.0
7C.5	31298	2.3	2.3	2.2	10.4	9.5	6.0	28.5	28.5	28.5	32.2	31.5	31.0
7C.1	32698	1.8	1.8	1.6	12.4	12.3	12.3	26.0	26.0	26.0	29.1	29.1	29.1
7C.2	32698	1.9	1.8	1.6	12.4	12.4	12.3	26.1	26.1	26.1	29.2	29.2	29.2
7C.3	32698	2.0	1.9	1.7	12.4	12.3	12.3	26.0	26.0	26.0	29.1	29.1	29.1
7C.4	32698	1.8	1.8	1.6	12.4	12.4	12.3	26.0	26.0	26.0	29.1	29.1	29.1
7C.5	32698	1.8	1.8	1.6	12.4	12.3	12.3	26.1	26.1	26.1	29.1	29.1	29.1
7C.1	41698	2.1	2.0	1.5	13.2	13.2	13.1	26.8	26.8	26.8	31.5	31.2	31.2
7C.2	41698	2.1	2.0	1.6	13.2	13.1	13.0	26.8	26.8	26.8	31.3	31.2	31.1
7C.3	41698	1.9	1.8	1.5	13.1	13.2	13.0	26.8	26.8	26.8	31.5	31.2	30.9
7C.4	41698	2.0	1.9	1.6	13.2	13.2	12.9	26.7	26.7	26.7	31.5	30.9	30.7
7C.5	41698	2.0	1.8	1.6	13.2	13.1	12.9	26.7	26.7	26.7	31.3	31.0	30.8
7C.1	50498	2.3	2.2	1.6	20	20	16.6	27.3	27.3	27.3	33.2	33.2	33.2
7C.2	50498	2.3	2.1	1.5	19	19	17.1	26.9	26.9	26.9	33.1	33.0	33.0
7C.3	50498	2.2	2.1	1.6	20	19	17.0	27.0	27.0	27.0	33.0	32.0	31.8
7C.4	50498	2.1	2.0	1.6	20	20	16.5	27.3	27.3	27.3	33.0	31.0	31.0
7C.5	50498	2.3	2.1	1.6	20	20	15.8	27.1	27.1	27.1	33.0	32.0	31.8

Table 3. Continued.

Sampling Position	Date (MMDDYY)	pH						Secchi Disk Depth (cm)		Alkalinity (mg l-1 $CaCO_3$)	Total Ammonia Nitrogen (mg l-1 $CaCO_3$)	Phosphate (mg l-1 $CaCO_3$)
		Top AM	*Mid AM*	*Bottom AM*	*Top PM*	*Mid PM*	*Bottom PM*	*AM*	*PM*			
7C.1	12998	8.8	8.8	8.8	9.4	9.3	9.3	46.5	47.5	300	0.041	0.305
7C.2	12998	8.9	8.9	8.9	9.2	9.3	9.3	46.5	47.5	273	0.052	0.340
7C.3	12998	8.9	8.8	8.8	9.2	9.2	9.2	46.5	47.5	314	0.048	0.325
7C.4	12998	8.9	8.9	8.8	9.3	9.3	9.3	46.5	47.5	302	0.030	0.325
7C.5	12998	8.9	8.9	8.9	9.2	9.2	9.2	46.5	47.5	313	0.046	0.340
7C.1	21398	8.9	8.9	8.9	9.5	9.5	9.5	31.5	28.5	295	0.046	0.295
7C.2	21398	8.9	8.9	8.9	9.5	9.4	9.4	31.5	28.5	280	0.054	0.325
7C.3	21398	8.9	8.9	8.9	9.5	9.5	9.4	31.5	28.5	300	0.041	0.325
7C.4	21398	8.9	8.9	8.9	9.4	9.4	9.4	31.5	28.5	296	0.065	0.275
7C.5	21398	8.9	8.9	8.9	9.5	9.4	9.4	31.5	28.5	310	0.047	0.295
7C.1	22698	8.8	8.7	8.7	9.4	9.4	9.3	29.5	29.5	315	0.061	0.390
7C.2	22698	8.8	8.8	8.7	9.5	9.5	9.4	29.5	29.5	295	0.048	0.375
7C.3	22698	8.7	8.7	8.7	9.5	9.4	9.3	29.5	29.5	290	0.046	0.390
7C.4	22698	8.7	8.6	8.7	9.5	9.4	9.4	29.5	29.5	284	0.076	0.390
7C.5	22698	8.7	8.7	8.7	9.5	9.4	9.4	29.5	29.5	268	0.080	0.410
7C.1	31298	8.6	8.6	8.6	9.1	9.0	9.0	47.5	41.5	365	0.011	0.370
7C.2	31298	8.6	8.6	8.6	9.1	9.0	9.0	47.5	41.5	360	0.004	0.285
7C.3	31298	8.6	8.6	8.6	9.0	9.0	8.9	47.5	41.5	363	0.026	0.335
7C.4	31298	8.6	8.6	8.6	9.0	9.0	9.0	47.5	41.5	355	0.024	0.350
7C.5	31298	8.7	8.6	8.6	9.1	9.1	9.1	47.5	41.5	365	0.007	0.300
7C.1	32698	8.7	8.7	8.7	9.4	9.4	9.4	48.5	44.5	342	0.065	0.420
7C.2	32698	8.7	8.8	8.8	9.3	9.3	9.3	48.5	44.5	352	0.046	0.375
7C.3	32698	8.8	8.8	8.8	9.4	9.4	9.4	48.5	44.5	336	0.026	0.285
7C.4	32698	8.7	8.7	8.7	9.4	9.3	9.3	48.5	44.5	341	0.009	0.356
7C.5	32698	8.7	8.7	8.7	9.4	9.4	9.4	48.5	44.5	346	0.041	0.350
7C.1	41698	8.8	8.8	8.8	9.6	9.5	9.5	45.5	42.5	298	0.026	0.365
7C.2	41698	8.8	8.8	8.8	9.6	9.4	9.3	45.5	42.5	324	0.009	0.385
7C.3	41698	8.7	8.7	8.7	9.4	9.3	9.3	45.5	42.5	326	0.036	0.285
7C.4	41698	8.7	8.7	8.7	9.5	9.4	9.2	45.5	42.5	336	0.012	0.346
7C.5	41698	8.8	8.8	8.8	9.6	9.5	9.3	45.5	42.5	310	0.038	0.300
7C.1	50498	8.5	8.5	8.4	10.3	10.3	10.2	38.5	33.5	288	0.075	0.385
7C.2	50498	8.6	8.6	8.5	10.3	10.2	10.2	38.5	33.5	320	0.034	0.378
7C.3	50498	8.5	8.5	8.5	10.2	10.2	10.0	38.5	33.5	315	0.028	0.292
7C.4	50498	8.5	8.5	8.4	10.2	10.1	10.1	38.5	33.5	324	0.015	0.345
7C.5	50498	8.5	8.5	8.5	10.3	10.2	10.1	38.5	33.5	316	0.030	0.316

Table 4. Survival, average weight, and feed conversion ratio of *O. niloticus* reared in cages fed compost and yeast diets prepared on meat grinder and a compression pellet mill at FAC (Phase 2). Values with similar letters are not significantly different; values with different letters are significantly different ($P = 0.05$).

Treatment	Average Mortality (%)	Final Average Weight ± s.d. (g)	Feed Conversion Ratio ± s.d.
COMPOST DIET			
Grinder	4.0 (a)	162.6 ± 4.6 (b)	3.3 ± 0.7 (d)
Pellet Mill	1.3 (a)	155.6 ± 9.7 (b)	2.8 ± 0.1 (d)
YEAST DIET			
Grinder	0.5 (a)	148.8 ± 4.6 (c)	2.6 ± 0.3 (d)
Pellet Mill	1.8 (a)	146.6 ± 8.8 (c)	3.1 ± 0.3 (d)

Table 5. Final average weight and feed conversion ratio of *O. niloticus* and hybrid red tilapia reared in tanks fed rice compost and commercial diets at Chino Valley High School, Arizona. Values with similar letters are not significantly different; values with different letters are significantly different ($P = 0.05$).

Treatment	Final Average *O. niloticus* Weight ± s.d. (g)	Final Average Red Tilapia Weight ± s.d. (g)	Feed Conversion Ratio ± s.d.
Commercial Diet	14.3 ± 5.7 (a)	16.4 ± 6.2 (b)	3.1 ± 2.7 (c)
Compost Diet, Pellet Mill	11.6 ± 5.9 (a)	14.8 ± 3.7 (b)	5.0 ± 3.1 (c)

more likely, the process was not 100% complete in providing all-male fish.

The large fish from each pond were each weighed and counted. These fish were presumed to be the survivors from the original stocking. The biomass of fingerlings was determined by weighing all of the fish that were in the obviously smaller cohort (Figure 5). The fingerlings were not counted. The results are presented in Table 2.

The average mortalities in the ponds fed the two experimental diets were not significantly different from one another, but were significantly greater than the average in the control ponds. The average weights of the fish fed the two experimental diets were also not significantly different from one another but were significantly greater than the fish in the control ponds. Feed Conversion Ratios (FCRs) for compost and yeast diets (1.2 and 1.2) were not significantly different. The biomass of fingerlings for all three treatments were not significantly different. Considering that these fish were supposed to be all-male populations, the number of fingerlings in the ponds was disappointing.

Phase 2

The hapa net cages were harvested on 4 May 1998. The fish were in the cages for 95 days. The dissolved oxygen levels varied in the ponds from a low of 1.1 mg l^{-1} at the bottom of the cages on a morning in January to saturated conditions of up to 20 mg l^{-1} in the afternoon in May. Temperatures ranged from a low of 25.1°C on a January morning to a high of 33.2°C on a May afternoon. The pH extremes in the ponds were recorded between the morning and afternoon of the last sampling date in May. The morning low pH was 8.4 and the afternoon high was 10.3 from the same location. This is indicative of a strong algae bloom driving the carbonate cycle to alter the pH. The Secchi disk readings did not demonstrate any obvious trends other than being slightly lower in the afternoon compared to the morning reading for the same day. Alkalinity did not display any obvious pattern and ranged from 268 to 365 mg l^{-1} $CaCO_3$. Total ammonia and phosphates also did not display any obvious patterns and ranged from 0.004 to 0.080 mg l^{-1} and 0.275 to 0.420 mg l^{-1}, respectively. More complete results are presented in Table 3.

The average mortalities in the hapa nets were very low, with some of the cages having 100% survival. There was no reproduction in any of the cages. The average weights of fish fed the two compost diets were significantly greater than the weights of fish fed the two yeast diets. There were no significant differences between either diet prepared on the pellet mill compared to preparation on the meat grinder (Table 4).

Feed conversions were not significantly different between any of the diets or preparation methods. However, none of the FCRs was very good compared to what would be expected with a commercial diet.

Chino Valley High School Study

The fish at the high school were stocked at an average weight of 5.0 g. At the end of the six-week period the fish were weighed individually. There were no mortalities in any of the replicates (Table 5).

The treatments did not exhibit any significant differences in final average weights or FCRs. However, this may have been because of insufficient numbers in the replicates. Considering the trend that was evident, extending the trial or having a larger population would have probably led to significant differences. Nevertheless, the rice diet did demonstrate that the fish would survive and grow when fed the relatively simple, low-cost, rice-based diet.

DISCUSSION

The trials in the Philippines demonstrated that the yeast and the composted rice straw could provide significant nutrition and contribute to the manufacture of simple, low-cost diets for tilapia culture. Additional trials should be conducted to compare these diets with commercially available diets, which most of the cage farmers and many of the pond producers are now using. Growth differences and cost differential could then be compared to determine the best value of feed to biomass produced. The trial conducted at Chino Valley High School in Arizona demonstrated that the rice compost diet did support growth and was close to the production achieved with the commercial diet, at least for the short period tested.

We were not able to determine if the yeast diet provided significantly different growth compared to the compost. Since the compost diet is much more readily available and would be lower in cost, it would be the preferable ingredient for future examination. A further analysis comparing these diets with commercial diets and standard pond fertilization may also be prudent, especially considering the rapid changes in commodity and feed prices in the Philippines and elsewhere in Southeast Asia.

One severe disappointment from the trial was the large amount of reproductive activity in the ponds stocked with genetically male tilapia (GMT) from the GMT program. We can not be sure that the ponds were not accidentally contaminated with females from outside the GMT program. But considering that all but one pond had reproduction, it is doubtful that all of the ponds received fish from outside the population stocked.

We realize that the treatment ponds should have demonstrated better survival and growth compared to the control ponds which received fertilization only; however, the more impor-tant point is that we generated these results with low costs feeds from readily available ingredients. Achieving this marginal increase in yield that will provide more marginal income than the marginal cost of the feed is the essence of economic progress.

A description of the project with results of the research and many photos of the ponds and fish are posted at the following website: <http://ag.arizona.edu/azaqua/philippines/clsu.htm>.

ANTICIPATED BENEFITS

The rapid increase in commodity prices for feed ingredients is a serious concern for aquaculture producers throughout Southeast Asia. In addition to their own consumption and domestic sales there is increased interest in generating high-quality tilapia fillets for export. High quality fillets are most often produced from cage systems and ponds receiving prepared feeds. Developing low-cost feeds that will allow tilapia farmers to produce high-quality fish for domestic and international markets. This is a goal of the Central Luzon State University (CLSU) biologists, but also a topic of request from two e-mails received directly from Filipino fish farmers.

The low-cost feeds we have developed and tested can be manufactured by the CLSU feed mill for sale to local farmers for further on-farm evaluation. This can be done on a cost recovery basis. If the diets prove popular with farmers, one commercial feed company said they would be interested in testing the formulations themselves. If successful, the benefit would be lower input costs and increased revenues for the growers using this type of feed.

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METHODS FOR STRAIN VARIATIONS IN SEX RATIO INHERITANCE AND METHODS FOR THE CONTRIBUTION FROM THE MALE AND FEMALE GENOME TO SEX INHERITANCE

Eighth Work Plan, Reproduction Control Research 1A and 1C (RCR1A and 1C)
Progress Report

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ABSTRACT

Effective and practical control of reproduction is the major constraint in tilapia culture. Uncontrolled reproduction can result in less than 25% of the adults being greater than 250 g after a six-month culture period, with the majority of the population being progeny less than 10 g each. Intraspecific breeding programs have been developed to exploit the sex inheritance mechanism in the tilapia *Oreochromis niloticus*. Females are said to be homogametic (XX) and males heterogametic (XY), but the sex inheritance of the progeny from a single pair often does not conform to the expected 50:50 ratio. This lack of conformity to a simple XX:XY sex inheritance pattern complicates the intraspecific breeding approach of developing YY males that would give all-male progeny. The identification of tilapia populations with minimal variation in progeny sex ratios from individual spawns would be a significant contribution to the development of a YY male breeding program. Three strains of *Oreochromis niloticus*—Egypt, Ghana, and Ivory Coast—were spawned in outdoor hapas at 28 to 32°C. A total of 44, 34, and 52 spawns from the Egypt, Ghana, and Ivory Coast strains, respectively, were successfully reared to a sexable size and the sex ratio of each spawn established. The mean percentage of males, females, or intersex fish did not differ among the three strains evaluated. A given male did not give consistent sex ratios when mated with different females. Multiple spawns from a given female also had variable progeny sex ratios.

INTRODUCTION

Effective and practical control of reproduction is the major constraint in tilapia culture. Uncontrolled reproduction can result in less than 25% of the adults being greater than 250 g after a six-month culture period, with the majority of the population being progeny smaller than 10 g each. Inter- and intraspecific breeding programs can result in populations with highly skewed sex ratios, but often give inconsistent results. Interspecific crosses have not proven to be practical due to difficulties in maintaining the parent species integrity.

Intraspecific breeding programs have been developed to exploit the sex inheritance mechanism in the tilapia *Oreochromis niloticus*. Females are said to be homogametic (XX) and males heterogametic (XY), but the sex inheritance of the progeny from a single pair often does not conform to the expected 50:50 ratio. This lack of conformity to a simple XX:XY sex inheritance pattern complicates the intraspecific breeding approach of developing YY males that would give all-male progeny. The sex ratios of individual spawns have been studied in only a limited number of strains of *O. niloticus*, and the observed variance in sex ratios may be related to strain differences. The identification of tilapia populations with minimal variation in progeny sex ratios from individual spawns would be a significant contribution to the development of a YY male breeding program.

METHODS AND MATERIALS

Three strains of *Oreochromis niloticus* were used during the study: Egypt, Ghana, and Ivory Coast. Brooders used ranged in size from 50 to 250 g. The populations have been maintained at Auburn University since 1982, 1982, and 1974, respectively. Paired matings by strain were accomplished using a 1:3 ratio, male to female inside 2-m^2 net hapas located in outdoor tanks. Hapas were checked on a ten-day cycle for the presence of fry or eggs in the mouths of the females. Females which spawned were tagged using Floy® tags as identifiers and placed with other males at random within the same strain for additional spawns.

The procedure for inspection was to crowd the brooders to one side of the hapa, remove the male to the unoccupied side of the hapa, and extract each female using a small dip net. Upon inspection of each female's mouth, eggs or fry were removed when present. Any extraneous fry were removed from the hapa upon completion of inspection. Eggs collected were incubated in McDonald jars until hatching occurred. Fry collected were also brought indoors for temporary rearing. Fry collected or hatched were then raised to an average size of 2 cm and were then relocated to outdoor hapas or grow-out ponds with a 29°C average daily temperature. Fry were stocked at 250 fry per hapa and 1000 fry per grow-out pond and raised to an average length of 7 cm, of which samples of 110 fish were preserved in formalin.

Additionally, randomly chosen groups of 250+ siblings averaging 8.7 mm in length were split into aquaria and raised under two temperature conditions. One half of the fry were raised at an elevated average daily temperature of 35.3°C for 45 days and the other half at ambient temperature with an average daily temperature of 28.3°C for 45 days. Fish were grown out in outdoor tanks at an average temperature of 29.8°C. When they reached a length of approximately 7 cm they were preserved in 10% formalin.

Determination of sex was accomplished using the gonadal squash method (Guerrero and Shelton, 1974). Each gonad was stained using Harris' hematoxylin with a 10X dilution and then

Table 1. Mean and range of sex ratios of progeny from pair spawns of Egypt, Ghana, and Ivory Coast strains of *Oreochromis niloticus.*

Strain	Number of spawns	% Males	% Females	% Intersex	Range in % males
Egypt	44	52.9	46.3	0.8	26-72
Ghana	34	54.7	44.9	0.4	16-77
Ivory Coast	53	50.6	49.0	0.4	7-100

crushed by placing an additional slide on top and pressing the two together. Visual inspection was then made at 100X magnification along the length of each gonad, which was determined to be teste, ovary, or intersex with the % ovarian tissue recorded.

RESULTS AND DISCUSSION

A total of 44, 34, and 52 spawns from the Egypt, Ghana, and Ivory Coast strains, respectively, were successfully reared to a sexable size and the sex ratio of each spawn established. The mean percentage of males, females, or intersex fish did not differ among the three strains evaluated (Table 1). There was considerable variation in the sex ratios of individual spawns, with the Ivory Coast strain the most variable, followed by Ghana and Egypt (CVs of 33.2, 21.2, and 19.4%, respectively). The frequency distribution of percent males per spawn for each strain is given in Figure 1.

Multiple spawns by a given male or female mated to a new fish were often highly variable. Seventeen males spawned with three or more females, with one individual producing nine spawns. Of these males, only 3 of 17 produced progeny where the percentage of males was between 40 and 60% in all sets. Seventy-six percent of the males gave one or more spawns with > 60% males, and 18% gave one or more spawns with < 40% males. A given male did not give consistent sex ratios when mated with different females. Only 3 of 17 males with three or more spawns gave progeny where the CV in percent males among spawns was 10% or less. The one male that sired nine sets of progeny gave one that was 16.3% males, four between 40 and 60%, and one that was 100% male.

Multiple spawns from a given female also had variable progeny sex ratios. Seven females gave three or more sets of progeny. Only two females consistently gave progeny where

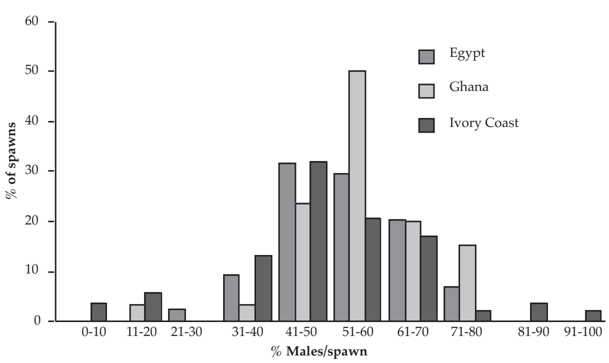

Figure 1. Variation in percentage of males in the progeny of pair spawns of Egypt, Ghana, and Ivory Coast strains of *Oreochromis niloticus*.

the frequency of males was between 40 and 60%. Three of seven gave one or more spawns with < 40% males, and three gave spawns with > 60% males. The CV in percent males among sets of progeny was 10% or less for only one female.

No one sex could be said to determine sex inheritance based on the observations to date. Where two or more spawns were obtained from a given pair, there were differences of 20% or more in the percentage of males among spawns from three of eight such pairs.

Nine spawns were successfully reared for 45 days at two temperatures (two Ghana, four Egypt, and three Ivory Coast). There was no difference in the percent males obtained when reared at 28.3°C and 35.3°C (Table 2). No one strain was more sensitive to the effect of temperature on sex ratios. Individual spawns did respond differently to temperature. In four spawns, siblings reared at the higher temperature had an increase in percent males of more than 10%, while the percent males from siblings from four spawns differed 10% or less at the two temperatures. The percent males in one set of siblings at 35.3°C was 20% less than the siblings at 28.3°C.

The variation in sex ratios among individual spawns was not unexpected from the Ivory Coast strain. Variation from 1:1 ratios of individual spawns has also been reported by Calhoun and Shelton (1983) from Ivory Coast strain Nile tilapia. The Ivory Coast strain of *O. niloticus* used in this study is highly inbred. The founder stock introduced in 1974 consisted of 100 to 200 juveniles from five to ten pairs of brooders at the Centro de Pesquisas Ictiologicas, Pentecoste, Ceara, Brazil, whose stock was founded from 50 to 100 fish introduced from the Station de Recherches Piscicoles, Bouake, Ivory Coast, in 1972 (Tave and Smitherman, 1980). Additional bottlenecks have occurred since that time. Abdelhamid (1988) compared the Auburn Ivory Coast strain of *O. niloticus* to six others and found 13.2% of the 38 loci to be polymorphic while the other strains were > 26% polymorphic. He found a mean heterozygosity of 0.018 for the Ivory Coast strain; the others ranged from 0.037 to 0.069. Tave and Smitherman (1980) established a predicted heritability of 0.04 ± 0.14 for the Auburn Ivory Coast strain. Teichert-Coddington and Smitherman (1988) found the realized heritability to be -0.10 ± 0.02 for the strain. These low levels of heritability reflect the significant level of inbreeding that has occurred in this line. Such an inbred line should also have a very inbred sex inheritance mechanism with little variation in observed ratios, but this was not the case. The high variability in sex ratios also occurred in the Egypt and Ghana lines.

The high degree of variation in individual spawns within a population and among repeat spawns of the same individual does not support a simple XX:XY sex-determining mechanism in any of the strains examined. Such lack of conformity has been encountered in other tilapia studies and explained as autosomal influence (Avtalion and Hammerman, 1978),

Table 2. Mean sex ratio of *Oreochromis niloticus* siblings of the Egypt, Ghana, and Ivory Coast strains reared 45 days at 28.3 and 35.3°C during the period of gonadal differentiation.

Strain	Temperature (°C)	% Males	% Females	% Intersex
EGYPT (N=4)				
	28.3	51.7	46.3	2.0
	35.3	57.8	41.4	0.8
GHANA (N=2)				
	28.3	53.5	45.5	1.0
	35.3	56.5	43.5	0
IVORY COAST (N=3)				
	28.3	55.6	43.9	0.5
	35.3	64.1	35.9	0

unequal potencies of X and Y (Shelton et al., 1983), multifactorial (Lester et al., 1989), crossing over (Wohlfarth and Wedekind, 1991), and monofactorial with autosomal or environmental sex-modifying factors (Mair et al., 1995). In any case, the variation in sex ratios from individual matings makes the development of YY breeding programs more complicated. The same events which produce skewed sex ratios in untreated populations of *O. niloticus* may also produce females in the expected all-male offspring of YY broodstock. Mair et al. (1997) found that YY males would on occasion sire sets of progeny that were not all male.

The variation in response to temperature further illustrates the degree of individual variation that may occur. Mair et al. (1990) and Baroiller et al. (1995) demonstrated how sex ratios of Nile tilapia could be altered by temperature and how the degree of response was dependent on the individual spawn. The variability in sex ratios in response to temperature by individual pairs and the variability of repeated spawns of a given male at ambient conditions in this study emphasize the need for selection of individual fish of known spawning histories for use in a YY breeding program.

Additional pairings will be made in the 1998 season of males and females with known progeny sex ratio history. Progeny from selected pairs will be nursed at two temperatures to determine the influence of temperature on such progeny.

ANTICIPATED BENEFITS

The variation in sex ratios among sets of progeny was not a function of strain, but appears instead to be a characteristic of the species. For a YY breeding program to be successful, individual fish will have to be tested with a number of mates and under a range of environmental circumstances in an attempt to develop a line of fish which conform to a simple XX:XY sex inheritance pattern. Work to date as part of this project has helped to provide insight as to the variation among individuals and the possibility of selecting for individuals that breed true to a given sex ratio. Continued selection based on the individuals identified to date may be able to provide the true breeding lines of fish needed to make a YY breeding program practical.

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Nile Tilapia Gamete Management for Chromosome Manipulation

Eighth Work Plan, Reproduction Control Research 1B (RCR1B)
Progress Report

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Abstract

Artificial propagation is an important component of chromosome manipulation. Spawning of Nile tilapia (*Oreochromis niloticus*) was manipulated by photoperiod and temperature control and through hormonal intervention. Four males and ten females produced 86 natural spawns, 41 of which developed to hatching. Artificial propagation resulted in 87 pairings, which were successfully used in 23 tau estimates and 11 UV experimental trials. A tau-curve was developed over temperatures ranging from 20.6 to 28.7°C with mitotic intervals from 73.8 to 30.1 min, respectively. A UV dose of 300 to 500 $J\ m^{-2}$ appears to be sufficient to inactivate the DNA of Nile tilapia eggs. Genetic color markers were identified by progeny testing.

Introduction

Artificial propagation of fishes is a requisite for chromosome manipulation. Control of spawning can be by habitat manipulation or through direct hormonal intervention (Shelton, 1989). A suitable temperature and controlled photoperiod will maintain reproductive activity in tilapias throughout the year, but hormone induction of spawning can improve predictability of the collection of freshly released gametes. Chromosome manipulation includes ploidy alteration or euploidy induction with a single parent genomic contribution. Retention of the first polar body permits induction of gynogenotes (meiogynotes) or triploid progeny while interference with first karyokinesis can result in gynogenotes (mitogynotes) or tetraploids. Diploidization of the paternal genome, or androgenesis, also is accomplished by interference with first mitosis. In the case of androgenesis and gynogenesis, either the female or male DNA, respectively, must be neutralized before the egg is activated, while in the case of ploidy manipulation both parental genomes are left intact.

Chromosome manipulation involves two basic treatments after obtaining fresh gametes (Thorgaard and Allen, 1986). For androgenesis, the female genome is inactivated by ultraviolet (UV) irradiation. Treated eggs are activated by normal spermatozoa, then diploidized by shocking to interrupt the first mitotic karyokinesis. In order to prevent chromosome separation, the shock is timed to coincide with metaphase and must be sufficiently severe to disrupt microtubule and spindle fiber formation. Selection of the type of shock (thermal—cold or hot—or pressure) depends on effectiveness and ease of application. Pressure shock is more complicated than thermal treatment. Thus, shock intensity, duration, and time of application must be optimally combined into a protocol for maximum yield of progeny. Further, because the rate of development is inversely temperature dependent, either the preshock incubation temperature must be standardized or the shock time must be calibrated to the temperature effect. Absolute shock time (minutes post-activation) can be transformed with reference to an index of development rate or mitotic interval, tau (τ_0), also in minutes (Dettlaff and Dettlaff, 1961). Shock time (τ_s) can be related to tau (τ_s/τ_0) to report shock protocol in a dimensionless index which is temperature-compensated (Dettlaff, 1986). Finally, evaluation of chromosome manipulation is verified by the use of a genetic marker that carries a phenotypic expression. A visual genetic marker greatly facilitates chromosome manipulation studies. Nile tilapia (*Oreochromis niloticus*) possess two color mutations, the blond and red phenotypes (McAndrew et al., 1988). One method for verification of chromosome manipulation of the Nile tilapia is to use normal-color females and blond-mutant males. This homozygous recessive trait, blond phenotype, would usually be appropriate; however, the Ivory Coast stock of Nile tilapia to be used for this study (at the University of Oklahoma) has had some introgression of the blond gene and must be progeny-tested before use. Alternatively, the red phenotype, which is a dominant gene, can be used as an egg source with normal-color males as sperm donors.

This report describes the following:

1) Efforts to improve the efficiency of collecting freshly ovulated eggs from Nile tilapia;
2) The development of a tau curve over the spawning temperature range;
3) Preliminary data on UV treatment of eggs for induction of androgenesis; and
4) Progeny tests to identify genetic markers in the broodstock of Nile tilapia kept at the University of Oklahoma.

Methods and Materials

Spawning

The stock of Nile tilapia kept at the University of Oklahoma originated in Ivory Coast; however, it has been hybridized to an unknown level with the Egyptian Lake Manzala stock. The Egyptian strain carries the blond and red genes (McAndrew et al., 1988). Spawning of Nile tilapia was maintained throughout the year by photoperiod management. Four to six females and one male were stocked in each of four large aquaria (550 l).

Water was aerated and was circulated at a rate of one turnover per day. Temperature was cycled; it was maintained at 26 ± 2°C for approximately one week, then elevated to 29 ± 2°C for one week. The light cycle was started by adjusting a timer to turn on the overhead lighting at 0100 h; the natural sunset regulated the end of the photoperiod, which totaled 20L:4D. Tilapia spawn eight to ten hours after the beginning of the light cycle (Myers and Hershberger, 1991). Ovulation and spawning readiness can be judged by courtship behavior, coloration, and papilla erection (Rothbard and Pruginin, 1975; Rothbard, 1979). Preliminary trials of hormone-induced ovulation were based on information from Gissis et al. (1988) who used a commercial gonadotropin-releasing hormone analogue (GnRHa) product (Dagin), which includes a dopamine antagonist. The injection level was 10 mg kg^{-1} and was compared with a luteinizing hormone-releasing hormone analogue (LHRHa) (without a dopamine antagonist) at the same dose and human chorionic gonadotropin (HCG) at 3500 IU kg^{-1}. Females were stripped after initiation of spawning or as judged from the courtship behavior characteristics described above.

Fertilization

Eggs were collected in a clean container, milt was expressed over the eggs, and water was added directly to initiate activation. Fertilized eggs were placed in incubators within 2 to 3 min at controlled temperature ± 0.2°C. Incubation temperature was regulated closely to document the developmental rate. Eggs were subsequently incubated in downflowing units (1-l capacity) with sufficient flow to gently tumble the developing embryos.

Tau Estimates

Developmental rate is defined as the duration of one mitotic cycle during early synchronous cleavage (Dettlaff and Dettlaff, 1961). The mean interval between the initiation of the first and third mitoses in 5 to 10% of the eggs was recorded at temperatures within the usual developmental range (20 to 30°C). Twenty to thirty eggs were examined under magnification at 5-min intervals. Tau curves have been used to facilitate chromosome manipulation studies in various fishes (Shelton and Rothbard, 1993; Shelton et al., 1997) and are a primary criterion in timing the shock for Nile tilapia.

UV treatment

Freshly ovulated eggs were stripped from females and allocated into six subsamples for differential UV exposures. Two to four hundred eggs were placed in each of six 10-cm petri dishes with enough water to provide slight buoyancy. Five dishes were placed in a UV crosslinker (FisherBiotech, FB-UVXL-1000) and exposed to 100 to 500 J m^{-2}. One subsample was not exposed to UV. The UV-treated eggs were then activated with freshly collected spermatozoa as described above, and after 30 min they were transferred to individual flow-through incubators. Development was monitored through hatching and swim-up stages.

Progeny Testing

Progeny from pair-spawned, individually tagged broodstock were hatched in the system described above. Swim-up fry were nursed in individual small-mesh hapas until pigment patterns were developed. Parental genotype for color mutations was inferred from ratios of progeny color pattern.

RESULTS AND DISCUSSION

Photoperiod manipulation shifted spawning activity to midday. Females ovulated/spawned between 8.7 and 14.5 h (mean = 11.4 h, n = 33) after the light-on cycle. There was no apparent correlation between the latent period and water temperature ranging from 23 to 28°C. Spawning was less frequent when temperatures were maintained below 25°C, but appeared more frequent and synchronized under the alternating high end of the temperature cycling.

During the 1997-98 period, eggs were collected from 86 natural pair spawnings, and an additional 87 pairings were made through stripping and artificial fertilization. Fertilization and hatching rate were variable for natural spawning and artificial fertilization; zero hatch data are not included for natural spawning or artificial fertilization. From 41 natural spawnings an average of 44% hatched compared to 18% hatch from 11 groups of eggs that were artificially fertilized; 16% of the larvae from natural spawning survived to swim-up, while only 9% of the larvae from artificial spawning survived to swim-up. Initiation of intraovarian egg resorption is common among tilapias and although it does not prevent ovulation of the deteriorated eggs, fertilization and hatching are poor (Peters, 1983). Some of the problem may also be in the type of incubation and the developmental stage of the egg when incubation outside the buccal cavity began. Hatch rate in down-flow incubators is better than in upwelling ones (Rana, 1986), but neither is as efficient as the natural system. Eggs removed from the buccal cavity early in development generally have lower survival than eggs left in the buccal cavity until nearer to hatching. Eggs fertilized in vitro must be incubated in artificial systems, and thus lower survival is expected.

Ovulation based on the light cycle has been a reasonable means of anticipating stripping time. Hormonal induction of ovulation would seem to be a logical extension, but cichlids have responded poorly to gonadotropic therapy (Rana, 1988), with the exception of the data from Gissis et al. (1988). In preliminary studies, seven tests with Dagin had a mixed response. In the first trial with six females, five ovulated; however, each subsequent trial was less successful. In two trials with Dagin, LHRHa, and HCG, only HCG increased ovulation rate over the control group. While controlled ovulation for the Nile tilapia is not too encouraging, the physiological characteristics of tilapia gametes provide advantages for chromosome manipulation. In contrast to most fishes, tilapia eggs are fertile for 3 to 6 h post-immersion in water (Myers et al., 1995) and sperm remain motile in water for several hours (Yeheskel and Avtalion, 1986). Even though the fertility of gametes should not deteriorate during UV treatment in comparison with other fishes, the relatively low fertilization and hatch rate for untreated eggs may neutralize these attributes.

Estimates of tau were made for 23 trials with temperatures ranging from 20.6 to 28.7°C (Figure 1). The calculated tau curve is described by the following equation:

$$\tau_0 = 10^{5.4167}\ C^{-2.7009}\ (r^2 = 0.90)$$

where

C = temperature in Centigrade.

The tau-temperature relationship was inverse and ranged from 73.8 to 30.1 min in the observed temperature range. Time to

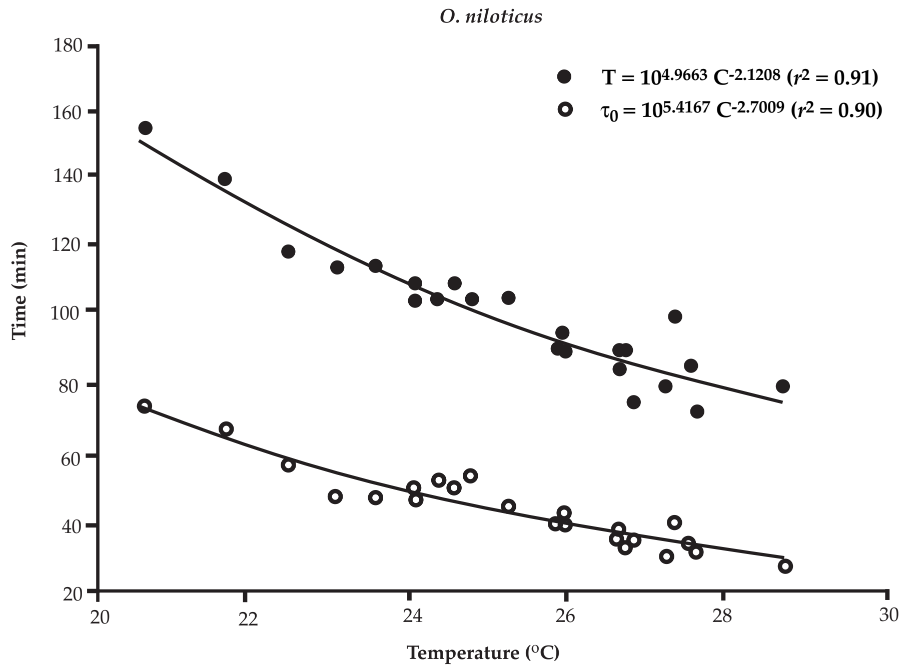

Figure 1. Mitotic interval (τ_0) and time to first mitosis (T) for *Oreochromis niloticus*.

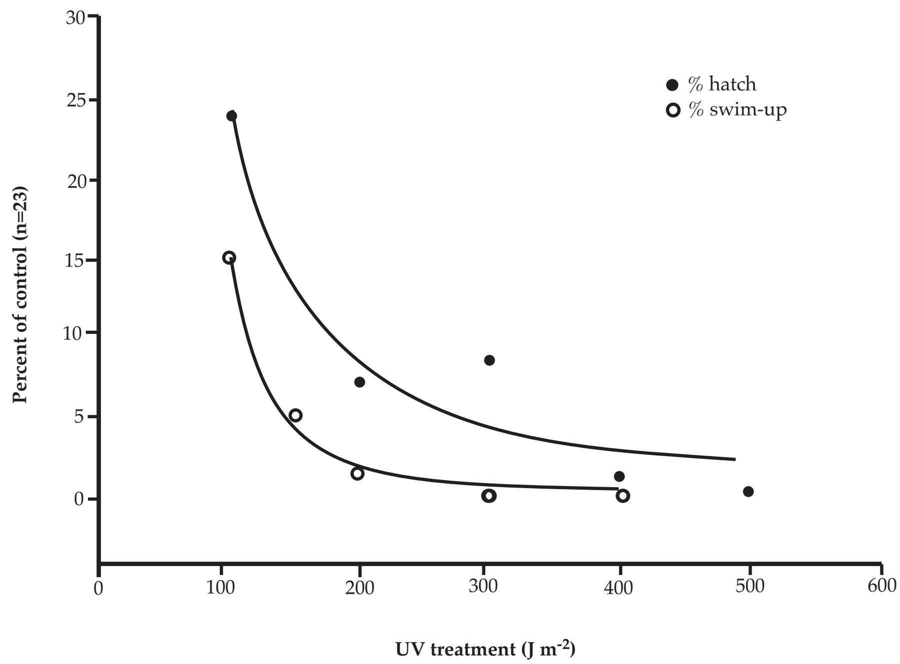

Figure 2. Effect of ultraviolet (UV) dose on hatch and swim-up rate for *Oreochromis niloticus*.

first mitosis (T) is also included because the relative time to first metaphase will be important in late shock protocol. The empirical relationship is characterized by the curve:

$$T = 10^{4.9663}\, C^{-2.1208}\ (r^2 = 0.91)$$

These working curves can be used to standardize shock treatments.

The UV treatment of eggs was tested in 23 trials, but useable data were obtained from only 11 tests. Hatch rate was generally reduced to zero at a dose of 400 to 500 J m^{-2}, but survival to swim-up was zero at 300 to 400 J m^{-2} (Figure 2). Note the apparent rise in percent hatch between 200 and 400 J m^{-2}, which might be evidence of a Hertwig effect (Chourrout and Itskovich, 1983). Again, relatively low levels of fertility (16% hatch and 8% survival to swim-up in the controls) complicate confidence in the relationship. These data are in general agreement with the dosage level of 400 to 600 J m^{-2} reported by Myers et al. (1995) to inactivate the ova genome in Nile tilapia.

Functional genetic color markers were examined for 31 pair spawnings between four males and ten females. Progeny tests indicated that two of the males were not carrying the recessive gene for the blond phenotype and five females were homozygous for normal color. Thus, eggs from these females can be used in androgenic trials with blond males.

Tilapia of the Ghana strain, which do not carry the blond gene, were received during this season and can be used as egg donors in the future. In addition, a founder stock of a strain of Nile tilapia with the red phenotype was obtained from Israel this year. This strain also can be used in the androgenetic studies, but from a different orientation because the red phenotype is dominant (McAndrew et al., 1988).

The most effective type of shock, thermal or pressure, must be addressed. Thermal shocks will be used for practical reasons because effectiveness is as good as or better than pressure shock. Don and Avtalion (1988a) used cold shock for tetraploid induction based on a comparison of hot and cold shocking for triploid induction (Don and Avtalion, 1988b). Heat or pressure shock to induce tetraploidy and mitotic gynogenesis should also provide an alternative for endomitotic protocol (Mair, 1993; Hussain et al., 1993; 1998); however, only one study has developed androgenetic protocol for tilapia (Myers et al., 1995). The timings for shock reported by Myers et al. (1995) at 27 min post-activation (28°C) and by Hussain et al. (1993) at 47 min (28°C) sharply contradict the optimal shock times of 78 min (28°C) and 92 min (26°C) post-activation reported by Shirak (1996) and Don (1989), respectively, even when adjusted for temperature. Therefore, these reported optimal times and shock types will be examined using the tau information acquired in this study.

Anticipated Benefits

Development of androgenesis for *O. niloticus* should directly provide an alternate means of producing YY-males for monosexing through breeding.

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STEROID IMMERSION FOR MASCULINIZATION OF TILAPIA: IMMERSION OF TILAPIA FRY IN MDHT

Eighth Work Plan, Reproduction Control Research 2A (RCR2A)
Final Report

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ABSTRACT

The effects of a single immersion of fry in the androgen 17α-methyldihydrotestosterone (MDHT) on masculinization of Nile tilapia were investigated. Previous experiments had demonstrated that two immersions in 500 μg l^{-1} of this steroid for three hours each on days 10 and 13 after fertilization resulted in greater than 90% male populations. In the study described below, tilapia fry were immersed once in 500 μg l^{-1} of MDHT for two hours on days 10, 11, or 13 after fertilization. Significant masculinization occurred only in the group immersed on day 13 after fertilization, and the proportion of males produced (79.3%) was not significantly different from the proportion of males produced (82.9%) after two immersions on days 10 and 13 after fertilization.

INTRODUCTION

The production of single sex populations offers several advantages in tilapia aquaculture, including enhanced growth and prevention of unwanted reproduction. A number of androgens have been shown to masculinize various tilapia species, including 17α-methyltestosterone (MT; summarized by Pandian and Varadaraj (1990) for *Oreochromis mossambicus*); mibolerone (Torrans et al. (1988) with *O. aureus*); fluoxymesterone (Phelps et al. (1992) with *O. niloticus*); norethisterone acetate (Varadaraj (1990) with *O. mossambicus*); 17α-ethynyltestosterone (Shelton et al. (1981) with *O. aureus*); 17α-methylandrostendiol (Varadaraj and Pandian (1987) with *O. mossambicus*); and trenbolone acetate (Galvez et al. (1996) with *O. aureus*).

Aquaculturists usually administer hormones to fish through the diet, but this method is prone to inefficiencies such as uneven exposure to steroid due to the establishment of feeding hierarchies or the availability of supplemental feed from pond primary productivity. Immersion of tilapia fry in steroid solutions may be one way to achieve masculinization and avoid these inefficiencies. This technique is well-developed in salmonid aquaculture (Piferrer and Donaldson, 1989; Feist et al., 1995); however, it remains largely experimental in tilapia culture. Most of the reported studies immersed tilapia fry in androgens for periods of over one week to five weeks (Varadaraj and Pandian, 1987; Torrans et al., 1988). Recently, Gale et al. (1995) demonstrated that immersion for just three hours in 17α-methyldihydrotestosterone (MDHT) on two days resulted in masculinization of Nile tilapia. The study described below was undertaken to determine if these findings could be extended through examination of the effects of a single immersion in MDHT.

METHODS AND MATERIALS

Breeding families of Nile tilapia, *Oreochromis niloticus*, obtained from Auburn University, were placed in 200-l aquaria (one male to three females). The temperature was maintained at 28 ± 2°C. Time of spawning was monitored every two hours. All spawning occurred between 4 and 7 pm. Once breeding occurred, the other fish were removed and the brooding female left to incubate the progeny. At 280 Celsius Temperature Units (CTU) post-fertilization, fry were removed from the tank and randomly assigned to experimental groups. A reference of 280 CTU was used because Gale et al. (1995) obtained 90-100% masculinization by immersing fry on 10 and 13 days post-fertilization (dpf) while maintaining the brooding females at a mean temperature of 28°C. In these experiments, a possible correlation between developmental stages and sensitivity to masculinization was sought, and CTU were estimated by multiplying the mean water temperature by the number of days, or estimated hourly when needed (e.g., day 10 at 28°C = 280 CTU). The fry used in this experiment came from an individual female. Each replicate was housed in a 3.8-l glass jar with dechlorinated tap water. The water in all treatments was maintained at 28 ± 2°C under constant aeration. Treatments consisted of immersions in either steroid or ethanol (EtOH), which were mixed 60 s before addition of fry. Steroids were obtained from Sigma Chemical Company (St. Louis, Missouri) and stored in stock solutions of ethanol (1 mg ml^{-1}).

Fry were immersed for two hours at 280, 310, or 364 (10, 11 or 13 dpf), or twice at 280 and 364 CTU in 500 μg l^{-1} of MDHT at a density of 33 fish l^{-1} in each replicate. Fish in the EtOH control group were immersed at 280 and 364 CTU. Each experimental group was triplicated. Fry were collected after each immersion, jars were thoroughly cleaned, and then fish were reallocated in fresh dechlorinated tap water. After seven days, fry were transferred to the Oregon State University Warm Water Research Laboratory, Corvallis, Oregon, and reared in 75-l fiberglass tanks in a recirculating system. Temperature and pH were monitored daily; ammonia, nitrites, dissolved oxygen, alkalinity, and hardness were checked weekly. Water temperature in the grow-out system was maintained at 28 ± 2°C. At 60 to 70 dpf, sex ratios were determined by examination of gonads using squash (10 and 40X) preparations after aceto-iron hematoxylin (Wittman, 1962) staining. The weights of sampled fish were recorded at this time.

Data were pooled from replicate tanks, because there was no evidence of tank effects within treatments (Fisher's test or ANOVA). Sex ratio and mortality data were analyzed using Fisher's exact test with exact p-values (a more conservative test than the chi-square test for small sample sizes) estimated in GraphPad Prism™. The mean final weights of sampled fish were analyzed for differences between groups using one-way ANOVA including mortality as a possible confounding variable. For all analyses, differences were considered statistically significant when the p-value (P) was less than 0.05.

RESULTS

The sex ratios of tilapia treated with a single immersion in MDHT at 364 CTU (13 dpf) or two immersions at 280 and 364 CTU (10 and 13 dpf) were significantly skewed towards males in comparison to those of controls (56.6% males; $P < 0.001$). Single immersion in MDHT at 364 CTU resulted in 79.3% males, which was not significantly different from the two immersions at 280 and 364 CTU (82.9% males). No significant masculinization effects were observed in groups immersed once in MDHT at either 280 CTU (10 dpf) or 310 CTU (11 dpf).

Mortality and final weight data were not significantly different among treatment groups. Water quality in rearing tanks was maintained close to the optimal values for tilapia culture (data not shown).

DISCUSSION

We have demonstrated that short-term immersion in steroid can result in masculinization of Nile tilapia. Similar results were reported by Gale et al. (1995). A single immersion in MDHT at 364 CTU (13 dpf at 28°C) was as effective as two immersions at 280 and 364 CTU. The current experiments did not result in the level of masculinization (> 93%) that Gale et al. (1995) achieved; however, the latter study used two 3-hour immersions whereas two 2-hour immersions were used in this study.

The lack of significant masculinization in tilapia exposed to MDHT for two hours at 280 or 310 CTU suggests that the period of sensitivity to steroid-induced masculinization is several days after the onset of feeding, in contrast to salmonids, which must be immersed as yolk-sac fry (Piferrer and Donaldson, 1989; Feist et al., 1995).

ANTICIPATED BENEFITS

We have successfully developed a technique for masculinizing Nile tilapia with a single immersion in masculinizing steroid. This latest development will increase the ease of use of immersion as an alternative to dietary treatment with androgens for sex inversion.

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PD/A CRSP SIXTEENTH
ANNUAL TECHNICAL REPORT

EFFECT OF FISH DENSITY ON EFFICACY OF MASCULINIZATION BY IMMERSION IN MDHT

Eighth Work Plan, Reproduction Control Research 2B (RCR2B)
Final Report

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ABSTRACT

The effect of fish density on the capacity of the synthetic androgen 17α-methyldihydrotestosterone (MDHT) was investigated. As in previous studies in this laboratory, significant masculinization occurred when fish were immersed in 500 $\mu g\ l^{-1}$ of MDHT for two hours at 280 and 364 CTU at a density of 33 fish l^{-1} (80.3% males vs. 56.7% males in the controls). When the density during treatment was increased to either 66 or 100 fish l^{-1}, MDHT immersion resulted in 71.7% males in both treatments, which was nearly significantly more than controls, and suggests an effect of stocking density on masculinization.

INTRODUCTION

Masculinization of tilapia for the production of male-biased populations continues to be an important tool for aquaculturists to prevent unwanted reproduction (which shunts energy away from growth towards gamete production) and to produce the sex with the larger growth potential. Previous work in our laboratory has shown that short-term immersion in androgenic steroids can result in masculinization of Nile tilapia (Gale et al., 1995; Fitzpatrick et al., 1998). These studies show that immersion in androgen has the potential to be an alternative to dietary treatment with steroids for the masculinization of tilapia. A variety of androgens—especially synthetic androgens—are effective masculinizing agents (Hunter and Donaldson 1983); however, there may be differences in their potency. Fitzpatrick et al. (1998) showed that a single immersion in the non-aromatizable synthetic androgen 17α-methyldihydrotestosterone (MDHT) at 364 CTU (Day 13 post-fertilization at 28°C) was as effective as two immersions in MDHT at 280 and 364 CTU. Either treatment resulted in significantly more males being produced than in the controls. While these results demonstrated the potential for immersion, they did not determine optimal treatment conditions. Another androgen trenbolone acetate (TBA) was recently reported to be an effective masculinizing agent when fed to tilapia (Galvez et al., 1996). While we have had variable success masculinizing tilapia by immersion in 17α-methyltestosterone (MT), we have recently begun to examine the efficacy of immersion in TBA.

In order to determine the best treatment conditions for masculinization by immersion, studies must be conducted on those factors that are believed to play a critical role in determining efficacy. For masculinization by immersion, the major factors are type of hormone, timing of treatment (relative to fish development), hormone dosage, duration of exposure, and density of fish during immersion. In both of these studies, the density of fish during immersion was maintained at 33 fish l^{-1}. Fitzpatrick et al. (1998) showed that significant masculinization by single immersion in MDHT could only be achieved by exposure at 364 CTU (Day 13). No significant masculinization effects were observed in groups immersed once in MDHT at either 280 (Day 10) or 310 CTU (Day 11). Thus, we have narrowed the period during which Nile tilapia are sensitive to immersion to after Day 11 in MDHT at 500 $\mu g\ l^{-1}$, at 364 CTU, and at 33 fish l^{-1}.

Because density, hormone dosage, and length of exposure are factors that may interact, a factorial design is needed to know the minimum dosage required, the highest density to use, and the shortest exposure needed. Little information has been generated regarding these factors, and because of a limitation in the availability of fry of a known age, the traditional designs involve one factor at a time. However, when another factor is tested, the best set for the previous factor tested may be affected by interactions among factors.

Because many factors may influence treatment efficacy, conducting a single experiment in which all factors are examined simultaneously at different levels would require large numbers of tanks and more tilapia fry than can be produced from a single spawning. Therefore, our approach up to this time has been to examine one factor at a time while holding all others constant. We will describe such a study on the effects of fish density which was based on the best treatment conditions reported in the PD/A CRSP Fifteenth Annual Technical Report (Fitzpatrick et al., 1998). However, this approach limits the amount of information that can be gained on the interactions among the various factors. Therefore, we will also describe another experiment that was carried out using a fractional factorial design (Kuehl, 1994) to examine multiple factors (hormone dosage, exposure duration, and fish density) simultaneously with the TBA. This design allows information to be obtained on factors of interest in the early stages of experimentation when the number of treatments exceeds the resources (Kuehl, 1994).

METHODS AND MATERIALS

Breeding families of Nile tilapia (*Oreochromis niloticus*) were placed in 200-l aquaria (one male to three females). The temperature was maintained at 28 ± 1°C. Time of spawning was monitored every 2 hours. All spawning occurred between 1600 and 1900 h. Once breeding occurred, the other fish were removed and the brooding female was left to incubate the progeny. At 280 Celsius Temperature Units (CTU) post-fertilization, fry were removed from the tank and randomly assigned to experimental groups. The first experiment was conducted simultaneously with the experiment reported in Fitzpatrick et al. (1998). Double immersions spaced several days apart (see below) were chosen as the best treatment timing. The second experiment used double immersions on consecutive days (see below) as the best treatment. Development of the fry was expressed in CTUs (mean water temperature in °C x the number of days since fertilization). The fry used in the experiment came from an individual female. Each replicate was housed in a 3.8-l glass jar with dechlorinated tap water. The water in all treatments was maintained at 28 ± 1°C under constant aeration. Treatments consisted of immersions in either steroid or ethanol (EtOH), which were mixed before addition of fry. Steroids were obtained from Sigma Chemical Company (St. Louis, Missouri) and stored in stock solutions of ethanol (1 mg ml^{-1}).

For experiment 1, fry were immersed for two hours at 280 and 364 CTU (10 and 13 days postfertilization; dpf), in 500 µg l^{-1} of MDHT at densities of 33, 66, 100, or 200 fish l^{-1} in each replicate. Fish in the EtOH control group were immersed at 280 and 364 CTU at a density of 33 fish l^{-1}. Each experimental group was triplicated.

For experiment 2, a fractional factorial design was used to examine the effects of fish density, hormone dosage, and exposure duration simultaneously. Fry were immersed at 364 and 392 CTU (13 and 14 dpf) in either TBA or EtOH. Fry densities were 12, 25, 50, 100, or 200 fish l^{-1}; hormone dosages were 62.5, 125, 250, 500, or 1000 µg l^{-1}; exposure duration was 0.75, 1.5, 3, 6, or 12 h. Because a fractional factorial design was used, only certain combinations of treatment conditions were used. To choose the combination of treatment factors to be used, a model was generated using Statistical Analysis Systems for Windows. Under this model, only replication around the middle treatment level for each factor is recommended. The fractional factorial design is effective in screening studies to check on many factors, with the assumption that only a few effects are important. However, the fractional factorial design carries the caveat that follow-up experiments must be conducted using suitable replication once the levels for the various factors are chosen.

Fry were collected after each immersion, jars were thoroughly cleaned, and then fish were reallocated in fresh dechlorinated tap water. Seven days after the final immersion, fry were transferred to Oregon State University's Warm Water Research Laboratory, Corvallis, Oregon, and reared in 75-l fiberglass tanks in a recirculating system. Temperature and pH were monitored daily; ammonia, nitrites, dissolved oxygen, alkalinity, and hardness were measured weekly. Water temperature in the grow-out system was maintained at 28 ± 1°C. At 60 to 70 dpf, sex ratios were determined by examination of gonads using squash (10 and 40X) preparations after aceto-iron hematoxylin staining (Wittman, 1962). The weights of sampled fish were recorded at this time.

For experiment 1, data were pooled from replicate tanks because there was no evidence of tank effects within treatments (Fisher's test or ANOVA). Sex ratio and mortality data were analyzed using Fisher's exact test with exact p-values (a more conservative test than the chi-square test for small sample sizes) estimated in GraphPad Prism™. The mean final weights of sampled fish were analyzed for differences between groups using one-way ANOVA, including mortality as a possible confounding variable. For all analyses, differences were considered statistically significant when the p-value (P) was less than 0.05. For experiment 2, the data were not analyzed statistically because of the sex ratio bias (see Results). Had the results been unbiased, the data obtained for each treatment combination would have allowed for the creation of a response surface. The response surface, contours primarily formed by linear and quadratic equations, may show how the response increases or decreases based on the interaction of the factors tested and indicates trends along levels of the factors.

RESULTS

Experiment 1: Effects of Density

Treatment with MDHT resulted in masculinization of tilapia (Figure 1). The percentage of males in the 33 fish l^{-1} treatment was significantly higher than in the control group (80.3% vs. 56.7%; $P = 0.004$), whereas the percentage of males in the 67 (71.7%) and 100 (71.7%) fish l^{-1} treatments were not quite significantly different from controls ($P = 0.06$). The proportion of males in the only replicate of the treatment with 200 fish l^{-1} (64.5%) was not significantly different from the control.

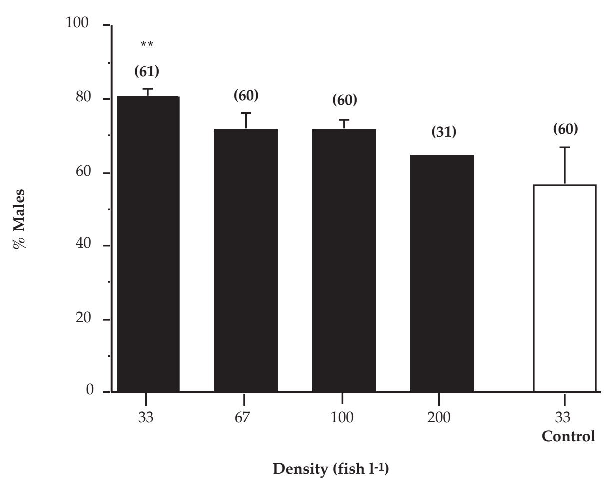

Figure 1. Effect of different fish densities during treatment on masculinization of Nile tilapia (*Oreochromis niloticus*) fry by two MDHT immersions. Sample size for each density is shown in parentheses. Masculinization ratios that were significantly different from controls are represented by asterisks ($P < 0.01$).

Mortality and final weight data were not significantly different among treatment groups. Water quality in rearing tanks was maintained close to the optimal values for tilapia culture (data not shown).

Experiment 2: Fractional Factorial

All control groups (immersed in EtOH or unimmersed) and treatment groups contained 100% males. Therefore, the data were not analyzed further.

DISCUSSION

Significant masculinization occurred when fish were immersed in 500 µg l^{-1} of MDHT for two hours at 280 and 364 CTU at a density of 33 fish l^{-1}. The ratios of males produced by MDHT immersion at the 66 and 100 fish l^{-1} were nearly significantly different than controls, and suggest an effect of stocking density on masculinization. The most effective stocking density in this study was 33 fish l^{-1}, which is nearly five times that reported by Torrans et al. (1988) in a study in which *O. aureus* were masculinized by immersion for five weeks in mibolerone.

Although a stocking density can be recommended on the basis of this experiment, further study is needed to assess the interaction of the major factors that influence susceptibility to androgen-induced masculinization. The fractional factorial design presented an opportunity to explore the influence of several major factors and their interactions; however, the control fish turned out to be all male. Such extreme sex ratios in tilapia, while obviously problematic in the current study, are not unusual (see Shelton et al., 1983). Nevertheless, determination of the effects of TBA dosage, fish density, and treatment duration on masculinization must be conducted using a brood with a more balanced sex ratio. An experiment using a similar fractional factorial design is now underway in our laboratory.

ANTICIPATED BENEFITS

We have successfully refined the technique for masculinizing Nile tilapia by immersion in masculinizing steroid. This latest development defines one of the key variables that affects the success of immersion and provides information critical to the use of immersion as an alternative to dietary treatment with androgens for sex inversion. The development of this new technology for masculinization of tilapia may enable farmers to masculinize tilapia with androgens while minimizing the risk of pond contamination with MT. Defining the critical stage of development when tilapia are susceptible to masculinization by immersion may also provide important clues as to when tilapia are susceptible to masculinization by treatments that do not involve hormones (e.g., temperature and pH).

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Masculinization of Tilapia Fry by Immersion in Trenbolone Acetate (TBA) at a Production Level

Eighth Work Plan, Reproduction Control Research (RCR2C)
Progress Report

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Abstract

The precocious reproduction of tilapias (*Oreochromis* spp.) had been a serious impediment to successful commercial tilapia production until all-male cultures techniques were developed. Dietary treatment with 17α-methyltestosterone (MT) is an effective means of producing all-male tilapia populations; however, the treatment requires a minimum of several weeks exposure. Administration of steroids to the water containing sexually undifferentiated fish has also been effective in altering sex ratios and may provide aquaculturists with a safe and cost-effective alternative to treating fry with food that contains MT. Immersion requires substantially shorter exposure periods and the steroid is contained for controlled filtration or biodegradation. *Oreochromis niloticus* fry were stocked into aquaria and treated at a density of 33 fish l^{-1} with a stock solution of trenbolone acetate (TBA) dissolved in ethanol at 500 mg TBA l^{-1} for six hours on day 9, 11, 13, or 15 post-hatch. Fish were harvested and mean length, weight and survival were determined. Fish were restocked into outdoor 20-m^2 tanks and reared to 5 cm or larger. Sex ratios were determined by gonadal squashes. There was no treatment effect on sex ratio of Nile tilapia. The non-TBA treatment had a mean of 49.1% males while TBA treatments for the different age groups ranged from 43.7 to 54.3% males. Survival ranged from 64.0 to 82.4% with no observed correlation between age at treatment and survival. Average length and weight at 20 days of age was not correlated to treatment nor survival.

Introduction

The precocious reproduction of tilapias (*Oreochromis* spp.) had been a serious impediment to successful commercial tilapia production until all-male culture techniques were developed. In comparison with mixed populations, all-male populations of tilapia provide several important advantages for aquaculture, including superior growth (males grow faster and larger than females) and prevention of unwanted reproduction (which diverts energy away from somatic growth). Some techniques, including the manual separation of males and selective hybridization, are technically feasible but introduce labor and management constraints to commercial operations. The administration of androgens during early life stages, commonly called "sex reversal," effectively produces all-male populations of tilapia. The efficacy and operational simplicity of the technique have led to dramatic worldwide increases in commercial production of this group of fishes.

Dietary treatment with 17α-methyltestosterone (MT) is an effective means of producing all-male tilapia populations; however, the treatment requires a minimum of several weeks exposure. Administration of steroids to the water containing sexually undifferentiated fish has also been effective in altering sex ratios and may provide aquaculturists with a safe and cost-effective alternative to treating fry with food that contains MT, because immersion will require substantially shorter exposure periods and the steroid will be contained for controlled filtration or biodegradation. This technique is well-developed in salmonid aquaculture (Piferrer and Donaldson, 1989; Feist et al., 1995); however, it remains largely experimental in tilapia culture. For *O. aureus*, immersion of fry in mibolerone at 0.6 mg l^{-1} for five weeks resulted in populations that were 82% male (the remaining fish were intersexual), and a 0.3 mg l^{-1} mibolerone immersion for five weeks resulted in less than 1% functional females (Torrans et al., 1988). Immersion of *O. mossambicus* in 17α-methylandrostendiol at 5 μg l^{-1} for 11 days beginning at seven or ten days post-hatching caused 100% masculinization (Varadaraj and Pandian, 1987). Fitzpatrick et al. (1997) were able to produce greater than 90% male populations of *O. niloticus* when trenbolone acetate was administered as a 2-h bath on days 11 and 13 post-fertilization.

These studies suggest that immersion may be an alternative method for inducing masculinization in tilapia, but whether it is functional on a production scale is unknown. Immersions by Fitzpatrick et al. (1997) were successful because treatment time was initiated as a function of water temperature and time of egg fertilization. Individual females were monitored to determine when ovulation occurred. In practice this degree of monitoring is not feasible, but it is possible to determine time of hatch and swimup within a few hours. Tilapia reproduction systems have been developed where eggs are collected in commercial quantities and incubated artificially (Macintosh and Little, 1995). Using such techniques, it is possible to monitor time of hatch and swimup and apply a hormone bath to fry when age to the nearest day is known.

Methods and Materials

Brood Nile tilapia (*O. niloticus*) were stocked outdoors into 2-m^2 hapas at a rate of one male and three females per hapa. Brood fish were examined every ten days and eggs or sac fry were removed. Eggs and sac fry were held in flowing water McDonald jars at 28 to 32°C, and swimup fry were collected as soon as they were strong enough to swim out of the incubator. Swimup fry were held until 9, 11, 13, or 15 days post-hatch.

At the appropriate age, fish were stocked in aquaria at a density of 33 fish l^{-1} and treated with a stock solution of trenbolone acetate (TBA) dissolved in ethanol at 500 mg TBA l^{-1} for six hours. Three replicate aquaria were treated with TBA on day 9, 11, 13, or 15 post-hatch. An additional three aquaria were stocked with nine-day post-hatch fry and treated six hours in an ethanol-only stock solution. Fish were held in aquaria until an age of 20 days and fed a non-hormone-treated feed four times per day. Fish were harvested and mean length, weight, and survival were determined. Fish were restocked into outdoor 20-m^2 tanks and reared to 5 cm or larger. Fish were harvested and preserved in 10% formalin for gonadal examination. Gonads from 100 fish per replicate were examined by the gonadal squash technique (Guerrero and Shelton, 1974) and classified as testes, ovaries, or intersex (if composed of both tissues).

RESULTS AND DISCUSSION

There was no treatment effect on the sex ratio of Nile tilapia (Table 1). The non-TBA treatment (control) had a mean of 49.1% males while TBA-treated fish in the age groups tested ranged from 43.7 to 54.3% males. Survival ranged from 64.0 to 82.4% with no correlation observed between age at treatment and survival. Average length and weight at 20 days of age was not correlated to treatment or survival.

Table 1. Effectiveness of trenbolone acetate (TBA) to alter sex ratios of four age groups (days post-hatch) of Nile tilapia. Treatments were given a six-hour bath at 500 mg TBA l^{-1}.

Age Group	% Males	% Females	% Intersex	% Survival
9-d, control	49.1	50.9	0	82.4
9-d, TBA	54.3	45.7	0	69.6
11-d, TBA	54.3	45.0	0.7	72.0
13-d, TBA	43.7	56.3	0	64.0
15-d, TBA	49.7	50.3	0	75.4

The lack of response to TBA treatment is not clearly understood. Fitzpatrick et al. (1997) found that TBA is effective in altering the sex ratio of Nile tilapia under a variety of treatment protocols. Because of its effectiveness in these studies and its wider commercial availability, it was recommended that TBA be used for field testing in Auburn instead of 17α-methyldihydro-testosterone. The protocol followed in this study, in which nine-day-old fry were treated, is similar to successful protocols used by Fitzpatrick (personal communication).

Previous trials at Auburn University in which younger Nile tilapia fry were treated with bath applications of TBA to alter the sex ratio were also unsuccessful. The results of previous trials and this study show that fish with post-hatch ages of 3, 7, 9, 10, 11, 13, and 15 days do not have altered sex ratios when immersed in 500 mg l^{-1} TBA for two to six hours. In one study that used fry from only one or two spawns (Gale, 1995), mestanolone given as a bath resulted in highly skewed tilapia sex ratios. In another study, in which fry from ten or more different spawns were used, sex ratios were not as dramatically skewed (Phelps, unpublished data).

The lack of intersex fish in the current study might suggest why there was no treatment response. When tilapia fry are fed androgen-treated feed at an inappropriate dose rate or for an inappropriate treatment period, intersex fish are common. Whether such a response should be expected from a hormone bath treatment is unknown. When bluegill (*Lepomis macrochirus)* with an initial age of 34 days were given 5-h baths in 1000 mg l^{-1} TBA over a three-day period, 93% male populations with no intersex were produced, but when similar age bluegill were fed TBA for 30 days the result was a 100% intersex population (Al-Ablani, 1997).

Differences in water quality may be a factor influencing results. The efficacy of a variety of chemicals when applied to water is affected by water quality. Alkalinity, total hardness, and pH often alter the efficacy or toxicity of a chemical dissolved in water. The soft water conditions (alkalinity, 29 ppm; total hardness, 32 ppm) also may have affected the results of this study. Additional studies will be required to determine the effect of water chemistry on androgens when applied as a bath treatment.

ANTICIPATED BENEFITS

Development of steroid immersion as an alternative treatment for masculinizing tilapia will minimize treatment time and potentially increase efficiency of exposure and safety in handling masculinizing steroids. This study has identified issues that must be addressed before the promotion of immersions as an alternative procedure for producing monosex tilapia.

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Detection of MT in Aquarium Water after Treatment with MT Food

Eighth Work Plan, Reproduction Control Research 3A (RCR3A)
Final Report

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Abstract

The following study tested the hypothesis that 17α-methyltestosterone (MT) persists in the environment after its use for masculinizing Nile tilapia (*Oreochromis niloticus*). Fry were treated with a masculinizing dose of MT (60 mg kg^{-1}) for four weeks beginning at the initiation of feeding in model ponds which consisted of 3.7-l jars that contained 3 cm of soil. Water and soil samples were taken before the onset of treatment and weekly beginning on the last day of treatment (water samples were also taken weekly during the four-week treatment period). Concentrations of MT were determined by radioimmunoassay, which revealed that the levels of MT in the water peaked between approximately 1 and 2 µg l^{-1} at 14 and 21 days after the onset of feeding. Concentration of MT in water decreased to background level by 35 days after the onset of feeding (one week after the end of treatment with MT-impregnated food). In contrast, the levels in the soil were 1.4 to 1.7 µg kg^{-1} at 28 days after the onset of feeding with MT-impregnated food and remained detectable in the soil at between 0.8 and 1.6 µg kg^{-1} through 49 days (three weeks after ending treatment with MT-impregnated food). These results suggest that MT persists in sediments for at least weeks after cessation of MT treatment, which raises the possibility that unintended exposure to MT may occur.

Introduction

Production of all-male populations of tilapia through treatment of fry with 17α-methyltestosterone (MT)-impregnated food has become common throughout the world. All-male populations often have greater growth potential because no energy is shunted toward reproduction and no competition with younger fish occurs (Green et al., 1997). Despite the success of this technique, significant "leakage" of MT into the pond environment may occur from uneaten or unmetabolized food. This leakage poses a risk of unintended exposure of hatchery workers as well as fish or other non-target aquatic organisms. Furthermore, in some countries, pond sediments are dredged and sometimes used to prepare soil for crop production, thereby spreading the risk of exposure to MT to terrestrial systems and to other aquatic systems. Therefore, determining the fate of MT in semi-closed systems such as ponds will yield important information on both safety and efficacy of MT use for masculinization. To determine if MT potentially remains within the pond environment, the following study was undertaken using model pond systems.

Methods and Materials

Methods for obtaining fry were the same as those described in technical reports RCR2A (pp. 17-18) and RCR2B (pp. 19-21) of this document. Breeding families of Nile tilapia, *Oreochromis niloticus*, were placed in 200-l aquaria (one male to three females) where water temperature was maintained at 28 ± 1°C. Once breeding occurred, the other fish were removed and the brooding female was left to incubate the progeny. Model ponds were set up two days before the expected time of fry release. Each model pond consisted of a 3.8-l jar containing 3 cm (approximately 500 g) of packed soil. In Experiments 1 and 2, soil was obtained from one of the dry Soap Creek (Oregon State University) ponds located north of Corvallis. In Experiment 3, soil was obtained from a meadowed hill near the Principal Investigator's house located north of Corvallis. Each model pond contained 3 l of dechlorinated tap water. Once the female released the fry from her mouth (usually at 280 Celsius Temperature Units (CTU) post-fertilization), fry were removed from the tank and randomly assigned to the model ponds at a stocking rate of 47 fry $container^{-1}$ (1 fry [3.3 cm]$^{-2}$, which corresponds to a recommended stocking rate for masculinization of 3,000 fry m^{-2} [Popma and Green, 1990]).

The following experimental groups were included for Experiments 1 and 2: MT-fed fish (at 60 mg kg^{-1} of food) and control fish (EtOH-treated food). An additional group (MT-fed fish with twice the amount of food as the normal MT group) was included in Experiment 3. MT food was made by spraying crushed flaked food with MT dissolved in EtOH; control food was made by spraying crushed flaked food with EtOH. In each experiment, additional jars were included that contained no fish but were subjected to the usual MT feeding regime or control diet. All treatments were triplicated. Fry were fed the treatment diets for four weeks (from 11 to 39 days post-fertilization; dpf) commencing the day after release from the female. Water temperature in the jars was maintained at 28 ± 1°C. Temperature and pH were monitored daily, while ammonia, nitrites, and dissolved oxygen were checked weekly. Feeding rate was at 20% of calculated body weight for the first 23 days of treatment and then 10% of calculated body weight through day 28 of treatment (Popma and Green, 1990). Initially, evaporative water loss was made up twice weekly. However, degradation of water quality (high ammonia, high nitrites) required water exchange of half the water at 18, 22, and 24 days of dietary treatment in Experiment 1; in Experiments 2 and 3, half the water was exchanged routinely twice weekly throughout the period of dietary treatment.

After 28 days of dietary treatment (40 dpf), fry were transferred to Oregon State University's Warm Water Research Laboratory, Corvallis, Oregon, and reared in 75-l fiberglass tanks in a recirculating system. Water temperature in the grow-out system was maintained at 28 ± 1°C and water quality parameters described above were monitored. At 60 to 70 dpf, sex ratios were determined by examination of gonads using squash (10 and 40X) preparations after aceto-iron hematoxylin staining (Wittman, 1962) . The weights of sampled fish were recorded at this time.

Water samples (25 to 50 ml) were collected with pipettes into 50-ml Falcon tubes and stored at -20°C until analysis for MT. Soil core samples were collected with 1.9-cm-diameter PVC pipes, placed in whirl pak bags, excess water poured off (Experiment 1) or collected into a separate 50-ml Falcon tube (Experiments 2 and 3), and the bags stored at -20°C until analysis. In Experiments 2 and 3, the excess water (called "interface" hereafter) samples were stored frozen at -20°C. For analysis of MT concentration, 1.0 ml of each water and interface sample and 0.2 g of each soil sample were extracted in 8 ml of diethyl ether, which was collected into new tubes after the aqueous phase was snap-frozen in liquid nitrogen. The extraction procedure was repeated and the ether extracts were pooled and dried down in a SpeedVac. Each dried extract was reconstituted in 1 ml of phosphate-buffered saline containing gelatin. Aliquots of the reconstituted extracts were removed and placed in 12x75-mm tubes for determination of MT concentration by radioimmunoassay (RIA). The RIA methods

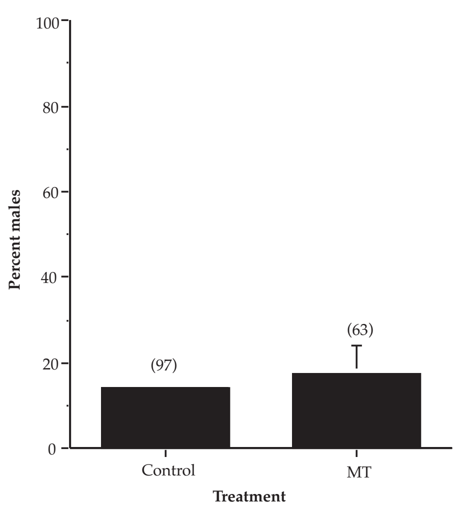

Figure 1. Effect of methyltestosterone (MT) on masculinization of *Oreochromis niloticus* fry by oral administration in Experiment 1. Fish were fed either a control diet or a diet containing 60 mg kg^{-1} of MT. Sample size for each treatment (pooled triplicates) is shown in parentheses.

followed the procedure outlined in Fitzpatrick et al. (1986; 1987). Standards of a known concentration of MT were made in EtOH and used in each assay to generate a standard curve. The assay was validated by demonstration of parallelism between serial dilutions of several samples and the standard curve, and by demonstration of low cross-reactivity with testosterone and 11-ketotestosterone. Furthermore, water samples were subjected to analysis by HPLC after extraction (as above), filtering, and reconstitution in MeOH to search for possible metabolites of MT. Extraction efficiency of MT for the RIA was checked by adding a known amount of ^{3}H-MT to water, soil, and interface samples (n = 6 for each), and then extracting the samples as described above. Once each of these tubes was reconstituted in 1 ml of phosphate-buffered saline containing gelatin; 0.5 ml was removed from each and the amount of radioactivity counted by scintillation spectroscopy (extraction efficiencies were 78.4% for water, 78.2% for soil, and 66.9% for interface).

For all experiments, sex ratio data were pooled from replicate tanks because there was no evidence of tank effects within treatments (Fisher's test or ANOVA). Intersex fish were counted as females for the purposes of analysis in order to be conservative. Sex ratio and mortality data were analyzed using Fisher's exact test with exact p-values (a more conservative test than the chi-square test for small sample sizes) estimated in GraphPad Prism™. Concentrations of MT in water, soil, and interface at the various sample times were not compared statistically because of the limited sample size (n = 3 per date) and because the goal of the study was descriptive (presence/ absence). The mean final weights of sampled fish were analyzed for differences between groups using one-way ANOVA including mortality as a possible confounding variable. For all analyses, differences were considered statistically significant when the p-value (P) was less than 0.05.

RESULTS

For Experiments 1 and 2, no significant effect of MT-treatment on sex ratio was observed. In Experiment 1, the percentage of males in the MT-treated group was 15.9%, which was not significantly different from the control group (17.3%; Figure 1). In Experiment 2, the MT-treated group had 86.7% males compared with 84.3% males in the control group (Figure 2). In Experiment 3 (Figure 3), the fish treated with MT at the normal ration had significantly more males (63.0%) than the controls (51.4%; $P = 0.0146$) and the fish treated with MT at twice the normal ration (45.7%; $P = 0.0038$). For all the experiments, the level of mortality was randomly distributed among treatments, with significant variation between replicates (data not shown).

The levels of MT were determined only for samples taken in Experiments 1 and 2. For jars that contained fish, the levels of MT in the water increased in Experiment 1 to an average of 1.2 µg l^{-1} after one week of feeding MT-impregnated food (Figure 4a). Concentrations of MT in the water remained elevated throughout the feeding treatment and declined to pretreatment levels by one week after the cessation of dietary treatment. There was a higher background level of MT for the soil; nevertheless, MT in the soil increased to a mean 1.7 µg g^{-1} of soil at the conclusion of dietary treatment with MT (Figure 4b) and remained elevated through the end of the experiment (three weeks after cessation of dietary treatment). In Experiment 2, similar results were found. Levels of MT in the water increased to 0.8 µg l^{-1} after one week and decreased to background levels within a week of cessation of dietary treatment (Figure 5a). Concentrations of MT in the soil increased to a mean of 1.4 µg g^{-1} of soil at the end of four weeks of dietary treatment with MT (Figure 5b) and remained well above background levels through the end of the experiment. The average interface level of MT was 0.2 µg ml^{-1} at the end of four weeks of dietary treatment and remained at this level through the end of the experiment. Variation in the levels of MT measured in the soil samples in both experiments was considerably higher than that in the water samples.

In jars that contained no fish but received the same amount of MT (data not shown), the average level of MT in the water was 2.3 µg l^{-1} at the end of week 1, 3.1 µg l^{-1} at the end of week 4 in Experiment 1, and at pretreatment levels by week 5. Mean level of MT in the soil for this experiment was 13.1 µg g^{-1} of soil at the end of week 4 and 8.9 µg g^{-1} of soil at the end of week 7. In Experiment 2, average MT concentration in the water was 2.7 µg l^{-1} at the end of week 1, 2.3 µg l^{-1} at the end of week 4, and at pretreatment level by the end of week 5. Mean soil MT was 5.1 µg g^{-1} of soil at the end of week 4 and 8.8 µg g^{-1} of soil at the end of week 7.

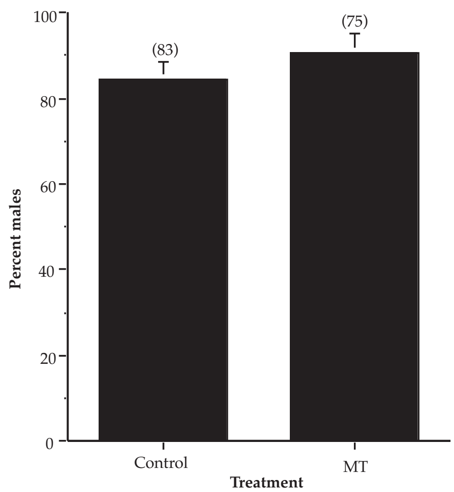

Figure 2. Effect of methyltestosterone (MT) on masculinization of *Oreochromis niloticus* fry by oral administration in Experiment 2. Fish were fed either a control diet or a diet containing 60 mg kg^{-1} of MT. Sample size for each treatment (pooled triplicates) is shown in parentheses.

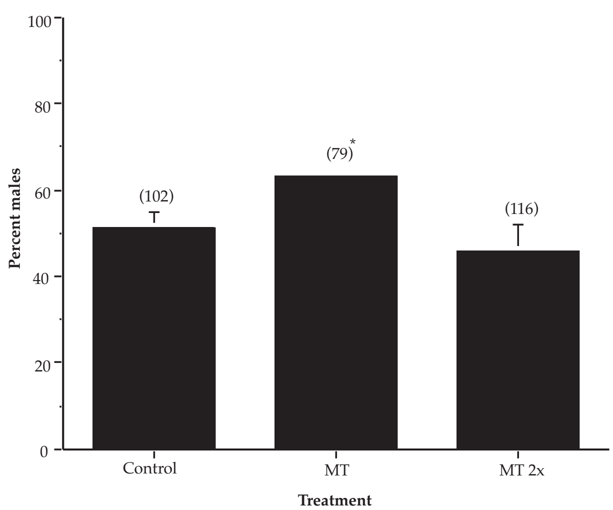

Figure 3. Effect of methyltestosterone (MT) on masculinization of *Oreochromis niloticus* fry by oral administration in Experiment 3. Fish were fed either a control diet, a diet containing 60 mg kg^{-1} of MT, or the MT diet at twice the ration (2X). Sample size for each treatment (pooled triplicates) is shown in parentheses. Statistically significant difference from control in the proportion of males is represented by an asterisk ($P < 0.05$).

DISCUSSION

These experiments demonstrate that considerable amounts of MT leak into the environment during dietary treatment. Although the levels of MT in the water peaked between approximately 1 and 2 µg l^{-1} at 14 and 21 days after the onset of feeding, the concentration decreased to background level by 35 days after the onset of feeding (one week after the end of treatment with MT-impregnated food). In contrast, the levels in the soil were 1.4 to 1.7 µg kg^{-1} at 28 days after the onset of feeding with MT-impregnated food and remained detectable in the soil at between 0.8 and 1.6 µg kg^{-1} through 49 days (three weeks after ending treatment with MT-impregnated food). Interface levels of MT were higher than background, but lower than peak levels found in the soil or water.

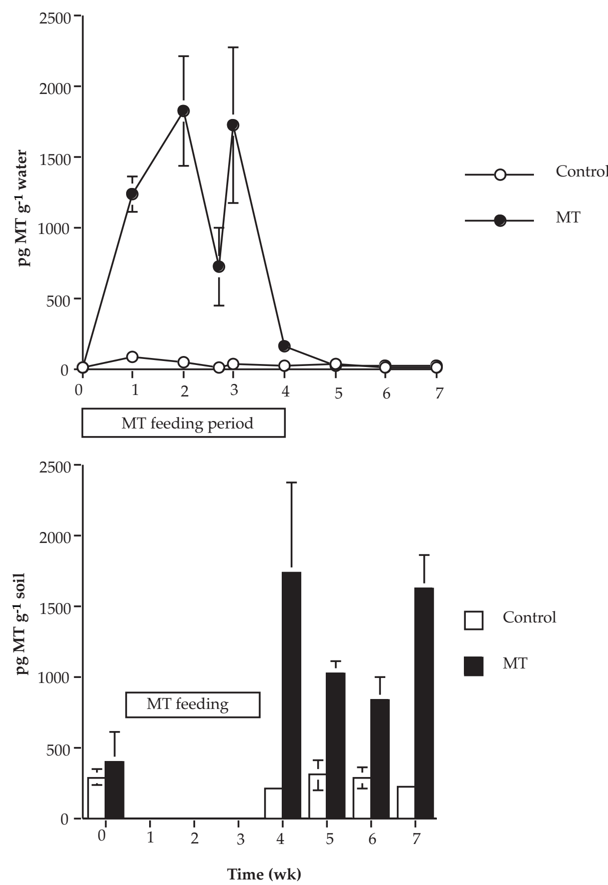

Figure 4. Levels of methyltestosterone (MT) in the environment during and after dietary treatment of *Oreochromis niloticus* fry in Experiment 1. Fish were fed either a control diet or a diet containing 60 mg kg^{-1} of MT. Means (± SE) of MT in water (A) and soil (B) are depicted (n = 3).

The total lack of masculinization resulting from dietary treatment with MT in Experiments 1 and 2 and limited masculinization in Experiment 3 are troubling but are not uncommon in production facilities around the world. The concentrations of MT in the diets were measured (data not shown) and established to be at the target dosage of 60 mg kg^{-1} of food. Therefore, the lack of masculinization was not due to improper diet preparation. Furthermore, treatment of jars without fish with the MT diet resulted in higher levels of MT in the water (during the treatment period) and soil (after the treatment period) than that found in jars containing fish, suggesting that the fish were exposed and were taking up MT. Individual broods of fish may be more or less susceptible to masculinization; however, in Experiment 1, fish from the same brood were successfully masculinized by immersion in trenbolone acetate (Contreras et al., 1997). Therefore, insensitivity to treatment does not explain the lack of masculinization. One possible explanation is that the deterioration of water quality within the jars may have limited the effectiveness of MT by stressing the fish; however, we have no other evidence to support this hypothesis at this time.

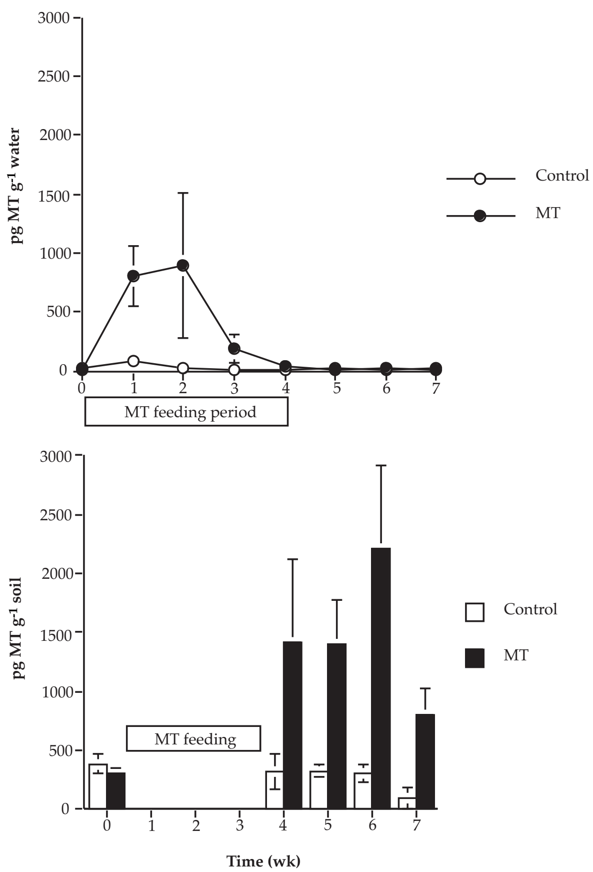

Figure 5. Levels of methyltestosterone (MT) in the environment during and after dietary treatment of *Oreochromis niloticus* fry in Experiment 2. Fish were fed either a control diet or a diet containing 60 mg kg^{-1} of MT. Means (± SE) of MT in water (A) and soil (B) are depicted (n = 3).

Nevertheless, we have established that in these model "ponds," treatment of tilapia with MT results in considerable leakage of the hormone into the environment. It rapidly disappears from the water, but remains in the soil for up to three weeks after the cessation of treatment. Thus, MT persists in the sediments for a considerable time after the end of treatment, posing a potential health risk to workers and an exposure risk to non-target fish and other organisms. Tilapia may disturb sediments when they build nests or search for food, leading to resuspension of MT from the soil into the water column. Thus, "rotating" the pond use from fry production to rearing or breeding will not reduce the risk of re-exposure.

ANTICIPATED BENEFITS

We have successfully demonstrated that the anabolic steroid 17α-methyltestosterone (MT) persists in the sediments of model ponds for at least several weeks after its use for masculinizing tilapia. This is the first time to our knowledge that residual MT has been shown to be stable in the pond environment. These findings raise concerns about the potential impact of such residual MT with regard to unintended exposure of pond workers as well as other fish and animals. These results suggest that should MT be used for masculinizing tilapia, extra care should be taken to protect workers and other biological components of the pond ecosystem from unintended exposure.

ACKNOWLEDGMENTS

Antisera specific to MT (UCB-Bioproducts SA) and ^{3}H-MT (Amersham) were generously donated by Dr. Gordon Grau of the Hawaii Institute of Marine Biology.

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Detection of MT in Pond Water after Treatment with MT Food

Eighth Work Plan, Reproduction Control Research 3B (RCR3B)
Abstract

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Abstract

The objective of this study is to determine if 17α-methyltestosterone (MT) can be detected in the treatment environment and if so, for how long after treatment. The field aspect of this study has begun. Nile tilapia fry are stocked in two 2-m^2 hapas at 2,000 $hapa^{-1}$. The hapas are located approximately 50 cm apart in a 400-m^2 earthen pond. One group is receiving a commercial trout ration that does not contain MT; the other receives a feed containing 60 mg MT kg^{-1} of feed. The fish will be cultured 28 days; after harvest, growth and survival will be determined and then in the same hapas the fish will be reared to sexual maturity and fed a non-hormone-treated feed. Preliminary soil samples were collected in 1997 and furnished to Dr. Fitzpatrick for MT assay and refinement of sampling protocols. Assay of these soils, which have had no history of exposure to MT, indicated levels of 269.3 to 1,553.3 pg g^{-1} of soil, suggesting that the assay for MT may cross-react with natural products in the soils. As part of the current field study, samples of water are being collected during the treatment period from within each hapa and at 2, 5, and 10 m from the hapas. Additionally, soil samples are being collected from directly under the hapas and at 2, 5, and 10 m from the hapas. These samples are frozen soon after collection for later assay.

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STRAIN VARIATIONS IN SEX RATIO INHERITANCE

Eighth Work Plan, Kenya Research 2 (KR2)
Abstract

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ABSTRACT

Pond D3 at Sagana Fish Farm, Sagana, Kenya, was dedicated to pair spawns and rearing of fry for this activity. In addition to work conducted in 1997, fry from 24 pair spawns were transferred to hapas from January through April 1998. Although more than 100 fry were obtained from most spawns, survival to 3 g was very low in the rearing hapas, and fewer than 25 fingerlings per spawn were obtained. This number was too low to complete the protocol as planned, and the fingerlings were discarded. Survivals of about 80% were obtained during sex reversal in similar hapas in a similar pond. The only difference is that fry being sex-reversed are reared at much greater densities than the single-spawn fry. To date, only six batches of single-spawn fingerlings with adequate survival beyond a size of 3 g have been obtained. These were initially reared in hapas, followed by three weeks in the hatchery. However, these batches still contained no more than 60 fish, which is an insufficient number for this study. Recently a blower has been installed in the hatchery and a complete diet has become available, so we plan to grow out single spawns in the hatchery after the end of the cool season (end of August). Temperatures in the cool season are too low (20°C and less) for growing tilapia fry in the hatchery.

Ed. Note: Kenya Research 2 (KR2), “Strain Variations in Sex Ratio Inheritance,” was to be a collaboration of the Africa CRSP project with an activity submitted by R. Phelps et al. as Study A in their proposal “Monosex Tilapia Production through Androgenesis.” For context, a summary of the original project description from the Eighth Work Plan is included:

The few populations of *O. niloticus* that have been studied give mean population sex ratios of 50:50 that would be expected from a XX:XY inheritance pattern but with considerable variation from 50:50 when individual pairs are considered. The source of this variation is unknown and may be a characteristic of the species or only the strain which was evaluated. A minimum of 50 pair spawns of non-hormone-treated *O. niloticus vulcani* will be made in outdoor hapas. Fry will collected and reared as individual sets to a minimum of 5 cm in length. The sex ratio of each set of progeny will be determined by examining the gonads of a minimum of 100 fish per set of progeny. Sex ratio data from each spawn will be analyzed by Chi square to determine whether it differs from the expected 50:50. The frequency distribution of all spawns within this strain will also be determined and compared across other strains that will be examined in the larger study.

Cite as: [Author(s), 1999. Title.] *In*: K. McElwee, D. Burke, M. Niles, and H. Egna (Editors), Sixteenth Annual Technical Report. Pond Dynamics/ Aquaculture CRSP, Oregon State University, Corvallis, Oregon, [pp. ___.]

MODEL EVALUATION AND APPLICATION TO THE ECOLOGICAL ANALYSIS OF INTEGRATED AQUACULTURE/AGRICULTURE SYSTEMS

Eighth Work Plan, Aquaculture Systems Modeling Research 1A (ASMR1A)
Progress Report

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ABSTRACT

A model developed to analyze the environmental impacts of aquaculture and the productivity and ecological function of integrated aquaculture/agriculture systems was evaluated using sensitivity analysis and model verification methods. The verified model was used to identify priority areas for future research in integrated aquaculture/agriculture systems and to study the long-term accumulation of nitrogen in pond sediments. Sensitivity analysis results showed that the most sensitive parameters were maximum specific phytoplankton production rate per unit of carbon, aerobic sediment depth, oxygen threshold for aerobic conditions, water infiltration rate, and organic matter sedimentation rate. Application of a qualitative evaluation of research priorities that combined sensitivity analysis and parameter availability identified stocking practices, sediment processes, and water management as priority areas for future research in integrated aquaculture/agriculture systems. Model verification was established by the successful replication of observed patterns for individual fish weight, dissolved oxygen, total ammonia nitrogen, sediment organic matter, sediment nitrogen, chlorophyll *a* biomass, and corn grain yield. A ten-year simulation showed a marginally greater increase in sediment organic matter concentration in ponds receiving chicken manure and artificial feed inputs when compared to ponds receiving a combination of chicken manure and plant wastes. Steady-state conditions for sediment organic matter concentrations were not achieved within the ten-year simulation period. These results were consistent with observations made in fish ponds but different from published model predictions. Based on the verification and application results, the model appears to be appropriate for analyzing the management of organic matter and nitrogen in integrated aquaculture/agriculture systems. The model is also useful for identifying research areas that may be important in the scientific understanding of these systems.

INTRODUCTION

The development of the integrated aquaculture/agriculture model has previously focused on modification of an existing aquaculture pond ecosystem model and the simplification of submodels for simulating soil nitrogen and water balance calculations in the agriculture component model (Jamu and Piedrahita, 1995, 1996, 1997). These modifications and simplifications were made to allow the use of the model to analyze integrated aquaculture/agriculture systems and the impacts of aquaculture on its surrounding environment. Activities discussed in this report concentrated on evaluation of model performance and application of the model to generate information useful for the scientific understanding of the integrated aquaculture/agriculture system. The specific activities performed were:

1) Model sensitivity analysis;
2) Model verification/validation; and
3) A modeling study to examine the effects of cycling pathways on system nitrogen retention (N output/N input) and productivity, and the long-term dynamics of pond sediment organic matter.

This report focuses on the sensitivity analysis of the model, with a brief discussion of the long-term organic matter dynamics component of the modeling study. Further details on the model and on this year's activities are available in Jamu (1998).

METHODS AND MATERIALS

Sensitivity Analysis

Sensitivity analysis involves varying model rate coefficients singly or in combination and then determining the changes in model output. Sensitivity analysis results are used to identify the most important model parameters and areas for future research. In addition, sensitivity analysis aids researchers in determining the level of precision required for measuring system parameters (Kitchell et al., 1977). Sensitivity analysis can also be used to test the robustness of model performance to small changes in parameter estimates.

The integrated aquaculture/agriculture model was subjected to a sensitivity analysis by varying rate coefficients based on the observed variability (mean ± 1 SD) for selected rate coefficients and parameters (initial values). Where such information was not available, a constant ± 50% (above and below a baseline value) adjustment was used. The percentage adjustment was determined on the basis of reported sensitivity results for aquaculture ponds from the literature (e.g., Lanhai, 1997; Schaber, 1996) and the observed variability of the different parameters in the PD/A CRSP Central Database (Pond Dynamics/Aquaculture CRSP, 1987-1991). The response variables for the sensitivity analysis were selected to reflect the objectives of the research with respect to nitrogen retention and to yield. Response variables were also selected on the basis of their utility in aiding the interpretation of the sensitivity analysis results. The comprehensive sensitivity analysis consisted of varying 22 parameters and determining the response for the following 11 state variables: water column nitrogen, sediment organic matter, nitrogen retention index (N output/N input), individual fish weight, crop soil nitrogen, chlorophyll *a* biomass, dissolved oxygen, water column organic matter, crop biomass, and terrestrial soil organic matter. The sensitivity analysis results were presented as a percent change and as a normalized sensitivity coefficient (NS) (Fasham et al., 1990). In order to determine the most sensitive parameters, the normalized sensitivity coefficients were ranked in descending order of importance. The cutoff point between the most sensitive and least sensitive parameters was identified with the aid of quantile plots or Q-Q plots (Swartzman and Kaluzny, 1987).

Model Verification

The integrated aquaculture/agriculture systems model was verified by graphically comparing model output to observed time series data from experiments conducted in Honduras (Third Work Plan, Experiment 1 [F301]) (PD/A CRSP Central Database, 1986), Malawi (Kauta and Kadwa, 1993; Jamu, 1993), and Thailand (Fourth Work Plan, Experiment 1 [C401]) (PD/A CRSP Central Database, 1987). Where adequate time series data were not available, tabular comparisons were used. The data used for model verification were independent from the data used for model calibration (Butare, Rwanda, Fourth Work Plan Experiment 3 [H403]) (PD/A CRSP Central Database, 1988). The time series data for experiments with three or more replicates were plotted as mean ± 1 SD. The model was evaluated as adequate or reliable when the model output followed the pattern of observed values and the model simulations were generally within one standard deviation.

Model Application

The uses of the model included: 1) identification of priority areas for future research and 2) investigation of long-term organic matter dynamics and their implications for sediment management.

Identification of Priority Areas for Future Research
The parameters that would benefit from future research were identified using a qualitative method that combined the rankings of sensitivity analysis results and parameter availability to arrive at the priority of a given parameter or process for future research (Kitchell et al., 1977). The parameters that were used in the qualitative evaluation were the most sensitive parameters with respect to nitrogen retention index (N output/N input), fish weight, crop grain yield, pond (water column and sediment) nitrogen, and organic matter.

Modeling Study: Long-Term Organic Matter Dynamics
Long-term simulations designed to follow the time trend of sediment organic matter were carried out for representative management scenarios for integrated ponds as follows:

(a) artificial feed at 3% mean body weight per day (BWD);
(b) chicken manure at 500 kg ha^{-1} wk^{-1}; and,
(c) a combination of chicken manure at 500 kg ha^{-1} wk^{-1} and crop waste at 25 kg ha^{-1} d^{-1}.

These management scenarios were simulated on the assumptions that pond sediments were not recycled to the agriculture component, pond water was used for agricultural irrigation, and the agricultural crop (maize) was fertilized at 160 kg N ha^{-1}. The model was run for ten years, and each year's simulation consisted of one wet and one dry season simulation. Each fish and crop simulation lasted 120 days, ending with a simulated pond harvest and draining. The model was then run for a seven-day period to simulate organic matter decomposition in the harvested pond. After seven days, the pond sediment moisture content was simulated to be under 12% and further sediment decomposition was considered to be negligible. The period between crops was considered to be a fallow period and lasted a total of 121 days per year.

Table 1. The effects of changes of ± 50% or ± 1 SD in different parameter values on some state and output variables. The results show the five most sensitive parameters ranked according to absolute magnitude of the normalized sensitivity (NS) values. Column headings are defined in the footnotes.

Sensitivity Parameter[1]	Response Variable	Baseline Value[2]	Sensitivity Value[3]	Parameter Change[4]	Baseline Simulation[5]	Sensitivity Simulation[6]	% Change	NS[7]
Water Infiltration Rate (m d^{-1})	Water column-N	0.007	0	-1 SD	39.89	346.24	767.9374	-7.6794
Maximum Specific Phytoplankton Production Rate per Unit of Carbon (mg O_2 (mg C)$^{-1}$ hr^{-1})	Chlorophyll *a* biomass	0.83	0.91	+1 SD	1.4090	0.9376	-33.4589	3.4714
	Chlorophyll *a* biomass	0.83	0.75	-1 SD	1.4090	1.8697	32.6973	3.3923
O_2 Threshold for Aerobic Conditions (mg l^{-1})	Nitrogen retention index	0.2	0.1	-50%	0.0962	0.2243	133.1788	-2.6636
	Water column-N	0.2	0.1	-50%	39.89	13.51	-66.1226	1.3225
Organic Matter Sedimentation Rate k (d^{-1})	Water column organic matter	0.05	0.025	-50%	4,307.40	6925.77	60.7880	-1.2158
Aerobic Sediment Depth (m)	Water column-N	0.001	0	-50%	39.89	2.29	-94.2617	0.9426

[1] Sensitivity parameter = Parameter whose value was changed by ± 1 SD or ± 50%.
[2] Baseline value = Calibrated parameter value
[3] Sensitivity value = Sensitivity parameter value after baseline value is varied by ± 1 SD or ± 50%.
[4] Parameter change = Magnitude of change in sensitivity parameter.
[5] Baseline simulation = Simulated value of response variable when the model is run using the baseline value.
[6] Sensitivity simulation = Simulated value of response variable when model is run using sensitivity value.
[7] Normalized sensitivity (NS) as defined by Fasham et al. (1990).

Table 2. Summary of a sensitivity analysis of model parameter evaluations and their projected impact on future research of nitrogen cycling and productivity of integrated aquaculture/agriculture systems. Parameters were evaluated qualitatively based on the observed variability of measurements, availability of data for the system, and sensitivity.

Parameter	Sensitivity	Availability	Research Priority
Organic Matter Sedimentation Rate	High	Medium	Medium
Maximum Specific Phytoplankton Production Rate per Unit of Carbon	High	High	Low
Initial Fish Weight	High	Low	High
Aerobic Sediment Depth	High	Low	High
Non-Phytoplankton Light Extinction Coefficient	High	Low	High
Irrigation Rate	High	Low	High
O_2 Threshold for Aerobic Conditions	High	High	Low
Water Infiltration Rate	High	Low	High
N Mineralization Rate	High	High	Low
Initial Sediment Organic Matter	High	Medium	Medium
Mineral Soil Organic Matter Decay Rate	High	Low	High

RESULTS

Because of the large number of response variables used in the sensitivity analysis, only the five most sensitive (absolute values) parameters are presented in this report (Table 1). The results indicate that, overall, the model is extremely sensitive to changes in water infiltration rate, maximum specific phytoplankton production rate per unit of carbon, oxygen threshold for aerobic conditions, organic matter sedimentation rate, and aerobic sediment depth. The model sensitivity results therefore suggest that these parameters require accurate estimation and/or calibration.

The results of the identification of processes that are likely to affect system productivity and nitrogen retention are presented in Table 2. The processes and management activities associated with initial fish weight, aerobic sediment depth, non-phytoplankton light extinction coefficient, crop irrigation rate, water infiltration rate, and mineral soil organic matter decomposition rate coefficient were identified as the most likely to benefit from future research in the integrated aquaculture/agriculture system.

Results of the modeling study simulating the long-term dynamics of organic matter in aquaculture pond sediments are presented in Figure 1. Pond sediment organic matter concentrations increased over time for all input regimes in the following order: chicken manure + plant waste > chicken manure > artificial feed. Simulated organic matter concentration decreased in the first four to five years in ponds receiving chicken manure and in those receiving artificial feed.

DISCUSSION

The largest normalized sensitivity value was obtained when the water infiltration rate was reduced to zero. It has been observed that water infiltration rates in ponds are variable both over time and within any given single site (Chikafumbwa, 1996; Teichert-Coddington and Carlos, 1994). Other factors that influence infiltration rates are pond inputs and soil type (Teichert-Coddington and Carlos, 1994). In the model, the pondwater infiltration rates were assumed to be constant. Although this assumption simplifies the incorporation of the

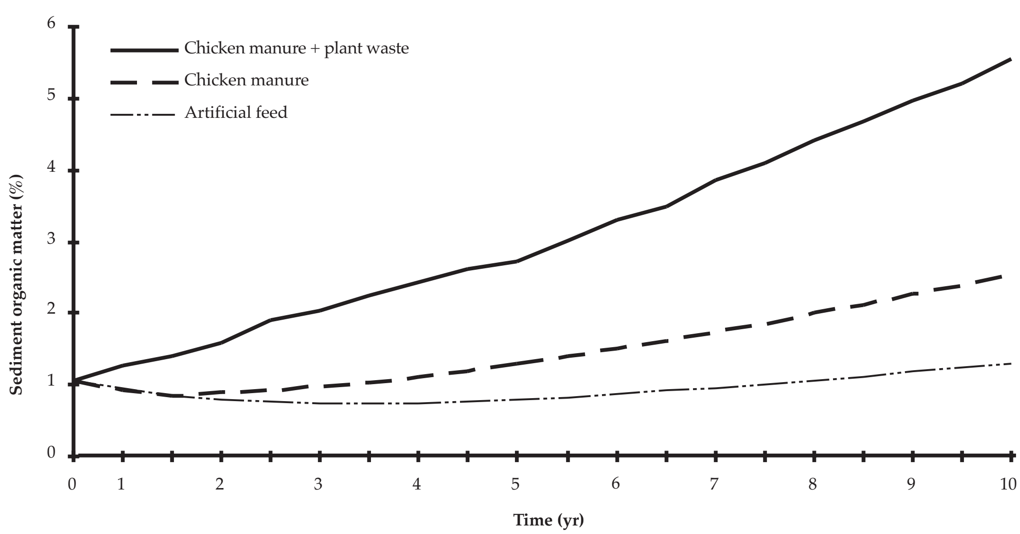

Figure 1. Simulated sediment organic matter concentration in the first 5 cm of pond soil for ponds fertilized with chicken manure at 500 kg ha^{-1} wk^{-1} and plant wastes at 25 kg ha^{-1} d^{-1}; ponds fertilized with chicken manure at 500 kg ha^{-1} wk^{-1}; and ponds where fish were fed at 3% mean body weight per day (BWD).

water infiltration rate term in the model, it is incorrect and could result in significant errors in the simulation of water column nitrogen.

Simulated sediment organic matter concentrations increased marginally over a ten-year period in the chicken manure and artificial feed treatments. The increase in sediment organic matter concentrations over time for chicken manure and artificial feed ponds were similar to those reported by Boyd et al. (1997) for aquaculture ponds in Thailand. The differences in sediment organic matter concentrations among the three simulated scenarios were due to differences in the composition of inputs and input rates. Plant wastes contain a large fraction of moderately decomposable organic fractions compared to chicken manure and artificial feed (Wang et al., 1985; Gohl, 1981) and therefore decompose at a slower rate than the other inputs. The results obtained here are different from model predictions by Avnimelech et al. (1995) whose model predicted that sediment organic matter concentrations approach steady state within a five-year period. The discrepancy between model predictions observed in this work and those of Avnimelech et al. (1993) may have been due to differences in underlying assumptions on the processes governing sediment organic matter decomposition. Avnimelech and co-workers assumed that the organic matter decomposition rate coefficient was constant over depth (20 cm) and time. In the model presented here, the overall organic matter decomposition rate coefficient changed with depth as the sediment became anaerobic and the fraction of recalcitrant total organic matter increased due to humification and depletion of labile organic matter fractions. The assumptions incorporated in the model with respect to a decrease in decomposition rate coefficient with depth are consistent with the observations of Munsiri and Boyd (1997).

ANTICIPATED BENEFITS

The results of the model sensitivity analysis, verification, and model application showed that the model is able to capture the general behavior of important variables in the integrated system and can be widely used in the research and management of integrated aquaculture/agriculture systems. Since the model has served to identify parameters that require accurate field measurements, priority areas of future research, and processes that are important to the scientific understanding of integrated systems, it should prove useful in the design of integrated aquaculture/agriculture and sediment management experiments and the overall management of nitrogen and organic matter in aquaculture ponds.

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Modeling of Temperature, Dissolved Oxygen, and Fish Growth Rate in Stratified Ponds Using Stochastic Input Variables

Eighth Work Plan, Aquaculture System Modeling Research 1B (ASMR1B)
Progress Report

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Abstract

A model has been developed for the prediction of water temperature, dissolved oxygen (DO), and fish growth using stochastically generated input weather variables. The model has been calibrated and validated using data from pond sites in Thailand, Honduras, and Rwanda. The model includes modules for the generation of weather parameter values and for the calculation of water quality and fish growth. The weather parameters generated include hourly solar radiation, air temperature, wind speed, and wind direction. The water quality variables modeled include water temperature, DO, total ammonia nitrogen, and phytoplankton (in terms of chlorophyll *a*). For modeling purposes, the water column is divided into three layers, each of which is considered to be fully mixed. Temperature and DO are calculated separately for each of the three layers resulting in simulations of stratified ponds. Given the stochastic nature of the weather input variables, the model must be run a number of times for a given set of pond management conditions. Typically, the model was run 20 times for each data set in the calibration and validation process. The simulation results obtained and presented in this report include mean, maximum, and minimum values for each time step. The simulated water temperature and DO are in good agreement with data for the Honduras and Rwanda sites; however, simulated and observed values for chlorophyll *a* at the Thailand site differ. Probability distributions for water quality and fish yield can be calculated from the simulation results and are useful to pond managers, planners, researchers, and teachers.

Introduction

Fish growth in aquaculture ponds is affected by water quality and food supply. These, in turn, are influenced by environmental parameters, which also determine the degree of water temperature and dissolved oxygen (DO) stratification. Weather is the major environmental factor influencing pond stratification, and knowledge of how water quality changes under varying weather conditions can be useful in improving water quality management. A computer model has been developed to simulate pond water temperature, DO, and fish growth under the effects of stochastically generated weather parameters. The components of the model include a weather generation module and calculations of water temperature, DO, phytoplankton (in terms of chlorophyll *a*), total ammonia nitrogen (TAN), and fish growth. Weather parameter values, including solar radiation, air temperature, wind speed, and wind direction, are generated based on statistical analysis of historical data. Water temperature and DO are simulated using a deterministic model based on a previously developed PD/A CRSP model (Culberson, 1993). Total ammonia nitrogen and chlorophyll *a* are simulated based on mass balance calculations (Lee et al., 1991). Fish growth is calculated using a bioenergetic model (Bolte et al., 1994; Jamu and Piedrahita, 1995) that can account for growth based on natural food (phytoplankton) as well as on artificial feed and other food sources.

The model is based on the assumption that only water temperature and DO are stratified, and only three layers are considered: top, middle, and bottom. Water temperature and DO are assumed to be uniform within each layer. However, phytoplankton and ammonia are assumed to be homogenous throughout the whole water column. Fish distribution in the water column is assumed to be uniform as long as DO concentration is above a critical value. If DO drops below the threshold in a given pond layer, the fish move to an adjacent layer in search of higher DO concentrations. If DO is below the threshold in all layers, the fish congregate in the surface layer.

During this reporting period, the work has concentrated on model validation. Many modifications have been made to the model during the calibration and validation process, including:

1) The initial values (at time zero for a given simulation) of DO, temperature, TAN, and chlorophyll *a* variables are assumed to follow normal distributions. Initial values are generated based on the means and standard deviations obtained from the observed data using a normal distribution function.
2) A temperature effect factor was added to all organic decomposition rates. These include the decomposition rates of fertilizers and other feeds.
3) A term to describe nitrogen diffusion from the sediment to the water column was added.

Model Calibration and Validation

The model has been calibrated and validated using data from three locations: Rwanda, Honduras, and Thailand. For each location, at least one experiment with three or four treatments was tested. The treatments varied the inputs of chicken manure, urea, and grass; they are listed in Table 1. For each location, data from one treatment were used for model calibration and the rest of the data were used for model validation. The process of model calibration consisted of tuning a few site-specific parameters.

SIMULATION RESULTS

The simulation results were obtained after running the model 20 times for a simulation period of 150 days for each data set using the Monte Carlo method. For the Honduras site, the model was calibrated using Treatment 3 (500 kg ha^{-1} wk^{-1} chicken manure) data and validated against Treatments 1, 2, and 4 (receiving 125, 250, and 1000 kg ha^{-1} wk^{-1} chicken manure, respectively). The simulated means and standard deviations for water temperature and DO for the three water layers are listed in Table 2. The ranges of the average temperature are from 26.4 to 26.8°C, 24.5 to 25.4°C, and 24.1 to 24.5°C for the surface, middle, and bottom layers, respectively. The simulated DO values indicate that average DO is higher under higher fertilization rates. The highest DO, and also the highest standard deviation for DO, occurs in Treatment 4. There is no noticeable difference between the average DO values for Treatments 1 and 2.

The simulated and observed hourly DO at the surface and bottom layers is shown in Figures 1 and 2. Since the hourly data were collected approximately one day every two weeks, the simulated and observed values for the three layers are

Table 1. CRSP data used for model calibration and validation. Units are kg ha^{-1} wk^{-1}. (CM = chicken manure; UR = urea; GR = grass.)

Location	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Replicates (ponds)
Honduras (F3d)	125 CM	250 CM	500 CM*	1000 CM	3
Thailand (C404) P:N = 1:5	44 CM +UR	100 CM +UR*	200 CM +UR		4
Rwanda (H403)	100 CM +400 GR*	100 CM +400 GR +28.2 UR	150 CM +600 GR	200 CM +800 GR	3

* Treatment used for model calibration

Table 2. Simulated temperature and DO for surface, middle, and bottom layers. The values represent means of hourly values obtained for the 150-day simulation for the Honduras site.

Parameter	Sensitivity	Availability	Research Priority
Organic Matter Sedimentation Rate	High	Medium	Medium
Maximum Specific Phytoplankton Production Rate per Unit of Carbon	High	High	Low
Initial Fish Weight	High	Low	High
Aerobic Sediment Depth	High	Low	High
Non-Phytoplankton Light Extinction Coefficient	High	Low	High
Irrigation Rate	High	Low	High
O_2 Threshold for Aerobic Conditions	High	High	Low
Water Infiltration Rate	High	Low	High
N Mineralization Rate	High	High	Low
Initial Sediment Organic Matter	High	Medium	Medium
Mineral Soil Organic Matter Decay Rate	High	Low	High

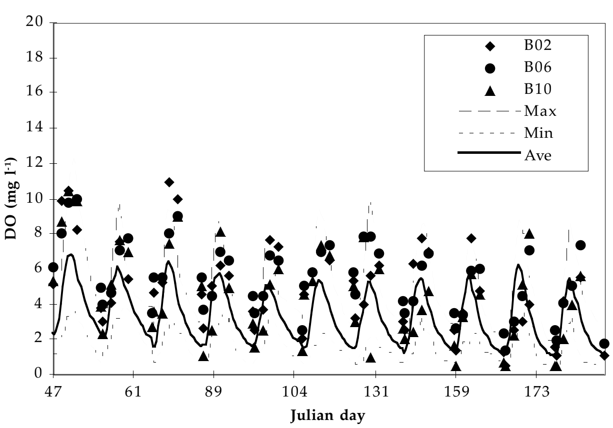

Figure 1. Simulated and observed dissolved concentrations of the surface layer for the Honduras site under Treatment 1 (125 kg ha^{-1} wk^{-1} chicken manure).

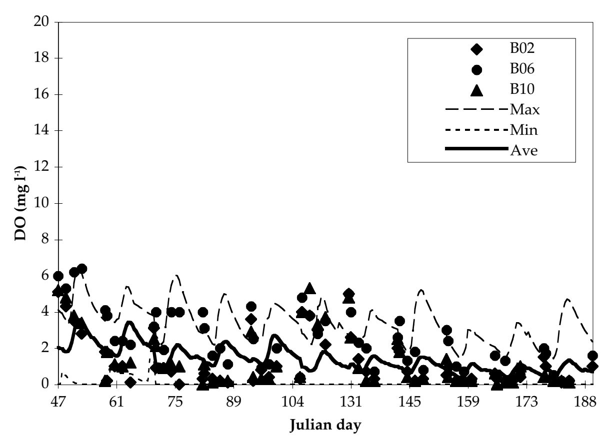

Figure 2. Simulated and observed dissolved oxygen concentrations of the bottom layer for the Honduras site under Treatment 1 (125 kg ha^{-1} wk^{-1} chicken manure).

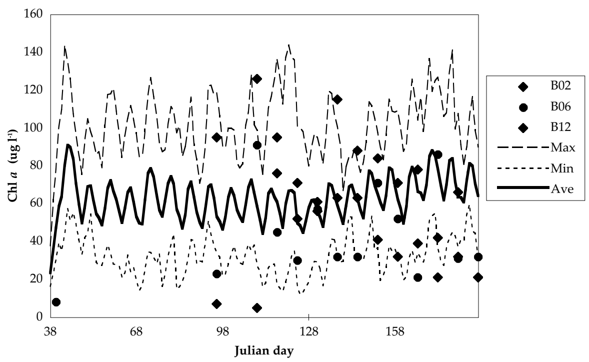

Figure 3. Simulated and observed chlorophyll *a* concentrations for the Honduras site under Treatment 1 (125 kg ha^{-1} wk^{-1} chicken manure).

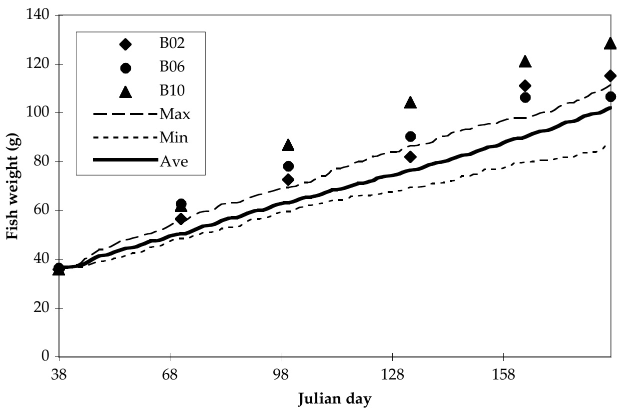

Figure 4. Simulated and observed fish weights for the Honduras site under Treatment 1 (125 kg ha^{-1} wk^{-1} chicken manure).

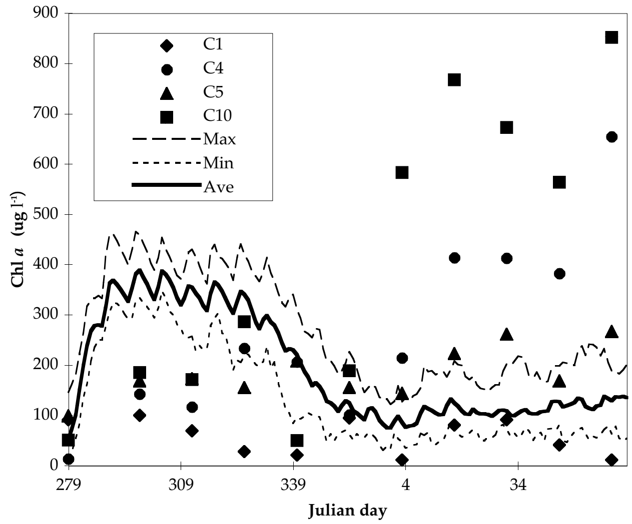

Figure 5. Simulated and observed chlorophyll *a* concentrations for the Thailand site under Treatment 2 (100 kg ha^{-1} wk^{-1} chicken manure).

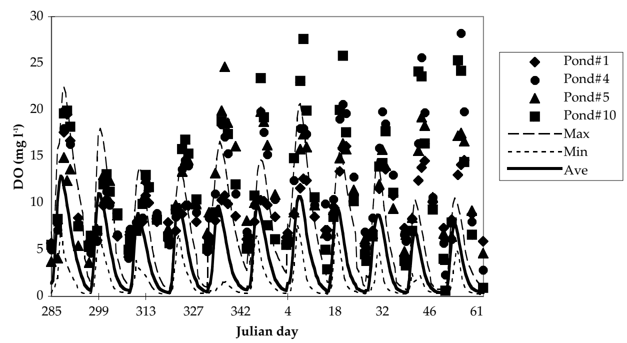

Figure 6. Simulated and observed dissolved oxygen concentrations of the surface layer for the Thailand site under Treatment 2 (100 kg ha^{-1} wk^{-1} chicken manure).

compared for the days that hourly data were collected. The simulated and measured chlorophyll *a* values are shown in Figure 3. Fish weights are shown in Figure 4.

For the Thailand site, the simulated concentrations of chlorophyll *a* are different from the field data for some ponds. Figure 5 shows a comparison of the simulated and obsserved data for Treatment 2. There are four ponds for the treatment; two of them have high concentrations of chlorophyll *a* after three months, and two do not. The comparison shows that the simulated values for chlorophyll *a* are much lower than the observed values from Ponds 4 and 1, but similar to the observed values from Ponds 1 and 5 (Figure 5). The simulated DO values are also lower than the observations from Ponds 4 and 10 (Figure 6). Since the ponds did not receive artificial food, the high variations of chlorophyll *a* directly affected the observed fish growth, which had a high variability (Figure 7). The simulation results did not show the same degree of variability.

In general, there was good agreement between simulations and data for the Rwanda site. This is illustrated by the comparison between simulated and observed fish weights (Figure 8).

DISCUSSION

The simulated water temperature and DO are in good agreement with data for the Honduras and Rwanda sites but not for the Thailand site. In general, the simulation results point out the capabilities and also the limitations of the model. Data used for model testing came from very different sites, and very few site-specific adjustments needed to be made to the model. The Thailand simulations showed the poorest agreement with data, and there was also significant variation between data obtained from replicate ponds. This variation was not reflected in the simulations, but it meant that the match between simulations and data was much better for some ponds than for others (Figures 5 and 6).

The simulation results (Figures 1 through 8) show the average, maximum, and minimum values obtained after 20 runs of the model. The variation is caused primarily by differences in the input weather variables, which were generated using statistical methods that include a random component. With few exceptions, the measured values of the different parameters are within the range defined by the maximum and minimum values obtained in the simulations.

The simulations showed that in several cases, the maximum and minimum DO values could be out of the tolerance range, or no-effects range, for some fish species. The model can be useful in identifying the proportion of days on which

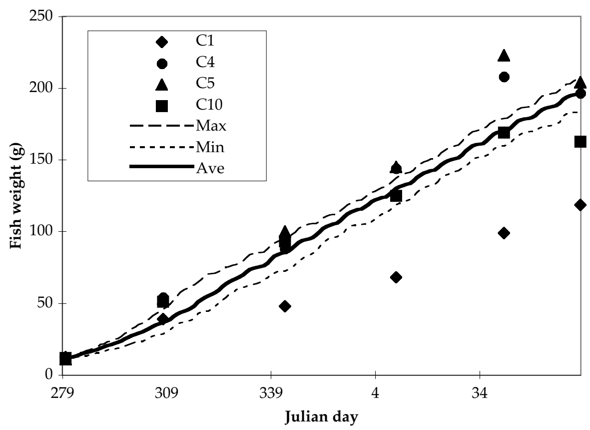

Figure 7. Simulated and observed fish weights for the Thailand site under Treatment 2 (100 kg ha^{-1} wk^{-1} chicken manure).

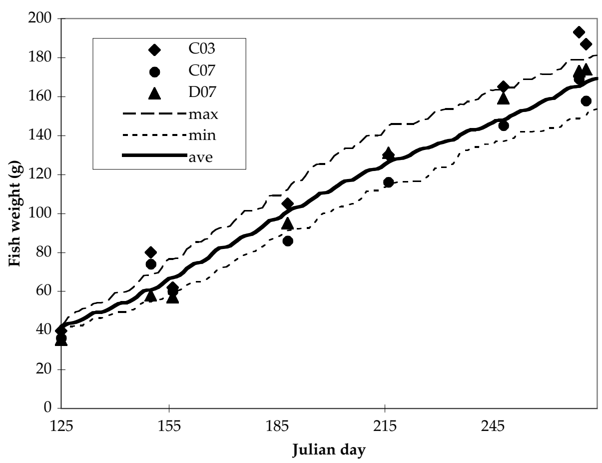

Figure 8. Simulated and observed fish weights for the Rwanda site under Treatment 1 (100 kg ha^{-1} wk^{-1} chicken manure and 400 kg ha^{-1} wk^{-1} grass).

tolerances are exceeded, and hence determine possible growth reductions or even the probability of fish kills. For example, Figures 1 and 2 show the variability of DO at the surface and bottom layers. The minimum DO value at the bottom layer is almost zero at every time step. As a result, fish will tend to avoid the bottom layer and be forced to occupy the middle and top layers. This causes a reduction in the effective pond volume, and may also cause stress to the fish because they are forced to move to areas of less-than-ideal light intensity, temperature, and food availability.

The effect of fertilization rate changes could be observed from the simulations obtained. The highest fertilization rate resulted in the highest DO for the Honduras simulations shown (Table 2). This treatment also resulted in the greatest degree of stratification (as indicated by differences between the three layers) and in the greatest DO variation over time. Simulation results like the ones presented in this report can be used to study the impact of fertilization rates. These simulations can be analyzed together with economic, environmental, and social constraints to select an appropriate fertilization rate for a given situation.

The poor simulation of chlorophyll *a* for the Thailand site highlights the limitations of the model. In addition, the between-pond differences observed for the replicates indicate that there are still many undetermined factors affecting pond water quality and fish yields. The model is a mathematical representation of what we know about fish ponds, and events or changes we cannot explain in practice cannot be explained by the model either. A better understanding of pond-sediment interactions, phytoplankton dynamics, and fish nutrition should be pursued to improve our ability to model and manage ponds effectively.

ANTICIPATED BENEFITS

The model provides the possible ranges of water quality and fish growth in stratified ponds using statistically generated weather values as inputs. The variability of water quality and fish yield over short and long terms also can be studied for varying feeding and fertilization regimes, fish size at stocking and harvest, pond location, and date of fish stocking and harvest. The model will be useful in the planning fish ponds, managing water quality, selecting pond sites, and analyzing alternative pond management strategies.

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DEVELOPMENT OF SUSTAINABLE POND AQUACULTURE PRACTICES FOR *PIARACTUS BRACHYPOMUS* IN THE PERUVIAN AMAZON

Eighth Work Plan, Peru Research 1 (PR1)
Final Report

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ABSTRACT

Piaractus brachypomus growth performance did not significantly differ in trials conducted in ponds stocked at 3,000 and 4,000 fish ha^{-1} in Iquitos, Peru. Fish initially weighing 27.5 g were fed a locally prepared diet (26.7% crude protein; 9.0% crude lipid) in rations ranging from 3 to 5% body weight per day. Fish were harvested after 153 days and had mean weights of 463.7 and 494.0 g in the low and high densities, respectively. Survival exceeded 90% in all ponds. Feed conversion efficiency was 53.6 and 60.4% for low and high densities, respectively. Fish in one pond of each density were reared for an additional five months and attained mean weights of 0.95 kg for the low density and 1.04 kg for the high density. Water quality levels generally remained throughout the trial within acceptable levels for tropical aquaculture. The study suggests the economic feasibility of rearing *P. brachypomus* in the Peruvian Amazon under intensive aquaculture. The combined cost of fingerlings (US$0.14 each, corrected for 90% survival) and feed (US$1.02 kg^{-1} to produce 1.0 kg fresh fish) is slightly above half of the price (US$2.08 kg^{-1}) for which the fish are sold in the Iquitos market. Currently, most farmers in the Peruvian Amazon grow fish using extensive techniques.

INTRODUCTION

A need exists to evaluate the aquaculture potential of local and native species and to develop appropriate culture technologies in the Peruvian Amazon. *Piaractus brachypomus*, native to the Orinoco and Amazon Rivers (Goulding, 1980), is an important food fish in the Amazon basin. However, little production technology has been developed and published. In addition, there has been inadequate attention to economic analyses, such as determinations of production cost. Such information is critical for the sustainable development of this new aquaculture species.

Presently the available broodstocks are generally taken from the natural environment, although some have been produced in aquaculture stations. The fish are captured as fry, fingerlings, juveniles, or adults and are then stocked in culture ponds and prepared as future broodstock. The selection of broodstock is made on the basis of external characteristics during the spawning season. Only in Brazil and Panama do culturists select broodstock based on individual performance (growth rate, quantity and quality of semen, fertilization rate, and fry production).

No standardization exists for stocking densities of fry or fingerlings (Campos, 1993). Likewise, no uniform fish diets are available in the region (Cantelmo et al., 1986; Ferraz de Lima and Castagnolli, 1989). This project provides information on the stocking densities necessary to efficiently and economically rear *Piaractus brachypomus* to marketable size (approximately 0.5 to 1.0 kg) using a prepared diet. Replicated pond studies were carried out in Iquitos at the Instituto de Investigaciones de la Amazonia Peruana (IIAP) pond facility.

METHODS AND MATERIALS

Initially *Colossoma macropomum* was the focal species of this study; however, due to a spawning failure, *Piaractus brachypomus* was substituted for the first year study, as approved by the PD/A CRSP Technical Committee co-chairs. *P. brachypomus* could not be obtained until March 1997 and were at an advanced fingerling size.

Six ponds, ranging in size from 1,015 to 5,320 m^2, were stocked with *Piaractus brachypomus* at two densities: three ponds at 4,000 fish ha^{-1} and three ponds at 3,000 fish ha^{-1}. The mean initial weight was 27.5 g with the exception of one replicate pond of the lower density treatment where the initial mean weight was 4.0 g. Data were collected from this replicate, but were not used in the density comparisons. A locally manufactured feed using available ingredients was fed (see Table 1 for feed composition and cost). Fish were fed 5% body weight per day (BWD) for the first month and 3% BWD for the remainder of the trial. Rations were divided into three feedings. Fish were sampled (10% minimum population) by seining every two weeks to record lengths and weights. At harvest, biomass, feed conversion efficiency (FCE; Stickney, 1994), specific growth rate (SGR; Ricker, 1975 modified by 100X), and condition factor (K; Piper et al., 1982) were calculated. The study commenced 29 April 1997 and continued until 29 September 1997. General water quality parameters (dissolved oxygen, temperature, conductivity, total ammonia nitrogen, carbon dioxide, pH, and chlorides) were measured daily in the early morning. Harvest data were analyzed using the Statistical Analysis System (SAS Institute, 1993) with an alpha of 0.05.

Table 1. Ingredients and costs in US dollars for feed[a] used in pond trials of *Piaractus brachypomus* in Iquitos, Peru (29 April to 29 September 1997).

Ingredient	Percent in Diet	Cost (US$ kg^{-1})[b]
Fish Meal	19.9	1.00 kg^{-1}
Soybean	19.9	0.72 kg^{-1}
Wheat	19.9	0.26 kg^{-1}
Rice	28.8	0.19 kg^{-1}
Corn Meal	9.9	0.68 kg^{-1}
Vitamin C	0.1	32.00 kg^{-1}[c]
Vitamin/Mineral Premix	1	
Fish Oil	0.5	1.60 kg^{-1}

[a] Proximate analysis of fingerling diet by Rebecca Lochmann (9% lipid, 26.7% protein, 92.5% dry matter).
[b] Ingredient prices varied over the course of the study. Feed costs averaged US$0.67 kg^{-1}.
[c] Cost reflects price of vitamin C and vitamin/mineral premix combined.

RESULTS

No differences ($P > 0.05$) existed at harvest in *P. brachypomus* weight (463.7 vs. 494.0 g), total length (27.1 vs. 28.0 cm), specific growth rate (1.8 vs. 1.9), condition (2.2 vs. 2.2), or feed conversion efficiency (53.6 vs. 60.4%) at the stocking densities of 3,000 and 4,000 fish ha^{-1}, respectively (Tables 2 and 3). Fish averaged 3.0 g d^{-1} growth over the course of the 153-d trial (Figure 1). Survival exceeded 90%. Fish from one pond of each density were grown to 28 February 1998. Their average weights were 0.95 and 1.04 kg for the 3,000 and 4,000 fish ha^{-1} densities, respectively.

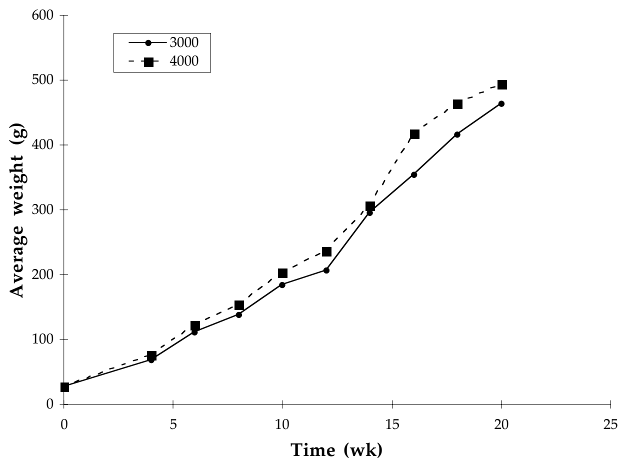

Figure 1. Average weight of *Piaractus brachypomus* at two different stocking densities (3,000 and 4,000 fish ha^{-1}) in Iquitos, Peru (29 April through 29 September 1997).

Table 2. Performance of *Piaractus brachypomus* at two densities in pond trials conducted in Iquitos, Peru (29 April to 29 September 1997).

Date	3,000 ha^{-1}				4,000 ha^{-1}			
	Weight (g)	*Total Length* (cm)	*SGR*[a]	*K*[b]	*Weight* (g)	*Total Length* (cm)	*SGR*[a]	*K*[b]
29 April	27.5	10.6	--	2.7	27.5	10.6	--	2.3
30 May	68.9	14.2	1.3	2.5	75.9	14.8	1.3	2.3
15 June	110.9	16.9	1.5	2.3	122.8	17.7	1.5	2.3
29 June	137.4	18.1	0.6	2.1	153.8	18.9	0.6	2.3
14 July	184.0	19.8	0.9	2.3	203.0	20.5	0.9	2.3
29 July	206.2	21.3	0.4	2.1	236.3	22.8	0.4	2.1
13 August	295.4	23.5	1.0	2.1	305.6	24.2	1.0	2.2
28 August	353.6	25.7	0.5	2.1	417.2	26.7	0.5	2.2
12 September	416.3	26.1	0.5	2.4	463.7	27.2	0.5	2.4
29 September	463.7	27.1	0.3	2.2	494.0	28.0	0.3	2.2
			1.8[c]				1.8[c]	

[a] Specific growth rate: SGR = ln (W_f) - ln (W_0)/T x 100; where W_f and W_0 = final and initial weights in g, respectively, and T = time in days.
[b] K = W/L^3; where W = weight in g and L = total length in cm.
[c] Composite.

Table 3. Feed conversion efficiency (%) for *Piaractus brachypomus* grown at two densities in ponds at Iquitos, Peru (29 April through 29 September 1997).

Sample Date	Stocking Density (fish ha^{-1})	
	3000	*4000*
29 April	--	--
30 May	103.9	121.9
15 June	134.6	160.9
29 June	60.6	63.8
14 July	76.4	92.4
29 July	32	45.3
13 August	102.8	71.4
28 August	45.2	95.7
12 September	49.6	30.5
29 September	27.4	17.9
TOTAL	53.6%	60.44%

Water quality varied among ponds (Table 4). Mean maximum and minimum temperatures over the course of the study were 31.7 and 29.3°C, respectively. Minimum dissolved oxygen levels generally remained above 1.0 mg l^{-1} and usually averaged in excess of 4.0 mg l^{-1}. Total ammonia nitrogen remained below 1.0 mg l^{-1} while carbon dioxide levels reached a high of 22 mg l^{-1} in one pond. These waters can be classified as soft (hardness = 20 mg l^{-1}; alkalinity = 20 mg l^{-1}; conductivity = 96 µohms cm^{-2}) and slightly acidic (morning pH ranging from 6.3 to 7.1).

DISCUSSION

We found no significant differences in grow-out performance of *P. brachypomus* when stocked in ponds at densities of 3,000 and 4,000 fish ha^{-1}. The mean fish growth rate of 3.0 g d^{-1} in this study is comparable to findings for *Colossoma macropomum* (Saint-Paul, 1986; Gunther and Boza Abarca, 1992). Both characids grow slightly better under intensive culture conditions than tilapia (Peralta and Teichert-Coddington, 1989) and similar to *Clarias* (Hogendoorn et al., 1983; Verreth and Den Bieman, 1987).

Feed conversion was excellent throughout the study. The exceptionally high values during the early stages of the study reflect the ability of *P. brachypomus* to filter-feed at the fingerling stage. These fish can also consume seeds and some plants found in the water. Fish that were fed for an additional five months (ten months total) reached about a kilogram in size (from 27.5 g). The prepared diet used in the study cost US$1.02 to produce 1.0 kg of whole fish. Fingerlings generally sell for about US$0.13 each. Food-size *P. brachypomus* sell in the Iquitos market for US$2.08 kg^{-1}.

Water quality remained well within the tolerances of *P. brachypomus* throughout the study. Of course, it must be recognized that these fish can reduce their metabolic rate during periods of stress. Oxygen levels would need to remain low for days rather than hours to adversely affect them.

P. brachypomus demonstrated considerable potential for intensive aquaculture in the Peruvian Amazon. No significant differences were found between the two densities. Accordingly, a density of at least 4,000 fish ha^{-1} can be recommended when supplemental feed is provided. Densities of 2,000 to 3,000 fish ha^{-1} are traditionally used in the region. Higher densities may be possible, but more studies will need to be conducted before making such recommendations. On 17 April 1998, triplicated ponds were stocked at 2,500, 3,250, and 4,000 *Colossoma macropomum* ha^{-1} at the same aquaculture facility used for *P. brachypomus*. The *Colossoma* are being fed the same diet that was used for *P. brachypomus*. The study will run until the end of September 1998, so that comparisons can be made between the two closely related characids.

Table 4. Early morning mean water quality levels (ranges in parentheses) of ponds used to rear *Piaractus brachypomus* at two different densities in ponds at Iquitos, Peru (29 April through 29 September 1997).

Parameter	Pond					
	1	*3*	*4*	*5*	*6*	*13*
DISSOLVED OXYGEN (mg l^{-1})	4.7 (1.0-7.1)	4.0 (1.5-8.5)	5.3 (2.0-8.2)	5.4 (1.7-10.5)	4.7 (0.5-8.2)	5.2 (2.2-8.2)
TEMPERATURE (°C)						
Minimum (mean)	29.4	29.8	29.1	28.8	29.5	28.8
Maximum (mean)	31.4	31.8	31.7	31.6	32.0	31.8
CARBON DIOXIDE (mg l^{-1})	9.7 (4-22)	7.7 (3-7)	6.3 (4-10)	5.3 (2-9)	7.8 (4-16)	6.4 (2-13)
pH	6.8 (6.6-7.6)	6.9 (6.9-7.0)	6.8 (6.4-7.1)	7.1 (6.5-7.4)	6.6 (6.0-7.0)	6.6 (6.0-7.0)
TOTAL AMMONIA NITROGEN (TAN) (mg l^{-1})	< 1	< 1	< 1	< 1	< 1	< 1
CHLORIDE (mg l^{-1})	21.4 (8-40)	6.3 (4-20)	6.2 (4-20)	5.7 (4-20)	6.4 (4-20)	5.8 (4-12)
CONDUCTIVITY (μ ohms cm^{-2})	161.9 (80-200)	95.2 (40-170)	86.3 (40-100)	82.4 (50-100)	79.5 (40-100)	71.7 (10-100)

ANTICIPATED BENEFITS

The most important outcome of this research was the demonstration that providing a prepared diet to *P. brachypomus* would be economical for local farmers. Farmers are currently using organic fertilizers and periodically providing fruits, nuts, and kitchen scraps. A few farmers occasionally feed their fish chicken feed. The prepared diet used in this study (26.7% protein and 9.0% lipid) was made from ingredients that are locally available. Considering the excellent growth rates that occurred (from 27.5 g to 1.0 kg in ten months), it appears that this diet meets or exceeds *P. brachypomus* nutritional needs. More detailed nutritional studies would provide support for the development of a local fish feed manufacturing capability. Results of the present and on-going study will be shared with local farmers during the Ninth Work Plan via various extension activities.

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Estuarine Water Quality Monitoring and Estuarine Carrying Capacity

Eighth Work Plan, Honduras Research 2-1 (HR2-1)
Progress Report

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Abstract

Water quality was monitored in estuaries of the shrimp-producing regions of southern Honduras. This project is a collaborative effort of universities, the private sector, and the public sector, with each group contributing time and resources to the overall effort. The project goal is to provide a scientific basis for estuarine management and sustainable development of shrimp culture in Honduras. Specific objectives are to: 1) detect changes in estuarine water quality; 2) formulate and validate predictive models for estuarine water quality; and 3) estimate assimilative capacity of selected estuaries in the shrimp-producing region of southern Honduras based on water quality, farm chemical budgets, and estuarine fluid dynamics. Samples were collected from June 1997 to June 1998 from 20 sites on 12 estuaries. Data were added to the database on estuarine water quality established in 1993. Nutrient sources for riverine estuaries include nutrient load in river discharge and rainfall or irrigation runoff from the watershed, and shrimp farm discharge. Changes in land-use patterns in the Gulf of Fonseca watershed also will affect estuarine water quality because of changes in runoff patterns and volumes. Examples of this effect already have been observed in the upper reaches of a couple of estuaries where stands of mangroves have died apparently because of sedimentation, which resulted from severe reduction of runoff caused by watershed land-use changes. Water quality in riverine estuaries continues to be influenced directly by seasonal variation in river discharge and watershed runoff, while embayments of the Gulf of Fonseca experience less seasonal variation in water quality. The impact of the El Niño in Honduras this past year was delayed and reduced rains, which resulted in higher observed salinity, total nitrogen, and chlorophyll *a* concentrations at sampling sites along riverine estuaries in comparison to 1996 and 1997. Embayment water quality was less affected by the El Niño. Declines in water quality in riverine estuaries were exacerbated with increasing distance upstream because water exchange with the Gulf of Fonseca decreases rapidly with distance upstream. No trends for total nitrogen or total phosphorus enrichment were evident in riverine estuaries or embayments during the period from 1993 to 1998. Total nitrogen and total phosphorus concentrations in riverine estuaries were reduced by 10 to 30% during the rainy season because of river discharge and watershed runoff.

Introduction

A long-term water quality monitoring project in estuaries of the shrimp-producing regions of Honduras was initiated in 1993 as part of the Pond Dynamics/Aquaculture Collaborative Research Support Program (Teichert-Coddington, 1995; Green et al., 1997a). This project is a collaborative effort of universities and the private and public sectors, with each group contributing time and resources to the overall effort. The goal of this monitoring effort is to provide a scientific basis for estuarine management and sustainable development of shrimp culture in Honduras. Specific objectives of the water quality monitoring are to:

1) Detect changes in estuarine water quality over time;
2) Formulate and validate predictive models for estuarine water quality; and
3) Estimate assimilative capacity of selected estuaries in the shrimp-producing region of southern Honduras based on water quality, farm chemical budgets, and estuarine fluid dynamics.

Since 1993 the project has generated a continuous, long-term, systematic database on estuarine water quality in shrimp-producing areas of southern Honduras.

Estuarine water quality was monitored at 13 sites on 6 different estuaries when the project began in 1993. During this past year, 20 sites on 12 estuaries were monitored. The number of sites sampled has varied from 13 to 20 on 6 to 12 estuaries. Variation in yearly sample size is attributed in part to farms closing for the dry season, farms going out of business, change of farm ownership, change in managers or technical staff responsible for collection and delivery of water samples to the lab, logistical difficulties (e.g., no transport available), or distraction caused by crisis situations on farm. There is an ongoing effort to maintain continuous participation in the project and to incorporate additional farms.

Results of estuarine water quality monitoring are summarized in this report. Modeling work and estimates of assimilative capacity of selected estuaries will be reported separately.

Methods and Materials

Estuarine water samples were collected from pump discharge on individual farms within one hour of high tide. It was assumed that the water samples collected represented a mixed water column sample of the estuary at the pump station because of the superficial vortex caused by the 60- to 90-cm-

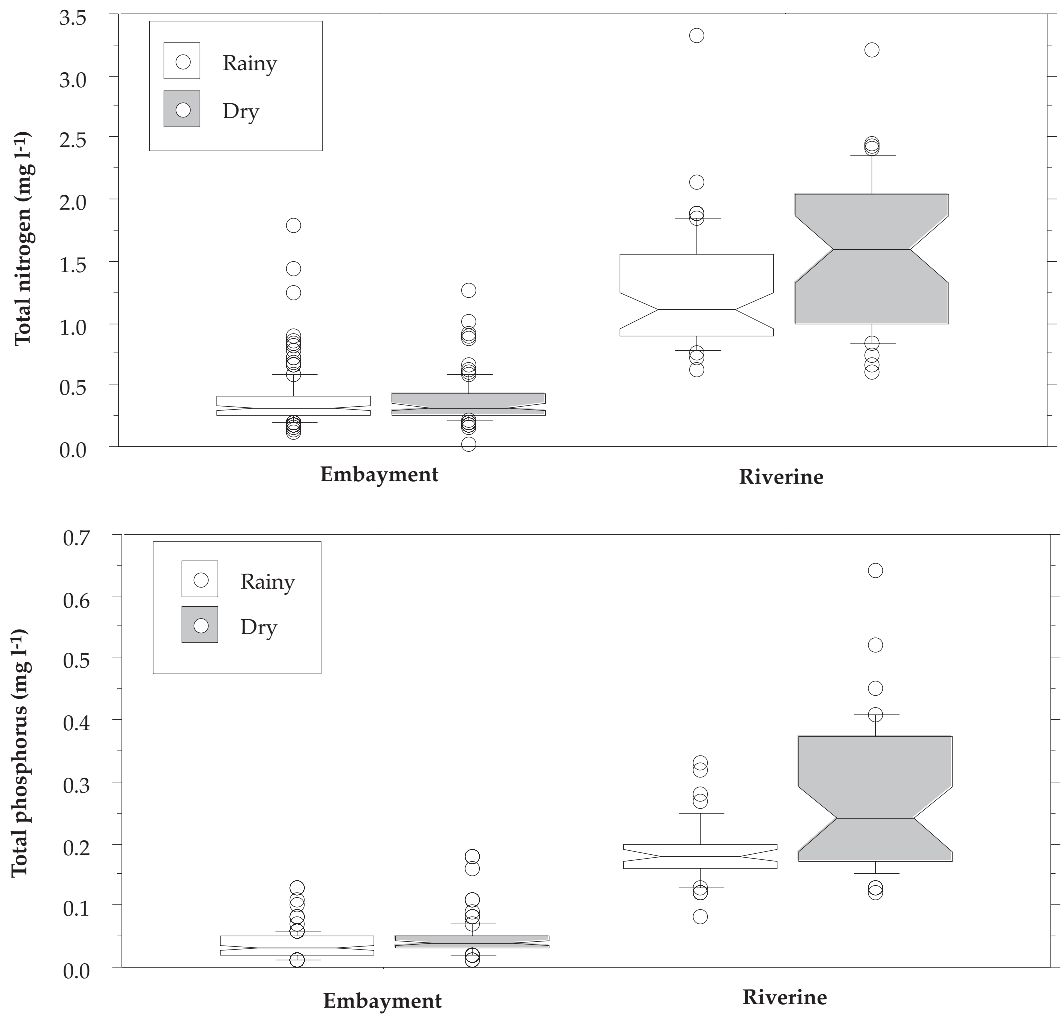

Figure 1. Comparison of median total nitrogen and total phosphorus concentrations in embayments (pooled data) and a riverine estuary, El Pedregal, using box plots. Data are from June 1997 to June 1998. Mid-June through mid-December was classified as the rainy season. The notches represent the 95% confidence limits around the median.

diameter pump intakes, which are located near the bottom of the estuary. Samples were placed on ice and transported to the water quality laboratory where analysis began within 12 hours of collection. The Choluteca River also was sampled weekly at La Lujosa, which is located downstream from the city of Choluteca and upstream from tidal influence.

Samples were analyzed for total settleable solids (APHA, 1985), nitrate-nitrogen by cadmium reduction to nitrite (Parsons et al., 1992), total ammonia-nitrogen (Parsons et al., 1992), filterable reactive phosphorus (Grasshoff et al., 1983), chlorophyll *a* (Parsons et al., 1992), total alkalinity by titration to pH 4.5 endpoint, salinity and BOD_2 (APHA, 1985), and reactive silicate (Strickland and Parsons, 1977). Total nitrogen and total phosphorus are determined by nitrate and phosphate analysis, respectively, after simultaneous persulfate oxidation in a strong base (Grasshoff et al., 1983).

Data collected from June 1997 to June 1998 were tabulated by sampling site. Box plots were used to compare total nitrogen and total phosphorus concentrations by estuary type (embayment or riverine) and season. Time-series graphs (1993 to 1998) of total nitrogen and total phosphorus concentrations were made using data from El Pedregal estuary (illustrative of riverine estuaries) and embayment estuaries (pooled data).

RESULTS

Results of water quality analyses by site are summarized in Table 1. Water quality in riverine estuaries is influenced directly by seasonal variation in river discharge and watershed runoff, while embayments of the Gulf of Fonseca experience less seasonal variation in water quality. Nutrient concentrations in riverine estuaries follow a cyclical trend that is controlled by season, with higher concentrations of total nitrogen and total phosphorus occurring during the dry season and lower concentrations occurring during the rainy season. Rains in southern Honduras generally begin in May, remain strong through June, taper off during July and August, and resume during September and October. However, the effects of the El Niño in Honduras during this past year were delayed and reduced rains. As a result, observed salinity, total nitrogen, and chlorophyll *a* concentrations were higher at sampling sites along riverine estuaries in comparison to 1996 through 1997.

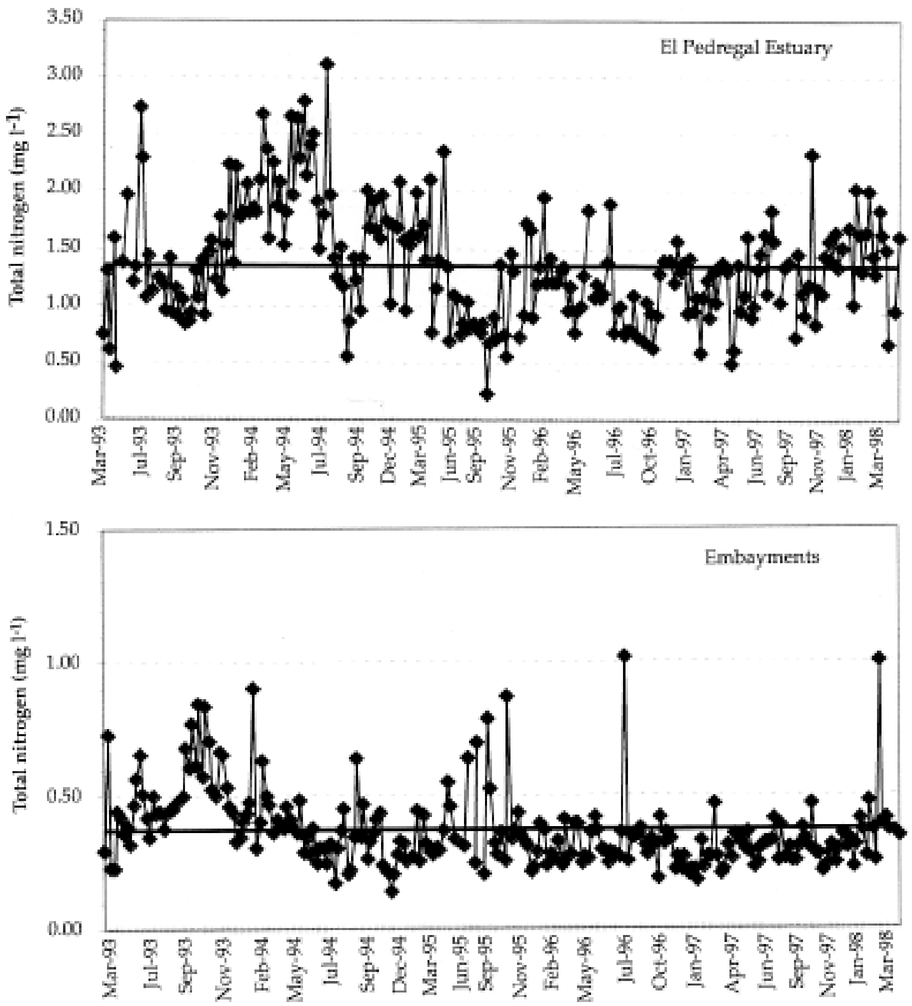

Figure 2. Mean total nitrogen concentration in the riverine El Pedregal estuary and embayments of the Gulf of Fonseca from 1993 to 1998. Total nitrogen concentration trends in other monitored riverine estuaries were similar to El Pedregal estuary. Solid horizontal line in each graph is the grand mean concentration during this period.

Nutrient concentrations in embayments were not affected noticeably by the El Niño.

During the rainy season, heavy watershed runoff and river discharge quickly flushed out riverine estuaries and reduced salinity to zero or nearly zero parts per thousand, while embayment salinities dropped only moderately. Concentrations of other nutrients in riverine estuaries decreased, but not to the degree observed with salinity because of the nutrient load carried by the increased river discharge and watershed runoff. Nutrient concentrations in embayments were lower and less affected by season than in riverine estuaries (Figure 1).

No trends for long-term total nitrogen or total phosphorus enrichment were evident in the El Pedregal estuary or embayments of the Gulf of Fonseca (Figures 2 and 3). Data from all embayment estuaries were pooled because of the small number of sampling sites. Trends in nutrient concentrations in other riverine estuaries were similar to those shown in Figures 2 and 3.

Water quality also varied with position in riverine estuaries (Figure 4). Total nitrogen concentration increased with distance upstream from the Gulf of Fonseca during both rainy and dry seasons; however, total nitrogen concentrations were lower in the rainy season. Concentrations of total phosphorus followed a similar pattern (Table 2), and similar patterns were observed in other riverine estuaries.

DISCUSSION

Water quality in riverine estuaries is related to season. Global climatic events such as El Niño, which provoked drought conditions in Honduras, exacerbate poor water quality conditions in riverine estuaries of the Gulf of Fonseca. In normal years, seasonal rains increase river discharge and watershed runoff, which serve to dilute nutrient concentrations in riverine estuaries. While salinity in riverine estuaries may be reduced to zero or nearly so during the rainy season because of massive freshwater inflow, total nitrogen and total phosphorus concentrations decrease only by 10 to 30% because of nutrient load in inflow. Changes in land-use patterns in the Gulf of

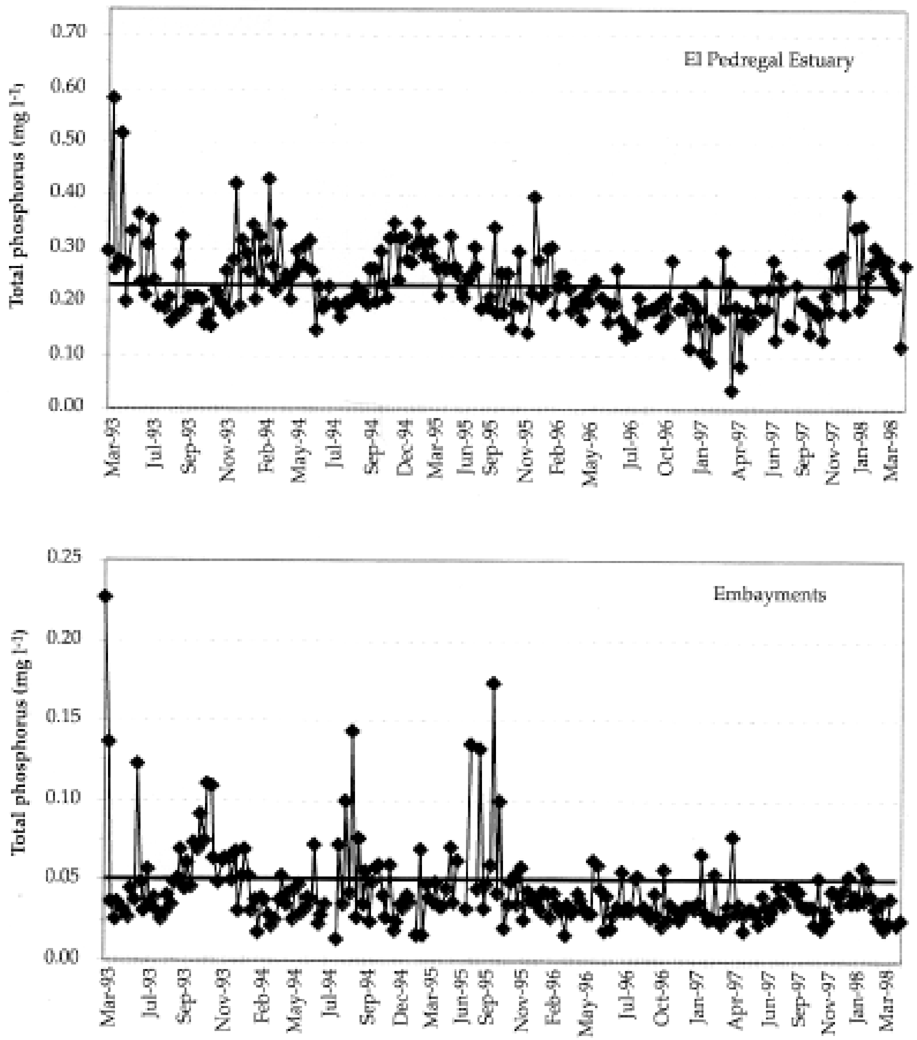

Figure 3. Mean total phosphorus concentration in the riverine El Pedregal estuary and embayments of the Gulf of Fonseca from 1993 to 1998. Total phosphorus concentration trends in other monitored riverine estuaries were similar to El Pedregal estuary. Solid horizontal line in each graph is the grand mean concentration during this period.

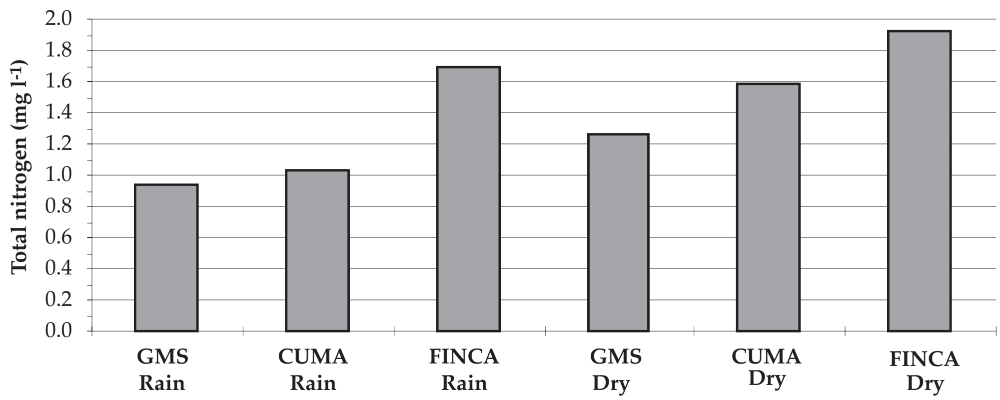

Figure 4. Total nitrogen concentrations in the San Bernardo estuary in relation to distance from the mouth of the estuary and season during the period from June 1997 to June 1998. The GMSB sample site is nearest to the Gulf of Fonseca and the FINCA SUR site is farthest. Mid-June through mid-December was classified as the rainy season.

Table 1. Summary of estuarine water quality at shrimp farm pump station sites in southern Honduras from June 1997 to June 1998. Sites are labeled as "riverine" or "embayment" depending on whether or not a river discharges directly into the estuary.

Variable	Mean	SD	Count	Minimum	Maximum	Median
AQUACULTURA FONSECA - RIVERINE						
Salinity (ppt)	19.83	12.38	32	3.00	48.00	18.50
Total Ammonia Nitrogen (mg l^{-1})	0.24	0.10	32	0.06	0.41	0.23
Total Nitrogen (mg l^{-1})	1.46	0.41	32	0.24	2.11	1.45
Nitrates + Nitrites (mg l^{-1})	0.15	0.12	32	0.02	0.53	0.13
Total Phosphorus (mg l^{-1})	0.25	0.06	32	0.14	0.36	0.24
Sol. Reactive Phosphate (mg l^{-1})	0.14	0.05	31	0.04	0.22	0.15
Total Alkalinity (mg l^{-1})	146.67	42.64	31	63.00	202.98	153.65
Chlorophyll *a* (mg m^{-3})	32.68	17.08	32	0.92	69.84	31.06
BOD_2 (mg l^{-1})	2.44	1.14	30	0.70	6.40	2.23
Settleable solids (mg l^{-1})	0.67	0.70	29	0.00	2.80	0.40
Reactive Silicate (mg l^{-1})	4.15	1.89	13	0.85	9.03	4.02
AQUACULTIVOS #1 - RIVERINE						
Salinity (ppt)	18.00	11.34	45	0.50	41.00	18.50
Total Ammonia Nitrogen (mg l^{-1})	0.14	0.10	43	0.02	0.46	0.12
Total Nitrogen (mg l^{-1})	1.16	0.41	45	0.48	2.17	1.05
Nitrates + Nitrites (mg l^{-1})	0.37	0.33	43	0.02	1.46	0.27
Total Phosphorus (mg l^{-1})	0.19	0.06	45	0.08	0.32	0.19
Sol. Reactive Phosphate (mg l^{-1})	0.12	0.04	43	0.05	0.21	0.11
Total Alkalinity (mg l^{-1})	126.30	37.36	42	49.00	198.65	128.03
Chlorophyll *a* (mg m^{-3})	25.38	20.69	43	2.53	111.31	20.07
BOD_2 (mg l^{-1})	1.90	0.69	41	0.65	3.60	1.85
Settleable Solids (mg l^{-1})	1.07	1.68	41	0.05	10.00	0.60
Reactive Silicate (mg l^{-1})	3.64	1.39	15	1.87	7.94	3.62
AQUACULTIVOS #2 - RIVERINE						
Salinity (ppt)	4.18	10.07	45	0.00	36.5	0.50
Total Ammonia Nitrogen (mg l^{-1})	0.07	0.09	43	0.01	0.54	0.04
Total Nitrogen (mg l^{-1})	0.99	0.55	45	0.26	2.46	0.86
Nitrates + Nitrites (mg l^{-1})	0.34	0.42	43	0.00	1.78	0.11
Total Phosphorus (mg l^{-1})	0.24	0.06	45	0.14	0.40	0.23
Sol. Reactive Phosphate (mg l^{-1})	0.18	0.06	43	0.04	0.29	0.16
Total Alkalinity (mg l^{-1})	136.34	62.47	42	46.00	300.72	123.05
Chlorophyll *a* (mg m^{-3})	35.61	37.20	43	0.00	165.44	23.18
BOD_2 (mg l^{-1})	2.57	1.40	41	0.25	5.80	2.35
Settleable Solids (mg l^{-1})	0.81	2.06	40	0.00	12.00	0.20
Reactive Silicate (mg l^{-1})	7.78	5.80	14	1.50	22.79	6.04
BIOMAR - RIVERINE						
Salinity (ppt)	26.11	6.73	37	15.50	46.00	25.00
Total Ammonia Nitrogen (mg l^{-1})	0.03	0.03	37	0.01	0.16	0.03
Total Nitrogen (mg l^{-1})	0.77	0.37	37	0.42	2.29	0.65
Nitrates + Nitrites (mg l^{-1})	0.17	0.09	37	0.00	0.37	0.17
Total Phosphorus (mg l^{-1})	0.15	0.06	37	0.06	0.33	0.13
Sol. Reactive Phosphate (mg l^{-1})	0.08	0.02	37	0.03	0.15	0.08
Total Alkalinity (mg l^{-1})	129.59	19.32	36	95.00	177.80	125.73
Chlorophyll *a* (mg m^{-3})	20.13	19.07	37	2.34	75.34	10.05
BOD_2 (mg l^{-1})	1.45	1.24	35	0.10	5.40	1.15
Settleable Solids (mg l^{-1})	0.96	1.73	31	0.00	7.00	0.20
Reactive Silicate (mg l^{-1})	2.34	0.76	14	0.74	3.37	2.46

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
CADELPA - RIVERINE						
Salinity (ppt)	20.11	13.43	39	2.00	51.00	15.50
Total Ammonia Nitrogen (mg l^{-1})	0.19	0.11	38	0.03	0.40	0.17
Total Nitrogen (mg l^{-1})	1.66	0.68	42	0.00	3.32	1.66
Nitrates + Nitrites (mg l^{-1})	0.11	0.13	38	0.01	0.57	0.06
Total Phosphorus (mg l^{-1})	0.28	0.11	40	0.13	0.64	0.25
Sol. Reactive Phosphate (mg l^{-1})	0.15	0.07	38	0.02	0.41	0.14
Total Alkalinity (mg l^{-1})	148.10	41.55	37	53.93	215.11	149.00
Chlorophyll *a* (mg m^{-3})	51.76	36.34	38	9.44	164.24	44.67
BOD_2 (mg l^{-1})	3.62	1.93	35	0.95	9.35	3.30
Settleable Solids (mg l^{-1})	0.35	0.43	36	0.00	2.00	0.20
Reactive Silicate (mg l^{-1})	4.25	1.51	14	0.94	7.51	4.49
CRIMASA - RIVERINE						
Salinity (ppt)	23.20	8.96	32	7.50	46.00	21.50
Total Ammonia Nitrogen (mg l^{-1})	0.09	0.08	32	0.00	0.27	0.07
Total Nitrogen (mg l^{-1})	1.15	0.39	32	0.56	2.15	1.11
Nitrates + Nitrites (mg l^{-1})	0.16	0.13	32	0.01	0.55	0.12
Total Phosphorus (mg l^{-1})	0.18	0.06	32	0.08	0.29	0.18
Sol. Reactive Phosphate (mg l^{-1})	0.11	0.04	32	0.04	0.23	0.12
Total Alkalinity (mg l^{-1})	129.68	24.69	31	75.00	182.58	131.26
Chlorophyll *a* (mg m^{-3})	31.45	32.13	32	2.41	124.32	16.60
BOD_2 (mg l^{-1})	1.87	0.92	30	0.50	4.55	1.67
Settleable Solids (mg l^{-1})	0.48	0.53	31	0.00	2.50	0.40
Reactive Silicate (mg l^{-1})	3.46	0.55	6	2.78	4.33	3.34
CULCAMAR - EMBAYMENT						
Salinity (ppt)	26.19	2.00	32	21.50	34.00	26.00
Total Ammonia Nitrogen (mg l^{-1})	0.16	0.02	31	0.00	0.05	0.01
Total Nitrogen (mg l^{-1})	0.52	0.71	32	0.23	4.11	0.36
Nitrates + Nitrites (mg l^{-1})	0.01	0.01	31	0.00	0.02	0.00
Total Phosphorus (mg l^{-1})	0.03	0.01	32	0.01	0.07	0.03
Sol. Reactive Phosphate (mg l^{-1})	0.01	0.05	31	0.00	0.30	0.00
Total Alkalinity (mg l^{-1})	114.09	11.88	30	88.00	133.62	113.45
Chlorophyll *a* (mg m^{-3})	9.80	10.69	31	1.70	41.78	4.82
BOD_2 (mg l^{-1})	1.17	0.64	28	0.05	2.50	1.10
Settleable Solids (mg l^{-1})	0.00	0.01	29	0.00	0.05	0.00
Reactive Silicate (mg l^{-1})	1.51	1.29	7	0.27	4.27	1.17
CUMAR - RIVERINE						
Salinity (ppt)	19.96	15.64	26	1.00	51.00	20.25
Total Ammonia Nitrogen (mg l^{-1})	0.12	0.08	26	0.01	0.34	0.11
Total Nitrogen (mg l^{-1})	1.31	0.53	26	0.62	3.14	1.28
Nitrates + Nitrites (mg l^{-1})	0.24	0.15	26	0.00	0.53	0.22
Total Phosphorus (mg l^{-1})	0.27	0.16	26	0.12	0.98	0.25
Sol. Reactive Phosphate (mg l^{-1})	0.18	0.05	26	0.11	0.34	0.19
Total Alkalinity (mg l^{-1})	153.39	43.33	26	84.45	222.36	146.52
Chlorophyll a (mg m^{-3})	33.39	21.57	26	4.65	106.80	30.45
BOD_2 (mg l^{-1})	2.42	1.00	26	1.05	4.50	2.20
Settleable Solids (mg l^{-1})	1.03	1.38	23	0.10	5.50	0.50
Reactive Silicate (mg l^{-1})	3.92	0.98	12	2.22	5.77	4.00

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
EL FARO - RIVERINE						
Salinity (ppt)	20.70	12.68	37	0.50	54.00	18.00
Total Ammonia Nitrogen (mg l^{-1})	0.13	0.09	36	0.02	0.42	0.13
Total Nitrogen (mg l^{-1})	1.53	0.52	37	0.78	2.95	1.43
Nitrates + Nitrites (mg l^{-1})	0.16	0.16	36	0.00	0.70	0.11
Total Phosphorus (mg l^{-1})	0.29	0.13	37	0.08	0.65	0.26
Sol. Reactive Phosphate (mg l^{-1})	0.19	0.07	36	0.08	0.38	0.18
Total Alkalinity (mg l^{-1})	177.08	55.38	35	46.00	280.50	172.00
Chlorophyll *a* (mg m^{-3})	39.84	38.51	36	0.00	177.72	31.83
BOD_2 (mg l^{-1})	2.57	1.37	33	0.60	5.30	2.70
Settleable Solids (mg l^{-1})	3.49	7.26	35	0.00	32.00	0.10
Reactive Silicate (mg l^{-1})	4.94	0.94	11	3.80	6.73	4.91
FINCA SUR #1 - RIVERINE						
Salinity (ppt)	16.50	9.22	29	2.00	44.00	16.00
Total Ammonia Nitrogen (mg l^{-1})	0.08	0.13	27	0.01	0.56	0.03
Total Nitrogen (mg l^{-1})	1.75	0.75	29	0.74	3.65	1.72
Nitrates + Nitrites (mg l^{-1})	0.42	0.08	27	0.00	0.26	0.01
Total Phosphorus (mg l^{-1})	0.33	0.09	29	0.18	0.51	0.31
Sol. Reactive Phosphate (mg l^{-1})	0.16	0.08	27	0.03	0.29	0.15
Total Alkalinity (mg l^{-1})	180.36	57.24	26	76.31	280.50	171.96
Chlorophyll *a* (mg m^{-3})	71.86	47.95	28	4.82	185.48	59.26
BOD_2 (mg l^{-1})	4.28	2.12	25	1.45	7.90	3.80
Settleable Solids (mg l^{-1})	0.80	1.43	25	0.00	6.50	0.20
Reactive Silicate (mg l^{-1})	4.14	1.53	6	1.20	5.47	4.36
FINCA SUR #2 - RIVERINE						
Salinity (ppt)	17.02	9.28	31	3.50	47.00	16.50
Total Ammonia Nitrogen (mg l^{-1})	0.06	0.07	29	0.00	0.27	0.03
Total Nitrogen (mg l^{-1})	1.77	0.59	31	0.66	3.16	1.60
Nitrates + Nitrites (mg l^{-1})	0.02	0.04	29	0.00	0.13	0.00
Total Phosphorus (mg l^{-1})	0.32	0.09	31	0.12	0.54	0.32
Sol. Reactive Phosphate (mg l^{-1})	0.16	0.07	28	0.01	0.27	0.16
Total Alkalinity (mg l^{-1})	179.36	56.05	28	84.45	277.44	172.98
Chlorophyll *a* (mg m^{-3})	65.66	37.04	30	19.53	148.80	55.92
BOD_2 (mg l^{-1})	4.00	1.94	28	0.80	8.30	3.53
Settleable Solids (mg l^{-1})	0.23	0.23	27	0.00	0.90	0.15
Reactive Silicate (mg l^{-1})	4.26	0.79	7	3.29	5.31	4.20
GMSB #1 - RIVERINE						
Salinity (ppt)	18.44	9.84	42	2.00	38.50	18.00
Total Ammonia Nitrogen (mg l^{-1})	0.14	0.08	40	0.03	0.32	0.13
Total Nitrogen (mg l^{-1})	1.08	0.32	42	0.60	1.88	0.99
Nitrates + Nitrites (mg l^{-1})	0.30	0.18	40	0.07	1.08	0.28
Total Phosphorus (mg l^{-1})	0.18	0.04	42	0.08	0.32	0.18
Sol. Reactive Phosphate (mg l^{-1})	0.11	0.03	40	0.06	0.23	0.11
Total Alkalinity (mg l^{-1})	124.35	36.58	38	25.00	210.12	127.10
Chlorophyll *a* (mg m^{-3})	21.70	16.34	40	2.57	80.59	15.82
BOD_2 (mg l^{-1})	1.47	0.67	38	0.50	3.75	1.38
Settleable Solids (mg l^{-1})	0.48	0.56	39	0.00	2.50	0.20
Reactive Silicate (mg l^{-1})	3.70	2.14	14	1.75	9.47	2.80

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
GMSB #2 - RIVERINE						
Salinity (ppt)	21.89	9.15	40	3.50	42.00	21.00
Total Ammonia Nitrogen (mg l^{-1})	0.09	0.06	39	0.01	0.24	0.08
Total Nitrogen (mg l^{-1})	1.08	0.62	41	0.29	4.08	0.88
Nitrates + Nitrites (mg l^{-1})	0.28	0.14	39	0.12	0.94	0.28
Total Phosphorus (mg l^{-1})	0.19	0.05	41	0.03	0.34	0.19
Sol. Reactive Phosphate (mg l^{-1})	0.13	0.04	39	0.08	0.27	0.12
Total Alkalinity (mg l^{-1})	134.31	32.93	38	52.00	225.42	136.60
Chlorophyll *a* (mg m^{-3})	17.94	15.32	39	2.37	72.45	13.78
BOD_2 (mg l^{-1})	1.42	0.61	36	0.30	2.85	1.40
Settleable Solids (mg l^{-1})	0.51	1.03	36	0.00	5.00	0.10
Reactive Silicate (mg l^{-1})	3.39	1.98	13	2.01	9.75	2.85
LA JAGUA - RIVERINE						
Salinity (ppt)	17.44	11.77	39	0.00	42.00	16.00
Total Ammonia Nitrogen (mg l^{-1})	0.17	0.12	37	0.01	0.48	0.13
Total Nitrogen (mg l^{-1})	1.30	0.45	40	0.46	2.35	1.21
Nitrates + Nitrites (mg l^{-1})	0.31	0.29	38	0.02	1.63	0.25
Total Phosphorus (mg l^{-1})	0.20	0.05	40	0.12	0.29	0.19
Sol. Reactive Phosphate (mg l^{-1})	0.13	0.03	37	0.07	0.18	0.12
Total Alkalinity (mg l^{-1})	135.61	37.56	36	50.88	196.45	135.68
Chlorophyll *a* (mg m^{-3})	33.12	19.68	38	6.52	83.15	28.53
BOD_2 (mg l^{-1})	2.63	1.43	34	1.05	8.00	2.58
Settleable Solids (mg l^{-1})	1.58	1.88	37	0.00	6.20	0.60
Reactive Silicate (mg l^{-1})	3.98	1.30	14	2.21	7.29	3.89
LAS ARENAS - EMBAYMENT						
Salinity (ppt)	26.88	3.13	43	22.50	35.50	26.00
Total Ammonia Nitrogen (mg l^{-1})	0.03	0.03	40	0.00	0.15	0.02
Total Nitrogen (mg l^{-1})	0.33	0.13	43	0.16	0.89	0.30
Nitrates + Nitrites (mg l^{-1})	0.02	0.04	39	0.00	0.26	0.01
Total Phosphorus (mg l^{-1})	0.02	0.01	43	0.00	0.05	0.02
Sol. Reactive Phosphate (mg l^{-1})	0.01	0.03	41	0.00	0.16	0.00
Total Alkalinity (mg l^{-1})	113.75	11.14	41	87.00	139.74	113.96
Chlorophyll *a* (mg m^{-3})	4.02	1.49	41	0.00	6.79	4.58
BOD_2 (mg l^{-1})	0.88	0.49	38	0.15	3.00	0.80
Settleable Solids (mg l^{-1})	0.01	0.05	40	0.00	0.30	0.00
Reactive Silicate (mg l^{-1})	0.72	0.18	13	0.24	0.88	0.77
LORETTE #1 - EMBAYMENT						
Salinity (ppt)	25.98	5.01	31	9.50	39.50	26.50
Total Ammonia Nitrogen (mg l^{-1})	0.04	0.03	31	0.00	0.14	0.03
Total Nitrogen (mg l^{-1})	0.53	0.30	32	0.00	1.44	0.47
Nitrates + Nitrites (mg l^{-1})	0.02	0.04	31	0.00	0.15	0.01
Total Phosphorus (mg l^{-1})	0.07	0.04	31	0.01	0.18	0.06
Sol. Reactive Phosphate (mg l^{-1})	0.02	0.04	31	0.00	0.14	0.00
Total Alkalinity (mg l^{-1})	133.92	15.59	30	99.72	169.32	133.30
Chlorophyll *a* (mg m^{-3})	9.88	8.27	31	0.00	34.75	8.39
BOD_2 (mg l^{-1})	1.78	1.26	30	0.20	6.05	1.40
Settleable Solids (mg l^{-1})	0.05	0.05	29	0.00	0.20	0.05
Reactive Silicate (mg l^{-1})	2.42	1.15	9	1.69	5.39	2.19

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
LORETTE #2 - EMBAYMENT						
Salinity (ppt)	25.13	5.27	31	10.00	39.50	25.50
Total Ammonia Nitrogen (mg l^{-1})	0.03	0.03	31	0.00	0.10	0.03
Total Nitrogen (mg l^{-1})	0.49	0.24	31	0.23	1.25	0.42
Nitrates + Nitrites (mg l^{-1})	0.03	0.04	31	0.00	0.16	0.01
Total Phosphorus (mg l^{-1})	0.05	0.03	31	0.02	0.18	0.04
Sol. Reactive Phosphate (mg l^{-1})	0.01	0.03	30	0.00	0.14	0.01
Total Alkalinity (mg l^{-1})	119.66	15.65	30	91.58	159.14	120.50
Chlorophyll *a* (mg m^{-3})	12.77	26.90	31	0.00	150.00	5.37
BOD_2 (mg l^{-1})	1.71	1.45	30	0.40	7.00	1.20
Settleable Solids (mg l^{-1})	0.13	0.32	28	0.00	1.50	0.00
Reactive Silicate (mg l^{-1})	1.98	1.23	9	1.16	5.11	1.62
CHOLUTECA RIVER AT LA LUJOSA						
Salinity (ppt)	0.00	0.00	46	0.00	0.00	0.00
Total Ammonia Nitrogen (mg l^{-1})	0.04	0.03	45	0.01	0.18	0.04
Total Nitrogen (mg l^{-1})	0.96	0.59	47	0.43	3.27	0.73
Nitrates + Nitrites (mg l^{-1})	0.45	0.56	45	0.00	2.51	0.22
Total Phosphorus (mg l^{-1})	0.27	0.10	47	0.11	0.63	0.25
Sol. Reactive Phosphate (mg l^{-1})	0.22	0.09	45	0.05	0.41	0.21
Total Alkalinity (mg l^{-1})	116.72	37.18	44	43.75	183.28	110.96
Chlorophyll *a* (mg m^{-3})	17.34	14.30	45	0.00	79.98	15.64
BOD_2 (mg l^{-1})	2.20	0.97	42	0.10	4.90	2.17
Settleable Solids (mg l^{-1})	0.53	1.59	43	0.00	9.40	0.05
Reactive Silicate (mg l^{-1})	11.86	7.49	15	0.88	24.57	9.33
SEA FARMS #1 - EMBAYMENT						
Salinity (ppt)	27.01	2.75	46	23.50	33.50	26.00
Total Ammonia Nitrogen (mg l^{-1})	0.05	0.03	44	0.00	0.12	0.04
Total Nitrogen (mg l^{-1})	0.27	0.07	46	0.11	0.48	0.27
Nitrates + Nitrites (mg l^{-1})	0.02	0.03	44	0.00	0.21	0.02
Total Phosphorus (mg l^{-1})	0.05	0.01	46	0.00	0.08	0.05
Sol. Reactive Phosphate (mg l^{-1})	0.03	0.01	44	0.00	0.05	0.03
Total Alkalinity (mg l^{-1})	116.20	7.50	43	97.00	13.66	117.00
Chlorophyll *a* (mg m^{-3})	5.33	4.05	44	0.00	25.39	4.74
BOD_2 (mg l^{-1})	0.79	0.44	42	0.20	2.20	0.78
Settleable Solids (mg l^{-1})	0.01	0.02	43	0.00	0.05	0.00
Reactive Silicate (mg l^{-1})	1.18	0.50	14	0.13	1.96	1.17
SEA FARMS #2 - EMBAYMENT						
Salinity (ppt)	27.28	2.98	46	23.00	34.50	26.00
Total Ammonia Nitrogen (mg l^{-1})	0.05	0.04	44	0.00	0.16	0.04
Total Nitrogen (mg l^{-1})	0.32	0.13	46	0.02	0.84	0.40
Nitrates + Nitrites (mg l^{-1})	0.02	0.02	44	0.00	0.08	0.02
Total Phosphorus (mg l^{-1})	0.02	0.01	46	0.00	0.05	0.02
Sol. Reactive Phosphate (mg l^{-1})	0.01	0.01	44	0.00	0.02	0.01
Total Alkalinity (mg l^{-1})	112.18	8.62	43	93.00	130.56	112.00
Chlorophyll *a* (mg m^{-3})	4.47	4.38	44	0.00	28.09	4.35
BOD_2 (mg l^{-1})	1.04	0.69	42	0.30	4.00	0.90
Settleable Solids (mg l^{-1})	0.00	0.02	43	0.00	0.10	0.00
Reactive Silicate (mg l^{-1})	0.53	0.15	15	0.24	0.76	0.54

Table 2. Total phosphorus concentrations in estuarine water in rainy and dry seasons at three sites (GMSB, CUMAR, and FINCA SUR) located at increasing distances upstream from the Gulf of Fonseca.

Monitoring Site	Total Phosphorus (mg l^{-1})	
	Rainy Season	*Dry Season*
GMSB	0.16	0.22
CUMAR	0.21	0.34
FINCA SUR	0.28	0.39

Fonseca watershed also will affect estuarine water quality because of changes in runoff patterns and volumes. Examples of this effect already have been observed in the upper reaches of a couple of estuaries where stands of mangroves have died because of sedimentation, which resulted from severe reduction of runoff caused by watershed land-use changes.

Nutrient concentrations in riverine estuaries increase during the dry season because of evaporation, evapotranspiration, reduced river discharge, the absence of watershed runoff, and shrimp farm discharge. Although river discharge drops dramatically and nutrient concentrations increase significantly during the dry season, total nutrient discharge by rivers is significantly lower during the dry season. In fact, river discharge can drop to zero during very dry years. Water quality in the upper reaches of riverine estuaries deteriorates during the dry season, making maintenance of water quality very difficult on farms located in these regions. The deterioration in water quality in riverine estuaries during the dry season is exacerbated because water exchange with the Gulf of Fonseca decreases rapidly with distance upstream (Teichert-Coddington, 1995). Some farms located in the upper reaches of estuaries close during the dry season, probably because of slow growth attributed to lower water temperatures (Teichert-Coddington et al., 1994) and impaired water quality.

Water quality in embayments is less variable because embayments have better exchange with the Gulf of Fonseca, which is low in nutrients. In addition, the Gulf of Fonseca has a high tidal range (1.5 to 3.5 m) which promotes water exchange and nutrient dilution with the Pacific Ocean. River discharge and watershed runoff result in lower salinities, but not as low as those observed in riverine estuaries. Mean total nitrogen and total phosphorus concentrations increased by 11 to 25% during the rainy season because of nutrient load in river discharge and watershed runoff.

Nutrient sources for riverine estuaries include nutrient load in river discharge and rainfall or irrigation runoff from the watershed, and shrimp farm discharge. Shrimp farmers must be acutely aware of estuarine water quality because often the same estuary serves as both the source of water for production ponds and the repository of production pond effluents. Nutrient concentration in shrimp farm effluents is the only source of estuarine nutrients that can be controlled by the farmer. The principal methods to achieve reduction of shrimp farm effluent nutrient load in Honduras are through:

1) A reduction in exogenous nutrient inputs to ponds (i.e., feeds and fertilizers); and
2) The control of development in terms of both new pond area and intensification of production systems.

Significant progress has been achieved in terms of feed use; feed conversion ratios have decreased from a mean of 3.2 in the early 1990s to 1.5 to 2.0 currently (Teichert-Coddington et al., 1991; Teichert-Coddington and Rodriguez, 1995; Teichert-Coddington et al., 1996; Green et al., 1997b). Results of PD/A CRSP research have demonstrated that feed protein content and daily feed ration can be decreased during the dry season without affecting yield (Teichert-Coddington and Rodriguez, 1995; Green et al., 1997b). Research on chemical fertilizer use and lower protein content diets is being conducted by some farms. Reduced use of exogenous nutrients in shrimp production during the dry season should reduce the environmental impact of shrimp farm effluents. Additionally, the development of assimilative capacity models for selected estuaries will provide information necessary in the formulation of strategies and regulations governing future development of shrimp farming.

ANTICIPATED BENEFITS

The estuarine water quality database serves to track long-term trends in estuarine water quality in shrimp-producing regions of southern Honduras. It serves to increase awareness among shrimp farmers of their relation to the environment and encourages them to pursue sustainable production strategies. Data from this study will be used to develop models of assimilative capacity for selected estuaries. The assimilative capacity models will provide information necessary in the formulation of strategies and regulations governing future development of shrimp farming.

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ANALYSIS OF HONDURAN SHRIMP FARM IMPACTS ON CHANNEL ESTUARIES OF THE GULF OF FONSECA

Eighth Work Plan, Honduras Research 2-2 (HR2-2)
Progress Report

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ABSTRACT

This report summarizes progress on a project to analyze water quality and hydromechanical data from the channel estuaries of the Gulf of Fonseca in Honduras and to develop suitable water quality models. The overall objective is to perform quantitative computation of the carrying capacity of the estuarine system for a viable shrimp farming industry. The study addresses Estero el Pedregal and Estero San Bernardo, which are typical of many of the river-channel estuaries within the larger Gulf of Fonseca along which shrimp farming is being developed. It has been established that hydrographic conditions in the regions in which shrimp farming operates, including tidal range and period, freshwater throughflow, physiography and morphology (especially the role of tidal flats), and tidal currents and related parameters—mixing and dispersion—are at least as important as chemical quality in the effects of farm effluent on estuary quality. Models are under development for tidal hydrodynamics, salinity, and dissolved oxygen. The lack of good field data has been the principal impediment to modeling these systems in the past, and the database has been considerably improved in the past several years due to the efforts of CRSP researchers, the Peace Corps, and concerned individuals and shrimp farms in the region.

INTRODUCTION

This project addresses the overall problem of establishing the assimilative capacity, i.e., the "carrying capacity," for shrimp mariculture in the Rio Choluteca delta areas of Honduras, on the Gulf of Fonseca. Because of the intensive development of this industry in recent years, the proximity of the shrimp farms, and the large volumes of daily water exchange, there is great concern that accumulation of waste byproducts from these mariculture facilities will impose a limit to the number of ponds that can be operated. This self-limiting density, if it exists, must be quantified as a basic management parameter; if the number of shrimp ponds exceeds this self-limiting density, the viability of the industry could be compromised.

The problem of shrimp aquaculture management requires an evaluation of water quality in the regions of existing and proposed shrimp farm operation, especially how that water quality is influenced by the anticipated wasteloads from the shrimp farms themselves and from other wastewater discharges that may be located in the region. The first step in the analysis is to establish the extent of impacts the existing shrimp farms have on the estuarine environment. This entails data collection and analysis, and the development of quantitative models. Both activities are underway. Data collection is being undertaken by Auburn University personnel in Honduras in a companion CRSP project (Green et al., 1999). The present project addresses data analysis and mathematical model development. Once developed, the mathematical model(s) will serve both a diagnostic and a prognostic function in management of the industry in this region.

Both data collection and mathematical model formulation must be commensurate with the level of detail required for accurate depiction of water quality and its controlling processes. The level of detail in both time and space is dictated by the geographical complexity of the watercourse and how variable that watercourse is in time. Estuaries in general, and those debouching into the Gulf of Fonseca in particular, are geometrically complex. Most of the Fonseca shrimp farms are located on dendritic, confluent channel estuaries that drain a mangrove-fringed tidal delta (see Wolanski, 1993). Temporal complexity is induced by both the high tidal exchange of the region and the variability in inflow due to the tropical Pacific climatology. The present study concentrates on two of the more important channel estuaries, Estero Pedregal and Estero San Bernardo, both in the eastern arm of the Gulf of Fonseca.

METHODS AND MATERIALS

Evaluation of assimilative capacity requires a suitable mathematical model to determine the concentrations of key parameters that result from a given level of wasteloading. In any watercourse, the concentration of a constituent is governed by transport processes (including mixing) and kinetic processes, so a model of that constituent must include a determination of hydrodynamic transports as well as a mass balance of the water quality constituents. In an estuary, assimilative capacity is a strong function of position. There will be areas in almost any estuary that are well-circulated and subject to regular water-mass replacement, which will generally have a high assimilative capacity. There will also be areas that are poorly circulated with frequent stagnation (dead zones), which will have a low assimilative capacity. The location of the hypothetical wasteload relative to well-circulated or poorly circulated zones, and relative to other existing wasteloads, is important to the ability of the estuary to assimilate that wasteload. Moreover, the distribution of critical regions of the estuary and the associated assimilative capacity will vary with hydrodynamic conditions. Therefore, a model is needed of space-time distribution of the concentration of controlling parameters in the estuary.

While the magnitude and geographical distribution of the mass influxes of contaminants are clearly an important control, an equally important control is the hydrodynamic capacity of the estuary for dilution and transport. For an estuary, the complex geometry and complicated hydrodynamics make data analysis and model formulation especially difficult. This is why the hydrography of an estuary must be understood in order to evaluate its water quality. In other words, the hydrography of the estuary dictates the relation between mass loads of contaminants and the severity of the resulting water quality decline. An action that alters either the hydrography or the waste loading has the potential of altering water quality. Shrimp farming can do either.

The work in the present project has proceeded along two separate but related directions. First is the acquisition, compilation, and analysis of data relating to the hydrography and water quality of the study estuaries. Second is the formulation and application of mathematical models. Data collection in the study area has been underway for several years, and most of these data pertain to the operation and metabolism of the shrimp ponds themselves. Estuary water was sampled at the intakes to the pond operations. In conjunction with the present study, data collection has been extended into the estuary channels. Methods and procedures of data collection activities for this phase of the work are described in Green et al. (1999). (In the present context, only those data sets being used in the analysis and modeling work are discussed.)

Data analysis is based upon closing volume and mass balances for subsections of the study estuaries on various time and space scales (see Ward and Montague, 1996, and references therein). In most cases, this has been carried out in conjunction with model development. Two models are presently being applied to the study estuaries. The first is a section-mean tidal hydrodynamic model (Dronkers, 1964; Vreugdenhil, 1989). This model is a numerical solution to the differential equations of momentum and continuity. The value of this model is that it provides a means to compute the tidal currents in the estuary based upon the tidal stage, which is measured or predicted at the mouth of the estuary. The currents, rather than tide stage, are really the important hydrographic feature, since it is the currents that are responsible for transport and tidal dispersion. The numerical solution is implemented in a program designed for operation on a DOS-based personal computer (PC).

The second model is a section-mean longitudinal mass budget model for the concentration of a substance along the axis of the estuary (Ward and Espey, 1971). The large-scale tidal-mean distribution of waterborne substances such as salinity, dissolved oxygen (DO), and nutrients varies on time scales of days to weeks, so this model is designed to depict these slower, long-term established concentration profiles. Again, the model is a numerical solution to the governing differential equations implemented in a code for operation on a PC platform.

Preliminary development and application of both of these models were made for the Pedregal system, presented in Ward (1995), and summarized in the following section. While these applications were illuminating, practically no field data from the systems existed at that time, and guesses had to be made for fundamental input data such as water depths, cross-sectional areas, zones of tidal inundation, salinity dispersion, and inflow. Moreover, the only water quality data extant for validating the models were those analyzed from intake samples at the shrimp farms, through a cooperative program between the shrimp farmers, Honduran agencies, and the CRSP (Teichert-Coddington, 1995). A prime objective of the present project is to incorporate field data from the study estuaries into the model development and application.

PROJECT ACCOMPLISHMENTS AND RESULTS

The systems given specific study in this project are the Pedregal and San Bernardo, two of several channel estuaries draining into the eastern arm of the Gulf of Fonseca. An important geometric feature of each of these systems is its declining cross-sectional area with distance upstream. These are horn-shaped estuaries, whose channels have a longitudinally diminishing capacity for flow, as well as an increasing resistance to flow. Another important geometric feature is the large tidal flats adjacent to the estuary, which communicate with the main tidal channel through small scoured tidal passes through the mangrove fringe. In such systems, tidal flats have the capacity to store a great amount of water on the rising tide, and release that water back to the tidal channel as the tide stage falls. The resulting tidal prism is much larger than would be anticipated based solely upon the cross section of the tidal channel.

Shrimp farming concessions have been granted extending over 30 km up the length of both systems, though shrimp farm development is presently limited to about the first 20 km. These shrimp farms eliminate the tidal flats, hydraulically isolating these areas by enclosure within levees to create the shrimp ponds. The farms exchange water between pond and estuary on each tidal cycle (12.4-hr period). For modeling purposes, data on actual producing-pond areas as of 1994 for the larger operations were compiled.

Hydrodynamics

Preliminary application of a tidal hydrodynamic model was made to the Pedregal system including its principal tributary, the Jagua (though a more complex model with additional branching channels could certainly be implemented). A record of tidal variation was obtained by Auburn personnel by installing a digital-logging pressure gauge at the Pedregal intake to the Granjas Marinas farm. Two segments of this tide were selected to represent high- and low-range scenarios and were used to drive the model at the mouth of the Pedregal. Time integrations of several tidal cycles were carried out, solving for tidal current and water level throughout the estuary, from which three fundamental hydrodynamic indicators were determined:

1) Length of the tidal excursion (the distance that a parcel of water moves on the flooding tide);
2) Average tidal-current speed, which is useful in estimating dispersion and in re-aeration; and
3) Tidal prism (the volume of water carried past a fixed point on the flooding tide, a direct measure of dilution volume).

Two scenarios were examined (Ward, 1995): 1) the pre-aquaculture geometry, with flooding tidal flats, as indicated on topographic maps of this region; and 2) 1994 shrimp-farm development, in which the tidal-flat areas were reduced by the amount of pond areas. Tidal excursions computed by the model appear to be on the correct order, compared to observations of Currie (1994) based on tracking buoys in the lower Estero Real, and were found to range approximately a factor of two between the two tidal conditions. The difference in tidal prism between the natural geometry and the shrimp-farm development is particularly striking. For the Pedregal, elimination of a total of 1,500 ha of tidal flat reduces the tidal prism in the lower reaches of the estuary by 10 to 35%, due to the reduction in the capacity of the estuary to store water on the rising tide. This translates to a direct reduction in the diluting capacity of the estuary's tidal exchange, and emphasizes the importance of better quantifying this aspect of shrimp pond installation.

Critical to this estimate are the inundation areas of tidal flats. For the preliminary model computations, these were judged ("eye-balled") from topographic maps of the Pedregal area. More recently, Mr. Felix Wainwright, a regional expert on the Fonseca mangrove swamps, has prepared a detailed map and accompanying report (Wainwright, 1996) for this project addressing tidal inundation along both the Pedregal and San Bernardo systems (the latter including a portion of Estero La Berberia, which is outside the scope of the present study, but should be examined at some point in the future). This work is based on his personal observations and field experience in the region, and is being used to re-segment the hydrodynamic model to better depict this aspect of estuary hydrography.

Estuary depth and cross-sectional areas are also needed for model input. In the preliminary model runs, these were estimated from informal surveys conducted by researchers from Auburn and University of Texas personnel in the lowermost reach of the Pedregal and guessed elsewhere. Since then, additional data on water depths have been obtained by a Peace Corps Volunteer (PCV) in the area and during water quality surveys carried out by Auburn University researchers. In addition, one of the major shrimp farms, Granjas Marinas San Bernardo (GMSB) assigned its surveyors to performing detailed cross-section surveys at three stations in the lower Pedregal and three stations in the lower Bernardo, adjacent to its concession. These survey data were transmitted late in 1997, and are being used to revise the input for the hydrodynamic model.

Water Quality

The distribution of various constituents in the estuary is the central concern in quantifying assimilative capacity and the potential for aquaculture self-limitation. This is determined by application of a mass-transport model, and in this study is approached using the same numerical segmentation as the tidal hydrodynamic model. There are two separate time scales involved for water quality: the intratidal, representing the upstream-downstream movement of the mass field in response to tides; and the intertidal, representing the long-term (weeks to months) trend of concentration distribution. The former is governed by tidal mechanics and short-timebase storms, while the intertidal time scale is governed by longer-term hydroclimatology and the evolution of conditions in the Gulf of Fonseca (primarily salinity structure). From the standpoint of evaluating carrying capacity for shrimp farm operations, the intertidal time scale is more important. In the present study, we are approaching this by application of a one-dimensional equilibrium-time model (section-mean tidal-averaged steady-state). We are also investigating the utility of a time-varying model, similar to that of Hauck and Ward (1980), to better represent response of the system to wet and dry seasonality. At present, two key constituents are being studied: salinity and dissolved oxygen.

Although salinity in an estuary is not really susceptible to management control, modeling of salinity nonetheless serves several important functions. First, because salinity is a natural, conservative tracer, it can be used to verify the ability of the model to compute advective and dispersive transport, by comparison of the model results to salinity data. (Other nonconservative parameters, such as dissolved oxygen or nutrients, cannot be used this way, because of the complicating effect of multiple sources and sinks on their concentrations.) Second, salinity exerts a control on some of the kinetic processes affecting other parameters; for example, oxygen saturation is reduced with increasing salinity. Third, the location of the horizontal salinity gradient can be an indicator for other processes potentially important to shrimp farming, especially the principal zone of density-current intrusion.

The DO model is more complex. DO in the estuary is the end product of several kinetic processes, all acting simultaneously. These include sources of oxygen through mechanical re-aeration and photosynthetic production, and sinks of oxygen through oxidation of organic matter in the water column and benthic fluxes on the estuary bed (e.g., Thomann and Mueller, 1987). The chief effect of shrimp farm effluent on DO is through the load of oxygen-demanding organics. For present purposes, biochemical oxygen demand (BOD) is being used to quantify this. In the model, BOD is computed first, then fed forward into the dissolved oxygen calculation. This requires inputs on the oxygen-demanding wasteloads, which are assumed to be the Rio Choluteca load and the effluents from shrimp ponds. For preliminary model computations, the latter were estimated from shrimp pond data collected by Auburn personnel. This model application demonstrated the importance of having better data on organic loads from shrimp ponds, and a more intensive data collection effort was implemented by CRSP researchers. These newer data are being compiled for use in the present project (Teichert-Coddington, pers. comm.).

The water quality of the estuaries, both in reality and in the model, is strongly dependent upon hydrology. For the preliminary model exercises on the Pedregal, hydrological conditions were determined based upon flows of the Rio Choluteca, which entered the lower Pedregal through the Jagua distributary (this has since been modified; see below). Two different levels of river flow were examined in the preliminary work, one corresponding to the dry-season base flow, the other to a moderate level of inflow that still allowed some salinity intrusion into the Pedregal (Ward, 1995). As matters turned out, under the higher flow regime, the BOD and DO of Estero la Jagua and the lower Pedregal were found to be dominated by the quality of the Rio Choluteca inflow (which includes the waste loads from the cities of Tegucigalpa and Choluteca), with the shrimp farms having only minor influence. This finding is consistent with those of CRSP researcher Teichert-Coddington based upon the chemical data he had collected along the estuary. The greatest impact of the shrimp farm operations on estuary quality was found to occur for the dry-season flow, and this would therefore be the condition under which self-limitation would be most pronounced. A recent development will modify this conclusion, however, namely that the Rio Choluteca has been diverted into another channel by an earthen dam, and presently does not debouch into the Jagua-Pedregal.

Obviously, there are no stream-gauging stations on the distributaries of the mangrove deltas. In this project, the flow in the Rio Choluteca (gauged in Choluteca) has thus far been used as an index to flows in the tidal periphery of Fonseca, but the adequacy of this estimation is now being questioned. The Rio Choluteca has a large watershed, extending into the highlands above Tegucigalpa, and its flow reflects the hydroclimatology of the entire area, basically the Pacific side of the continental divide. The channel estuaries on Fonseca, however, have low-lying swampy watersheds that are limited in area to the immediate periphery of the Gulf. While these exhibit the same overall seasonal shift in climate as this region of Central America, viz. alternation of dry and wet seasons (see Ward, 1995), they are responsive to a much more marine climatology. We are presently exploring the possibility of estimating the runoff into these channel estuaries from rainfall data in the region.

Field data on instream concentrations comprise an indispensable component of a modeling study, both to help quantify terms in the model for which no external measurements exist, and to appraise the predictive accuracy of the model. The preliminary model applications were based upon estuary data from 1994 on salinity and DO in the Pedregal. These data came from analyses of water samples drawn from the intakes of the shrimp ponds. While these data are valuable in many respects, they suffer from the following problems: 1) too sparse a sampling network (limited to locations of farm intakes); 2) too limited sampling of the longitudinal extent of the estuary; and 3) lack of information about stratification. There was a clear necessity to perform surveys in the estuaries themselves, from their mouths at the Gulf of Fonseca and extending a substantial distance upstream. Since 1994, a number of such surveys have been carried out. Those data sets that have been processed, compiled and in use in the present work are summarized in Table 1. (Additional surveys have been performed but data compilation has not been completed.) The surveys marked with a double asterisk (**) in Table 1 were carried out by a PCV on assignment in the Choluteca region.

DISCUSSION AND PROJECT STATUS

Once a model is available, it allows evaluation of alternative scenarios, such as determining the relative importance of geographical location, physical parameters, hydrography, and kinetics. As an example, the preliminary model was applied to demonstrate the importance of geographical location on the effect of a shrimp farm on the estuary water (see Ward, 1995). The model was used to determine the DO in the Jagua (under dry-season conditions) for successive locations of a single shrimp farm from 1.5 to 13 km upstream from the confluence with the Pedregal. With distance upstream, there is a reduction in estuary cross section, tidal prism, and mixing (dispersion), so the same organic mass load results in a higher BOD concentration, and has a greater impact on DO. With the farm located farther upstream than 10 km, the DO in the estuary was driven to levels too low for aquatic life. This experiment illustrated the facts that: 1) the impact of a specific shrimp farm depends not only upon its load but its location within the estuary and 2) that a mass load in such a highly dispersive system as these river-channel estuaries affects quality a great distance both downstream and upstream from the point of discharge.

Under a projected future scenario based upon full development of the farm concessions extant in 1995, the model predicted both the Pedregal and the Jagua to have dry-season DOs below a critical value of 3 mg l^{-1}. Although these results were based upon estimates (i.e., judgments and guesses) of estuary physiography, hydromechanics, kinetics, and hydrology, they indicated the potential to exceed the assimilative capacity of both systems at the projected level of future development. Concerns expressed by the CRSP project team and the shrimp farm interests themselves have led to a moratorium on new farm development in Honduras until the assimilative capacity can be better quantified.

In the present study, we are continuing the focus on salinity and DO. The same kind of modeling could be applied, with some minor modifications, to nitrogen and phosphorus nutrients and to specific toxicants such as ammonia or indicators such as chlorophyll *a*. While modeling for other parameters exceeds the present scope, for longer-term purposes, data collection in Honduras and the model formulation in this project are addressing these expanded

Table 1. Inventory of field data sets for Honduran estuaries. DO = dissolved oxygen; S = salinity; T = temperature.

Estuary	Date(s)	Parameters	Number of Stations	Sampled Reach (km)	Comments
PEDREGAL					
	Jan-Dec 93	DO	1	n/a	daily AM & PM*
	21 Nov 94	S/T/DO	11	21	vertical profiles**
	10 Mar 95	S/T/DO	10	21	vertical profiles**
	4 Mar 96	S/T/DO	7	11	vertical profiles
	11 Mar 96	S/T/DO	7	11	vertical profiles
	19 Mar 96	S/T/DO	7	11	vertical profiles
	26 Mar 96	S/T/DO	7	11	vertical profiles
	3 Apr 96	S/T/DO	7	11	vertical profiles
SAN BERNARDO					
	20 Jan 95	S/T/DO	9	28	vertical profiles**
	11 Mar 95	S/T/DO	8	25	vertical profiles**
	17 Mar 96	S/T/DO	8	13	vertical profiles
	25 Mar 96	S/T/DO	8	13	vertical profiles
	1 Apr 96	S/T/DO	8	13	vertical profiles

* Data from farm intake
** Data runs made at both high and low tidal stages

objectives. A model developed using field data with specific physiographic and hydrographic inputs can be used to better define critical conditions. Such a model can also be used to evaluate any number of different shrimp farm development scenarios, to see which would be possible given the hydrographic environment and which would result in unacceptably degraded water quality.

On a broader perspective, there are additional aspects of the hydromechanics and water quality of the Honduras environment that are not being addressed in the present study, but may need attention in the future. For example, the channel estuaries draining Nicaragua are expected to become the focus for intensified shrimp farm development. Several field and/or planning studies have already been performed addressing these estuaries, e.g. SAPROF Team (1992) and Currie (1994, 1996). Thus far, no modeling has been carried out nor planned, but clearly the same management concerns as in Honduras must be addressed in Nicaragua. Moreover, the combined shrimp industry in both countries, operating in such proximity, will probably need to be evaluated for carrying capacity limitations of the Fonseca system. There are other kinds of operational problems for which the type of model being developed in the present project would not be appropriate, but for which others would. Some of the deeper, more energetic sub-estuaries of the Fonseca system, such as Estero de los Barrancones and others near Salvador, may require more complex models, which perhaps include the vertical dimension. The interaction between individual farms, in which the effluent from one farm is drawn into the intakes of another, may necessitate detailed field studies and (if modeling is necessary) higher-dimensioned and more refined modeling.

The single greatest future concern, beyond characterization of the channel estuaries, is a larger-scale hydrographic analysis, quantifying the exchange between these estuaries and the adjacent Gulf of Fonseca, and the renewal of Fonseca water by exchange with the Pacific. A concerted data collection effort in the Gulf of Fonseca proper, with high resolution in the eastern arm out from the shrimp farming regions, would be immensely valuable in illuminating its hydrography. The design of such a program has been outlined for some time (Ward, 1994), but because sampling in the waters of three different countries would be involved, its implementation must be negotiated at the highest levels of the respective governments. Despite protracted efforts of CRSP and other agencies in the region, the data collection program has not yet been initiated. Another alternative is the application of an advanced primitive-equation estuary hydrodynamic model such as the Princeton Ocean Model. Specifications for such a modeling study have been formulated by this project, and the work is presently being considered by the U.S. Environmental Protection Agency.

ANTICIPATED BENEFITS

The formulation of models using water quality and estuarine dynamics data for predicting carrying capacity of estuaries will be of incalculable benefit to the shrimp industry and Honduran government agencies charged with land use planning and environmental regulation. Environmental management of estuarine systems and regional land use planning cannot be accurately accomplished without the models, because reasonable estimations of carrying capacity would be impossible. The Honduran government has in fact stopped further shrimp farm development until an objective determination of carrying capacity has been achieved for the various estuaries. The program of data collection and carrying capacity estimation implemented by the CRSP can be used as a model by other countries in the region with similar issues to resolve.

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INFLUENCE OF DAILY WATER EXCHANGE VOLUME ON WATER QUALITY AND SHRIMP PRODUCTION

Eighth Work Plan, Honduras Research 3 (HR3)
Final Report

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ABSTRACT

Daily water exchange is a common practice in semi-intensive shrimp culture in Central America. Rationales for water exchange are to improve pond dissolved oxygen concentrations and to flush out nutrients before they reach toxic levels. However, the benefit of water exchange in semi-intensive shrimp culture has been poorly demonstrated. Two experiments were conducted in Honduras to determine the effects of daily water exchange and emergency water exchange on shrimp production, and to develop nitrogen and phosphorus chemical budgets. Ten 0.93-ha ponds located on a commercial shrimp farm were used for this completely randomized design study to test two water exchange regimes: water exchanged at 10% of pond volume per day, six days per week; and water exchanged only in response to early morning dissolved oxygen concentrations ≤ 2.0 mg l^{-1}. Ponds were stocked with hatchery-spawned post-larval (PL) *Peneaus vannamei* at 15 PL m^{-2}. A survival rate of 50% was assumed because of Taura Syndrome effects on hatchery-produced larvae. The experiment was conducted during the rainy season (109-day duration) and during the dry season (96-day duration). Gross yield of *P. vannamei* was not affected significantly by the different water exchange regimes during either the rainy season or dry season experiment. Gross yield averaged 1,060 and 997 kg ha^{-1} during the rainy season, and 637 and 689 kg ha^{-1} during the dry season for the daily and emergency exchange treatments, respectively. Feed conversion ratios averaged 1.45 and 1.2 during the rainy and dry season experiments, respectively. Pond water quality variables during each study were affected significantly by water exchange regime; water quality tended to be better in ponds with daily water exchange. Exchange water and feed were the two largest sources of nutrients to ponds during both seasons. Shrimp harvest accounted for 23 to 24% and 40 to 45% of total nitrogen inputs in the daily and emergency exchange treatments, respectively, while exchange discharge accounted for 56 to 69% and 16 to 22% of total nitrogen inputs, respectively. Phosphorus harvested as shrimp accounted for 13% and 18 to 24% of total phosphorus inputs in the daily and emergency exchange treatments, respectively, and water exchange accounted for 45 to 62% and 12% of total phosphorus inputs, respectively.

INTRODUCTION

Shrimp culture in Honduras and other parts of Central America is practiced at the semi-intensive level, where final stocking rates vary from 5 to 11 shrimp m^{-2}, and daily water exchange rates average 10% of pond volume. In semi-intensive culture, water is exchanged primarily to correct low early morning oxygen concentrations. It is also thought to discharge metabolites which hinder shrimp growth. The benefit of water exchange has been poorly demonstrated. Some studies cast doubt on the need for water exchange in shrimp farming when aeration is used (Hopkins et al., 1993; Hopkins et al., 1994). However, semi-intensive shrimp farming in Central America uses no aeration and is firmly based on water exchange, usually on a daily basis (Teichert-Coddington, 1995). On the other hand, preliminary evidence from past experiments indicates that water exchange could be reduced without impact on shrimp production. Excessive water exchange wastes fuel, contributes to deterioration of pumps and sedimentation of water supply canals and ponds, and may increase total nutrient discharge from ponds.

The objectives of these experiments were to determine the effects of daily water exchange and emergency water exchange on shrimp production, and to develop nitrogen and phosphorus chemical budgets.

METHODS AND MATERIALS

Ten 0.93-ha (± 0.04 ha SD) ponds located on a commercial shrimp farm on a riverine estuary of the Gulf of Fonseca, Honduras, were used for this completely randomized design study to test two water exchange regimes. Water was exchanged at 10% of pond volume per day, six days per week, or only in response to early morning dissolved oxygen concentrations ≤ 2.0 mg l^{-1}. In a dissolved oxygen emergency (when early morning DO was ≤ 2.0 mg l^{-1}), up to 25% of the pond volume was exchanged. No water exchange occurred during the first three weeks of culture. In all water exchanges, water first was discharged and then added to refill ponds. Data for all water exchange events were recorded. Total material exchange per pond during weekly water exchange was calculated by subtracting mass discharge from mass intake. The experiment was conducted during the rainy season and repeated during the dry season.

Ponds for the rainy season experiment were stocked with hatchery spawned post-larval (PL) *Penaeus vannamei* at 150,000 PL ha^{-1} (15 PL m^{-2}) on 25 to 26 May 1997; five randomly selected ponds were stocked the first day, and the remaining five the following day. Stocking of ponds for the dry season experiment also took place over two days (15 to 16 January 1998). A survival rate of 50% was assumed because of Taura Syndrome effects on hatchery-produced larvae. Most of the mortality was assumed to occur during the first month following stocking. Shrimp in the rainy season experiment were harvested 109 days after stocking (12 to 13 September 1997) by completely draining ponds. Dry season experiment ponds were harvested by draining on 21 to 22 April 1998 (96 days after stocking). Total weight of shrimp was obtained for each pond. Mean individual weight was determined by weighing a sample of 300 shrimp per pond.

Shrimp were fed a 20% or 39% protein commercially formulated ration during each experiment at the discretion of the farm manager (Table 1). The 39% protein feed was offered when shrimp growth based on weekly sampling appeared to have stagnated. Shrimp were fed six days per week beginning on 18 June 1997 for the rainy season experiment and on 10 February 1998 for the dry season experiment. Feed rate for all ponds was based on the theoretical feeding curve for *P. vannamei*:

$$\text{Log}_{10}Y = -0.899 - 0.56\text{Log}_{10}X$$

where

Y = the feed rate as a percent of biomass and
X = the mean shrimp weight in grams.

Daily feed rate was calculated for individual ponds, and then averaged so that all ponds received the same quantity of feed on a daily basis. Feed was offered once daily. Shrimp growth was monitored weekly by cast net samples of each pond's population. Feed rate was adjusted weekly based on shrimp samples. Feed conversion ratio (FCR) was calculated as the weight of feed offered divided by gross yield of whole shrimp.

Water quality variables in each pond were measured weekly in pond and intake water. Intake water was sampled from supply canals, while pond water was sampled by pooling a minimum of six column samples collected at random within the pond. Pond water and replacement water samples were obtained with a column sampler. Water samples were analyzed for pH measured potentiometrically, nitrate-nitrogen by cadmium reduction (Parsons et al., 1992), total ammonia-nitrogen (Parsons et al., 1992), soluble reactive phosphorus (SRP) (Grasshoff et al., 1983), chlorophyll *a* (Parsons et al., 1992), total alkalinity by titration to pH 4.5 endpoint, salinity, and 2-d biochemical oxygen demand (BOD_2) at 20°C. Total nitrogen and total phosphorus were determined by nitrate and phosphate analysis, respectively, after simultaneous persulfate oxidation (Grasshoff et al., 1983). Pond chemical budgets were developed for phosphorus and nitrogen. Dissolved oxygen (DO) concentration and temperature were measured in ponds twice daily (0400 and 1600 h) at 25 cm below the water surface. Pond soils were sampled (2.5 cm-deep cores, five sub-samples per pond pooled for analysis) were analyzed for phosphorus, nitrogen, organic matter, and pH before and after the rainy season experiment following methodology given by Munsiri et al. (1995). Analyses were conducted at the Auburn University Soil Testing Laboratory.

Data were computer analyzed by unpaired t-test using the Statview 5 software package (SAS, 1998). Percent data were arcsin transformed prior to analysis. Differences were declared significant at alpha level 0.05.

RESULTS

Pond water temperatures normally show significant seasonal variation, with lower temperatures occurring from December

Table 1. Nutrient composition and calculated protein content of formulated shrimp rations used during the rainy and dry season shrimp (*Penaeus vannamei*) production experiments in Honduras.

Variable	Rainy Season		Dry Season	
	20% Protein	*39% Protein*	*20% Protein*	*39% Protein*
Dry Matter (%)	89.29	89.52	90.88	89.94
Nitrogen (% of dry matter)	3.35	6.29	3.31	6.40
Phosphorus (% of dry matter)	1.24	1.16	0.93	0.92
Protein (%N x 6.25)	20.9	39.3	20.7	40.0

Table 2. Mean (± SD) gross yield of shrimp, final weight, survival, and food conversion ratio (FCR) during the rainy and dry seasons for *Penaeus vannamei* reared in 1-ha earthen ponds with daily water exchange (10% of pond volume) or emergency water exchange (to maintain dissolved oxygen concentrations ≥ 2.0 mg l^{-1}) (n = 5).

Variable	Rainy Season		Dry Season	
	Daily	*Emergency*	*Daily*	*Emergency*
Gross Yield (kg ha^{-1})	1,060 ± 83.2	997 ± 141.5[a]	637 ± 68.5	689 ± 76.6[a]
Individual Weight (g $shrimp^{-1}$)	12.3 ± 1.86	10.7 ± 1.44[a]	8.7 ± 0.97	8.4 ± 1.04[a]
Survival (%)	52 ± 0.7	59 ± 0.4[a]	46 ± 0.7	51 ± 0.9[a]
Feed Conversion Ratio	1.4 ± 0.09	1.5 ± 0.19[a]	1.2 ± 0.15	1.2 ± 0.16[a]

[a] No significant difference between treatment means within season ($P > 0.05$).

through February (Teichert-Coddington et al., 1994). However, the El Niño effect was developed fully in Honduras during 1997 and resulted in little seasonal variation in pond water temperatures. Mean early morning water temperatures were 30.0 and 29.2°C during the rainy and dry season experiments, respectively (Figure 1). There was one storm event per season that caused a significant reduction in pond temperatures during a three- to five-day period.

Gross yield of *P. vannamei* was not affected significantly by water exchange regime during either the rainy season or dry season experiment (Table 2). Shrimp survival also did not differ significantly between treatments in either experiment and averaged 52% across both experiments (Table 2). Shrimp growth and final weight were similar for both water exchange regimes during both experiments (Table 2; Figure 2). Feed conversion ratios averaged 1.45 and 1.2 during the rainy and dry season experiments, respectively (Table 2).

Pond water quality variables during each study were affected significantly by water exchange regime (Table 3). Where differences were significant, water quality tended to be better in ponds with daily water exchange. Mean total salinity was significantly lower in ponds with daily water exchange during both seasons (Table 3). As would be expected, pond salinities were greater during the dry season (Table 3). Significantly higher concentrations of total nitrogen were measured in ponds subjected to emergency water exchange during both seasons (Table 3). During the rainy season experiment total nitrogen concentrations in ponds were similar until week 11 when concentrations increased in the emergency water exchange treatment ponds (Figure 3). Total nitrogen concentration was greater in emergency water exchange ponds throughout most of the dry season experiment (Figure 3). Significant treatment differences in total phosphorus concentrations were detected only during the rainy season experiment (Table 3). Total phosphorus began to accumulate in emergency water exchange treatment ponds beginning about week 9 of the rainy season experiment (Figure 4). No significant differences in total phosphorus were detected between treatments during the dry season, although concentrations in emergency water exchange treatment ponds were higher (Table 3; Figure 4). Mean chlorophyll *a* concentration began to increase in emergency water exchange treatment ponds beginning week 10 of the rainy season experiment, and resulted in significantly greater chlorophyll *a* concentration (Table 3, Figure 5). Dry season experiment chlorophyll *a* concentrations were more variable and did not differ significantly between treatments (Table 3; Figure 5). Mean BOD_2 was significantly greater in the emergency water exchange treatment during the rainy season experiment, but no significant differences were detected during the dry season experiment (Table 3). Weekly variation in mean treatment BOD_2 was similar to that observed for chlorophyll *a* treatment means (Figure 6). Treatment affected mean early morning DO significantly during the rainy season experiment (Table 3). Mean early morning pond DO concentrations tended to be lower in the emergency exchange treatment, especially in the latter part of each culture cycle (Figure 7).

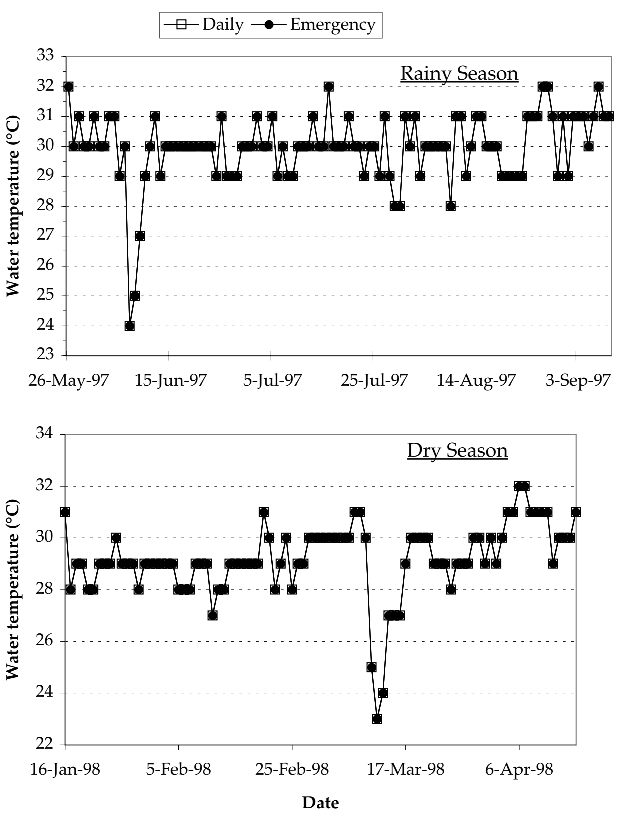

Figure 1. Mean early morning water temperature in 1-ha earthen shrimp production ponds managed with daily water exchange (10% pond volume) or emergency water exchange (to maintain dissolved oxygen concentrations ≥ 2.0 mg l^{-1}).

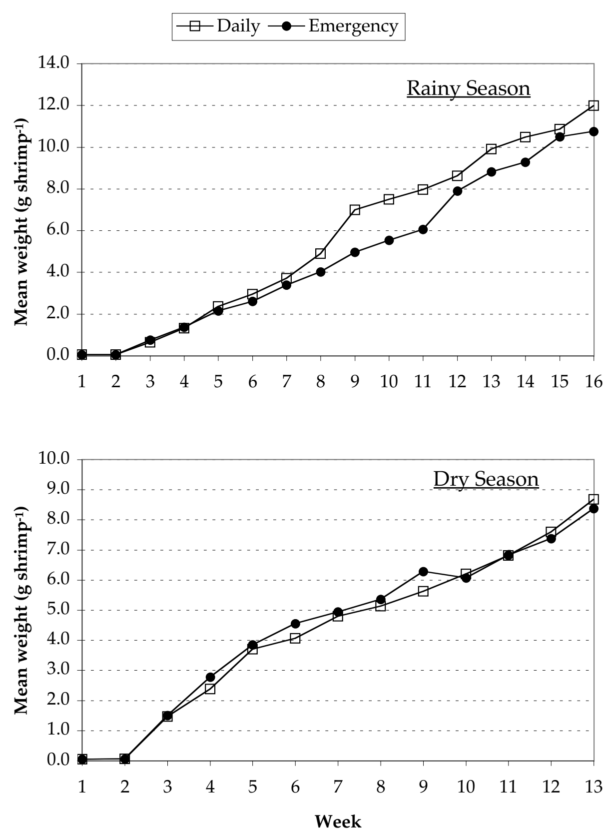

Figure 2. Growth of shrimp in 1-ha earthen ponds during rainy and dry season experiments in Honduras to test the effects of daily or emergency water exchange.

Table 3. Means (± SD) of water quality variables by treatment during rainy and dry season experiments to test effects of water exchange rates (daily or emergency) on *Penaeus vannamei* production in earthen ponds in Honduras (n = 5).

Variable	Rainy Season		Dry Season	
	Daily	*Emergency*	*Daily*	*Emergency*
pH	8.6 ± 9.34	8.6 ± 9.22[a]	8.5 ± 9.76	8.5 ± 9.43[a]
Salinity (g l^{-1})	19.7 ± 0.73	22.5 ± 0.63[c]	34.4 ± 0.16	36.9 ± 0.78[c]
Total Nitrogen (mg l^{-1})	1.0 ± 0.02	1.5 ± 0.011[c]	1.1 ± 0.11	1.6 ± 0.31[c]
Total Ammonia-Nitrogen (mg l^{-1})	0.016 ± 0.001	0.020 ± 0.002[b]	0.028 ± 0.004	0.036 ± 0.005[b]
Nitrate-Nitrite-Nitrogen (mg l^{-1})	.001 ± 0.0004	0.002 ± 0.0004[a]	0.000 ± 0.0000	0.002 ± 0.004[a]
Total Phosphorus (mg l^{-1})	0.19 ± 0.005	0.27 ± 0.013[c]	0.20 ± 0.025	0.26 ± 0.059[a]
Soluble Reactive Phosphorus (mg l^{-1})	0.09 ± 0.008	0.12 ± 0.009[c]	0.08 ± 0.021	0.11 ± 0.040[a]
Total Alkalinity (mg l^{-1} as $CaCO_3$)	109.5 ± 18.47	129.8 ± 5.42[b]	174.0 ± 2.59	191.59 ± 6.16[c]
Chlorophyll *a* (mg m^{-3})	19.0 ± 1.13	45.0 ± 11.08[c]	14.9 ± 5.26	21.1 ± 7.9[a]
BOD_2 (mg O_2 l^{-1})	2.5 ± 0.14	3.8 ± 0.38[c]	2.6 ± 0.49	3.4 ± 0.82[a]
Early Morning DO (mg l^{-1})	4.7 ± 0.07	4.3 ± 0.26[c]	4.8 ± 0.39	4.3 ± 0.39[a]

[a] No significant difference between treatment means within season ($P > 0.05$).
[b] Significant difference between treatment means within season ($P < 0.05$).
[c] Highly significant difference between treatment means within season ($P < 0.01$).

Nitrogen and carbon concentrations in pond sediments were higher in the final samples compared to the initial samples (Table 4). Changes in pond sediment phosphorus concentrations and pH were variable between initial and final samples (Table 4).

Exchange water and feed were the two largest sources of nutrients to ponds during both seasons (Table 5). In ponds receiving daily water exchange, exchange water provided 46 to 54% of total nitrogen input and 32 to 48% of total phosphorus input. Exchange water provided 10 to 13% of total nitrogen

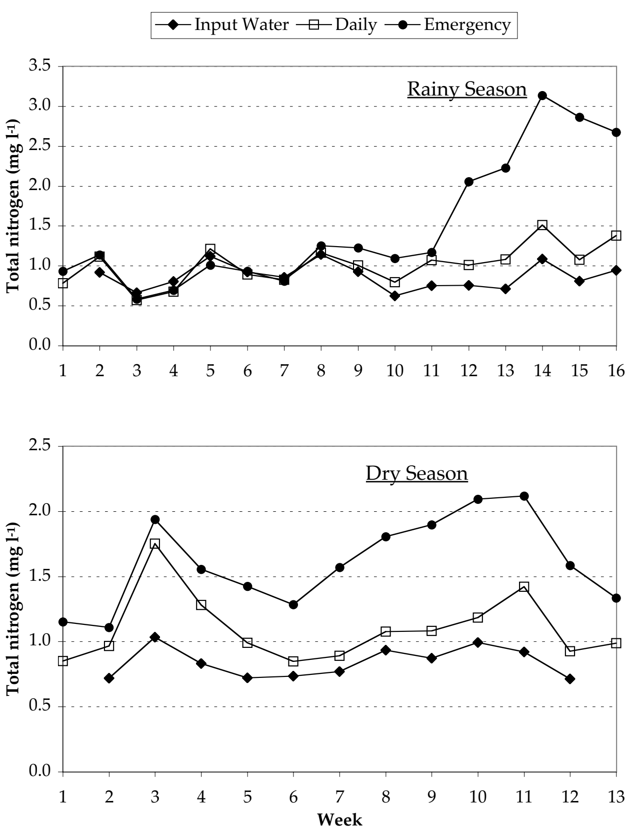

Figure 3. Mean total nitrogen concentrations in ponds [managed during rainy and dry season experiments with daily water exchange (10% pond volume) or emergency water exchange (to maintain dissolved oxygen concentrations ≥ 2.0 mg l^{-1})] and in inlet water.

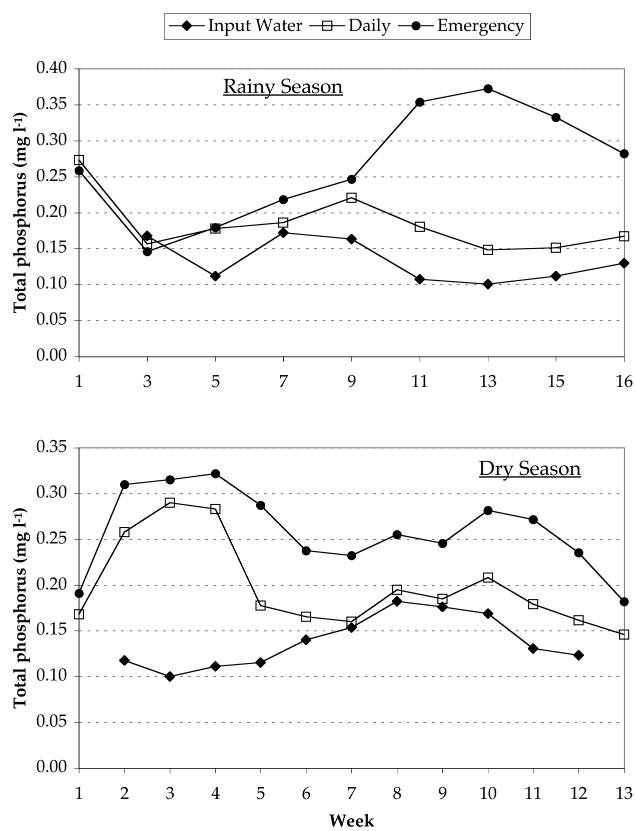

Figure 4. Mean total phosphorus concentrations in ponds [managed during rainy and dry season experiments with daily water exchange (10% pond volume) or emergency water exchange (to maintain dissolved oxygen concentrations ≥ 2.0 mg l^{-1})] and in inlet water.

input and 5 to 11% of total phosphorus input in ponds in the emergency exchange treatment. Nitrogen and phosphorus inputs as feed were 36 to 48% and 42 to 59% of total inputs, respectively, in the daily exchange treatment, and 66 to 79% and 72 to 83% of total inputs, respectively, in the emergency exchange treatment. Total nutrient inputs were greater in the daily exchange treatment. Shrimp harvest accounted for 23 to 24% and 40 to 45% of total nitrogen inputs in the daily and emergency exchange treatments, respectively, while exchange discharge accounted for 56 to 69% and 16 to 22% of total nitrogen inputs, respectively. Phosphorus harvested as shrimp accounted for 13% and 18 to 24% of total phosphorus inputs in the daily and emergency exchange treatments, respectively, and water exchange accounted for 45 to 62% and 12% of total phosphorus inputs, respectively. Unrecovered nitrogen was 11% and 9 to 17% of total nitrogen inputs in the daily and emergency exchange treatments, respectively. Unrecovered phosphorus was 37 to 58% and 47 to 58% of total phosphorus

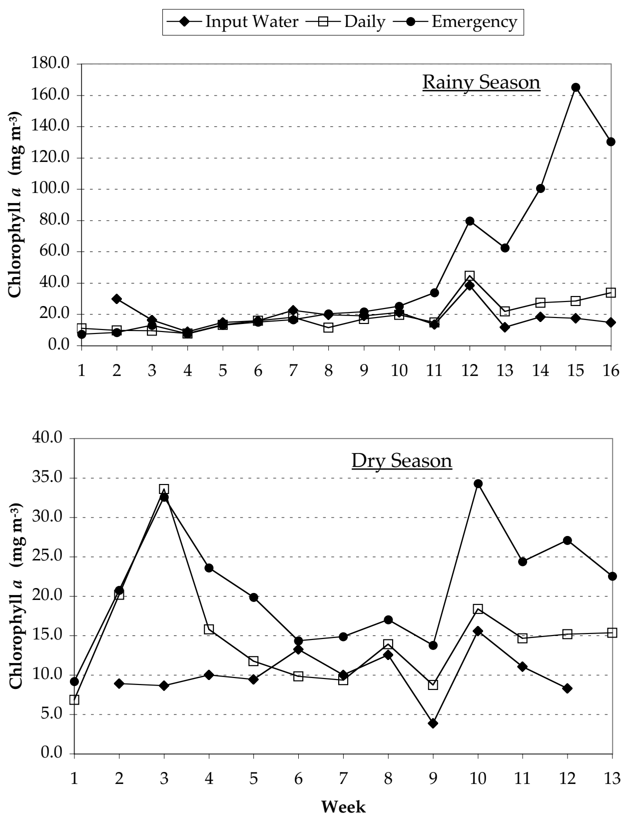

Figure 5. Mean chlorophyll *a* concentrations in ponds [managed during rainy and dry season experiments with daily water exchange (10% pond volume) or emergency water exchange (to maintain dissolved oxygen concentrations ≥ 2.0 mg l^{-1})] and in inlet water.

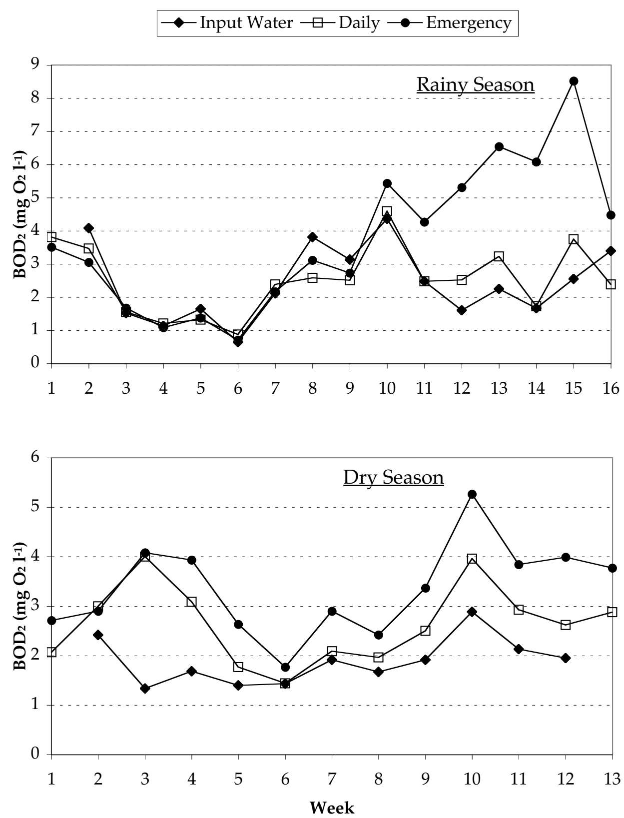

Figure 6. Mean two-day biochemical oxygen demand (BOD_2) in ponds [managed during rainy and dry season experiments with daily water exchange (10% pond volume) or emergency water exchange (to maintain dissolved oxygen concentrations ≥ 2.0 mg l^{-1})] and in inlet water.

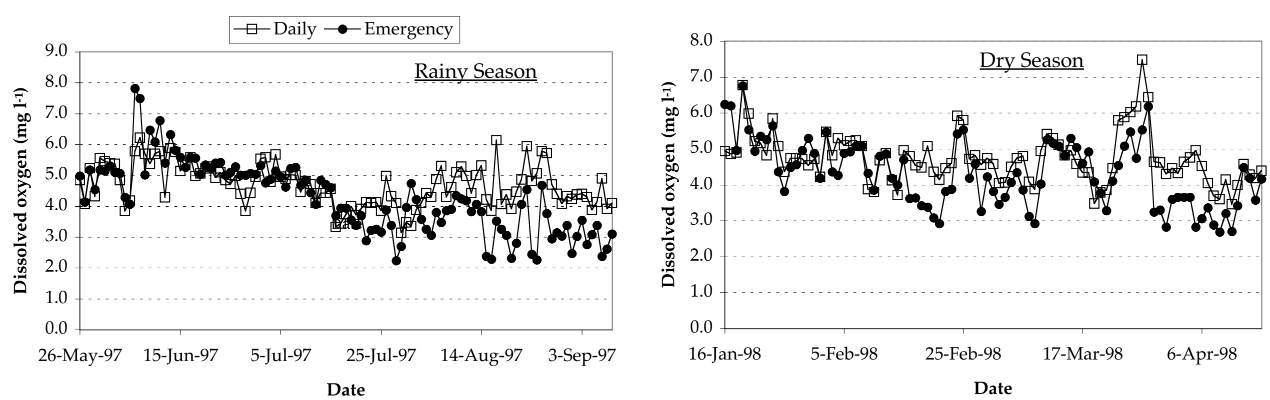

Figure 7. Mean early morning dissolved oxygen concentrations in 1-ha earthen shrimp production ponds managed with daily water exchange (10% pond volume) or emergency water exchange (to maintain dissolved oxygen concentrations ≥ 2.0 mg l^{-1}).

inputs in the daily and emergency exchange treatments, respectively. Nitrogen and phosphorus harvested in shrimp increased when feed was calculated as the only exogenous nutrient input into the pond. Harvested shrimp accounted for 50 to 64% and 51 to 67% of feed nitrogen, and 22 to 32% and 22 to 34% of feed phosphorus in the daily and emergency exchange treatments, respectively.

DISCUSSION

Dry season shrimp yields were lower than rainy season yields in spite of a < 1°C difference in mean early morning water temperature. Pond salinity during the dry season experiment averaged 35 g l^{-1}, approximating full-strength sea water. During the final month of the dry season experiment, pond salinities were sometimes hypersaline, but never exceeded 45 g l^{-1}. Dry season shrimp yields in Honduras always are lower than yields obtained during the rainy season (Teichert-Coddington et al., 1994). Teichert-Coddington et al. (1994) reported that temperature and salinity affect shrimp production, but that mean monthly temperature is the most important variable affecting shrimp yields.

Shrimp gross yield, growth, survival, and feed conversion ratio were not affected significantly by water exchange regime. The principal reasons given by producers for water exchange are to correct episodes of low DO and to flush ponds of metabolites that may impede shrimp growth. Significant differences in mean water quality variables were observed during the rainy season experiment, but not during the dry season experiment. In spite of many water quality treatment means having similar magnitudes during both studies, there was greater variability in the data from the dry season, which precluded detection of significant differences. Daily water exchange during the rainy season resulted in significantly lower mean water quality variables, but gross yield did not differ significantly, although the daily exchange gross yield was about 6% higher. Mean early morning DO did differ significantly between treatments during

Table 4. Results of initial and final pond sediment analyses for the rainy season experiment. Samples of the top 2.5 cm of pond sediment were collected for analysis.

Pond	Nitrogen (%)		Phosphorus (mg kg^{-1})		Carbon (%)		pH	
	Initial	*Final*	*Initial*	*Final*	*Initial*	*Final*	*Initial*	*Final*
VRE01	0.07	0.12	106.46	50.35	0.71	1.06	7.55	7.34
VRE02	0.06	0.19	103.30	88.43	0.76	1.44	7.55	7.27
VRE03	0.09	0.17	67.26	85.46	0.99	1.26	7.46	7.14
VRE04	0.05	0.13	105.16	102.18	0.64	1.05	7.03	7.35
VRE05	0.05	0.10	113.14	82.12	0.63	1.06	7.56	7.24
VRE06	0.13	0.19	77.84	63.54	1.15	1.39	7.35	7.22
VRE07	0.14	0.18	49.61	60.20	1.22	1.41	7.17	7.35
VRE08	0.12	0.20	57.78	82.30	1.05	1.40	7.20	7.02
VRE09	0.10	0.19	68.93	63.54	1.05	1.36	7.19	7.29
VRE10	0.16	0.20	55.18	63.17	1.37	1.61	7.08	7.38

Table 5. Mean gains, losses, and unrecovered quantities (in kg) of nitrogen and phosphorus in 1-ha earthen shrimp (*Penaeus vannamei*) production ponds managed with daily water exchange (10% pond volume) or emergency water exchange (to maintain dissolved oxygen concentrations ≥ 2.0 mg l^{-1}) (n = 5).

Variable	Rainy Season				Dry Season			
	Daily		*Emergency*		*Daily*		*Emergency*	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
GAINS								
Shrimp Stock	0	0	0	0	0	0	0	0
Canal Water								
Initial Flooding	8.36	2.34	7.89	2.20	7.73	1.54	9.27	1.54
Exchange Inflow	61.52	9.01	7.85	1.00	45.13	7.65	6.20	1.01
Feed	63.32	16.52	59.54	15.53	29.95	6.51	30.54	6.64
LOSSES								
Shrimp Harvest	31.89	3.70	30.22	3.44	19.01	2.10	20.51	2.24
Pond Water								
Exchange Discharge	74.56	12.55	16.47	2.17	56.76	9.74	7.14	1.08
Draining	11.75	1.42	21.94	2.35	9.28	1.43	10.75	1.55
UNRECOVERED	15.00	10.20	6.65	10.78	-2.23	2.44	7.61	4.32

the rainy season and was lower in the emergency exchange treatment during the later part of the production cycle that corresponded to an accumulation of nutrients in ponds. Fewer water quality treatment differences during the dry season experiment may be related to the lower quantity of feed used and to the nutrient load in exchange water. The absence of significant differences in shrimp production and the presence of significant treatment differences in water quality variables do not demonstrate conclusively that daily water exchange is not beneficial. Certainly as practiced, beginning several weeks after pond stocking, water exchange is not being employed optimally. Water exchange did have a significant impact on water quality variables during the last four to six weeks of the rainy season culture period. Relying strictly on emergency water exchange will be perceived by producers as too risky, especially since water quality deterioration occurs in the latter part of the production cycle when producers have the greatest investment in their crop. A compromise solution would be to delay initiation of daily water exchange until week 10 of the production cycle.

Feed and exchange-water nitrogen and phosphorus inputs as a percent of total inputs in daily water exchange treatment ponds were similar to results reported previously (Teichert-Coddington et al., 1996; Green et al., 1997). Inputs of feed and exchange-water nitrogen as a percent of total inputs in emergency exchange treatment ponds were similar to data reported for ponds with no water exchange (Boyd, 1985; Daniels and Boyd, 1989). Total nitrogen and phosphorus inputs in emergency exchange ponds were 40 to 45% and 30 to 40% lower, respectively, than in daily exchange ponds because of the reduced nutrient load in the exchange water. Greater quantities of nutrients are added to and discharged from ponds when water exchange occurs on a daily rather than emergency basis.

ANTICIPATED BENEFITS

Results of these experiments demonstrate that water exchange regime does not significantly affect shrimp production, but can result in significant reduction in some water quality variable concentrations. These data support reduced water exchange frequency for semi-intensive shrimp culture in Honduras, which will reduce nutrients added to and discharged from ponds and will reduce pumping costs.

ACKNOWLEDGMENTS

Jaime Lopez and Gustavo Flores are thanked for their assistance during these experiments. This research was made possible through collaboration with the Dirección General de Pesca y Acuicultura, Secretaría de Agricultura y Ganadería, Honduras, and shrimp producers of the Honduran National Association of Aquaculturists (ANDAH).

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WATER EXCHANGE TO RECTIFY LOW DISSOLVED OXYGEN

Eighth Work Plan, Honduras Research 4 (HR4)
Abstract

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ABSTRACT

In Central America semi-intensive shrimp production technology is used by many producers. Semi-intensive production technology is characterized by final stocking rates of 5 to 11 shrimp m^{-2}, daily water exchange at ≤ 10% of pond volume, and use of 20 to 25%-protein feeds. The role of water exchange in semi-intensive shrimp culture is being evaluated in Honduras. Recently completed research (HR3) indicated that daily or emergency water exchange did not affect significantly shrimp production, but that water quality was better in ponds that received daily water exchange. However, differences in water quality generally did not become pronounced until the latter half of the 12- to 16-week production cycle. Producers may find unacceptable the risk associated with utilizing an emergency-only water exchange policy. However, it appears that the current standard practice of initiating water exchange the fourth week post-stocking is not the most efficient exchange strategy. This experiment builds on the previous experiment. The objectives of this experiment are to evaluate the effect of time of initiation of water exchange on pond dissolved oxygen, water quality, and shrimp production. Nine 0.93-ha ponds located on a commercial shrimp farm in southern Honduras are being used for this completely randomized design study. Water will be exchanged at 10% of pond volume per day, six days per week beginning four, seven, or ten weeks after stocking. The experiment is being conducted during the rainy season and will be repeated during the dry season. Ponds for the rainy season experiment were stocked with hatchery-spawned post-larval *Penaeus vannamei* at 150,000 PL ha^{-1} (15 PL m^{-2}) on 14 August 1998. Shrimp are fed six days per week beginning two weeks after stocking. Feed rate for all ponds is based on the theoretical feeding curve for *Penaeus vannamei*:

$$\mathrm{Log}_{10}Y = -0.899 - 0.56\mathrm{Log}_{10}X$$

where

Y = feed rate as a percent of biomass and
X = mean shrimp weight in grams.

Daily feed rate is calculated for individual ponds and then averaged so that all ponds receive the same quantity of feed on a daily basis. Feed is offered once daily. Shrimp growth is monitored weekly by cast net samples of each pond's population. Feed rate is adjusted weekly based on shrimp samples. Water quality variables in each pond are measured monitored weekly in pond and intake water. Water samples are analyzed for pH measured potentiometrically, nitrate-nitrogen by cadmium reduction, total ammonia-nitrogen, soluble reactive phosphorus, chlorophyll *a*, total alkalinity by titration to pH 4.5 endpoint, salinity, and 2-d biochemical oxygen demand at 20°C. Total nitrogen and total phosphorus are determined by nitrate and phosphate analysis, respectively, after simultaneous persulfate oxidation. Dissolved oxygen concentration and temperature are measured in ponds twice daily (0400 and 1600 h) at 25 cm below the water surface.

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Management to Minimize the Environmental Impacts of Pond Draining: Effect of Harvest Draining Technique on Water Quality and Fish Growth

Eighth Work Plan, Thailand Research 3 (TR3)
Final Report

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Abstract

An experiment was conducted to assess the effect of different harvest draining techniques of fish ponds on water quality and fish growth in subsequent culture cycles. Fifteen tilapia ponds of 200 m^2 were harvested using five different harvest draining techniques. After harvest, these ponds were stocked with Nile tilapia (*Oreochromis niloticus*) at 2 fish m^{-2}. Fish with an initial size of 11 to 13 g were cultured for 106 days in a fertilized pond system. Harvest draining techniques as treatments were: (A) Ponds were not drained, and fish were harvested by seining using tea seed cake as an anesthetic toxicant; (B) Ponds filled with canal water were completely drained after liming, and fish were harvested from a harvesting pit; (C) Ponds filled with canal water were completely drained, and fish were harvested from a harvesting pit; (D) Ponds filled with drainage water from harvest of adjacent ponds used in a previous experiment (equivalent to Treatment E of this study) were half-drained and seined twice, then completely drained to collect the remaining fish; and (E) Ponds filled with canal water were half-drained and seined twice, then completely drained to collect the remaining fish. None of the treatment means of water quality parameters (dissolved oxygen, pH, Secchi disk depth, alkalinity, total ammonium nitrogen, nitrite nitrogen, nitrate-nitrite nitrogen, total nitrogen, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, total suspended solids, and volatile suspended solids) were significantly different ($P > 0.05$) between treatments. Similarly, fish growth, net fish yield, and survival did not differ ($P > 0.05$) between treatments. Fish growth and net yield from undrained ponds (Treatment A) were 1.32 ± 0.15 g d^{-1} and 15.7 ± 4.2 kg ha^{-1} d^{-1}, respectively. Fish growth and net yield from ponds filled with drainage water of other ponds (Treatment D) were 1.11 ± 0.16 g d^{-1} and 17.3 ± 3.1 kg ha^{-1} d^{-1}. The results suggest that environmental impacts of pond draining can be minimized either by harvesting fish without draining or by draining pond water into empty ponds without affecting the water quality for fish growth.

Introduction

Pond fertilization is an essential management practice in aquaculture to enrich the nutrients in pond water (Boyd, 1990; Pillay, 1990). Nutrient application through a combination of organic and inorganic materials is an efficient system for tilapia ponds (Knud-Hansen et al., 1993). Moreover, supplemental feeding of tilapia in fertilized ponds increases harvest size as well as fish yield (Diana et al., 1996). Such fertilization results in minimal increases in concentrations of phosphorus (P) and nitrogen (N) in pond waters during grow-out (Diana et al., 1994). Overflow of such waters during rain events do not load nutrients in receiving waters beyond normal levels (Schwartz and Boyd, 1994b). However, the water quality of effluents discharged at harvest draining decreases considerably due to accumulation of materials in pond bottom water near the soil-water interface (Pillay, 1992). Moreover, draining of pond water after seining further increases pollutants in effluent waters (Boyd, 1978; Schwartz and Boyd, 1994a; Seok et al., 1995; Lin et al., 1998). Several strategies of draining and harvesting could minimize the environmental impacts of pond effluents (Hollerman and Boyd, 1985; Schwartz and Boyd, 1995; Kouka and Engle, 1996; Tucker et al., 1996; Ghate et al., 1997; Lin et al., 1998).

Management of draining and harvesting of aquaculture ponds may reduce effluent load; however, such management should not adversely affect the growth and production of aquaculture products. In this study we assess the effects of harvest draining techniques on pond water quality and fish growth in subsequent production cycles.

Methods and Materials

This experiment was conducted in fifteen tilapia ponds of 200 m^2 surface area, which were previously harvested using five different harvest draining techniques in the first experiment of the study (Lin et al., 1998) at the Asian Institute of Technology, Thailand. The harvest draining techniques as experimental treatments were as follows:

- T_1) Fish were harvested by seining using tea seed cake to anesthetize fish and ponds were not drained;
- T_2) Ponds were limed (75 ppm calcium hydroxide) 24 hours prior to harvest, completely drained, and fish were collected from a harvesting pit;
- T_3) Ponds were completely drained and fish were collected from a harvesting pit;
- T_4) Ponds were drawn down to 50 cm and fish were harvested by two seinings, followed by complete

draining and collection of remaining fish from a harvesting pit; and

T_5) Ponds received the same draining and harvesting technique as in treatment T_4, but the pond water was drained into the empty ponds of treatment T_4 (not discharged).

The experiment incorporated three blocks. The locations of the treatments within blocks were assigned on a random basis, with the exception that ponds in treatments T_4 and T_5 had to be adjacent to facilitate drainage of water from ponds in treatment T_5 to ponds in treatment T_4. All the ponds except those in treatments T_1 and T_4 were refilled with canal water. Ponds in treatment T_1 were undrained, whereas ponds in treatment T_4 were refilled with drainage water from ponds in treatment E (equivalent to treatment T_5) during harvest of the previous experiment (Lin et al., 1998).

Pond water depths were maintained at 1.2 ± 0.1 m by weekly topping with canal water. All ponds were fertilized weekly with 1.2 kg urea (28 kg N ha^{-1}) and 0.7 kg triple superphosphate (TSP) (7 kg P ha^{-1}). Sex-reversed male Nile tilapia of 11.5 to 13.2 g size were stocked at 2 fish m^{-2} on 15 July 1997. Fish were cultured for 106 days and harvested on 29 October 1997.

Pond water column samples, taken biweekly at 0900 h, were analyzed for total alkalinity, total ammonium nitrogen, nitrite nitrogen, nitrate-nitrite nitrogen, total nitrogen, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, total suspended solids, and total volatile solids using standard methods (Raveh and Avnimelech, 1979; APHA, 1980; Egna et al., 1987). Temperature, dissolved oxygen, pH (at 20 cm below the surface), and Secchi disk depth were also measured *in situ* according to the same schedule. In addition, monthly diel measurements of temperature, dissolved oxygen, pH, alkalinity, and total ammonium nitrogen were conducted at 0600, 0900, 1400, 1600, 1800, and 0600 h in each pond.

Data were analyzed statistically by analysis of variance using the Statgraphics 7.0 statistical software package. Mean fish growth (g d^{-1}), net fish yield (kg ha^{-1} d^{-1}), and survival (%) were calculated for each treatment. Means and ranges of water quality parameters from biweekly measured data were also calculated for each treatment. All means were given with

Table 1. Mean stocking size, harvest size, growth, net fish yield, and survival of Nile tilapia cultured for 106 days in earthen ponds in different treatments: (T1) undrained ponds; (T2) limed, completely drained, and filled with canal water; (T3) completely drained and filled with canal water; (T4) half drained, seined, completely drained, and filled with drainage water of T5; and (T5) half drained, seined, completely drained, and filled with canal water.

Treatment	Pond #	Mean Stocking Size (g)	Mean Harvest Size (g)	Mean Growth (g d^{-1})	Net Fish Yield (kg ha^{-1} d^{-1})	Survival (%)
T_1						
	3	11.5	118.1	1.01	16.3	83
	6	12.0	170.3	1.49	22.6	78
	11	12.8	167.7	1.45	8.1	33
	Mean	12.1	152.0	1.32	15.7	65
	± SE	0.4	17.0	0.15	4.2	16
T_2						
	1	11.5	294.0	2.67	39.2	75
	7	12.2	113.3	0.95	15.0	81
	12	13.2	110.4	0.93	11.4	67
	Mean	12.3	172.6	1.52	21.9	74
	± SE	0.5	60.7	0.58	8.7	4
T_3						
	2	11.8	137.5	1.19	23.0	97
	8	12.5	61.1	0.46	4.4	59
	15	12.5	116.5	0.98	4.3	30
	Mean	12.3	105.0	0.88	10.6	62
	± SE	0.2	22.8	0.22	6.2	19
T_4						
	4	12.2	96.6	0.80	11.0	73
	10	12.2	148.1	1.28	20.3	81
	13	12.8	145.9	1.26	20.5	83
	Mean	12.4	130.2	1.11	17.3	79
	± SE	0.2	16.8	0.16	3.1	3
T_5						
	5	11.8	128.0	1.10	18.9	88
	9	12.2	113.1	0.95	16.0	86
	14	13.0	110.9	0.92	15.3	85
	Mean	12.3	117.3	0.99	16.7	86
	± SE	0.4	5.4	0.06	1.1	1

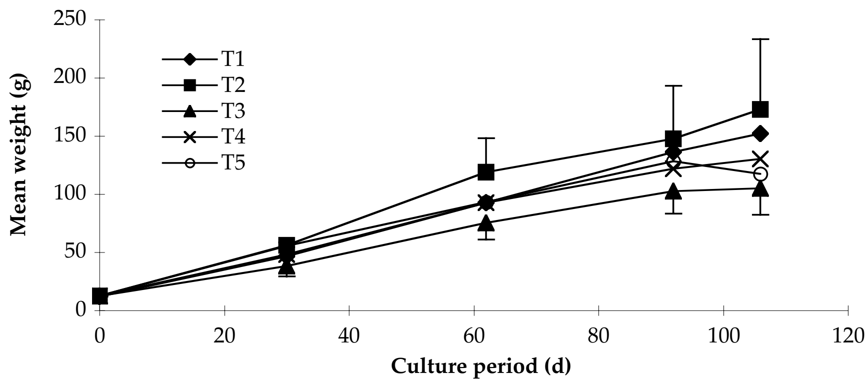

Figure 1. Mean monthly growth of tilapia in different treatments listed in Table 1.

± 1 standard error (SE), and differences were considered significant at an alpha level of 0.05.

RESULTS

Mean values for harvest size, growth, net yield, and survival of tilapia obtained from each pond and treatment are shown in Table 1. All means for growth, net yield, and survival were not different ($P > 0.05$) between treatments. Mean fish growth ranged from 0.88 ± 0.22 g d^{-1} in treatment T_3 to 1.52 ± 0.58 g d^{-1} in treatment T_2; similarly, harvest size varied from 105.0 ± 22.8 g in T_3 to 172.6 ± 60.7 g in T_2 (Figure 1). The lowest mean value in T_3 and highest in T_2 were affected by exceptionally low and high growth, respectively, in one replicate of each treatment (Table 1). The lowest mean survival in treatment T_3 (62 ± 19%) and highest mean survival in T_5 (86 ± 1%) were also not different ($P > 0.05$; Figure 2). Lower survival rates were obtained in Pond 15 (30%), Pond 11 (33%), and Pond 8 (59%), where hybrid catfish (*Clarias gariepinus* x *C. microcephalus*) and snakehead (*Channa striatus*) were found during harvest. Mean net fish yield ranged from 10.6 ± 6.2 kg ha^{-1} d^{-1} in T_3 to 21.9 ± 8.7 in T_2. Fish growth and net yield obtained from undrained ponds (treatment T_1) were 1.32 ± 0.15 g d^{-1} and 15.7 ± 4.2 kg ha^{-1} d^{-1}, respectively. Similarly, fish growth and net yield from ponds filled with drainage water during harvest draining (treatment T_4) were 1.11 ± 0.16 g d^{-1} and 17.3 ± 3.1 kg ha^{-1} d^{-1}. Tilapia reproduction occurred in only two ponds, with little recruitment in Pond 7 and 3.5 kg of recruitment in Pond 13.

Table 2 presents a summary of the physico-chemical parameters of pond waters measured at biweekly intervals at 0900 h for each treatment. Biweekly mean values of dissolved oxygen, pH, alkalinity, total ammonium nitrogen, nitrite nitrogen, total nitrogen, soluble reactive phosphorus, total phosphorus, Secchi depth, chlorophyll *a*, total suspended solids, and volatile suspended solids over time during the experimental period are shown in Figures 3 and 4. Similarly, mean monthly diel dissolved oxygen, pH, alkalinity, and total ammonium nitrogen recorded over a 24- hour period are shown in Figure 5 and Table 3. Mean values for water quality

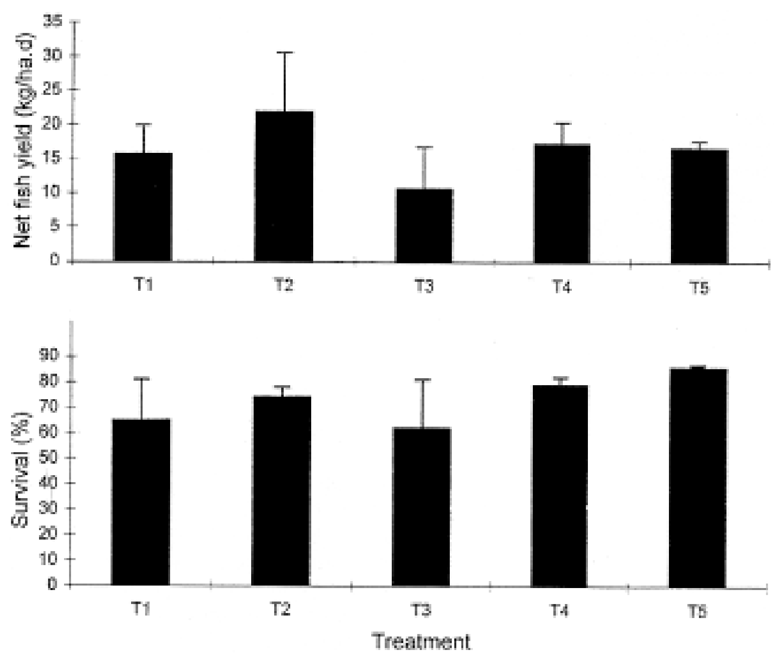

Figure 2. Mean (± SE) net fish yield and survival for different treatments listed in Table 1.

Table 2. Mean and range values for physico-chemical parameters of pond water measured biweekly at 0900 h over the experimental period in different treatments.

Physico-Chemical Parameters	T_1	T_2	T_3	T_4	T_5
Temperature (°C)	28.9 ± 0.2 (28.5-29.3)	29.1 ± 0.2 (28.9-29.4)	29.1 ± 0.1 (29.0-29.4)	29.0 ± 0.1 (28.9-29.2)	29.0 ± 0.1 (28.9-29.2)
Dissolved Oxygen (mg l^{-1})	1.4 ± 0.2 (1.2-1.8)	2.0 ± 0.6 (1.4-3.2)	1.9 ± 0.1 (1.7-2.1)	1.3 ± 0.2 (0.9-1.7)	1.8 ± 0.1 (1.7-2.0)
pH	8.2 (8.0-8.7)	8.4 (8.1-9.0)	8.1 (7.9-8.3)	8.0 (7.8-8.4)	8.4 (8.3-8.5)
Secchi Disk Visibility (cm)	12.5 ± 1.8 (10.4-16.1)	13.3 ± 2.0 (11.0-17.3)	15.1 ± 1.8 (12.1-18.4)	11.3 ± 0.6 (10.0-12.0)	15.0 ± 0.8 (13.5-16.4)
Alkalinity (mg l^{-1} $CaCO_3$)	166.8 ± 17.2 (142.8-200.0)	171.9 ± 17.7 (139.3-200.3)	157.2 ± 8.1 (144.5-172.4)	132.7 ± 26.2 (83.0-172.0)	162.1 ± 3.1 (159.0-168.3)
Total Ammonium Nitrogen (mg l^{-1})	1.3 ± 0.3 (0.8-1.4)	0.8 ± 0.1 (0.6-0.9)	1.4 ± 0.3 (1.0-1.9)	1.0 ± 0.3 (0.7-1.6)	1.0 ± 0.2 (0.7-1.3)
Nitrite Nitrogen (mg l^{-1})	0.3 ± 0.1 (0.2-0.4)	0.3 ± 0.1 (0.1-0.5)	0.4 ± 0.0 (0.4-0.4)	0.4 ± 0.1 (0.3-0.5)	0.4 ± 0.1 (0.2-0.5)
Nitrate and Nitrite-Nitrogen (mg l^{-1})	1.4 ± 0.2 (0.7-1.8)	1.2 ± 0.5 (0.3-1.9)	1.0 ± 0.3 (0.6-1.5)	1.5 ± 0.2 (1.1-2.0)	1.0 ± 0.2 (0.7-1.4)
Total Nitrogen (mg l^{-1})	5.7 ± 0.7 (4.8-7.1)	5.0 ± 0.3 (4.6-5.7)	5.0 ± 0.3 (4.5-5.4)	5.6 ± 0.2 (5.2-5.4)	5.3 ± 0.2 (5.0-5.8)
Soluble Reactive Phosphorus (mg l^{-1})	0.5 ± 0.2 (0.2-0.8)	0.4 ± 0.0 (0.3-0.5)	0.4 ± 0.1 (0.2-0.5)	0.3 ± 0.1 (0.1-0.4)	0.2 ± 0.0 (0.2-0.2)
Total Phosphorus (mg l^{-1})	0.9 ± 0.2 (0.6-1.3)	0.8 ± 0.1 (0.7-0.9)	0.7 ± 0.1 (0.5-0.8)	0.8 ± 0.0 (0.7-0.8)	0.6 ± 0.0 (0.6-0.7)
Chlorophyll *a* (μg l^{-1})	123.1 ± 19.5 (91.7-158.8)	127.8 ± 30.6 (78.1-183.5)	67.3 ± 14.6 (38.3-85.1)	117.1 ± 33.2 (68.8-180.8)	124.8 ± 23.3 (98.4-171.3)
Total Suspended Solids (mg l^{-1})	163.6 ± 32.1 (114.4-223.9)	115.6 ± 23.7 (69.8-149.2)	116.8 ± 24.9 (74.3-160.7)	120.8 ± 3.9 (113.7-127.3)	150.7 ± 25.2 (114.7-199.2)
Volatile Suspended Solids (mg l^{-1})	34.5 ± 0.7 (33.3-35.8)	31.7 ± 2.6 (27.3-36.3)	24.3 ± 5.0 (15.6-32.9)	31.1 ± 4.5 (23.1-38.7)	33.1 ± 1.9 (29.3-35.6)

parameters were not significantly different ($P > 0.05$) between treatments. However, there were lower alkalinity levels in ponds filled with water drained during harvest (treatment T_4), soluble reactive phosphorus and total phosphorus in seined and drained ponds (treatment T_5), and chlorophyll *a* and volatile suspended solids in completely drained ponds without seining (treatment T_3) (Figures 3 and 4). Mean monthly diel profiles also showed lower alkalinity in T_4 where ponds were filled with drainage water from ponds treated similarly to T_5 (Figure 5). Mean concentrations of total ammonium nitrogen were lowest in limed and completely drained ponds (treatment T_2) and highest in completely drained ponds without liming (treatment T_3).

DISCUSSION

The mean growth of tilapia in undrained ponds (1.32 ± 0.15 g d^{-1}) was not different ($P > 0.05$) than the growth in drained and filled ponds (0.88 ± 0.22 to 1.52 ± 0.58 g d^{-1}). Similarly, growth in ponds which were filled with harvest drainage water (1.11 ± 0.16 g d^{-1}) was similar to growth in ponds filled with fresh canal water. Mean net yield and mean survival were also not different ($P > 0.05$) between drained and undrained ponds and between ponds filled with pond drainage water and ponds filled with canal water. The amount of waste discharged during harvest draining of 1-ha fish ponds is estimated to be 161 to 1,100 kg of BOD_5, 39 to 141 m^3 of settleable matter, 59 to 98 kg of total nitrogen and 3.2 to 10.4 kg of total phosphorus using the techniques of complete draining with and without seining (Schwartz and Boyd, 1994a; Seok et al., 1995; Lin et al., 1998). Harvesting fish without draining or by draining pond water into empty ponds allows the ponds to retain nutrients and minimizes the environmental impacts of pond draining without affecting fish growth and yield.

Though mean water quality parameters were not significantly different between treatments, total alkalinity in ponds filled with drainage water was lower than in those filled with canal water. However, alkalinity of undrained ponds was comparatively high, which might be due to the application of tea seed cake. Total ammonium nitrogen was lower in limed and drained ponds. Liming followed by draining increases nitrogen concentration in the effluent, which may be resuspended from the bottom (Lin et al., 1998). Removal of nitrogen in larger quantities during draining of limed and drained ponds (as in treatment T_2) might have resulted in lower total ammonium concentrations in effluent. Fish mortality was higher (40 to 70%) in ponds with mean total ammonium nitrogen > 1.5 mg l^{-1} (Table 1; Figure 3). Total phosphorus and soluble reactive phosphorus concentrations were lower in ponds in which both seining and draining procedures were performed. Ponds with lower chlorophyll *a* (38.3 and 68.8 µg l^{-1}) and volatile suspended solids (15.6 and 23.1 mg l^{-1}) in Pond 8 of treatment T_3 and Pond 4 of treatment T_4, respectively, resulted in lower fish growth (0.46 and 0.80 g d^{-1}, respectively) (Table 1).

As there were no significant differences between harvest draining techniques on subsequent water quality and fish growth, the results suggest that the environmental impacts of pond draining could be minimized either by harvesting fish without draining or by using drainage water in empty ponds where plankton feeder fish like tilapia can be stocked. Similarly, insignificant differences to fill water quality have been reported between annually drained and undrained ponds (Hollerman and Boyd, 1985; Seok et al., 1995).

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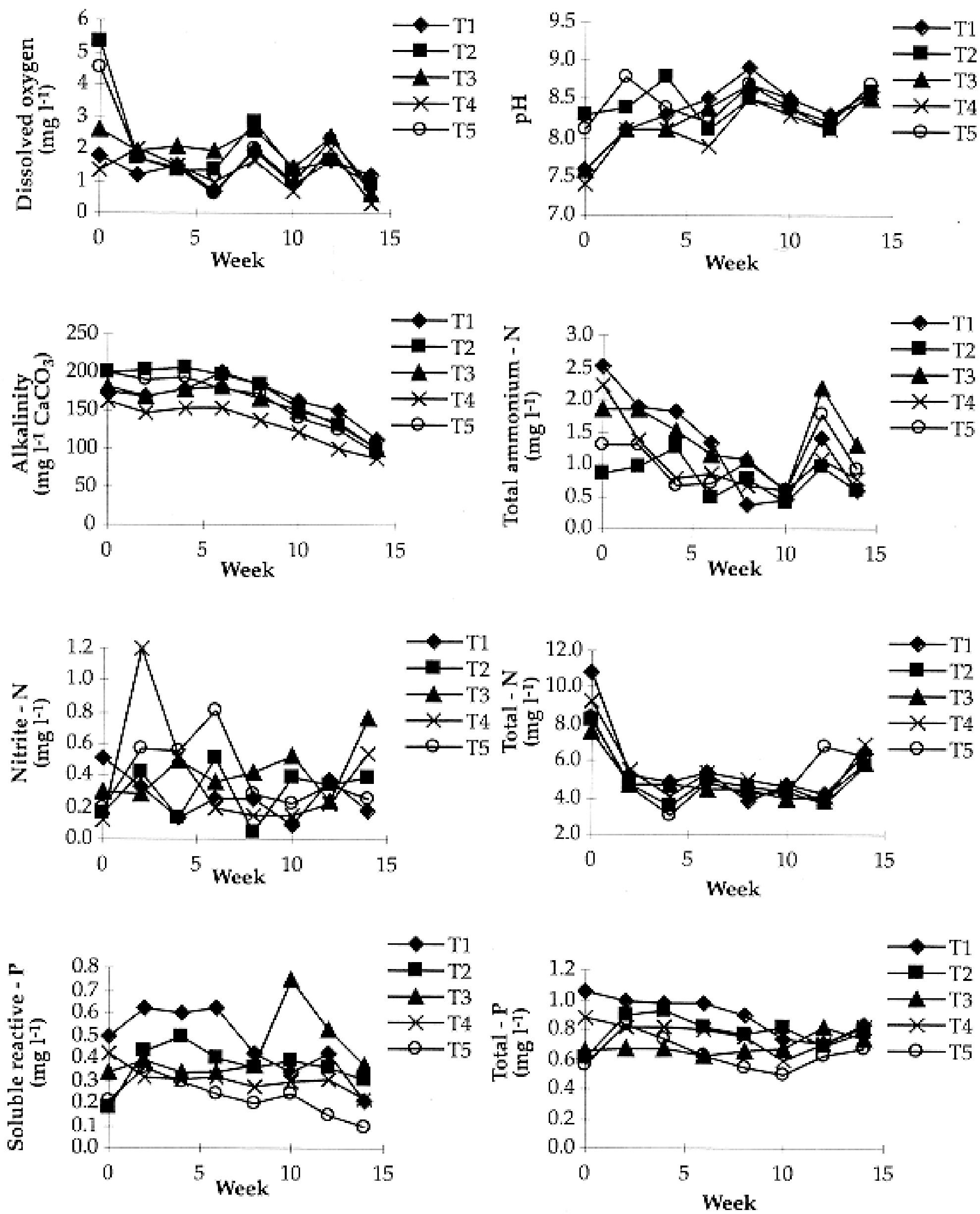

Figure 2. Means net fish yield and survival for different treatments listed in table 1.

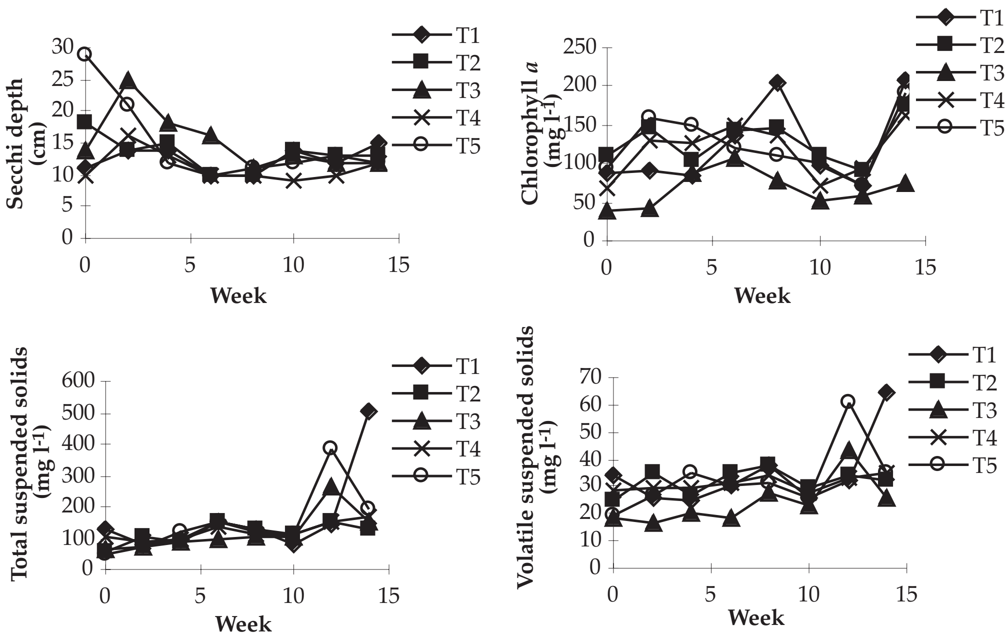

Figure 4. Mean biweekly Secchi depth, chlorophyll *a*, total suspended solids, and volatile suspended solids measured at 0900 h over the experimental period for treatments listed in Table 1.

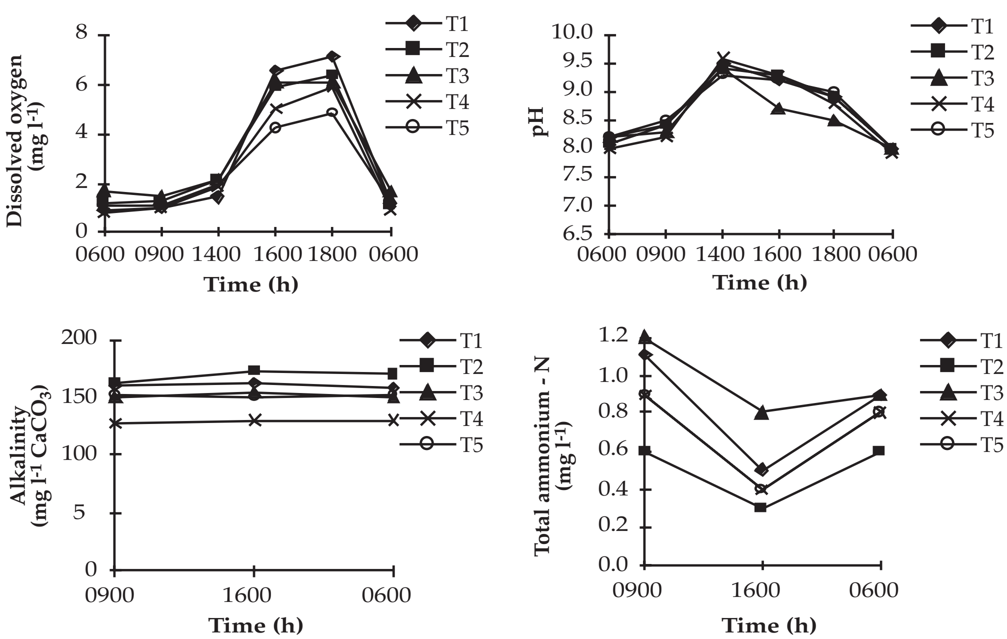

Figure 5. Mean monthly diel profile of dissolved oxygen, pH, alkalinity, and total ammonium nitrogen over the experimental period for treatments listed in Table 1.

Table 3. Mean monthly diel profile of water quality parameters over experimental period.

Parameters	Treatment	0600 h	0900 h	1400 h	1600 h	1800 h	0600 h
Temperature (°C)	T1	28.9 ± 0.2	29.0 ± 0.2	30.3 ± 0.2	30.8 ± 0.1	30.5 ± 0.2	29.0 ± 0.2
	T2	29.0 ± 0.2	29.1 ± 0.2	30.0 ± 0.3	30.4 ± 0.3	30.5 ± 0.1	28.9 ± 0.2
	T3	29.1 ± 0.2	29.2 ± 0.1	30.2 ± 0.1	30.9 ± 0.1	30.7 ± 0.3	29.1 ± 0.1
	T4	29.0 ± 0.0	29.2 ± 0.1	29.9 ± 0.1	30.6 ± 0.3	30.4 ± 0.1	29.0 ± 0.0
	T5	28.9 ± 0.1	29.1 ± 0.1	29.8 ± 0.1	30.3 ± 0.1	30.3 ± 0.0	29.0 ± 0.1
Dissolved Oxygen (mg l^{-1})	T1	0.9 ± 0.2	1.0 ± 0.1	1.4 ± 0.5	6.5 ± 0.6	7.1 ± 0.2	1.2 ± 0.1
	T2	1.2 ± 0.5	1.3 ± 0.6	2.1 ± 1.4	5.8 ± 2.3	6.4 ± 2.0	1.1 ± 0.7
	T3	1.7 ± 0.2	1.4 ± 0.0	2.2 ± 0.7	6.1 ± 1.5	6.1 ± 1.3	1.6 ± 0.1
	T4	0.8 ± 0.1	1.0 ± 0.3	1.8 ± 0.6	5.0 ± 1.4	5.9 ± 1.5	0.9 ± 0.1
	T5	1.1 ± 0.2	1.1 ± 0.2	2.0 ± 0.4	4.2 ± 0.3	4.8 ± 0.8	1.2 ± 0.2
pH	T1	8.2	8.4	9.5	9.2	8.9	8.0
	T2	8.1	8.4	9.4	9.3	8.9	8.0
	T3	8.2	8.3	9.7	8.7	8.5	8.0
	T4	8.0	8.2	9.6	9.3	8.8	7.9
	T5	8.2	8.5	9.3	9.2	9.0	8.0
Alkalinity (mg l^{-1} $CaCO_3$)	T1		161 ± 16		162 ± 3		158 ± 16
	T2		163 ± 18		172 ± 23		170 ± 22
	T3		150 ± 7		159 ± 9		150 ± 7
	T4		127 ± 24		130 ± 24		130 ± 26
	T5		152 ± 4		149 ± 5		152 ± 3
Total Ammonium Nitrogen (mg l^{-1})	T1		1.1 ± 0.2		0.5 ± 0.2		0.9 ± 0.2
	T2		0.6 ± 0.2		0.3 ± 0.1		0.6 ± 0.1
	T3		1.2 ± 0.1		0.8 ± 0.2		0.9 ± 0.3
	T4		0.9 ± 0.2		0.4 ± 0.1		0.8 ± 0.1
	T5		0.9 ± 0.2		0.4 ± 0.1		0.8 ± 0.0

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Economic and Social Returns to Technology and Investment and Risk Analysis of Pond Management Strategies

Eighth Work Plan, Marketing and Economic Analysis Research 1 and 2 (MEAR1 and 2)
Progress Report

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Abstract

Analyses of economic and social returns to technology and investment and for risk analysis require farm production data. Twenty-one shrimp farm owners and managers were interviewed in Honduras in March, 1998, representing approximately 1/3 of the total number of shrimp farms in the country. The total hectareage represented in the study sample was 54% of the total hectareage in shrimp production in the country. Survey data were entered into an EXCEL spreadsheet for summarization and cross-tabulation. Most of the farms participating in the survey had yields of shrimp that were either in the range of 1,000 - 1,500 lb of head-off shrimp/ha/yr (33%) or 1,501 - 2,000 lb/ha/yr (38%). Farms that stocked PL's at higher rates achieved higher yields. Farms that stocked more than 20 PL/m^2 achieved yields greater than 1,500 lb/ha/yr while those stocking 15 PL/m^2 had lower yields. Farms with yields over 2,000 lb/ha/yr also fed more than 15 lb/ha/d during the dry season. Over half of the respondents fertilized ponds, but most of these were small and medium-sized farms. Most large farms did not fertilize at all. Large farms also tended to be more reliant on hatchery-raised PL's, than were small and medium-sized farms. Shrimp farms appeared to exhibit economics of scale in that large farms tended to have lower costs per hectare than smaller farms.

Introduction

The complete analyses for both these studies depend upon survey data collected in Honduras. Survey instruments were designed, translated into Spanish, pre-tested, modified, and administered in Honduras. Originally, ANDAH (Asociacion Nacional de Acuicultores de Honduras) suggested that the questionnaire could be distributed and collected by them. They were particularly interested in a workshop that I would present at the same time. The questionnaires were distributed, but the original response was very poor. It became clear that it would take several weeks to conduct direct personal interviews to complete the survey. Given the prior commitment to the presentation of training workshops, there was not adequate time during that visit to also conduct an adequate number of direct interviews. While ANDAH and CRSP personnel attempted to continue to collect the questionnaires, there was little success. In March, a graduate student was sent to Honduras to conduct direct personal interviews. He returned with the needed information and began to compile it. This report summarizes the survey information collected. The originally proposed analyses are underway now that the data are in hand and will be discussed in detail in the final report to be submitted by December 31, 1998.

Table 1. Size distribution of farms in Honduras

Size	Number of farms	% of total	Area (ha.)	% of total
10-150 ha.	44	66%	2710.13	22%
150-400 ha.	17	25%	4605.75	37%
More than 400 ha.	6	9%	5089.28	41%
Total	67		12405.16	

Methods and Materials

Twenty-one shrimp farms were interviewed during March, 1998 (Table 2). This sample represents approximately 1/3 of the total number of shrimp farms in the country (Table 1). Of the total sampled, 38% ranged from 10-150 ha in size, 43% ranged in size from 150-400 ha, and 19% were more than 400 ha in size. The total hectareage represented in the study sample was 54% of the total hectareage in shrimp production in the country.

Survey data were entered into an EXCEL spreadsheet for summarization and cross-tabulation. Relevant tables and graphs were prepared.

Results

Yield

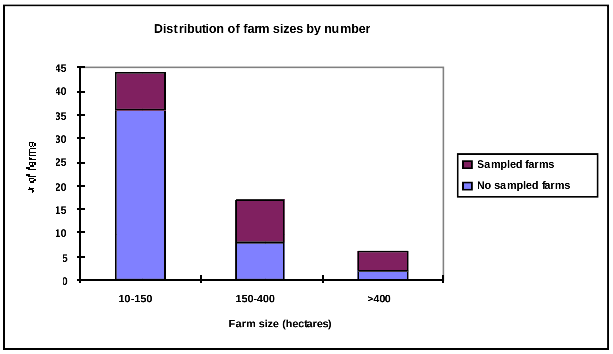
Table 3 indicates the yield distribution of sampled farms by farm size. Approximately 67% of medium-sized (150-400 ha) farms had yields between 1,500 and 2,000 lb/ha/year. Half of the small (10-150 ha) farms had yields of between 1,000 and 1,500 lb/ha/year. No medium-sized farm reported yields less than 1,000 lb/ha/year.

Stocking Density

Large farms did not stock more than 20 PL/m^2, Table 4. Seventy-five percent of the large farms stocked less than

Table 2. Size distribution of sampled farms

Size	Number of farms	% of total	Area (ha.)	% of total
10-150 ha.	8	38%	318.22	5%
150-400 ha.	9	43%	2856.5	42%
More than 400 ha.	4	19%	3580	53%
Total	21		6754.72	



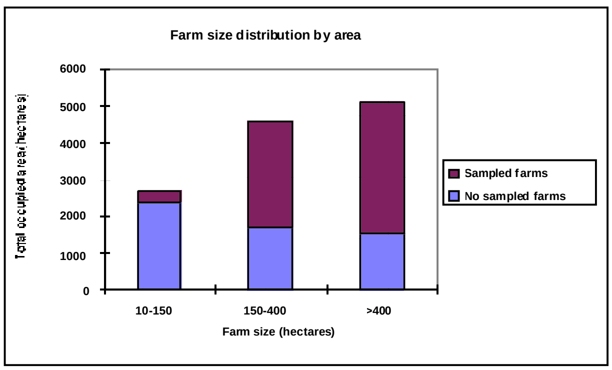
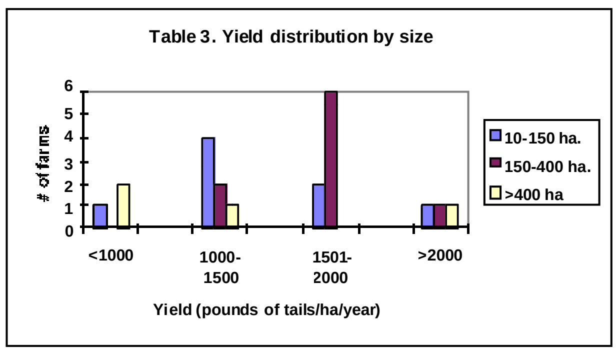


Table 3. Yield distribution of sampled farms and correlation with size

Yield (pounds of head-off shrimp/ha/year)	Number of farms	%	Distribution by size [1]	% [2]
Less than 1000	3	14%	1	13%
			0	0%
			2	50%
1000-1500	7	33%	4	50%
			2	22%
			1	25%
1501-2000	8	38%	2	25%
			6	67%
			0	0%
More than 2000	3	14%	1	13%
			1	11%
			1	25%
Total	21	100%	21	

[1] The first number of each range corresponds to the number of farms with sizes between 10-150 hectares, the second number to the number of farms between 150 and 400 hectares and the third number to the number of farms larger than 400 hectares.

[2] These percentages indicate the proportion of farms within a given farm size that are grouped in the same yield range. For instance, 13% of small-sized farms, 0% of medium-sized farms and 50% of large-sized farms have yields lower than 1000 pounds/ha/year.



- 67% of medium-sized farms have yields between 1500 and 2000 pounds/ha/year. 50% of small farms have yields between 1000 and 1500 pounds/ha/year.
- No medium farm report yields lesser than 1000 pounds/ha/year.

15 PL/m^2 and the remaining 25% of the large farms stocked between 15 and 20 PL/m^2. Medium-sized farms were more variable in terms of stocking densities with 33% of farms reporting stocking densities of less than 15 PL/m^2, 44% stocking 15-20 PL/m^2, and 22% stocking more than 20 PL/m^2. Most farms (63%) in the smallest size category stocked 15-20 PL/m^2, with an additional 25% stocking at less than 15 PL/m^2 and 13% stocking more than 20 PL/m^2.

Feeding Rates - Dry Season

Most (63%) of the small farms responding to the survey fed at rates of less than 15 lb/ha/day, Table 5. An additional 25% did not feed, while 13% fed more than 15 lb/ha/day. Of the medium-sized farms, 33% did not feed, 56% fed less than 15 lb/ha/day, and 11% fed more than 15 lb/ha/day. All of the largest farms in the study fed their ponds. Seventy-five percent fed less than 15 lb/ha/day and 25% fed more than 15 lb/ha/day.

Feeding Rates - Wet Season

Feeding was a more common practice in the wet season and shrimp were fed at higher rates in the wet season than in the dry season, Table 6. Of the small farms, 25% fed less than 15 lb/ha/day, 63% fed 15-25 lb/ha/day, and 13% fed more than 25 lb/ha/day. Of the medium-sized farms, 33% fed less than 15 lb/ha/day, 33% fed 15-25 lb/ha/day, and 33% fed more than 25 lb/ha/day. Of the large farms in the study, 75% fed 15-25 lb/ha/day and 25% fed more than 25 lb/ha/day.

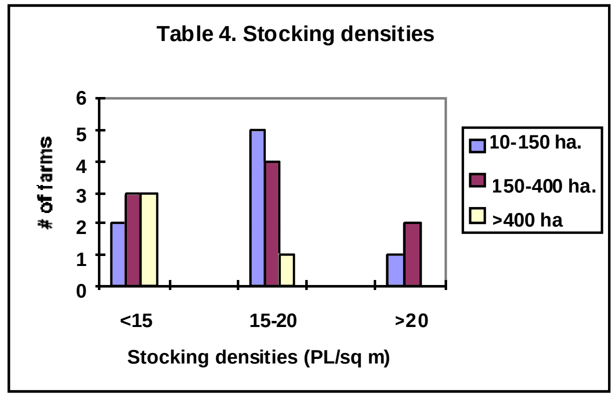
Shrimp Prices and Farm Size

Shrimp prices vary with shrimp size. There is no relationship between the size of the shrimp farm and the size of shrimp. Nearly half (48%) of the respondents sold shrimp for more than 50 Lempiras/lb, Table 7. Another 33% of respondents sold shrimp for 41-50 Lempiras/lb, while 19% sold shrimp for less than 40 Lempiras/lb.

Table 4. Stocking densities for the winter and correlation with size

Stocking density (PL/m²)	Number of farms	%	Distribution by size [1]	% [2]
Less than 15	8	38%	2	25%
			3	33%
			3	75%
15-20	10	48%	5	63%
			4	44%
			1	25%
More than 20	3	14%	1	13%
			2	22%
			0	0%
Total	21	100%	21	

[1, 2] See notes from Table 3.

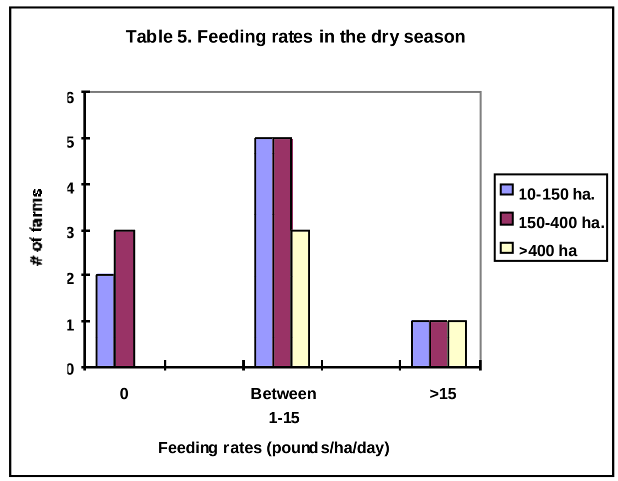


- Large farms do not stock more than 20 PL/m².

Table 5. Feeding rates in the dry season and correlation with size

Feeding rates (pounds/ha/day)	Number of farms	%	Distribution by size [1]	% [2]
0	5	24%	2	25%
			3	33%
			0	0%
Less than 15	13	62%	5	63%
			5	56%
			3	75%
More than 15	3	14%	1	13%
			1	11%
			1	25%
Total	21		21	

[1, 2] See notes from Table 3.

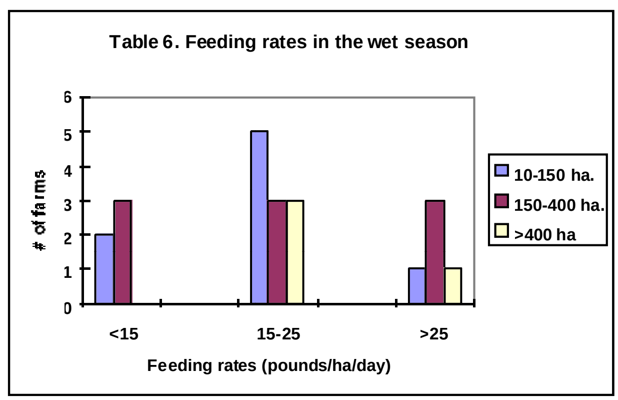


- Large farms keep feeding during the dry season.

Table 6. Feeding rates in the wet season and correlation with size

Feeding rates (pounds/ha/day)	Number of farms	%	Distribution by size [1]	% [2]
Less than 15	5	24%	2	25%
			3	33%
			0	0%
15-25	11	52%	5	63%
			3	33%
			3	75%
More than 25	5	24%	1	13%
			3	33%
			1	25%
Total	21		21	

[1, 2] See notes from Table 3.



- Large farms do not feed less than 15 pounds/ha/day.

Feed Price and Farm Size

Over half of the respondents (52%) purchased feed for 301-400 Lempiras/quintal of feed, 24% paid 251-300 Lempiras/quintal, 19% paid 201-250 Lempiras/quintal, and 5% paid less than 200 Lempiras/quintal, Table 8. Farms of different sizes did appear to pay different feed prices. For example, no large farm paid more than 300 Lempiras/quintal for feed and no small farm paid less than 300 Lempiras/quintal.

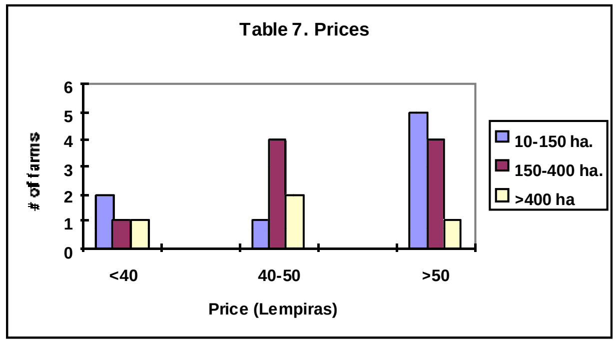
Fertilization

Over half of the respondents (62%) fertilized shrimp ponds, Table 9. Over half (63% and 78%) of small and medium-sized

Table 7. Variation of prices and correlation with size

Price (Lempiras [3])	Number of farms	%	Distribution by size [1]	% [2]
Less than 40	4	19%	2	25%
			1	11%
			1	25%
41-50	7	33%	1	13%
			4	44%
			2	50%
More than 50	10	48%	5	63%
			4	44%
			1	25%
Total	21	100%	21	

[1, 2] See notes from Table 3.
[3] 1 US Dollar = 13 Lempiras

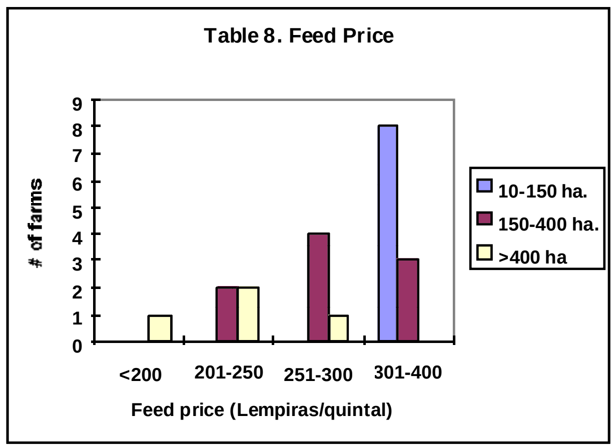


- Prices depend on shrimp size. There is not a correlation between farm size and shrimp price.

Table 8. Feed price and correlation with size

Feed price (Lempiras/quintal)	Number of farms	%	Distribution by size [1]	% [2]
Less than 200	1	5%	0	0%
			0	0%
			1	25%
201-250	4	19%	0	0%
			2	22%
			2	50%
251-300	5	24%	0	0%
			4	44%
			1	25%
301-400	11	52%	8	100%
			3	33%
			0	0%
Total	21	100%	21	

[1, 2] See notes from Table 3.

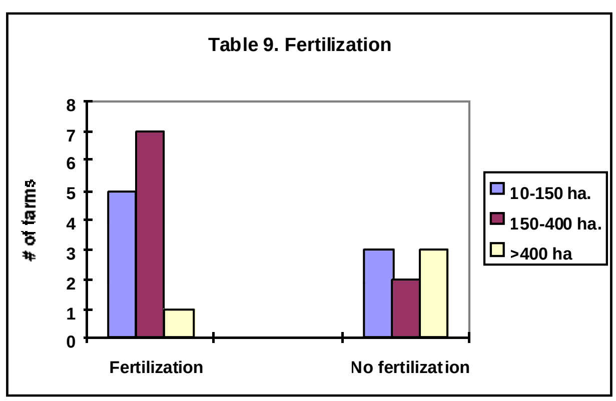


- No large farm pays more than 300 Lempiras/quintal.
- No small farm pays less than 300 Lempiras/quintal.

Table 9. Fertilization

	Number of farms	%	Distribution by size [1]	% [2]
Fertilization	13	62%	5	63%
			7	78%
			1	25%
No fertilization	8	38%	3	37%
			2	22%
			3	75%
Total	21	100%	21	

[1, 2] See notes from Table 3.

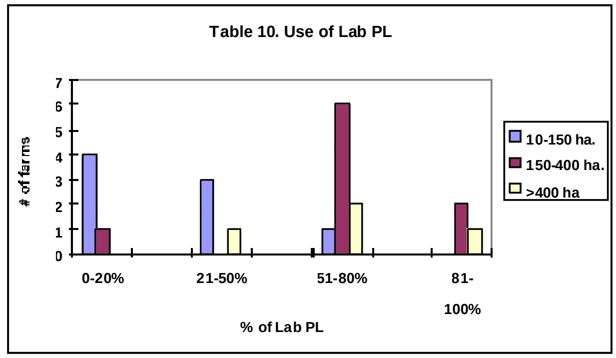


- There was only one large farm reported to fertilize ponds. The decision to fertilize depends mainly on the location of the farm.

Table 10. Use of Lab Post-larvae

	Number of farms	%	Distribution by size [1]	% [2]
0-20% Lab PL	5	24%	4	50%
			1	11%
			0	0
21-50% Lab PL	4	19%	3	37%
			0	0%
			1	25%
51-80% Lab PL	9	43%	1	13%
			6	67%
			2	50%
81-100% Lab PL	3	14%	0	0%
			2	22%
			1	25%
Total	21	100%	21	

[1, 2] See notes from Table 3.

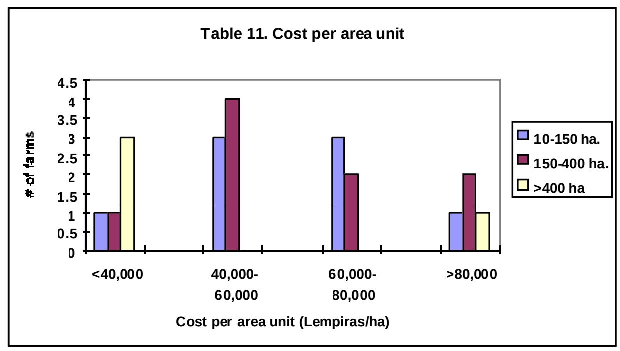


- There is a trend among small farms to rely more on wild PL, which is cheaper. Medium and large farms prefer to work with lab PL.

Table 11. Cost per area unit

Costs per area unit (Lempiras/ha)	Number of farms	%	Distribution by size [1]	% [2]
Less than 40,000	5	24%	1	13%
			1	11%
			3	75%
40,000-60,000	7	33%	3	38%
			4	44%
			0	0%
60,000-80000	5	24%	3	38%
			2	22%
			0	0%
More than 80,000	4	19%	1	13%
			2	22%
			1	25%
Total	21	100%	21	

[1, 2] See notes from Table 3.



- Large farms tend to have smaller costs per area unit, but this also depends on the strategy chosen by managers.

farms fertilized, while 75% of the large farms did not fertilize at all. In fact, there was only one large farm that reported fertilizing ponds. However, the decision to fertilize or not depends mainly on the location of the farm.

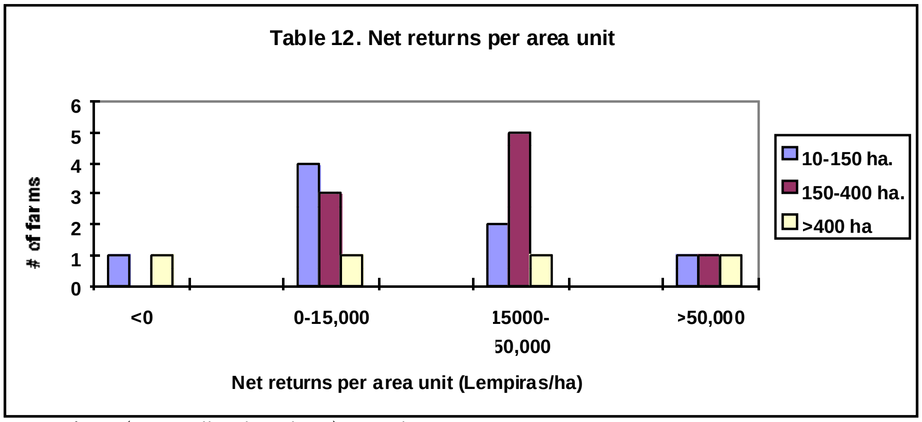
Use of Hatchery - Raised Post-Larvae

Post-larvae can be obtained either from the wild or purchased from hatcheries. Wild-caught PL's are less expensive and are considered to be hardier and provide better survival than hatchery-raised PL's. More small farms tended to use a higher percentage of wild-caught PL's. Half (50%) of small farms purchased only 0-20% of their PL's from hatcheries, Table 10. On the other hand, half (50%) of large farms purchased from 51-80% of their PL's from hatcheries.

Table 12. Net returns per area unit

Net returns per area unit (Lempiras/ha)	Number of farms	%	Distribution by size [1]	% [2]
Negative returns	2	10%	1	13%
			0	0%
			1	25%
Less than 15,000	8	38%	4	50%
			3	33%
			1	25%
15,000-50,000	8	38%	2	25%
			5	56%
			1	25%
More than 50,000	3	14%	1	13%
			1	11%
			1	25%
Total	21	100%	21	

[1, 2] See notes from Table 3.



- Two farms (one small and one large) report losses.
- 50% of small farms have net returns lesser than 15,000 Lempiras/ha. 56% of medium farms achieve returns between 15,000 and 50,000 Lempiras/ha.

Table 13. Benefit over cost ratio

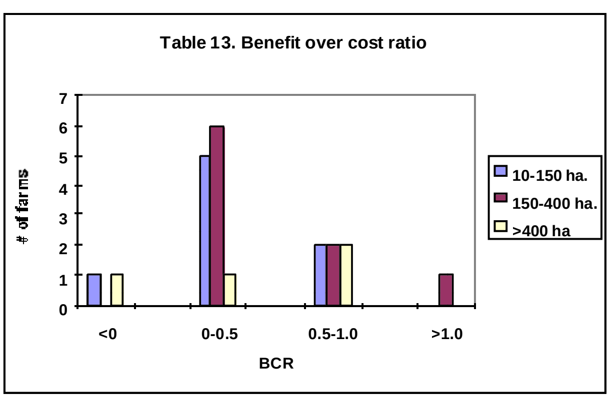
BCR	Number of farms	%	Distribution by size [1]	% [2]
Less than 0	2	10%	1	13%
			0	0%
			1	25%
0-0.5	12	57%	5	63%
			6	67%
			1	25%
0.5-1.0	6	29%	2	25%
			2	22%
			2	50%
More than 1.0	1	5%	0	0%
			1	11%
			0	0%
Total	21	100%	21	

[1, 2] See notes from Table 3.

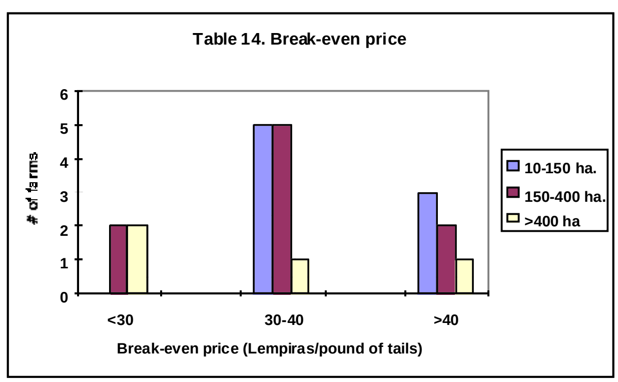
Table 14. Break-even price

Break-even price (Lempiras)	Number of farms	%	Distribution by size [1]	% [2]
Less than 30	4	19%	0	0%
			2	22%
			2	50%
30-40	11	52%	5	63%
			5	56%
			1	25%
More than 40	6	29%	3	38%
			2	22%
			1	25%
Total	21	100%	21	

[1, 2] See notes from Table 3.



- There is one medium farm reported to have a BCR higher than 1.0.



- No small farm has a break-even price lesser than 30 Lempiras.

Cost Per Hectare

Most aquaculture farms exhibit strong economies of scale. Shrimp farms appear to also exhibit economies of scale in that large farms participating in the study tended to have lower costs per hectare than smaller farms. Three-fourths of large farms had costs of less than 40,000 Lempiras/ha while only 13% of small farms and 11% of medium-sized farms had costs this low, Table 11. Thirty-eight percent and 44% of small and medium-sized farms, respectively, had costs of 40,000-60,000 Lempiras/ha and 38% and 22% of small and medium-sized farms, respectively had costs of 60,000-80,000 Lempiras/ha.

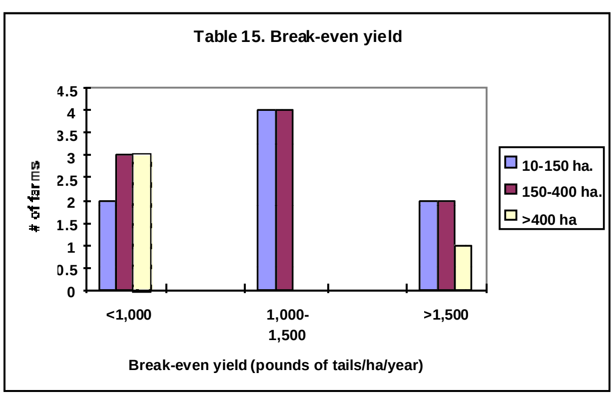
Net Returns from Shrimp Farming

Few shrimp farms in the study were losing money. Half (50%) of the small farms generated net returns of less than 15,000 Lempiras/ha, while 33% of the medium-sized farms and 25% of the large farms also generated this range of net returns, Table 12. Over half (56%) of the medium-sized farms had net returns of 15,000-50,000 Lempiras/ha while 25% of small and of large farms generated net returns in this same range. Twenty-five percent of the large farms, 11% of the medium-sized farms, and 13% of the small farms had net returns of more than 50,000 Lempiras/ha.

Table 15. Break-even yield

Break-even yield (pounds of head-off shrimp/ha/year)	Number of farms	%	Distribution by size [1]	% [2]
Less than 1000	8	38%	2	25%
			3	33%
			3	75%
1000-1500	8	38%	4	50%
			4	44%
			0	0%
More than 1500	5	24%	2	25%
			2	22%
			1	25%
Total	21	100%	21	

[1, 2] See notes from Table 3.



- Break-even yield is a function of the strategy chosen by managers, not of farm size.

Shrimp Yields and Stocking Rates

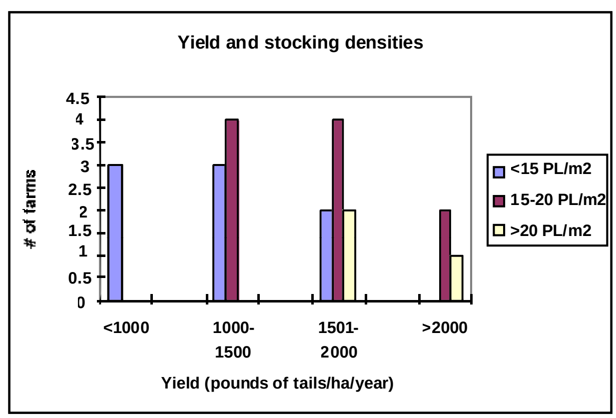
Most of the farms participating in the survey had yields of shrimp that were either in the range of 1,000-1,500 lb of head-off shrimp/ha/yr (33%) or 1,501-2,000 lb/ha/yr (38%), Table 16. Another 14% each had yields of less than 1,000 lb/ha/yr or more than 2,000 lb/ha/yr. Farms that stocked PL's at higher rates achieved higher yields. For example, farms that stocked more than 15 PL/m^2 achieved yields higher than 1,000 lb/ha/yr, while farms that stocked more than 20 PL/m^2 achieved yields

Table 16. Yield and correlation with other variables

Yield (pounds of head-off shrimp/ha/year)	Number of farms	%	Distribution by stocking densities [3]		% [4]
Less than 1000	3	14%	<15	3	100%
			15-20	0	0%
			>20	0	0%
1000-1500	7	33%		3	43%
				4	57%
				0	0%
1501-2000	8	38%		2	25%
				4	50%
				2	25%
More than 2000	3	14%		0	0%
				2	67%
				1	33%
Total	21	100%	21		

[3] Ranges of stocking densities are those used previously in Table 4 (Less than 15, 15-20 and more than 20 PL/m^2). Farms within a given yield range are distributed by reported stocking densities. For instance, there are 8 farms yielding between 1501 and 2000 pounds/ha/year, 2 of which stock less than 15 PL/m^2, 4 stock 15-20 PL/m^2 and the other 2 stock more than 20 PL/m^2.

[4] These percentages correspond to the distribution of farms within a given yield range.



- Farms stocking more than 15 PL/m^2 achieved yields higher than 1000 pounds/ha/year.
- Farms stocking more than 20 PL/m^2 achieved yields higher than 1500 pounds/ha/year.
- All farms that obtained low yields stocked under 15 PL/m^2.

higher than 1,500 lb/ha/yr, and all farms that obtained low yields stocked less than 15 PL/m[2].

The farms that yielded more than 2,000 lb/ha/yr fed more than 15 lb/ha/day during the dry season. None of the farms that fed less than this amount produced yields over 2,000 lb/ha/hr. Those farms that fed at less than 15 lb/ha/day produced yields of either 1,000-1,500 lb/ha/day or 1,501-2,000 lb/ha/day. Similar patterns were observed with feeding in the wet season. Farms that fertilized obtained yields higher than 1,000 lb/ha/yr.

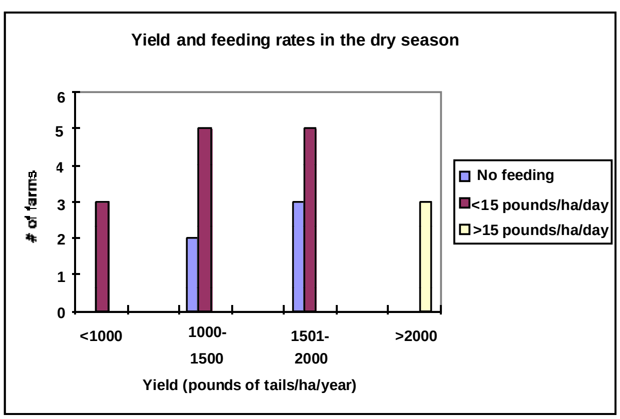
ANTICIPATED BENEFITS

Results of the analysis to estimate the economic and social returns to technology and investment will provide justification for the continued funding of PD/A CRSP research through quantification of the program's benefits and impacts. This study will provide the first estimates of the social and economic returns generated by the PD/A CRSP over time.

Results of the risk analysis of pond management strategies will provide important insights into the integration of CRSP technologies into host country farming systems and is intended to provide recommendations for increasing incomes of farmers and rural communities.

Yield (pounds of head-off shrimp/ha/year)	Number of farms	%	Correlation with feeding rates-dry season [5]		% [4]
Less than 1000	3	14%	No feeding	0	0%
			<15	3	100%
			>15	0	0%
1000-1500	7	33%		2	29%
				5	71%
				0	0%
1501-2000	8	38%		3	38%
				5	63%
				0	0%
More than 2000	3	14%		0	0%
				0	0%
				3	100%
Total	21	100%	21		

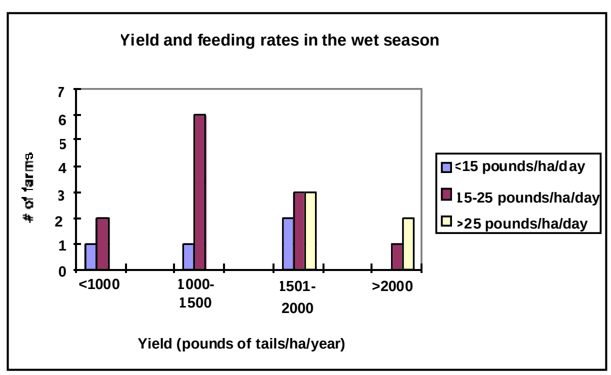
[4] These percentages correspond to the distribution of farms within a given yield range.
[5] These ranges are those used previously in Table 5.



- Farms that yielded more than 2000 pounds/ha/year fed more than 15 pounds/ha/day during the dry season.

Yield (pounds of head-off shrimp/ha/year)	Number of farms	%	Distribution by feeding rates-wet season [6]		% [4]
Less than 1000	3	14%	<15	1	33%
			15-25	2	67%
			>25	0	0%
1000-1500	7	33%		1	14%
				6	86%
				0	0%
1501-2000	8	38%		2	25%
				3	38%
				3	38%
More than 2000	3	14%		0	0%
				1	33%
				2	67%
Total	21	100%	21		

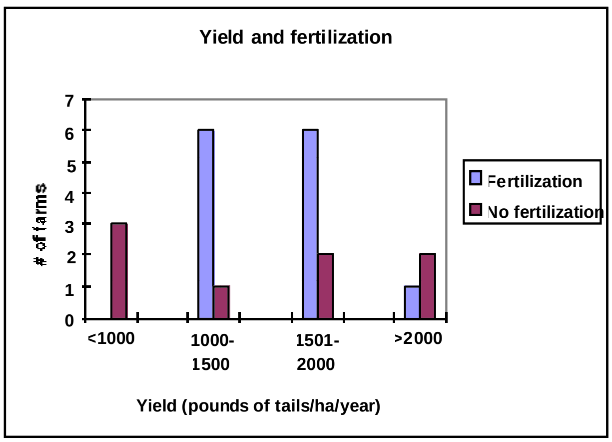
[4] These percentages correspond to the distribution of farms within a given yield range.
[6] These ranges are those used previously in Table 6.



- Farms that fed more than 25 pounds/ha/day yielded more than 1500 pounds/ha/year.

Yield (pounds of head-off shrimp/ha/year)	Number of farms	%	Correlation with fertilization [7]		% [4]
Less than 1000	3	14%	No fertilization	0	0%
			Fertilization	3	100%
1000-1500	7	33%		6	86%
				1	14%
1501-2000	8	38%		6	75%
				2	25%
More than 2000	3	14%		1	33%
				2	67%
Total	21	100%	21		

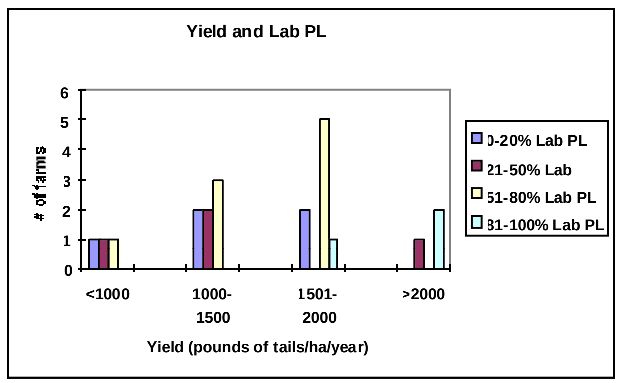
[4] These percentages correspond to the distribution of farms within a given yield range.
[7] These categories are those used previously in Table 9.



- Farms that fertilized obtained yields higher than 1000 pounds/ha/year.

Yield (pounds of head-off shrimp/ha/year)	Number of farms	%	Correlation with Lab PL [8]		% [4]
Less than 1000	3	14%	0-20%	1	33%
			21-50%	1	33%
			51-80%	1	33%
			81-100%	0	0%
1000-1500	7	33%		2	29%
				2	29%
				3	43%
				0	0%
1501-2000	8	38%		2	25%
				0	0%
				5	63%
				1	13%
More than 2000	3	14%		0	0%
				1	33%
				0	0%
				2	67%
Total	21	100%	21		

[4] These percentages correspond to the distribution of farms within a given yield range.
[8] These ranges are those used previously in Table 10.



- Farms that stocked Lab PL for the most part (81-100%) yielded more than 1500 pounds/ha/year.

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TILAPIA PRODUCER PERCEPTIONS AND PRACTICES IN FIVE PD/A CRSP COUNTRIES

Eighth Work Plan, Adoption and Diffusion Research 1A (ADR1A)
Progress Report

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ABSTRACT

The PD/A CRSP site in Sagana, Kenya, is situated in the highlands of Central Province, which provide excellent growing conditions for many types of farm enterprises. This is mainly due to the great abundance of fertile volcanic soil in the lands around Mount Kenya. The area is well watered and cool temperatures make the area very productive in food crops, but other factors affect the potential for fish culture. Central Province had about 2,230 fishponds in 1995. In contrast, the Lake Basin area (Western and Nyanza Provinces) has about 5,000 to 10,000 active ponds, although there were as many as 25,000 in the area during the mid sixties and mid seventies. This article summarizes the results of a five-year program of farm-level surveys conducted in five PD/A CRSP countries, updating previous reporting with new data from tilapia producers in Central Province. Kenya is the new PD/A CRSP site in Africa, and data were collected from practicing fish farmers in 1998.

INTRODUCTION

The Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) is a global research network organized to generate basic scientific data that may be used to advance aquacultural development. One of a family of research programs funded by the United States Agency for International Development, this CRSP focuses on improving the efficiency of aquaculture systems—in many projects working with the culture of Nile tilapia (*Oreochromis niloticus*). Much of the work of the PD/A CRSP has been directed to specifying optimum ways that farmers can feed and fertilize their ponds to increase fish yields. The PD/A CRSP has identified many of the needed parameters that apply across diverse environments.

The PD/A CRSP began work in 1982 in Thailand, and subsequently in the Philippines, Honduras, Rwanda, Indonesia, and Panama. Research continues today in Thailand, the Philippines, Honduras, the US, and, until recently, Rwanda. At each site, the goal is the same: to identify constraints to aquaculture production and to design responses that are environmentally and culturally appropriate. The Kenya effort continues the effort in the context of the unique constraints and food security needs of East Africa.

The highlands in Kenya's Central Province provide excellent growing conditions for many types of farm enterprises. This is mainly due to the abundance of fertile volcanic soil that originated from Mount Kenya. The area is well watered and cool temperatures make the area very productive in food crops, but other factors affect the potential for fish culture. In contrast with Western and Nyanza Provinces, the populace of Central Province has not traditionally consumed fish, nor has the area received concentrated fish culture extension assistance over the years. However, fish culture is intended to provide some of the needed protein and to serve as an alternative source of income. Central Province had approximately 2,230 fishponds in 1995. The species produced were tilapia, carp, and trout. In contrast, the Lake Basin area (Western and Nyanza Provinces) had approximately 5,000 to 10,000 active ponds, although there were as many as 25,000 in the area during the mid sixties and mid seventies.

Kenya is the new PD/A CRSP site in Africa; data were collected from practicing fish farmers in 1998. Research at Sagana Fish Farm focuses on tilapia culture, an enterprise with high potential to augment the array of alternatives available to local farmers.

This paper summarizes the results of a five-year program of farm-level surveys that begin to specify the extent to which research processes are serving farmers in five of the seven PD/A CRSP countries.

MATERIALS AND METHODS

Sample Size and Data Collection

Data were collected from tilapia farmers in five PD/A CRSP countries: Kenya, Rwanda, Honduras, Thailand, and the Philippines. The following sections detail the procedures employed in each country and the approach used to analyze the data. Table 1 summarizes the number of respondents interviewed from each country.

Kenya

Data were obtained from interviews with 43 active Kenyan fish farmers from the five districts in Central Province during winter 1998. The survey was revised and adapted in English and then translated into Kiswahili. Interviews were conducted in Kiswahili.

Table 1. Number of respondents by region of tilapia farmers in PD/A CRSP countries, 1992-98.

Country	Respondents	
	Number	*Percent*
KENYA DISTRICTS – 1998		
Kiambu	4	9
Kirinyaga	7	17
Muranga	11	25
Nyandarua	5	12
Nyeri	16	37
(Total)	(43)	(100)
RWANDA COMMUNES – 1992		
Gishamvu	10	7
Karago	19	14
Kayove	16	12
Kigembe	20	15
Mugambazi	26	19
Ndusu	10	7
Nyamabuye	19	14
Tumba	16	12
(Total)	(136)	(100)
HONDURAS DEPARTMENTS – 1993		
Atlantida	5	10
Colon	4	7
Comayagua	9	18
Copan	9	18
Cortes	9	18
El Paraiso	5	10
Francisco Morazon	1	2
Olancho	4	7
Santa Barbara	3	6
Yoro	2	4
(Total)	(51)	(100)
PHILIPPINE PROVINCES – 1995		
Bulacan	14	28
Nueva Ecija	9	18
Pampanga	11	22
Tarlac	16	32
(Total)	(50)	(100)
THAILAND PROVINCES – 1995		
Ayutthaya	22	39
Nakhon Pathom	14	25
Pathum Thani	20	36
(Total)	(56)	(100)

Tilapia farmers were identified through referrals from Fisheries Department personnel, knowledgeable local individuals, and fish farmers who knew of neighbors raising tilapia. Central Province is distinguished by the presence of Nairobi in its southernmost district. Although Central Province is not a major tilapia producing area, because of Nairobi's large population and the positive geographic and climatic conditions of the area, there exists a clear need and high potential for increased production. Thus, Central Province represents the primary target population for PD/A CRSP research in Kenya.

Rwanda
Data were obtained from interviews with 136 active Rwandan fish farmers in eight local administrative districts (communes) during the winter and early spring of 1992. Interviews were conducted with 120 active fish farmers randomly selected from National Fish Culture Service (SPN) extension rolls. An additional 16 active farmers who had not received extension assistance were interviewed. See Molnar et al. (1993) for details.

Honduras
Data were obtained from interviews with 51 active Honduran fish farmers in 10 of 15 Honduran departments during the fall of 1993. The survey instrument was translated into Spanish and all interviews were conducted in Spanish. Tilapia farmers were identified through referrals made by Peace Corps volunteers working in fish culture, Honduran extension personnel, and farmers who identified neighbors raising tilapia. The departments were chosen to represent the major tilapia production regions in the country.

Philippines
Data were obtained from interviews with 50 Philippine fish farmers in 4 of 15 provinces on the main island of Luzon during winter 1994. Tilapia farm operators in Bulacan, Nueva Ecija, Pampanga, and Tarlac provinces were interviewed. The survey was revised and adapted and then translated into and conducted in Tagalog.

Names of tilapia farmers were obtained from lists of farmers who had purchased fingerlings at the Freshwater Aquaculture Center at Central Luzon State University in Muñoz. Farmers were interviewed and asked to identify neighbors who raised tilapia who also were approached for interviews. Interviews were conducted with 50 active fish farmers in provinces north of Manila and the City of Angeles in Central Luzon, the major tilapia production region in the country.

Thailand
Data were obtained from a sample of 56 active Thai fish farmers in 3 of Thailand's 75 provinces—Ayutthaya, Pathum Thani, and Nakhon Pathom—in central Thailand during winter 1994. The survey was revised, adapted, and translated into the Thai language. All interviews were conducted in Thai.

Tilapia farmers were identified through referrals made by Department of Fisheries extension personnel, knowledgeable local individuals, and fish farmers identifying neighbors raising tilapia. The provinces chosen represented major tilapia production regions in southcentral Thailand, the major aquaculture region in the country, located directly north of Bangkok.

Representativeness

There are limits to the ability of these data to extrapolate to wider populations of fish farmers and other regions of the selected nations (Casley, 1988). The 1998 Kenya sample is the smallest of the five. Some of the study procedures were compromised due to security problems in two northern districts of Kenya that made travel unsafe and costly for the interviewer. The 1992 Rwanda sample is more representative than the samples drawn in the other countries. It is nationwide, a larger number of interviews were obtained, and the range of variability in the population of fish farmers is smaller in Rwanda. Molnar et al. (1994) previously examined the Rwanda data in detail, but the aggregate findings presented here allow comparative analysis across five PD/A CRSP sites. Similarly, Molnar et al. (1996) previously examined survey data from four sites, but the Kenyan data are presented here for the first time. The number of farmers in each sample—save Rwanda—are inadequate for statistical estimation of population parameters; they do, however, provide information about practicing fish farmers where none is otherwise available.

RESULTS

Respondent Characteristics

Table 2 describes the individual and household characteristics of study respondents. Women comprised approximately one-third of the Kenyan sample, one-fourth of the respondents in Rwanda and Thailand, but only approximately one-tenth of the Honduran and Philippine tilapia farmers we contacted.

Most Kenyan farmers were in the middle age categories, between the ages of 25 and 64. The Rwandan farmers were younger and the Philippine farmers tended to be older than farmers in the other countries. Most farmers were married. A somewhat higher proportion of the Philippine farmers was over age 65.

Nearly all the Kenyan, Rwandan, Honduran, and Philippine households had children under age ten, but only approximately half the Thai families had young children. Philippine families had the fewest children between the ages of 10 and 18 and the most children over age 18.

Kenyans and Rwandans had the largest households; 64 and 65%, respectively, reported having six or more members. Approximately one-half the respondent households in each of the other countries were that large.

Land Holding

Table 3 profiles the land holdings of study respondents. Honduran farms were much more fragmented than the others, as all respondents reported nine or more parcels in their farms. In Kenya, Thailand, Rwanda, and the Philippines, most farmers had relatively consolidated holdings of one to three pieces of land.

Approximately 5% of the Rwandan respondents did not own any land, primarily young people farming in groups formed to use communal lands for aquaculture. In the face of burgeoning numbers of young people seeking farm land, local authorities prefer to grant land use rights to groups rather than individuals. In Thailand, 19% said they did not own land. Young Thai farmers in the study area face rising land prices associated with the growth of the greater Bangkok region. Nearly all respondents in Kenya, Honduras, and the Philippines owned some land. These data also reflect on the relative standing of fish farmers in the social structure of each nation and the level of development in each context.

Kenyan and Honduran farmers did not rent much land from others, but in Rwanda two-thirds said they rented land. About 44% of Thai farmers rented land from others; they also were more likely to rent land out. Only 8% of the Rwandan farmers said they rented land to others.

As in Honduras, about 41% of the Kenyan farmers thought they had more land than their neighbors. In contrast, three-quarters of the Rwandan fish farmers felt that they had less land than their neighbors did; one-third of the Thai farmers felt they had less land, compared to 15% of the farmers from the other countries. About half the Philippine respondents said they had “about the same [amount of land] as people around here.” Hondurans were about equally split between those who felt they had more land and those who felt they owned the same amount of land.

Farm Enterprises

The farm enterprises maintained by tilapia farmers are portrayed in Table 4. Three-quarters of the Kenyan farmers

Table 2. Respondent characteristics of tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
GENDER OF RESPONDENT					
Male	70	71	86	91	76
Female	30	29	14	9	24
AGE OF RESPONDENT					
Less than 25	0	12	8	4	4
25 to 34	19	25	24	20	13
35 to 44	23	33	25	23	32
45 to 54	28	13	27	21	25
55 to 64	28	12	12	14	19
65 or Older	2	5	4	18	7
AGE OF CHILDREN					
Under Age 10	72	81	98	98	47
Age 10 to 18	61	71	51	38	45
Over Age 18	100	41	41	57	43
NUMBER IN HOUSEHOLD					
Two or Less	2	1	8	15	6
Three to Five	12	34	38	40	47
Six or More	64	65	54	45	47

Table 3. Land ownership of tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
NUMBER OF PIECES OF LAND					
1-3 Parcels	100	18	0	93	94
3-9 Parcels	0	63	0	7	4
9 or More	0	19	100	0	2
LAND OWNED					
None	2	5	0	2	19
Some or All	98	95	100	98	81
LAND RENTED					
None	98	43	98	89	56
Some	2	69	2	11	44
LAND RENTED TO OTHERS					
None	93	92	100	95	85
Some	7	8	0	5	5
COMPARED TO OTHERS, HOW MUCH LAND DO YOU HAVE?					
More	42	10	43	33	26
About Same	34	15	43	51	42
Less	24	75	14	16	32

Table 4. Enterprises on tilapia farms of five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
WHAT ANIMALS RAISED?					
Cattle	84	83	62	32	15
Goats	51	78	5	32	0
Pigs	7	41	45	43	31
Chickens	77	23	69	80	51
Ducks	16	14	19	32	36
Rabbits	26	11	5	0	0
Sheep	28	--	--	--	--
Other	14	19	12	50	8
RAISE ANIMALS WITH FISH?					
No	90	100	72	60	31
Yes	10	0	28	40	69
WHAT GIVES MOST CASH?					
Vegetables	33	0	49		9
Rice	2	0	2	36	36
Bananas	16	19	2	56	31
Fruit Crops	9	0	2	13	53
Fish	7	0	30	27	93
Sugar Cane	2	0	4	86	0
Livestock	19	0	34	4	62
Corn/Maize	21	10	15	25	0
Other	63	36	49	9	0
Sorghum	0	29	0	9	0
Cabbage	0	10	0	0	0
Sweet Potatoes	0	83	0	0	0
Beans	0	10	0	0	0
Taro	0	16	0	0	0
Cassava	0	63	0	0	0
Irish Potatoes	0	12	0	0	0
Sweet Peas	0	9	0	0	0

reported having chickens and one-half said they had goats. Chickens were the most commonly reported animal enterprise, except in Rwanda. In Rwanda, 83% said they had cattle, nearly as many had goats, and about 41% had pigs. Cattle were nearly as popular in Honduras, followed by pigs. In the Philippines, the second most common animal enterprise was "other," reflecting the widespread husbandry of water buffalo. About a third reported owning cattle, goats, pigs, and ducks.

No single animal enterprise dominated the farming system in the Thailand sample. Approximately one-third of the farmers had ducks and pigs. The Thai farmers also were more likely to integrate animal production with aquaculture, as more than two-thirds of the Thai farmers sampled reported integrating tilapia culture with some type of animal enterprise. At present, integrated fish-animal production systems are only in the demonstration phase in Rwanda and are not widely adopted in the Philippines.

Fish was the main source of cash income for about 90% of the Philippine and Thai farmers. Coffee and maize are important sources of cash for Kenyan farmers. Sweet potatoes, followed by cassava, were identified as providing the most cash income by more than 80% of the Rwandan farmers. In Honduras, vegetables and other crops (mainly coffee) provided the most farm income.

Pond Location and Water Source

More than 80% of the Rwandan farmers had a single pond, as shown in Table 5. In contrast, more than half the Kenyan farmers and 70% of the Philippine and Honduran farmers had more than one pond. About three-quarters of the Honduran farmers had less than a quarter hectare of ponds; one-half the Thai farmers had ponds a quarter hectare in size, but only one-third of the Philippine farmers did. Nearly all Kenyan ponds were small, i.e., less than a quarter hectare in size.

Most Kenyans obtained water for their ponds from streams or springs. Honduran farmers supplied their ponds from a variety of sources, most frequently identifying lakes or reservoir sources. Thai farmers depended most on irrigation canals, while Philippine farms indicated the least dependence on any single source. Nearly all Kenyan and Rwandan ponds used gravity flow, but most Thai farmers had pumps.

More than half the Thai farmers, one-third of the Philippine farmers, and one-quarter of the Rwandan farmers reported problems getting enough water to keep ponds full.

The location of the fish pond relative to the household is significant. Ponds near households are easier to monitor.

Table 5. Pond location and water source for tilapia farms in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
NUMBER OF PONDS OWNED					
One	45	84	16	9	39
Two	33	11	12	20	26
Three or More	22	5	72	71	35
AREA OF PONDS					
< .25 Hectare	96	--	76	48	34
0.25 to 1 Hectare	2	--	20	48	58
> 1 Hectare	2	--	4	4	8
PROBLEMS WITH WATER SUPPLY					
No	89	76	82	66	45
Yes	2	24	18	34	55
WHERE ARE PONDS?					
Next to House	12	--	66	36	79
< 1 km	83	--	12	35	6
1 to 3 km	5	--	2	22	9
More than 3 km	0	--	20	7	6
WATER SOURCE					
Well	5	--	2	9	0
Spring	40	--	8	7	0
River or Stream	43	--	18	14	2
Lake or Reservoir	0	--	48	0	2
Irrigation Canal	2	--	14	13	64
Collected Runoff	5	--	0	16	0
Combination	5	--	10	41	32
WATER SUPPLY TO POND					
Pumped	0	0	16	42	96
Gravity Flow	98	100	82	38	2
Combination	2	0	2	20	2

Family members can attend to the pond as well as give regular surveillance to deter theft. About 79% of the Thai fish ponds were located next to the house, as were two-thirds of the Honduran ponds and one-third of the Philippine ponds. Only 5% of the Kenya ponds were more than a kilometer from the house, but only 12% were next to the house.

In Rwanda, fish ponds are always located in the marshy valley bottoms (marais). These lands are communally owned and individual farmers are given relatively secure use concessions, but no houses are permitted. Consequently, ponds usually are some distance from homesteads built on the hillsides of this mountainous nation. In some areas, group or family members take turns guarding harvestable fish at night. Some farmers hire watchmen to protect the ponds and other crops. In general, ponds that were not under regular household surveillance were most vulnerable to theft.

Fish Feeding

Farmers in the five countries fed their tilapia a variety of items, reflecting differences in the intensity of aquaculture practiced in each nation (Table 6). Feeding and fertilization often represent overlapping activities for the subsistence-level tilapia farmer. In Rwanda, respondents primarily understood questions about feeding in terms of the amount and kind of organic materials they put in their ponds. At the other sites, farmers primarily understood feeding as the use of commercial, purchased feeds.

Kitchen waste and vegetation were the most commonly used items in Kenya, but leaves and manure were most frequent in Rwanda. Chicken litter and commercial feed were most often mentioned in Honduras. In Thailand, farmers most often utilized rice bran, commercial feed, and chicken litter. A similar pattern to Thailand was noted in the Philippines, although rice bran was used more often.

Commercial feed was not used in Rwanda, and three-quarters of the Kenyan farmers and two-thirds of the Honduran and Philippine farmers did not use commercial feeds. Thai farmers were most dependent on commercial inputs to raise their tilapia crops. They also used the most diverse variety of purchased feeds, reflecting the high level of availability of different feed types and a greater willingness to use feeds for other animals for the fish as well.

Honduran and Rwandan farmers were most likely to report inadequacies in feed availability on their farms. About 7% of the Rwandan farmers said that they never had enough inputs for their ponds.

Table 6. Feeding practices used by tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
THINGS MOST OFTEN FED					
Termites	0	6	0	0	0
Bees Wax/Larvae	0	2	0	0	0
Leaves	0	87	0	0	0
Manure	0	67	0	0	0
Beer Waste	0	32	0	0	0
Kitchen Waste	72	0	14	2	12
Fresh Vegetation	74	0	16	6	34
Rice Bran	12	0	14	61	34
Dead Animals	0	0	0	0	8
Slaughter Waste	12	15	4	0	2
Purchased Feed	16	0	41	32	42
Chicken Litter	7	0	0	37	45
Other	14	8	57	0	2
Grass Cuttings	0	28	0	0	0
Compost	0	28	0	0	0
Inorganic N	0	0	8	48	61
Chicken Feed	0	0	0	2	0
Fish Feed	0	0	0	0	0
USE OF COMMERCIAL FEED					
Only	2	--	21	10	7
Mainly	0	--	10	24	20
Both Equally	5	--	6	2	0
Use No Feed	78	100*	63	64	73
TYPE OF FEED PURCHASED					
None Purchased	72	100*	43	25	0
Rice Bran	8	0	14	35	36
Rabbit Pellets	0	0	8	0	0
Chicken Feed	7	0	2	3	2
Fish Feed	5	0	21	33	28
Other	2	0	12	0	34

*Imputed data

Fertilization

Table 7 shows the use of lime and fertilizer in the five samples. Farmers apply lime to their ponds to increase the alkalinity (and pH) of the pond and foster primary productivity. At the time of this survey, Kenyan farmers had not limed their ponds in the past year, nor had 95% of the Philippine farmers. Three-quarters of the Thai farmers used lime, as did almost half of the Honduran farmers.

In Rwanda, commercial fertilizer represents a cash outlay that subsistence farmers prefer to avoid and is generally not applied to fish ponds. Because commercial fertilizer is not used or recommended for fish ponds, questions about liming and fertilization were not asked in Rwanda.

Honduran farmers typically use cattle and chicken manure as fertilizer for their ponds. Chicken manure is the most frequent pond fertilizer in Thailand and the Philippines. Given the pervasive use of integrated systems in Thailand, ponds are most frequently fertilized with poultry manure in that country.

About 73% of the Thai farmers fed their fish several times a day. The multiple daily feedings that are required with integrated poultry and duck production literally spill over into the tilapia crop. Poultry houses are typically located directly over the fish pond, so feed and litter are nearly continuously deposited into the pond.

Honduran farmers reported a high level of attentiveness to their ponds. About one-quarter of the Rwandans fed their fish several times a week or less. Feeding in the Rwanda case refers primarily to the provision of manure and other inputs, some of which are directly consumed. These items mainly serve as nutrients to foster primary productivity in the ponds.

About 85% of the Kenyan farmers said they visited their ponds once or more daily. Rwandan farmers indicated the least attentive approach to fish farming, as only one-half said the ponds were visited every day. Philippine farmers spent the most time at their ponds when they visited them, while Thai farmers spent the least amount of time.

Fingerlings

Rwandan farmers were dependent on government hatcheries for fingerlings. No commercial fingerling production has developed yet in Rwanda or Kenya, although fingerling sales

Table 7. Fertilization practices of tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
POND FERTILIZER USED *					
Urea	2	--	0	14	0
0-46-0	0	--	0	0	9
18-46-0 (DAP)	5	--	10	2	0
Other N-P-K	--	--	24	79	49
Chicken Manure	9	--	29	70	53
Cattle Manure	81	--	37	4	6
Compost	0	--	0	2	25
HOW OFTEN FERTILIZE?					
Several Weekly	2	--	27	0	69
Weekly	8	--	18	11	10
Several Monthly	8	--	14	19	2
Monthly	28	--	10	21	0
Less Often	43	--	21	43	4
Never	13	--	10	6	15
LIMED PONDS LAST YEAR?					
No	100	--	57	95	26
Yes	0	--	43	5	74
HOW OFTEN VISIT PONDS?					
Several Daily	22	0	39	34	73
Every Day	65	53	37	36	19
Almost Daily	7	2	14	25	0
Several Weekly	2	32	2	5	6
Once a Week	2	13	6	0	0
Several Monthly	2	0	2	0	2
TIME USUALLY SPENT					
Less than an Hour	85	34	18	4	79
About an Hour	12	48	30	5	11
Two or Three Hours	0	14	20	16	4
More than Three Hours	2	5	32	75	6

*Multiple responses possible

are reported between neighboring farmers. Mixed-sex fingerlings from local ponds constitute a primary source of most fish crops in Rwanda and Kenya. Table 8 profiles the fingerling sources used by fish farmers in the other countries. Few private farm dealers exist in Honduras. The private sector provided fingerlings to more than 80% of the Thai farmers and about 37% of the Philippine operators. In each country, most farmers were using Nile tilapia (*Oreochromis niloticus*).

Thai and Philippine farmers tend to densely stock the smallest fingerlings available. Honduran farmers tended to stock somewhat larger fingerlings. All-male tilapia were stocked in each country, although mixed-sex production was the normal mode of production in Rwanda and Kenya. Even though farmers would seek all-male fingerlings, they often received mixed sexes.

Chemically induced sex reversal was the most commonly employed method of producing all-male tilapia fingerlings by government stations and large-scale commercial operators at all the sites. It is notable that 84% of the Thai farmers did not know the method by which all-male tilapia fingerlings were produced.

Stocking and Grow-Out Practices

Table 9 suggests that nearly all farmers grew a single crop of tilapia each year. Most Kenyan farmers grew one or two crops. In Honduras, almost one-half reported two or more crops, and in the Philippines two-thirds obtained two crops per year. Although most of these questions were not asked in Rwanda, cooler water may slow fish growth and lengthen the crop cycle to eight months or more, thus decreasing the potential number of crops per year. Warmer water, the stocking of larger fingerlings, or the harvest of a smaller fish may have accounted for why more than a quarter of the Honduran farmers reported growing tilapia in less than 180 days.

Nearly all the Thai farmers in the study practiced polyculture, raising other species of fish in the same pond. One-third of the Kenyan and Honduran farmers reported stocking other species, but only 11% of the Philippine farmers did so. Although the question was not asked, polyculture is generally not practiced in Rwanda. In Honduras and Thailand, the additional stocked species tended to be a predator fish such as Guapote tigre or snakehead, respectively.

Philippine farmers were least likely to stock a predator fish. Although not reflected in the survey data, the practice of stocking a predator fish was not yet used in Rwanda. The presence of a predator eliminates small fish and reduces the impact of unwanted tilapia reproduction. The predator species generally is not viewed as another crop or enterprise, given the relatively small number that are stocked. Small tilapia are undesirable because they compete for feed with the market-

Table 8. Fingerling sources for tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
WHERE OBTAIN FINGERLINGS?					
Government Hatchery	29	--	57	40	4
Research Station	0	--	18	0	0
Hatchery Station	0	--	6	0	0
Private Dealer	7	--	2	37	82
Neighbor	21	--	2	7	9
Own Ponds	33	--	16	9	9
Other	10				
TYPE OF FINGERLINGS USED					
Natural-Colored	--	--	63	7	100
Red-Colored	--	--	6	0	0
Other (Black & Red)	--	--	31	93	0
TILAPIA SPECIES USED					
Oreochromis niloticus	--	--	100	96	100
O. mossambicus	--	--	0	0	0
O. aureus	--	--	0	2	0
Hybrids	--	--	0	2	0
KIND STOCKED					
Mixed-Sex	90	100	4	0	0
All-Male	0	0	88	93	100
Both	5	0	8	7	0
Both (Separate Ponds)	5	--	--	--	--
ALL-MALE FINGERLING METHOD					
Hybridization	0	--	2	11	2
Sex Reversal	0	--	76	78	10
Hand-Sexing	0	--	20	11	2
Combination	0	--	2	0	2
Don't Know	100	--	0	0	84

Table 9. Stocking and grow-out practices used by tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
CROPS PER POND					
One	64	--	54	25	95
Two	28	--	40	66	5
Three or More	5	--	6	9	0
None Recently	3	--	--	--	--
CROP CYCLE LENGTH					
< 180 Days	55	--	50	94	10
180 to 240 Days	10	--	14	6	6
More than 240 Days	35	--	36	0	84
OTHER FISH WITH TILAPIA					
No	63	--	64	89	2
Yes	37	--	36	11	98
STOCK PREDATOR SPECIES					
No	68	--	6	71	2
Yes	32	--	94	29	98
PROBLEMS RESTOCKING					
No	--	76	78	70	96
Yes	--	24	22	30	4
USUAL STOCKING DENSITY					
Less than 1 m^{-2}	--	--	13	13	9
1 m^{-2} or More	--	--	87	87	91
SIZE OF FINGERLINGS STOCKED					
Less than 3 cm	25	--	46	70	86
3 to 5 cm	64	--	40	16	14
5 to 10 cm	8	--	12	5	0
More than 10 cm	0	--	2	0	0
Mixed Sizes	3	--	0	9	0

size fish. Fingerling availability was a problem for 30% of the respondents in the Philippines, 24% in Rwanda, 22% in Honduras, and only 4% in Thailand.

Water Management

Table 10 shows how fish farmers use and move water. To maintain the quality of water in farm ponds, farmers often add additional water or use an aerator to provide additional oxygen to the fish. The most immediate symptoms that cause farmers to intervene are piping fish (fish that surface to draw oxygen rich water into their mouths) and, in extreme cases, dead fish. Some ponds with large populations of intensively managed large fish also may require additional water to dilute excessive amounts of fish waste.

Water exchange was the most frequently used strategy to maintain water quality by all the Thai farmers, more than half the Philippine farmers, and approximately one-quarter of the Honduran farmers. Approximately 80% of the Honduran farmers said they never exchanged water, suggesting that they understood the procedure but were rarely required to use it (or did not have enough water to do it). About 37% of the Philippine respondents said they never exchanged water.

Farmers were asked to report the presence or absence of various types of equipment on their farms. Kenyan farmers were most likely to have a wheelbarrow. Honduran farmers were most likely to have a vehicle. Philippine farmers were most likely to have a net, and more Thai farmers had a water quality test kit and a scale.

Harvest Practices

All Philippine farmers relied on their own or family labor to harvest their fish and did not hire any (Table 11). Most labor for harvesting fish was usually supplied by family members in Kenya. Honduran farmers were most likely to pay laborers for harvest of their ponds. Approximately 15% of the Kenyan farmers reported labor problems in the harvest process.

Some farmers partially harvested to sell only larger fish, fill an order, provide a certain amount of cash, harvest only a quantity of fish that could be marketed with certainty, or avoid

Table 10. Water management strategies used by tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
AERATE OR EXCHANGE					
Exchange Water	--	--	24	59	100
Use an Aerator	--	--	0	0	0
Use Both	--	--	0	0	0
Use Neither	100	--	76	41	0
HOW OFTEN EXCHANGE WATER?					
Never Exchange	100	--	80	38	2
Every Day	--	--	8	7	2
Almost Daily	--	--	2	2	2
Several Times a Week	--	--	4	2	4
Once a Week	--	--	2	4	16
As Needed	--	--	4	47	74
WHAT EQUIPMENT ON FARM?					
Truck	0	--	71	16	
Harvest Net	23	--	71	84	38
Water Test Kit	0	--	4	0	6
Water Pump	7	--	18	75	98
Aerator	5	--	2	2	0
Oxygen Meter	0	--	2	2	0
Scale	12	--	90	26	100
Wheelbarrow	80	--	0	0	22

Table 11. Harvest practices used by tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
HIRE HARVEST LABOR?					
No, Self	56	-	6	9	0
No, Family	13	-	29	91	8
Yes, Laborers	10	-	65	0	28
Buyer Harvested	3	-	0	0	64
HAD HARVEST PROBLEMS ?					
No Labor Used	56	--	26	66	9
No Problems	28	--	66	28	89
Yes, Difficulty	15	--	8	6	2
USUALLY PARTIAL HARVEST?					
Usually Partial	78	36	37	69	6
Partial and Large	3	0	22	21	17
A Single Harvest	19	64	41	10	77
MEAN SIZE HARVESTED					
Less than 120 g	12	--	4	13	6
120 to 249 g	27	--	18	49	26
250 to 499 g	58	--	35	27	33
500 to 749 g	0	--	29	11	27
Greater than 750 g	3	--	14	0	8

Table 12. Marketing practices of tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
ANY CASH LAST HARVEST?					
No	54	60	13	2	0
Yes	46	40	87	98	100
HOW MUCH SOLD?					
None for Cash	55	7	6	4	0
Less than Half	8	33	92	20	0
Half for Cash	8	12	2	76	4
More than Half	28	48	0	0	96
DID MIDDLEMAN BUY?					
No	97	98	51	21	0
Yes, Some of it	0	2	47	23	31
Yes, All of it	3	0	2	56	69
SELL ANY TO RESTAURANTS?					
No	97	98	71	92	98
Yes, Some of it	3	2	29	8	2
Yes, All of it	0	0	0	0	0
SOLD ANY IN THE MARKET?					
No	92	86	92	70	93
Yes, Some of it	5	13	8	19	5
Yes, All of it	3	1	0	11	2
ANYONE ELSE?					
No	95	58	18	26	41
Pond Bank Sales	5	42	82	74	59

cash outlays for the labor that might otherwise be required for a complete harvest. Partial harvesting was most common in Kenya and the Philippines. Farmers in Thailand and Rwanda tended to do a single large harvest, while Honduran farmers used a combination of harvest practices.

Thai farmers tended to harvest all the fish at one time and were most likely to have the buyer's labor crew harvest the fish. Buyers harvest the fish they purchase from farmers as part of the marketing transaction. In Honduras and Thailand, harvest labor was typically accomplished by paid workers engaged either by the farmer or the buyer. Family labor did the work in about one-quarter of the Honduran situations.

In Rwanda, approximately one-half of the ponds are group ponds. Previous work (Molnar et al., 1994) shows that members of the group or their family members supply the labor at harvest time. Some private farmers hire laborers or organize neighbors to work for a share of the harvest when it is time to drain the pond. About two-thirds of the Rwandans reported one large harvest, for which cooperative labor arrangements usually are made. Kenyan farmers tended to have smaller ponds and single harvests.

In Rwanda, we estimated that about 80% of the farmers harvest an average fish less than 120 g. Lack of feeds, cool waters due to high elevations in most locales, but primarily lack of nutrient inputs all tend to lengthen the time necessary to grow larger fish.

Farmers tended to harvest larger fish in Honduras, as more than two-thirds reported harvesting fish larger than 200 g. The Philippine operators had a similar harvest size preference, though a few more harvest smaller fish. In Thailand, however, more than half the sample harvested fish less than 200 g in size. Most of the fish harvested in Kenya were between 250 and 499 g.

Marketing

Only a small proportion of each sample reported fish harvested solely for home consumption or barter, i.e., not sold for cash (Table 12). Most sold some of their fish for cash, though one-third of the Rwandans said that they sold less than half the harvest for cash. Only 46% of the Kenyan and 40% of the Rwanda respondents sold fish for cash. Previous research suggests that much of the fish in Rwanda was used for home consumption or bartered for harvest labor. In Honduras, 87% said they sold more than half of their fish for cash. Nearly 100% did so in both the Philippines and Thailand.

Middlemen purchased fish from all the Philippine farmers, three-fourths of the Thailand farmers, almost half the Hondurans, but nearly none of the Rwandans. Farmers that sold tilapia to restaurants were more common in Honduras. Direct marketing was more common in the Philippines, where 30% reported selling fish in the market. The most common marketing method for farmers in all countries was pond bank sales to neighbors and others who came to the ponds at harvest. The surrounding populace's word-of-mouth

Table 13. Marketing problems experienced by tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
TROUBLE SELLING TILAPIA					
No	92	79	82	100	69
Yes	8	21	18	0	31
PROBLEMS WITH PRICE					
No	88	77	90	100	44
Yes	12	23	10	0	56
CAN SELL AT LOWER PRICE					
No	64	27	36	76	50
Yes	36	13	64	24	50
SOME DON'T LIKE TILAPIA					
No	80	66	84	100	85
Yes	20	34	16	0	15
LARGER EASIER TO SELL					
No	10	28	58	15	4
Yes	90	72	42	85	96
SOLD FINGERLINGS					
No	56	49	84	74	94
Yes	44	51	16	26	6
TROUBLE SELLING FINGERLINGS					
No, Did Not Sell	50	42	84	70	94
No Problems	44	31	16	30	4
Yes, Problems	6	27	0	0	2

knowledge about prospective harvests or understanding of the farmer's willingness to partial harvest for immediate sale remained the primary means for marketing tilapia for most small- and medium-scale farmers.

Marketing Problems

Table 13 shows that Kenyan farmers had few problems marketing the fish they produced. Philippine farmers indicated the least trouble marketing their fish. Marketing difficulties of some kind were reported by about one-third of the Thai respondents and 20% of the Honduran and Rwandan respondents. Over one-half of the Thai farmers reported difficulties securing the price they wanted for their tilapia. Honduran farmers were the most confident about being able to sell their tilapia at some price, even if it was not what they originally offered.

About 20% of the Kenya sample and one-third of the Rwanda sample said that many people in their area did not like tilapia. Around 15% of the Honduran and Thai respondents felt this way, but no Philippine respondent said this. Of the five countries, the Philippines seemed to have the highest consumer acceptance of tilapia. With the exception of Honduras, most respondents felt that larger fish are easier to sell. This was particularly true in Thailand and Kenya.

Fingerling sales to other farmers were most common in Kenya and Rwanda, where more than one-half the respondents reported such transactions. Private fingerling sales among farmers is an important indicator of sustainability, especially where government services are unreliable or unavailable in much of the country.

Fingerling sales between farmers were least common in Thailand (6%), largely because a network of private dealers is well developed there. Dealers are less common in Honduras, but a small segment reported fingerling sales (16%), as did a few more in the Philippines (26%). Rwandan farmers and, to a lesser extent, Kenyan farmers apparently were most actively seeking to sell fingerlings—largely because the mixed-sex production strategy that they employed yields many small fish. About one-half sold fingerlings, but about one-half of the fingerling sellers reported problems in making the sales they wanted. Few of the respondents in other countries reported problems selling fingerlings.

Impacts on Households

Table 14 shows a series of questions profiling the impacts of fish culture on households. About 78% of the Philippine farmers thought that there were points in the annual farm cycle when the pond was too much work. This figure was 37% in Thailand, and only 7% in Kenya. Previous work suggests that Rwandan women are much more likely to report these difficulties (Molnar et al., 1994).

Table 14. Pond impacts on households of tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
POND IS SOMETIMES TOO MUCH WORK					
No	93	--	78	22	63
Yes	7	--	22	78	37
TILAPIA FITS WELL WITH OTHER ACTIVITIES OF HOUSEHOLD					
No	10	17	36	9	21
Yes	90	83	64	91	79
POND MAKES IT HARDER TO CARE FOR OTHER CROPS					
No	93	94	92	100	94
Yes	7	6	8	0	6
POND MAKES IT HARDER TO TAKE CARE OF FAMILY					
No	100	95	94	100	91
Yes	0	5	6	0	9
POND MAKES OTHER HOUSEHOLD WORK HARDER					
No	98	94	90	98	92
Yes	2	6	10	2	8
TILAPIA CASH EASIER TO BUY THINGS FOR FAMILY					
No	70	95	27	14	8
Yes	30	5	73	86	92

About 90% of the Kenya and Philippine respondents felt that tilapia fit well with other farm activities, but only 64% of the Honduran and 79% of Thai farmers thought so. The latter respondents were slightly more likely to report problems completing household work or taking care of their family. Few respondents noted problems associated with the tilapia enterprise in taking care of other crops, taking care of the family, or completing other household work.

Kenyan and Rwandan farmers were much less likely to indicate that tilapia cash made it easier to buy things for their families, given the relatively small amount of cash produced by tilapia in each locale. In Kenya, only 30% felt this way, and 5% of the Rwandans agreed with this statement. In contrast, three-quarters or more of the respondents in the Philippines, Honduras, and Thailand noted the benefits of additional cash for their households as something associated with the tilapia crop.

Pond Conflicts

Table 15 shows respondents' experiences with a series of problems sometimes encountered by tilapia farmers. Thai farmers were most likely to note problems over water resources emanating from the tilapia crop (57%), an issue noted by only a few of the other respondents. Philippine operators had few problems with predators eating their fish, but this was an issue for farmers in each of the other countries.

Theft was a concern for 44% of the Honduran farmers and 29% of the Kenyan farmers. In contrast, only 20% or so of the Rwandan and Thai respondents noted this as an issue, and only 11% did so in the Philippines. Thai farmers were most likely to agree that tilapia were easier to steal, though one-third of the Honduras respondents thought so as well.

Prospects for the Pond

Kenyan farmers were least likely to think that their fish pond produced enough to be worth the work they put into it. In comparison, twice as many Rwandans thought it was (Table 16). Nearly 90% thought that the tilapia pond was the best use of the land it occupied, though the Thai sample was somewhat less positive.

Most respondents thought tilapia culture was the best use of the land it occupied. Nearly all the Philippine respondents were planning more ponds, as were 74% of the Kenyans. In contrast, only 39% of the Honduran respondents and 29% of the Thai respondents were contemplating expansion. Only 11% of the Rwandan farmers expected to add ponds to their farming system.

Only 54% of the Rwandan farmers and 72% of the Kenyan farmers were happy with tilapia as a type of fish to grow; they desired a larger, faster-growing fish. Nonetheless, more than 90% of respondents in the other nations were happy with tilapia as a type of fish to grow.

Only 3% of the Kenyan farmers felt that tilapia was more profitable than other crops, and 85% thought it was less

Table 15. Pond conflicts experienced by tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya **N = 43** (%)	**Rwanda** **N = 136** (%)	**Honduras** **N = 51** (%)	**Philippines** **N = 50** (%)	**Thailand** **N = 56** (%)
CONFLICTS OVER WATER					
No	88	--	94	100	43
Yes	12	--	6	0	57
BIRDS OR OTHER ANIMALS EATING TILAPIA FROM PONDS					
No	40	31	24	95	4
Yes	60	69	76	5	96
PEOPLE STEALING TILAPIA					
No	71	78	56	89	81
Yes	29	22	44	11	19
TILAPIA ARE EASIER TO STEAL					
No	88	97	62	80	55
Yes	12	3	38	20	45

Table 16. Prospects for the fish pond according to tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya **N = 43** (%)	**Rwanda** **N = 136** (%)	**Honduras** **N = 51** (%)	**Philippines** **N = 50** (%)	**Thailand** **N = 56** (%)
TILAPIA PRODUCE ENOUGH TO BE WORTH THE WORK					
No	65	28	8	7	10
Yes	35	72	92	93	90
TILAPIA POND BEST USE OF LAND IT USES ON THE FARM					
No	12	11	12	0	24
Yes	88	89	88	100	76
PLANNING MORE PONDS					
No	26	89	61	2	71
Yes	74	11	39	98	29
GENERALLY HAPPY WITH TILAPIA AS A FISH TO RAISE					
No	28	46	6	2	6
Yes	72	54	94	98	94
TILAPIA COMPARED TO OTHER ACTIVITIES					
More Profitable	3	--	23	90	78
About the Same	1	--	17	8	8
Less Profitable	85	--	60	2	14

profitable. The perceived profitability of tilapia relative to other farm activities was highest in the Philippines, where 90% thought it was more profitable than other crops. About 78% thought so in Thailand. In Honduras, 23% thought it was more profitable. About 60% of the Honduran respondents thought that tilapia was less profitable than their other activities.

Overall, Kenyan and Honduran farmers were least happy with the returns from tilapia, although Thai farmers were less convinced that tilapia ponds were the best use of the land. Thai farmers with irrigation in the Bangkok marketing area have many enterprise choices and marketing opportunities.

Technical Assistance

In Kenya, 95% of respondents said they had seen an extensionist in the past year. About 88% had done so in the past month (Table 17). Kenya has an extensive extension system for fisheries and aquaculture, but currently lacks resources for staff training and educational materials.

Aquacultural extension services were making frequent contacts with farmers in Rwanda prior to the civil war. At the time of the study, a well-trained cadre of extension personnel was supported by donor funds. Most farmers received regular visits if they wanted them. The Rwandan respondents also were somewhat more likely to report some type of extension contact in the past.

A highly professional, relatively well-organized extension and research system is in place in Thailand. Nonetheless, about one-third of the Thai respondents indicated that they had never had contact with an extension representative.

The Philippines has no national extension program. Budget problems limited on-farm extension work to a small number of extensionists supported solely by provincial-level governments.

In Honduras, high inflation has degraded salaries, travel budgets, and morale for extension personnel. These conditions, coupled with high levels of personnel turnover, contributed to the low impact of extension in that country. In Honduras, one-third of the respondents indicated that they had had no contact

Table 17. Technical assistance sources used by tilapia farmers in five PD/A CRSP countries, 1992-98.

	Kenya N = 43 (%)	Rwanda N = 136 (%)	Honduras N = 51 (%)	Philippines N = 50 (%)	Thailand N = 56 (%)
LAST EXTENSION CONTACT					
Never Contacted	0	6	35	22	35
In Past Month	88	75	26	46	50
Months to Year	7	6	10	14	4
Over a Year	5	13	29	18	11
LAST STATION CONTACT					
Never Contacted	--	--	4	25	62
In Past Month	--	--	38	43	17
Months to Year	--	--	22	14	6
Over Year	--	--	36	18	15
PEACE CORPS CONTACT					
No	88	--	16	100	100
Yes	12	--	84	0	0
UNIVERSITY CONTACT					
No	--	--	80		
Yes	--	--	20	28	75
				72	25
WANT EXTENSION HELP					
No	0	90	0	2	17
Yes	100	10	100	98	83
MAIN OBSTACLES TO LARGER HARVESTS					
The Species	0	45	11	0	0
No Inputs	0	59	9	0	0
Water too Cold	0	9	2	0	0
Understanding	0	2	36	0	0
Water Quality	2	0	0	95	40
Pond Leaks	10	0	5	0	0
Kind of Inputs	0	0	23	0	0
No Extension	0	0	5	0	0
Other	0	2	9	5	60

with extension. More contacts were noted with Honduran fish stations that supply fingerlings and some technical assistance to farmers.

In Honduras, Peace Corps has been very active in fish culture, as has the staff of Zamorano University and several other institutions. Kenya and Honduras were the only countries where Peace Corps contacts were reported.

About one-third of the Honduran and Thai farmers had no extension contact. Most Kenyan, Thai, and Philippine farmers wanted extension help in the future, but farmers in Rwanda and Honduras were not certain.

Farmers were asked about the main factors preventing larger harvests. Water quality was the biggest issue in Kenya, Thailand, and the Philippines. The matter was referred to simply as "the pond" in Rwanda. Manure and compost availability was the obstacle most frequently cited in Rwanda. Honduran farmers noted "my understanding" as the major obstacle to obtaining larger harvests from their ponds.

CONCLUSIONS

This report has provided a socioeconomic profile of tilapia culture in five PD/A CRSP countries. One of the signal contributions of this study is the cross-national comparative data obtained from fish farmers across the globe. A common interview guide and data matrix provide a framework for contrasting and understanding the practice of tilapia culture. Similarities in technology and approach to aquaculture also can be counterpoised to the great differences in market receptivity, price, and dietary role of tilapia in each country. In particular, the data reported here complement experimental and biological information about how tilapia are grown and used. The findings show how farmers feed their fish, who they sell them to, and what kinds of problems they are experiencing.

Results of this study suggest that tilapia mean different things to different segments of the rural population. Clearly the wealth or income level of the grower enters into the amount of capital investment and risk to be undertaken, but off-farm employment and life cycle considerations also play a role in determining the production strategies employed and the kinds of benefits individuals seek from the fish culture enterprise.

Tilapia growers in each of the countries face vastly different institutional systems supporting tilapia production (Veverica and Molnar, 1996). The impacts of the PD/A CRSP are muffled by the inherent characteristics of the research process, the nature of institutional functioning in developing countries, and the dynamism of the information environment for aquacultural technologies.

ANTICIPATED BENEFITS

The communication process linking experimental pond to farm practice involves several layers of translation and transmission (Cernea, 1991). Many factors interact to affect the nature and extent of impact PD/A CRSP scientists and research programs have on national aquacultural institutions and farm practice (Huisman, 1990). Experimental findings are at base experimental; that is, they reflect controlled conditions and careful measurement of a focused set of factors. Farm conditions reflect variable physical and management situations that often mitigate the impact of effects identified by repeated experimental trials. The data presented here provide empirical specification of the needs and preferences of the actual intended beneficiaries of the PD/A CRSP. As such, they provide a baseline or template for interpreting the cumulative impact of PD/A CRSP activities and a starting point for identifying new directions and emphases that will help realize the promise of aquaculture for farmers and their families in developing countries.

ACKNOWLEDGMENTS

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THE INFLUENCE OF FISH CULTURE TECHNOLOGY, EXTENSION METHODOLOGY, AND SOCIOECONOMICS ON SUCCESS OF FISH CULTURE ON LIMITED-RESOURCE FARMS

Eighth Work Plan, Adoption/Diffusion Research 2 (ADR2)
Progress Report

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ABSTRACT

The governments of Panama and Guatemala installed family and community fish pond projects to improve household nutrition and economic well-being in the 1980s. Financial assistance to both countries to support the construction and installation of fish ponds was provided by USAID. This research team made a rapid evaluation of 39 family fish ponds and 21 community fish ponds in Guatemala and Panama, respectively, during June 1998. The rapid evaluation of fish pond sites was followed at a later date by interviews with active and non-active project participants to learn the reasons for sustainability or abandonment of fish ponds. Of the 39 family fish ponds visited in Guatemala, 14 were abandoned, 20 were poorly cared for and were considered underutilized, and 5 were well cared for. In Panama, 6 community pond projects were abandoned and 15 were still utilized. Of the projects still utilized, 6 no longer cultured fish and grew only rice in some ponds and 9 continued to culture fish. Only 2 of the 9 projects culturing fish were considered well-managed, while the 7 remaining projects had average or poor fish pond management. Data from 46 household interviews in Guatemala and 114 household interviews in Panama are being entered into a computerized database for further evaluation. A final report will be available by early 1999.

INTRODUCTION

The United States Agency for International Development (USAID) funded projects in Panama and Guatemala during the 1980s that studied the nutritional and economic impacts of fish culture on rural families and communities. Staff members in the Department of Fisheries and Allied Aquacultures at Auburn University provided technical assistance in fish culture to the governments of Panama and Guatemala during this period. Many of the family ponds in Guatemala and all the community fish ponds in Panama were integrated with livestock to increase fish yields. Investigators returned to Panama and Guatemala 14 and 10 years, respectively, after the termination of USAID and Auburn University participation to determine the status of the fish pond projects.

METHODS AND MATERIALS

Thirty-nine randomly selected family fish pond projects in Guatemala and all 21 cooperative fish pond projects in Panama were visited from 8 June to 3 July 1998. Visits to fish pond projects were coordinated by host country collaborators in Guatemala and Panama. Sites were rapidly evaluated by the investigators during visits to determine the status of the fish ponds. Follow-up interviews with fish pond project participants were performed by host country collaborators during July and August 1998. Forty-six household interviews from five provinces were completed in Guatemala and 114 household interviews from 20 communities with fish ponds were completed in Panama. Additionally, profiles on the services and facilities, social/political organization, changes in local economic conditions, and fish culture technology diffusion were collected in 20 Panamanian communities containing fish pond projects. Economic data were collected not only to assess individual incentives for aquaculture but also the effects of "external" factors on incentives. External factors included other crops grown, other livestock operations, non-farm cash opportunities, the seasonality of cash needs and sources, and the motivation to pursue aquaculture. Also, the farming system at each site was documented to determine how aquaculture complemented or competed with the other activities of the system. Unfortunately, no fish harvest data from projects in Guatemala nor Panama were recorded by participants and thus, these data were not available for a cost/benefit analysis. At present, data collected from questionnaires are being entered into a computer database for further analysis.

RESULTS AND DISCUSSION

Preliminary analyses based on rapid site evaluations were made on 21 and 39 projects in Panama and Guatemala, respectively. Fourteen family ponds were without care and water and were considered abandoned in Guatemala. Twenty ponds still contained water and a few fish but were not directly important to household food supply and were considered underutilized. Five ponds were still well-attended, stocked with fish, and considered important to the household. None of the family ponds visited was integrated with livestock. Many ponds poorly utilized to grow fish were more important as water storage reservoirs for crop irrigation and livestock watering during the dry season. Principal reasons for abandonment or underutilization of the fish ponds were fish theft, lack of water during the dry season to fill ponds, lack of fingerlings to stock ponds, and death, ill health, or emigration to the US of the adult male household member.

In Panama, 6 community fish pond projects were abandoned while 15 were still utilized. Of the 15 pond projects still in use, 6 had turned some of their fish ponds into rice paddies and no longer cultured fish. Nine communities still cultured fish in some of their ponds and fertilized their ponds with manures collected from animals raised next to the ponds. Only two of the nine projects still culturing fish were considered well managed and one of these projects was controlled by a church and not community members. Principal reasons for abandonment and underutilization of fish ponds were organizational and financial problems with project groups, lack of water to fill ponds in the dry season, pond leakage and seepage, inability to obtain bank loans to purchase livestock and livestock feeds, and land ownership disputes.

Further insights into the reasons for success or failure of fish pond projects in Panama and Guatemala will be obtained when interview data are processed. A draft of the final report should be ready before mid to late December 1998 and the completed final report by 1 February 1999.

ANTICIPATED BENEFITS

The goal of PD/A CRSP research is to improve animal protein sources in less developed countries. Results of CRSP research must be transferred to farmers in order to attain this goal. What are the elements that insure that new technology will be accepted and sustained by target farmers? What have we learned from past small-pond fish culture projects that will assist CRSP researchers and host country governments to design appropriate research and outreach activities? At present, the CRSP is directing research toward limited-resource farmers interested in feeding their families and selling excess fish for cash. Reevaluation of fish culture projects with limited-resource farmers may demonstrate that research efforts should be targeted at resource-rich farmers who sell their entire crop for cash if fish supplies in developing countries are to be significantly increased.

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TRAINING

Eighth Work Plan, Kenya Research 4 (KR4)
Final Report

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ABSTRACT

Training of farm personnel and university students at Sagana Fish Farm, Sagana, Kenya, was undertaken under the Eighth Work Plan to ensure the success of the overall project in Kenya. Training was planned and carried out in three main areas:

a) Training of station field personnel in fish sampling, fish handling, and fish transport;
b) Training of technicians in the areas of water, soil, and feed sampling, in laboratory glassware cleaning, and in computer operation; and
c) Training of university students in a variety of topics relevant to aquaculture in Africa.

Sagana field crew members received approximately 100 hours of practical instruction in seining techniques, seine maintenance, fry harvest for sex reversal, fish handling, and stratified sampling. Fish survival in between-pond transfers at Sagana has improved markedly as a result of this training, increasing from less than 30% at the beginning of CRSP involvement at Sagana to a current level of 95 to 100%. Laboratory technicians have received training on water quality analyses, proper washing of glassware, lab safety, and equipment maintenance. All water quality analyses and sampling procedures called for in standard CRSP sampling protocols are now carried out routinely by the lab staff.

Four M.S. students and one undergraduate student received stipends during the 1997-98 reporting period. Three of the M.S. students finished their research in April, and all three will file an "intention to submit" form to their university by the end of July 1998. The fourth student will continue his studies under activities planned under the Eighth Work Plan. One student used data obtained during her studies at Sagana to make an easy-to-follow feed schedule for workers at the station and trained two laborers in procedures for the production of all-male tilapia fry. Three more undergraduates have arrived at Sagana for practical training.

Individuals trained under this activity are already contributing to improved daily farm operations at Sagana, as reflected in greatly improved fish survival after transport, and are conducting analyses in the laboratory. University students have had first-hand experience with farm operations, have worked on real-world aquaculture problems as part of their studies, and have increased their understanding of how to plan and conduct aquaculture research. They should be able to apply what they have learned as they finish their university studies and move out into various parts of the aquaculture sector in Kenya. These benefits will continue to accrue as this type of training continues at Sagana under subsequent work plans.

INTRODUCTION

Training of Kenyan personnel and university students at Sagana Fish Farm was planned as part of the Eighth Work Plan because the development of these participants' capacities to successfully carry out routine farm operations and to plan and conduct aquaculture research is critical to the overall success of the Kenya project. Training was planned and carried out in three main areas:

a) Training of station field personnel in fish sampling, fish handling, and fish transport;
b) Training of technicians in the areas of water, soil, and feed sampling, in laboratory glassware cleaning, and in computer operation; and
c) Training of university students in a variety of topics relevant to aquaculture in Africa.

FIELD CREW TRAINING

Approximately 100 hours of practical instruction was provided to the seine crew and their supervisors on seining techniques, seine maintenance, fry harvest for sex reversal, fish handling, and stratified sampling. The crew learned the techniques but often neglected to apply what they had learned when the resident researcher was not present. Consequently, a new crew was trained between April and June 1998. Members of this new crew were selected for their abilities to work without supervision when necessary. Fish survival in between-pond transfers at Sagana has improved markedly as a result of this training. Survival rates were less than 30% before training of the first crew, increased to 50 to 100% after training of the first crew (depending on the presence or absence of the resident researcher), and has now reached 95 to 100% with the second crew, whether or not the resident researcher is present.

LABORATORY TECHNICIAN TRAINING

James Karuri (lab technician) and Thomas Ndegwa (lab assistant), as well as all M.S. students working at Sagana Fish Farm, have received training on water quality analyses, proper washing of glassware, lab safety, and equipment maintenance. All water quality analyses and sampling procedures called for in standard CRSP sampling protocols are now carried out routinely by the lab staff. The lab staff will next learn some analyses of feeds and soils that can be done with equipment currently on hand. Mr. Karuri, the lab technician, and Mr. Maina, the computer operator, can now make standard curves and calculate concentrations.

UNIVERSITY STUDENT TRAINING

Four M.S. students and one undergraduate student received stipends during the 1997-98 reporting period. Three of the M.S. students finished their research in April 1998, but a few analyses are still needed before their theses can be completed. All three students will file an “intention to submit” form to their university by the end of July 1998. The fourth M.S. student (Soil Sciences, University of Nairobi) is awaiting approval of funding for the irrigation/fish production experiment submitted as part of the Ninth Work Plan before beginning his research. He has received instruction in pond soil sampling techniques and has helped in the sampling and analysis of soils for Experiment 3 of the Eighth Work Plan.

Judy Kimamo, undergraduate at Jomo Kenyatta University of Agriculture and Technology (JKUAT), finished a three-month practical training session during which she followed the tilapia sex-reversal process, calculated treatment costs, made growth curves, and recorded survival over the treatment period. She then used her data to make an easy-to-follow feed schedule for workers at the station and trained two laborers in procedures for the production of all-male tilapia fry.

Three more undergraduates have arrived at Sagana for practical training: George Thuku, Moi University, from 11 to 31 May 1998; Winifred Sena Kaki, Moi University, 11 May to 23 June 1998, and Paul Wamwea Wabitah, from Kenyatta University, from 20 May through 31 August 1998. Additional graduate students are scheduled to begin their research after July 1998.

ANTICIPATED BENEFITS

Individuals trained at Sagana are already contributing to improvements in daily farm operations at the farm, including pond-side operations such as seining, fish handling, and sampling, in addition to conducting analyses in the laboratory. These benefits are already being seen at Sagana, for example, in the increased fish survival observed after transport around the farm. University students who work at the farm are gaining first hand experience with farm operations that they might not otherwise have been exposed to, have worked on real-world aquaculture problems as part of their studies, and have increased their understanding of how to plan and conduct aquaculture research. They should be able to apply what they have learned as they finish their university studies and move out into various parts of the aquaculture sector in Kenya. These benefits will continue to accrue as this type of training continues at Sagana under subsequent work plans.

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REGIONAL OUTREACH IN AFRICA

Eighth Work Plan, Kenya Research 5 (KR5)
Progress Report

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ABSTRACT

Regional outreach activities were undertaken under the Eighth Work Plan as a means of disseminating information developed through CRSP research; giving CRSP researchers opportunities to learn about fish culture practices, research priorities, and research activities in other parts of Africa; encouraging efforts to create linkages between research and extension activities in the region; and in general continuing the process of making contacts and regionalizing CRSP efforts in Africa. In an effort to disseminate information to extension personnel, CRSP researchers attended meetings of District Fishery Officers of Central Province and a meeting for Provincial Fisheries Officers (Kenya). During these meetings the PD/A CRSP was described, pond management recommendations were outlined, proposed on-farm trials were discussed, pond census forms were distributed, information was provided on sex-reversed tilapia, and the results of our first experiment at Sagana Fish Farm were presented. Students doing research at Sagana in connection with that experiment also presented short summaries of their research findings. Several regional meetings were attended by CRSP personnel during the reporting period. The first was the 5th Session of the Organization of African Unity's Scientific, Technical, and Research Commission (OAU/STRC) Inter-African Committee and Symposium on Oceanography, Sea and Inland Fisheries, Mombasa, Kenya, 4-8 May 1998, hosted by Fred Pertet, member of the OAU/STRC and Host Country Principal Investigator for the Africa Project. Karen Veverica and Bethuel Omolo also attended this meeting, which provided an excellent opportunity to publicize the CRSP and to present Sagana Fish Farm as an ideal aquaculture training site. Veverica and Omolo also attended the 8th annual East African Environmental Network (EAEN) conference, 29-30 May 1998 in Nairobi, where they presented an invited paper entitled "An overview of aquaculture practices in East Africa: Potential environmental impacts and prospects for sustainable livelihoods." CRSP Africa Project team members from Kenya and the US plan to attend a Fisheries Society of Africa (FISA) meeting scheduled to take place in Grahamstown, South Africa, 13-19 September 1998, and have submitted abstracts for five presentations. In addition, CRSP researchers contacted the conference organizers to inquire about and encourage the inclusion in the conference of a special discussion session on the status, constraints, and priorities of aquaculture in Africa. This has been accepted and Jim Bowman will serve as rapporteur for the session, to be entitled *Aquaculture in Africa—Quo Vadis*. These outreach efforts are helping to inform interested regional parties about the CRSP; to develop a better understanding of regional research needs among CRSP participants and others; and to encourage communication and the formation of linkages among regional organizations and individuals interested in aquaculture. It is anticipated that participation in the upcoming FISA conference will greatly increase the level of benefits realized under this activity.

INTRODUCTION

Regional outreach activities were planned under the Eighth Work Plan as a way to disseminate information derived from CRSP research; to give CRSP researchers opportunities to learn about fish culture practices, research priorities, and research activities in other parts of Africa; to encourage efforts to create linkages between research and extension activities in the region; and in general to continue the process of making contacts and regionalizing CRSP efforts in Africa. Plans for carrying this out included conducting short courses for extension agents in Kenya and actively participating in regional meetings and conferences, including in particular meetings of the Fisheries Society of Africa.

EFFORTS TO FACILITATE EXTENSION AGENT SHORT COURSES

The initial plan was to participate in courses given at the Naivasha Training Center for fisheries officers and to contact the Lake Basin Development Authority (LBDA) to offer short courses for extension agents. However, after submission of the Eighth Work Plan, the Naivasha Training Center was handed over to the Kenya Wildlife Service, and fisheries officers are no longer trained there. Also the LBDA in Kisumu has not pursued aquaculture activities during the last two years, so it could not be used for training. In an effort to disseminate information to extension personnel, meetings of District Fishery Officers of Central Province were attended, and a meeting was held for Provincial Fisheries Officers.

During the first meeting, held 25-26 November 1997, Karen Veverica presented an overview of pond management recommendations and presented the PD/A CRSP to attendees. The proposed on-farm trials were discussed and pond census forms were distributed.

For the second meeting, held 7-8 April 1998, Veverica presented information on sex-reversed tilapia and offered collaborating farmers all-male fingerlings to compare with mixed-sex fingerlings on their farms. Guidelines for record keeping and pond management were handed out. The results of the experiment on rice bran and fertilization (see "Relative contribution of supplemental feed and inorganic fertilizers in semi-intensive tilapia production" in this report) were presented. Each of the students doing research at Sagana (see "Training" in this report) presented a short summary of his or her research findings.

Attendance at Regional Meetings

The Aquaculture for Local Community Development program (ALCOM) has had uncertain funding so other regional meetings were attended. These included:

1. Fifth Session of the OAU/STRC Inter-African Committee and Symposium on Oceanography, Sea and Inland Fisheries, Mombasa, Kenya, 4-8 May 1998. Fred Pertet, member of the Scientific, Technical and Research Commission (STRC) of the Organization of African Unity (and Host Country Principal Investigator for the Africa Project) hosted this session. Representatives from Cameroon, Ghana, Kenya, Mauritania, Nigeria, Senegal, Tunisia, the FAO, and the Southeast Asian Programme in Ocean Law, Policy and Management (SEAPOL) attended.

Karen Veverica and Bethuel Omolo attended the meeting and set up a table with CRSP publications and descriptions of the PD/A CRSP program. This was an excellent opportunity to publicize the CRSP to attendees from several countries and to present Sagana Fish Culture Station as an ideal training site.

2. Karen Veverica and Bethuel Omolo attended the 8th Annual EAEN (East African Environmental Network) Conference, 29-30 May 1998, at the Louis Leakey Memorial Hall, National Museums of Kenya, Nairobi. They presented an invited paper entitled "An overview of aquaculture practices in East Africa: Potential environmental impacts and prospects for sustainable livelihoods." Member countries in the EAEN are Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, and Uganda. The EAEN is a regional non-profit NGO committed to sustainable development in East Africa. Papers are published in a proceedings volume.

Participation in Fisheries Society of Africa (FISA) Meetings

No FISA conferences have been held since the beginning of our collaboration in Kenya, so it has not been possible to carry out this part of the activity before now. However, a FISA meeting is now scheduled to take place in Grahamstown, South Africa, 13 to 19 September 1998. CRSP/Africa team members plan to attend this meeting, and have submitted abstracts for five presentations to be made at that conference, including:

- *A review of lime requirement determination methods for aquaculture ponds*, by J.R. Bowman
- *Use of grasses from pond levees to promote* Oreochromis niloticus *(Cichlidae) production: application rates, methods and resulting water quality*, by K.L. Veverica and E. Rurangwa
- *Semi-intensive* Oreochromis niloticus *(Cichlidae) and* Clarias gariepinus *(Clariidae) polyculture in ponds receiving rice bran and chemical fertiliser in Kenya*, by W.M. Gichuri, K.L. Veverica, J.G. Omondi, P.N. Mwau, P.I. Bilal, and K.N. Mavuti
- *Current status and problems of fisheries in Kenya*, by F. Pertet
- *Present status of the fish fauna and fisheries of Lake Baringo, Kenya*, by F. Pertet

In addition, the CRSP Africa Project team contacted the conference organizers in February to inquire about the possibility of including in the conference a special discussion session on the status, constraints, and priorities of aquaculture in Africa. This has been accepted and Jim Bowman will serve as rapporteur for the session, to be called *Aquaculture in Africa—Quo Vadis*. According to FISA organizers, the purpose of this session will be to look at what has been done in the past to promote aquaculture in Africa; to look at the successes and failures that have occurred; and to discuss how the sub-Saharan region might become an important player in aquaculture in the future.

Anticipated Benefits

The results of these efforts are contributing towards informing interested parties in the region about the CRSP; developing a better understanding of research needs in the region among CRSP participants and others; and encouraging communication and the establishment of linkages among regional organizations and individuals interested in the development of aquaculture in Africa. We anticipate that participation in the upcoming FISA conference in South Africa will greatly increase the level of benefits realized under this activity.

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High-Input Green Water On-Farm Trials in Northeast Thailand

Eighth Work Plan, Thailand Research 4 (TR4)
Final Report

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Abstract

This report presents the results of high-input on-farm trials with farmers in Northeast Thailand. Based on AIT on-station trial results, technical recommendations for high-input green water culture were extended to 12 farmers through the Aquaculture Outreach Program (AOP). Pond size varied greatly among the project farmers, averaging 658 m^2. Measurements of water color indicated turbid water existed in most project farmers' ponds, which were poor in natural feed and unfavorable for fish growth. All the project farmers, upon receiving seed, started nursing fry in hapas in their ponds. The size of hapas varied greatly among farmers, averaging 5 m^3. The average number of fry released into a hapa for nursing was estimated to be 2,333, ranging from 800 to 4,000. The duration of nursing fry in hapas ranged from 30 to 57 days with an average of 41 days. Pig concentrate and rice bran (2:1) were recommended as supplementary feed for fry throughout nursing. On average, farmers fed 130 g of pig feed concentrate and 76 g of fine rice bran per day per 1000 fry. Density of fry during nursing, which was largely affected by the size of hapas, ranged between 93 and 556 m^{-3} with an average of 242 m^{-3}. The survival rate of the fry at the end of nursing in most of the farms was estimated to be 75%, with a range of 44 to 80%). Farmers were advised to stock 2 to 3 fish m^{-2} in ponds; actual stocking density was 3.1 fish m^{-2}. The culture period, recommended at six months, varied from four months for two farmers whose pond water level dropped rapidly after the cessation of the rainy season, to eight to eleven months for most farmers. Farmers were advised to apply fertilizers (urea and TSP) at weekly intervals at the rate of 4 kg N and 1 kg P ha^{-1} d^{-1}, respectively. Only two farmers reported that they applied urea at the recommended rate. Most farmers applied P at a higher rate than recommended. Despite AOP recommendations and support for the monoculture of sex-reversed tilapia for the on-farm trial, a number of farmers mixed other fish species in their pond. Total fish production was found to vary from one pond to another. Extrapolated yield (averaging 944 kg rai^{-1}, with a range of 292 to 1322 kg rai^{-1}) was higher than that expected on the basis of on-station trials (600 kg rai^{-1}). Virtually all project farmers experienced a substantial increase in fish yield, which was associated with a change in water color from turbid to green or dark green after application of urea and TSP. At the end of the trial, virtually all the participant farmers were very satisfied with the significant increase in fish production from their ponds. Average yields were nearly three times higher from high-input green water practices compared to previous years' yield without such practice. The average estimated gross margin (Baht 17,000 rai^{-1} in 7.5-mo culture period) in this trial was also higher than expected.

Introduction

The Asian Institute of Technology (AIT) Aquaculture Outreach Program (AOP), through its project based in Udorn Thani province in Thailand, has been working directly with farmers and local institutions in developing and disseminating appropriate aquaculture techniques, which aim at bringing about sustainable increases in fish production on small-scale farms in Northeast Thailand. Between 1989 and 1993, a large number of farmers in the region became aware of the AOP recommendations for fry nursing and pond fertilization. These recommendations, the application of ruminant manures and modest inputs of urea, allow for a substantial increase in fish production with only a small investment.

By 1993, however, in the context of Thailand's rapidly growing economy, these technical recommendations, aimed at increasing production for food self-sufficiency, were insufficient to fulfill the growing aspirations of farmers to produce a surplus for the buoyant local market. In recent years, fish consumption has greatly exceeded local supply in Northeast Thailand. Consequently, disadvantaged consumers were paying a relatively high price for their fish products because the shortfalls were made up by imports from the central region. Although fertilization of ponds with ruminant manure and other on-farm wastes—previous AOP recommendations—could produce fish at minimal costs, fish yields were correspondingly low (on average < 500 kg ha^{-1} yr^{-1}). Moreover, introduction/improvement of aquaculture in small-scale agriculture systems was constrained by the limited scope of on-farm resources to be integrated into fish culture. Therefore, intensification through fertilization of fish ponds with low-cost, off-farm inputs was considered a viable option to increase the fish yields of small-scale agriculture systems.

One relatively low-cost technology to increase fish yield on small-scale farms is the fertilization of ponds with chemical fertilizers. Pond fertilization has been an on-station research area of the Pond Dynamics/Aquaculture CRSP project at AIT for a number of years (Lin et al., 1997). Study results demonstrated that fish yields of appropriately fertilized ponds could exceed 4,000 kg ha^{-1} yr^{-1}, a nearly 10-fold increase over that in traditional farms of Northeast Thailand. Similarly, in other on-station experiments conducted in Northeast Thailand that applied urea and triple superphosphate (TSP), an extrapolated yield of sex-reversed tilapia was 5,049 ± 231 kg ha^{-1} yr^{-1} (808 kg rai^{-1} yr^{-1}) (AOP, 1992). Given the farmers' demand for new technology and AITs on-station experiment results, the AOP developed a further round of recommendations emphasizing use of low-cost, off-farm inputs, namely urea and TSP, for fertilizing fish ponds. Liming ponds with low alkalinity was also recommended. Hence, fertilization of the pond with inorganic fertilizers to produce a surplus of fish over the amount required for household consumption was introduced as a potential source of income.

In Thailand, tilapia fills an important niche in providing low-cost animal protein to poorer urban and rural people and ranks as the most important cultured freshwater fish. However, one of the major setbacks in tilapia culture is the species' prolific fecundity, which leads to overpopulation of the ponds, subsequent high competition, and hence the production of tiny fish with low value (Ufodike and Madhu, 1986; Szyper et al., 1995). An effective solution to the problem of uncontrolled reproduction is the culture of monosex male progenies, which combine the benefits of population control with the faster growth of male stock. In a number of earlier AOP trials, all-male culture of tilapia produced larger, more uniformly sized fish. To address the problems of uncontrolled breeding and recruitment of tilapia, culture of hormonally sex-reversed tilapia was recommended for this on-farm trial.

In 1994, the first year of high-input green water on-farm trials, three farmers in Udorn Thani, who had previously taken part in project trials, volunteered to follow the recommendations. Outreach staff from the Udorn Thani office visited all three farmers fortnightly in order to keep detailed records. Significant increases in fish yield resulting from the first-year on-farm trial encouraged the expansion of the recommendations throughout the region (AOP, 1995). Later, in 1995/96, AOP, in collaboration with the Department of Fisheries (DOF), carried out high-input on-farm trials with a total in 12 farmers of Udorn Thani, Nakorn Phanom, and Sakorn Nakorn provinces of Northeast Thailand. This report presents the results of these high-input on-farm trials.

METHODS AND MATERIALS

The high-input on-farm trial was jointly carried out by the AOP and the DOF. Provincial Fisheries Officers selected and recruited the trial farmers, who volunteered to take part in the on-farm trials (Table 1). AOP and DOF staff jointly visited all farms, estimated pond size, and assessed water quality by testing alkalinity and water color prior to stocking. Stocking density and lime and fertilizer requirements for each pond were also estimated on the basis of the AOP (Table 2).

The AOP has not commonly supported trials with inputs or credit, but the "culture" of the DOF in conducting on-farm

Table 1. Distribution of the participant farmers by location, high-input on-farm trial, Thailand.

Location	Number	Farmer's Name
UDORN THANI		
	1	Mr. Tongsoon
NAKORN PHANOM		
	2	Mr. Phai
	3	Mr. Chairat
	4	Mr. Sopar
	5	Mr. Boonsong
	6	Mr. Kampong
	7	Mr. Sunan
SAKORN NAKORN		
	8	Mr. Prasobchai
	9	Mr. Wantamid
	10	Mr. Sagnuansak
	11	Mr. Surin
	12	Mr. Tawatchai

Table 2. Technical recommendations for high-input, green-water on-farm trials. On the basis of on-station and on-farm trials, total fish yield at the end of 6-mo grow-out period is expected to be 600 kg rai^{-1}.

Pond Inputs:

Input	Input Rate (rai^{-1})	Considerations
Lime	200 kg only once in the beginning	apply when alkalinity ($CaCO_3$) is < 50 mg l^{-1}
Urea 46:0:0	9.8 kg wk^{-1} (6.1 g m^{-2} wk^{-1})	apply after dissolving in water
TSP 0:46:0	5.6 kg wk^{-1} (3.5 g m^{-2} wk^{-1})	soak overnight in water and mix thoroughly before applying to pond
Chicken Manure	depends on availability	amount of urea and TSP should be adjusted with the amount of manure applied (N: 4 kg ha^{-1} d^{-1} and P :1 kg ha^{-1} d^{-1})

Stocking Recommendation:

Stocking Density	Species	Stocking Period	Considerations
2-3 fingerlings m^{-2} (3,200-4,800 fingerlings rai^{-1})	Sex-reversed tilapia	6 mo	nursing fry in hapa prior to stocking [Recommended size to stock: 5 g (6-8 cm)]

demonstrations has been to offer input support. The DOF officers were not confident that they could recruit farmers in the absence of such inputs and agreed to help the project farmers with some amount of lime, urea, and TSP free of charge. Considering the scarcity of sex-reversed tilapia in the region, AOP staff supplied seed free of charge to all project farmers.

District Fisheries Extension Officers visited project farmers regularly. In order to record the activities carried out by the farmers, the AOP staff and the DOF Fisheries Officers visited farms fortnightly. The AOP conducted a short questionnaire survey after the complete harvest of fish from all project farmers' ponds.

Technical Recommendations

Introduction and promotion of aquaculture into small-scale rice-based farms raises concerns about alternative use of resources. Fertilization of fish ponds with off-farm inputs (urea and TSP) is hoped to become a viable option, since it does not interfere with the existing resource allocation pattern of small-scale farming systems. Additionally, use of inorganic fertilizers does not put excessive economic burden (in comparison to intensive aquaculture) on the farmers since they are relatively inexpensive. In a number of on-station trials, daily supplements of inorganic fertilizers at the rate of 4 kg nitrogen (N) and 1 kg phosphorus (P) ha^{-1} as urea and TSP, respectively, were found to produce optimum yields. Hence, based on AIT on-station trial results, a package of technical recommendations for high-input green water trials was developed (Table 2).

RESULTS AND DISCUSSION

Farming Systems of the Project Farmers

The farm holding size of project farmers ranged from 0 to 50 rai with an average of 21 rai (1 rai = 6.25 ha). The average farm holding size of the project farmers was found to be nearly 25% less than the average of the 1988 AOP baseline survey in the region (Table 3).

Almost all project farmers cultivated their own land. However, a couple of farmers rented-in or rented-out the land for cultivation. The area under cultivation in the project farms was smaller than the size of holdings and was estimated to range from 3 to 39 rai with an average of 16 rai (Table 3).

All the project farmers had nuclear families consisting of husband, wife, and one or more children. All of the farmers relied mainly on family labor for all agricultural activities. In most cases, the husband and wife comprised the labor force in the family. Average family size of the project farmers was five, with an average labor force of two to three. In contrast to these average figures, Mr. Sopar, a project farmer of Nakorn Phanom, reported that five of his six family members worked on his farm. Therefore, he was able to cultivate all 30 rai of his land. By contrast, despite his large farm holding (50 rai), Mr. Surin, whose labor force size was three, cultivated 35 rai, and Mr. Phai cultivated even less (21 rai), as his labor force was only two: himself and his wife.

Livestock rearing activities among the project farmers also varied greatly. Except for Mr. Sunan of Nakorn Phanom, all of the farmers owned livestock and/or poultry. Cattle was the most common species, raised by two-thirds of the project farmers, followed by pigs, raised by one-third. Poultry farming was not popular; only three farmers—Mr. Phai, Mr. Sopar, and Mr. Surin—were involved in rearing chickens. Mr. Tongsoon, the only farmer to own buffalo, possessed the most large animals (nine cattle and three buffaloes) among the project farmers. Ownership of livestock and poultry by the project farmers is presented in Table 4.

Aquaculture Subsystem of the Project Farmers

Fish culture was found to be a relatively new activity (average 4.6 yr) for most of the farmers. For five farmers, it was a newly introduced subsystem in their farm, as they had been raising fish for only one year. By contrast, Mr. Phai, a farmer of Nakorn Phanom, had been culturing fish for 30 years (Table 5). Virtually all the project farmers reported that they supplied negligible amount of supplementary feed and animal manure to the pond and that they had experienced very slow growth and low fish yields from their ponds.

Pond Characteristics

Pond size varied greatly among the project farmers. The average pond size was estimated to be 658 m^2. Mr. Tongsoon

Table 3. Size of holding, area under cultivation, household size, and household labor force of the project farmers.

Farmer's Name	Size of Farm Holding (rai)	Cultivated Land (rai)	Family Size (number)	Family Labor Force (number)
Mr. Tongsoon	16	39	4	2
Mr. Phai	50	21	4	2
Mr. Chairat	15	8	5	3
Mr. Sopar	30	30	6	5
Mr. Boonsong	14	14	7	2
Mr. Kampong	7	5	4	2
Mr. Sunan	14	14	3	2
Mr. Prasobchai	-	3	5	2
Mr. Wantamid	11	9	4	2
Mr. Sagnuansak	8	8	5	2
Mr. Surin	50	35	3	3
Mr. Tawatchai	20	7	6	2
Mean (SD)	21.4 (15.4)	16.0 (12.3)	4.7 (1.2)	2.4 (0.9)

Table 4. Ownership of livestock and poultry by the project farmers.

Farmer's Name	Cattle	Buffalo	Pigs	Chickens
Mr. Tongsoon	9	3	-	-
Mr. Phai	-	-	-	100
Mr. Chairat	4	-	10	-
Mr. Sopar	3	-	-	320
Mr. Boonsong	-	-	7	-
Mr. Kampong	-	-	2	-
Mr. Sunan	-	-	-	-
Mr. Prasobchai	7	-	-	-
Mr. Wantamid	4	-	-	-
Mr. Sagnuansak	1	-	3	-
Mr. Surin	5	-	-	-
Mr. Tawatchai	4	-	-	72
Mean	5	-	6	164

Table 5. Pond size, water color, and farmers' involvement in fish culture.

Farmer's Name	Pond Size (m^2)	Water Color at Start of Experiment[1]	Involvement in Fish Culture (yr)
Mr. Tongsoon	1,440	2	1
Mr. Phai	800	5	30
Mr. Chairat	640	3	2
Mr. Sopar	1,300	1	1
Mr. Boonsong	400	2	3
Mr. Kampong	350	1	1
Mr. Sunan	345	2	1
Mr. Prasobchai	494	1	2
Mr. Wantamid	896	1	6
Mr. Sagnuansak	885	2	4
Mr. Surin	380	2	4
Mr. Tawatchai	300	2	0
Mean (SD)	686 (386)	2.0 (1.3)	4.6 (8.2)

[1] Scaling for water color: 1 (clear), 2 (turbid), 3 (greenish and turbid), 4 (light green), 5 (green), and 6 (dark green).

and Mr. Sopar owned the largest ponds (1,440 and 1,300 m^2, respectively), whereas the pond of Mr. Tawatchai was the smallest (300 m^2). The pond size data are presented in Table 5.

Water quality was assessed in all project farmers' ponds prior to commencing the trial (Table 5). The overall average water color (2.0) presented in Table 5 indicated turbid water in most of the project farmers' ponds, indicating that the ponds were poor in natural feed and not favorable for fish growth. Most of the project farmers were not aware of the significance of fertile green water as fish culture is a relatively new activity for most of them. However, the water in Mr. Phai's pond was green (5.0). The color suggested that plenty of natural food was available in the pond and reflected his much greater experience.

DOF and AOP Support

In line with the understanding reached at the start of the project, the AOP supplied sex-reversed tilapia fry to the project farmers. Additionally, the AOP supported farmers with some feed, particularly pig feed concentrate and fine rice bran, for raising fry in hapas. But other input support (urea, TSP, lime, and feed during nursing), which was to be supplied free of charge by the DOF, varied from district to district. Mr. Tongsoon of Udorn Thani did not receive any input support from Provincial Fisheries Officers because the area was under an ongoing Agricultural Extension Project and the farmers were supposed to seek support from the Bank of Agriculture and Agricultural Cooperatives (BAAC) if needed. The farmers of Sakorn Nakorn accepted the DOFs input support but wanted to buy fertilizer on their own. Therefore, only six farmers, all from Nakorn Phanom, were the beneficiaries of DOF input support for the entire six-month culture period (Table 6).

Nursing Details

All the project farmers, upon receiving seed, started nursing fry in hapas in their ponds. Fry with an average size of 1 cm were distributed to 11 farmers the last week of February 1995. Mr. Tongsoon had to delay nursing since the water level in his pond was inadequate to start nursing in February. Therefore, upon his request, the AOP officials supplied fry to Mr. Tongsoon

Table 6. DOF and AOP input support to project farmers.

Farmer's Name	Fry[1] (Number)	Feed[1] (kg)		Fertilizers and Lime[2] (kg)			Total Support (Baht equivalent)
		Pig Feed Conc.	*Rice Bran*	*Urea*	*TSP*	*Lime*	
Mr. Tongsoon	4,000	4	2				1,258.0
Mr. Phai	3,200	6	-	200	100	50	3,745.5
Mr. Chairat	1,600	4	2	100	50		4,006.0
Mr. Sopar	3,200	2	1	250	100	60	4,148.0
Mr. Boonsong	800	2	1	47	27	5	929.0
Mr. Kampong	1,200	2	1	57	32	50	1,281.0
Mr. Sunan	1,200	2	1	73	20	60	1,316.9
Mr. Prasobchai	1,000	2	1				329.0
Mr. Wantamid	4,000	2	1				149.0
Mr. Sagnuansak	3,000	2	1				929.0
Mr. Surin	3,000	2	1				929.0
Mr. Tawatchai	2,000	2	1				989.0
Mean (SD)	2,050 (1,179)	2.7 (1.3)	1.2 (0.4)	121.2	54.8	45.0	1,667.5 (1,432.5)

[1] AOP Support
[2] DOF Support

Table 7. Nursing details in high-input on-farm trial, Thailand.

Farmer's Name	Hapa Size (m^3)	Size at Start of Nursing (cm)	Size at End of Nursing (cm)	Days Nursed	Fry at Start of Nursing	Density at Nursing (fry m^{-3})	Survival at End of Nursing (%)
Mr. Tongsoon	20.3	2	8	35	4,000	198	99.5
Mr. Phai	20.3	2	6	56	3,200	158	84.4
Mr. Chairat	4.9	1	7	40	1,600	329	44.1
Mr. Sopar	20.3	1	8	31	3,200	158	96.9
Mr. Boonsong	4.9	1	7	41	800	165	68.8
Mr. Kampong	4.9	1	7	57	1,000	206	77.5
Mr. Sunan	4.9	1	6	30	1,200	247	1.6
Mr. Prasobchai	5.4	1	6	35	1,000	185	95.5
Mr. Wantamid	20.3	1	7	43	4,000	198	75.0
Mr. Sagnuansak	5.4	1	7	30	3,000	556	96.7
Mr. Surin	32.4	1	7	43	3,000	93	100.0
Mr. Tawatchai	4.9	1	8	51	2,000	412	65.0
Mean (SD)	12.4 (9.7)	1.2 (0.4)	7.0 (0.7)	41.0 (9.6)	2,333 (1198)	242 (130)	75.4 (28.9)

the third week of March. The details of nursing are presented in Table 7.

Hapa size varied greatly among the farmers. The hapas of two-thirds of the project farmers were approximately 5 m^3. By contrast, four farmers had hapas 20 m^3 or larger. The average size of nylon hapas used for nursing was estimated to be 12.4 m^3.

The average number of fry released into hapas for nursing was estimated to be 2,333. Numbers stocked ranged from 800 (Mr. Boonsong) to 4,000 (Mr. Tongsoon and Mr. Wantamid). In general, variation in the number of fry nursed by the project farmers was related to pond size, since the AOP staff had estimated the number of fry required to maintain the recommended density (2 to 3 fish m^{-2}) at the time of stocking.

The duration of nursing fry in hapas ranged from 30 to 57 days with an average of 41 days. Despite a wide range in nursing duration, the size of fingerlings at the end of nursing was estimated to lie in the narrow range of 6 to 8 cm. This was because stocking density and feeding management while nursing fry in nylon hapas varied greatly among the project farmers. Water quality also has an important role in the growth of fry during nursing. In general, the size of fingerlings at the end of nursing in all the farms was related to the duration of nursing and amount of supplementary feed supplied.

Pig concentrate and rice bran applied at a 2:1 ratio were recommended as supplementary feed for fry throughout nursing. On average, farmers fed 130 g of pig feed concentrate and 76 g of fine rice bran per day per 1000 fry. Thus, on average, farmers followed the ratio recommended by the AOP. Mr. Tongsoon, who nursed 2-cm fry for only 35 days and supplied 340 grams of feed per 1000 fry per day (the highest rate among all the project farmers), had 8-cm fingerlings at the end of nursing. By contrast, Mr. Wantamid, who nursed fry for 43 days but with the minimum quantity of supplementary feed, had 7-cm fingerlings at the end of nursing. In addition to pig feed concentrate and rice bran, a number of project farmers reported that they had supplied some other inputs during nursing. Morning glory, a common vegetable crop, was a popular supplementary feed.

Density of fry during nursing, which was largely affected by the size of hapas, ranged from 93 fry m^{-3} (Mr. Surin) to 556 fry m^{-3} (Mr. Sagnuansak), with an average of 242 fry m^{-3}. Despite the large variation in fry density, its effect on growth was not obvious. Density is expected to affect growth of fry if *in situ* production of natural feed (plankton) is occurring; however, as presented earlier (Table 5), water in most of the ponds was clear or turbid, suggesting a very low availability of natural feed (plankton) at the beginning of the trial. But feeding during nursing varied widely among the participant farmers. Hence, the wide variation in time required for fingerlings to reach lengths of 7 to 8 cm was due to the different amounts and types of feed supplied by the farmers during nursing.

The survival rate of fry at most of the farms was estimated to be 75% or more (up to 100%), except for three farmers—Mr. Tawatchai, Mr. Boonsong, and Mr. Chairat. The survival rate of their ponds fell between 44 and 70%. Mr. Sunan, who supplied pig fat as a supplementary feed during nursing, had < 2% fry survival. It appears that the supplement of pig fat killed virtually all the fry in his hapa. Later, the DOF Extension Officers resupplied Mr. Sunan with 1,000 fingerlings of tilapia, common carp, *Puntius*, and *Pangasius*.

Stocking Density

As mentioned earlier (Table 2), farmers were advised to stock 2 to 3 fish m^{-2}. There is an inverse relationship between total number of fish stocked and the growth of an individual fish in a culture facility. Maintenance of proper stocking density aims to produce the maximum biomass of the optimum or desired size fish from a culture facility. While maintaining stocking density, attempts should be made to ensure a balance among total food demand for fish growth, *in situ* production of natural feed, and supplementary feed in the pond.

Prior to seed distribution, pond size was estimated on all farms. Based on pond size and the recommended stocking density, the total number of fry to stock was estimated and farmers were supplied with the sex-reversed tilapia fry accordingly. Therefore, average stocking density, 3.1 fish m^{-2}, remained quite close to or within the recommended range (2 to 3 fish m^{-2}) in all farmers' ponds, except in Mr. Surin's and Mr. Boonsong's. The former stocked 8 fish m^{-2}, the highest (and extreme) stocking density among the project farmers, and the latter stocked only 1 fish m^{-2}, the lowest (Figure 1).

Culture Period

The culture period, recommended for six months, varied notably among the farmers. Two farmers, namely Mr. Phai and Mr. Wantamid, had to terminate the trial after four months as water level in their ponds dropped rapidly after the cessation of the rainy season. By contrast, a number of farmers whose ponds retained sufficient water extended the culture period, which, in general, ranged between 8 and 11 months. The farmers' preference for larger fish was the main reason for extending the culture period. A total of six farmers, though they cultured fish for the extended period, also followed a multiple harvesting strategy in order to fulfill household consumption as well as cash needs. By contrast, Mr. Sopar, who had another pond with enough fish for household consumption, continued fish culture for 11 months. Market price was another factor that led some farmers to extend the culture period. Mr. Sagnuansak and Mr. Sopar harvested most of their stock at the time of the visit of Princess Sirindhorn, a member of Thai Royal family, to the village school since the price of fish in the local market was high at that time.

Pond Fertilization

Pond fertilization during the culture period varied greatly among the farmers. DOF support, scheduled for the specified experimental period, was discontinued after six months; however, a number of project farmers raised fish for more than six months. After free input support was discontinued, fertilization practice among the DOF-supported farmers started to vary to a greater extent than before. Details of the project farmers' pond fertilization practices are presented in Table 8.

All the project farmers, following the AOP recommendation, applied lime in their ponds prior to commencing the trial. The average amount of lime applied was estimated to be 1,160 kg ha^{-1}, but the amount applied varied widely. Mr. Surin applied lime at an extrapolated rate of nearly 4,000 kg ha^{-1}, the highest rate among all farmers. By contrast, Mr. Wantamid applied at the rate of 112 kg ha^{-1}, the lowest rate among participant farmers.

Farmers were advised to apply fertilizers (urea and TSP) at weekly intervals at the rate of 4 kg N and 1 kg P ha^{-1} d^{-1}, respectively. In the beginning, based on the recommendation, AOP staff assisted the project farmers in estimating the weekly requirement of these fertilizers for their ponds.

Though all the participant farmers applied urea as a pond input, only two farmers, Mr. Tongsoon and Mr. Tawatchai, reported that they applied the recommended quantity. Others applied either less or more than the recommended rate. Mr. Phai applied the highest amount of urea, at an extrapolated rate of around 21 kg ha^{-1} d^{-1}. He also applied organic manure in his pond. Therefore, total N supplied to Mr. Phai's pond was estimated to be excessively high (10.5 kg ha^{-1} d^{-1}), more than twice the recommended rate. Two other farmers, Mr. Sunan and Mr. Sagnuansak, also applied an excessive amount of urea; both of them applied N at a rate 50% higher than recommended. The rest of the farmers applied 2 to 4 kg N ha^{-1} d^{-1}, except Mr. Wantamid, who applied N at the lowest rate (only 5% of the recommended rate).

Most farmers applied P at a higher rate than recommended. The average rate of application of TSP was nearly two times the recommended rate (1.9 kg ha^{-1} d^{-1}). Mr. Phai, who applied an excessively high rate of N, also applied the highest amount of TSP (5 kg P ha^{-1} d^{-1}). By contrast, Mr. Surin and Mr. Wantamid did not apply TSP at all. Mr. Prasobchai was the only farmer who applied TSP at the recommended rate.

In addition to urea and TSP, all farmers reported that they applied animal and/or poultry manure to their ponds. Mr. Phai, who applied N and P at extremely high rates, also applied approximately 650 kg of chicken manure to his pond. Mr. Wantamid and Mr. Surin applied a considerable amount of buffalo and cattle manure to their ponds, which contributed to the P supply to some extent since neither of them applied TSP. Both inorganic and organic sources are considered when estimating the total N and P supply in the pond. Hence, the total N and P supplies presented in Figure 2 represent the sum of inorganic fertilizers and organic manure.

The application of animal manure was often based on its availability at the farm (Table 4). However, two farmers applied chicken manure as an off-farm input. Mr. Tongsoon and Mr. Sagnuansak applied chicken manure as a pond input, although they did not own any chickens. By contrast, Mr. Tawatchai, despite having chickens and cattle on his own farm, applied cattle manure but not chicken manure (Table 8).

Species Stocked

Despite AOP recommendation of and support for the monoculture of sex-reversed tilapia for the on-farm trial, a

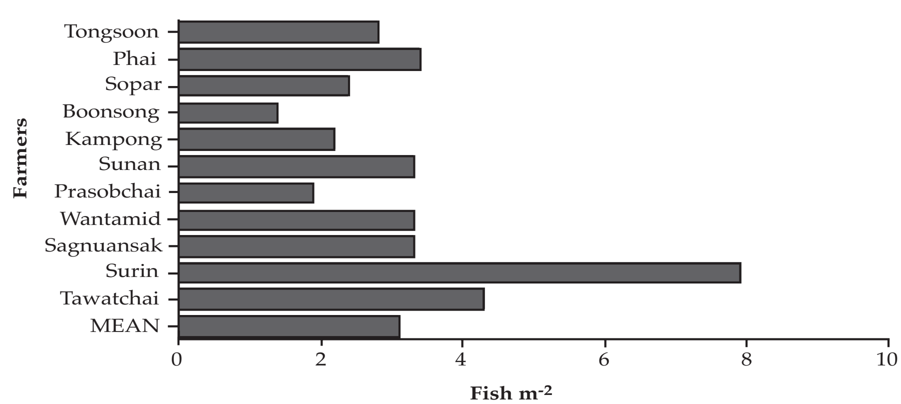

Figure 1. Estimated stocking density in farmers' ponds in high-input on-farm trial.

Table 8. Pond fertilization during culture period.

Farmer's Name	Culture Period (d)	Lime Added before Culture Period (kg pond-1)	Urea		TSP		Manure (kg pond-1)		
			kg pond-1	*N kg ha-1 d-1*	*kg pond-1*	*P kg ha-1 d-1*	*Buffalo/ Cattle*	*Chicken*	*Pig*
Mr. Tongsoon	150	40	150	3.47	150	3.3	1,000	360	
Mr. Phai	120	80	200	10.4	100	5.1		650	
Mr. Chairat	330	25	150	3.3	50	1.1			96
Mr. Sopar	270	60	224	3.1	100	1.4		448	
Mr. Boonsong	270	5	47	2.1	27	1.2			120
Mr. Kampong	270	50	57	2.9	32	1.6			180
Mr. Sunan	150		73	6.5	20	1.8		50	
Mr. Prasobchai	120	25	28	3.0	10	1.0			1,500
Mr. Wantamid	270	10	10	0.3		0.0			420
Mr. Sagnuansak	270	200	30	5.9	200	3.9		150	200
Mr. Surin	270	150	34	1.8		0.1		1,150	
Mr. Tawatchai	240	50	50	4.1	30	2.3		2,760	
Mean (SD)	228 (72)	63 (60.5)	110 (93)	3.6 (1.5)	72 (64)	1.8 (1.5)			

number of farmers mixed other fish species in their ponds. These additional species did not appear to have a significant effect on stocking density or yield in most of the farmers' ponds. Mr. Sunan, a farmer of Nakorn Phanom, stocked a mix of different species since virtually all the sex-reversed tilapia fry supplied to him died at the time of nursing. Therefore, Mr. Sunan practiced polyculture for his on-farm trial.

Harvesting and Yield

As mentioned earlier, the project farmers followed different strategies for stocking, feeding, and harvesting. Total fish production also varied from one pond to another. It is interesting that average extrapolated yield (944 kg rai^{-1}) was estimated to be higher than the expected yields based on on-station trials (600 kg rai^{-1}) (Table 9). Moreover, average yield recorded in these trials was higher than that recorded in a similar trial with three farmers—namely Mr. Sawat, Mr. Bang, and Mrs. Vichai—of Udorn Thani in 1995. Among other factors, the difference between the recommended (6-month) and practiced (average 7.5-month) culture periods contributed to higher average yield estimated from these on-farm trial results. Data analysis revealed a positive correlation (correlation coefficient = 0.56) between total yield and culture period. Similarly, a positive relation was established between total yield and stocking density (correlation coefficient = 0.51).

Extrapolated yields ranged from 292 to 1,322 kg rai^{-1}. Mr. Tawatchai produced 244 kg of fish from his pond, which was equal to an extrapolated yield of nearly 1,300 kg rai^{-1}. The higher yield recorded in Mr. Tawatchai's pond was associated with the optimum stocking density (Figure 1), extended culture period (nine months), and adequate fertilization (Figure 2). Mr. Sunan's harvest had the highest extrapolated yield, slightly higher than that recorded in Tawatchai's pond, and was probably associated with polyculture of larger fingerlings. The yield presented in Table 9 is total fish harvested from the pond. For a number of cases, the yield presented is the cumulative yield of multiple harvests. For others, it represents a single harvest at the end. The varying harvest strategies (single vs. multiple) and culture periods selected by the farmers might also have affected the total yield, causing differences in yield per unit area.

Significance of the Trial

The significance of this high-input on-farm trial is discussed in terms of change in water color, farmers' perceptions of the trial, and three interrelated aspects of aquaculture—production, socioeconomic, and environmental concerns.

Water Color

At the beginning of the on-farm trial, when water quality was assessed, Mr. Phai was the only farmer with green water in his pond. Mr. Phai, who had been raising fish for 30 years, was aware of the significance of water color for fish growth. In the other farms, pond water was either clear or turbid prior to commencement of the trial. However, when water quality was assessed at the end of the trial, most of the ponds had become green or dark green (Figure 3). The observed change in water color was due to the growth of plankton as a result of fertilization. Virtually all project farmers experienced a substantial increase in fish yield, which was associated with the change in water color from turbid to green or dark green (rich in plankton) after application of urea and TSP. As indicated by the change in water color, *in situ* production of an ample amount of natural feed was accomplished by applying low cost off-farm inputs, thus achieving the main objective of this on-farm trial.

Farmers' Perceptions

At the end of the trial, virtually all the participant farmers were very satisfied with the significant increase in fish production from their ponds. Ten out of twelve farmers expressed that they had decided to continue this practice in the coming years. Two farmers, namely Mr. Chairat and Mr. Kampong, though satisfied with the production, expressed difficulties in purchasing fertilizers (due to either unavailability or expense), particularly TSP, in the local market. When asked about difficulties in following the recommendations, all the participant farmers reported that the recommendations were very easy to follow and they were confident that they could continue the practice without technical assistance in the years to come. Moreover, farmer-to-farmer dissemination of the high-input fertilization technology was evident. Virtually all the project farmers reported that they had relayed the recommendations to their relatives and/or neighbors.

In general, most of the farmers were satisfied with the size of fish obtained at the end of the trial. However, three farmers, namely

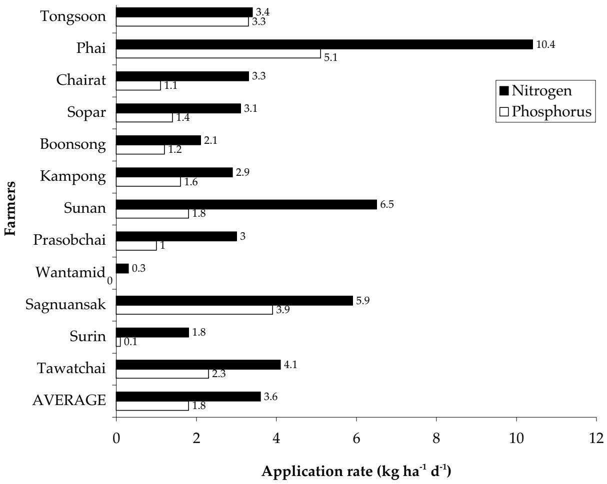

Figure 2. Average N and P (kg ha^{-1} d^{-1}) applied during culture period.

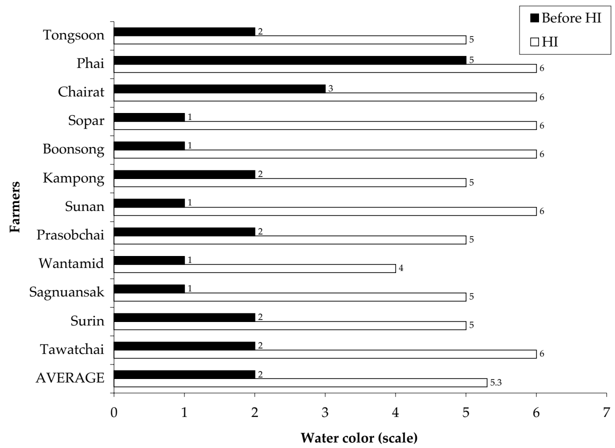

Figure 3. Water color of the participant farmers' ponds before and after high-input fertilization (HI). Scaling for water color: 1 (clear), 2 (turbid), 3 (greenish + turbid), 4 (light green), 5 (green), and 6 (dark green).

Mr. Sunan, Mr. Wantamid, and Mr. Tawatchai desired larger fish (2 to 3 fish kg^{-1}) than they had obtained (4 to 5 fish kg^{-1}). Mr. Surin, who had stocked at an excessively high density (8 fish m^{-2}), was the only farmer to express dissatisfaction about the size of individual fish obtained at the end of the trial. Since the individual fish remained quite small, Mr. Surin desired a minimum size of 6 fish kg^{-1}. Overall, farmers' perceptions regarding high-input green water technology were highly satisfactory.

Production

Though the trial was carried out with a limited number of participant farmers, the recommendation was found to be one of the viable alternatives to increase fish production under low-input farm conditions. Despite limited control over the trial, the average yield recorded (944 kg rai^{-1}) was higher than the expected yield (600 kg rai^{-1}) based on on-station results. Moreover, all project farmers, except Mr. Prasobchai, reported a significant increase in fish yield in 1995/96 over the previous year. Average yields were nearly three times higher using high-input green water practices than previous years' yields without using these practices (Figure 4).

The average extrapolated fish yield recorded in a similar on-farm trial carried with three Udorn farmers in 1995 was 460 kg rai^{-1} (AOP, 1995). Interestingly, in this study average production was estimated to be 944 kg rai^{-1} (> 50% higher than the expected yield [600 kg rai^{-1}] on the basis of on-station trial results). However, on-station trial results were based on a six-month culture period. By contrast, the average culture period in this study was 7.5 months (range: 4 to 11 months). The average extrapolated yield of the four farmers—Mr. Tongsoon, Mr. Phai, Mr. Prasobchai, and Mr. Wantamid—who raised fish for six months or less was still estimated to be higher (668 kg rai^{-1}) than the expected yield. Four other farmers—Mr. Kampong, Mr. Sunan, Mr. Surin, and Mr. Tawatchai—who cultured fish for nine months harvested an extrapolated yield of nearly 1,200 kg rai^{-1} or greater. Mr. Prasobchai was the only farmer whose production remained below the on-station trial yield (Figure 4). Hence, fertilization of pond water by using low-cost off-farm inputs (urea and TSP) has proved to be a promising

Table 9. Culture period and fish yield in the high-input on-farm trial.

Farmer's Name	Culture Period (m)	Fish Yield		
		kg pond^{-1}	kg ha^{-1}	kg rai^{-1}
Mr. Tongsoon	5	743	5,159.7	825.6
Mr. Phai	4	358	4,475.0	716.0
Mr. Chairat[1]				
Mr. Sopar	11	780	6,000.0	960.0
Mr. Boonsong	9	180	4,500.0	720.0
Mr. Kampong	9	260	7,428.6	1,188.6
Mr. Sunan	9	285	8,260.9	1,321.7
Mr. Prasobchai	5	90	1,821.9	291.5
Mr. Wantamid	4	510	5,692.0	910.7
Mr. Sagnuansak	9	490	5,536.0	885.9
Mr. Surin	9	300	7,894.7	1,263.2
Mr. Tawatchai	9	244	8,116.7	1,298.7
Mean (SD)	7.5 (2.5)	385 (222)	5,899 (1953)	943.8 (312.5)

[1] Final harvest data of Mr. Chairat are not presented since he had migrated by the time fish were harvested.

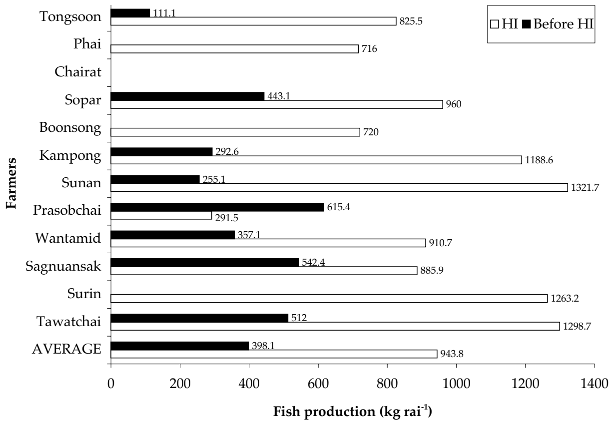

Figure 4. Fish production (per rai) before and after high-input (HI) pond fertilization. A number of farmers started this trial in a new pond. Therefore, fish yield before the high-input on-farm trial was no available in those cases.

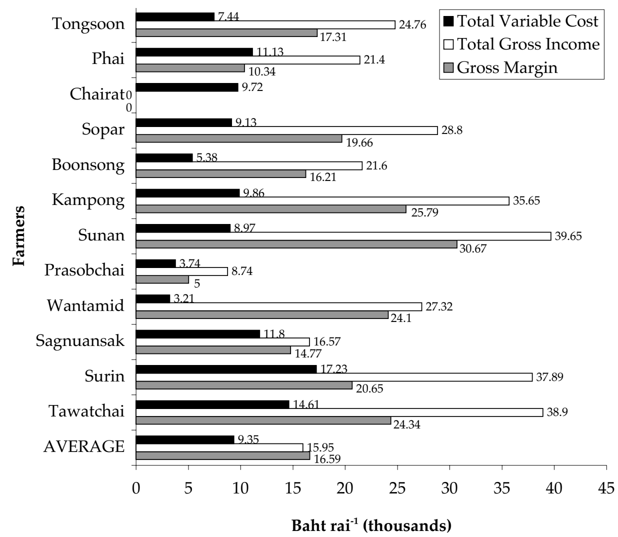

Figure 5. Gross margin analysis of high-input on-farm trial (HI).

recommendation due to its tremendous potential to increase fish production under small-scale farm conditions.

Socioeconomic Aspects

Application of inorganic fertilizers (urea and TSP) as opposed to pig manure and night soil for greening pond water is a widely acceptable option for many societies. Therefore, farmers are not hesitant to use this technology in order to fulfill their household needs for fish. Additionally, surplus fish production over household consumption can be sold in the market to a wide range of consumers.

Prior to commencing the trial and based on the on-station results, expected total variable cost (per rai) for fertilization of

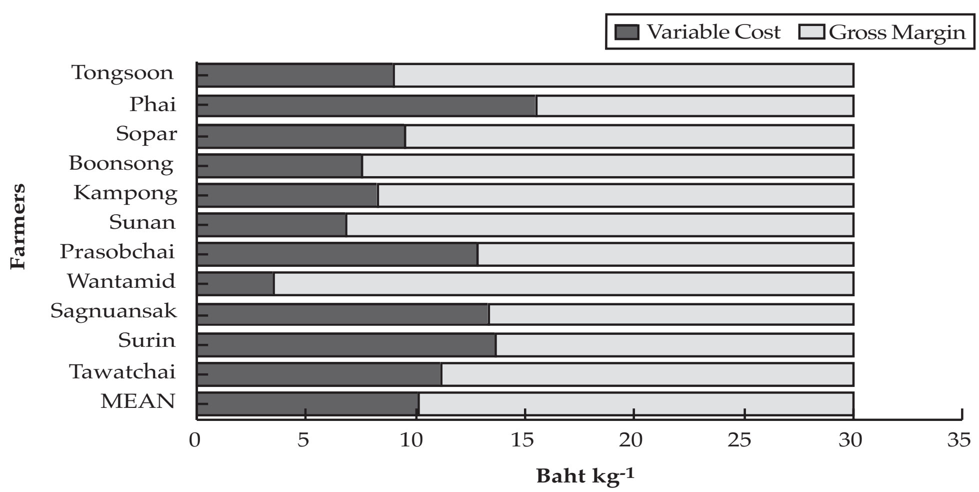

Figure 6. Total variable costs and gross margin of fish production (per kg) in high-input on-farm trial. Market price of fish at the time of survey in Northeast Thailand local markets was around 30 Baht kg^{-1}.

Table 10. Estimated costs of high-input trials based on the recommendation for a one-rai pond.

Input	Price per Unit (Baht)	Amount per Week	Total Amount	Total Cost (Baht)
Sex-Reversed Tilapia Fry Fingerlings	0.5	-	3,000	1,500.0
Urea (kg)	5.0	9.8	251	1,255.0
TSP (kg)	8.0	5.6	140	1,120.0
Lime (kg)	1.0	-	200	2,00.0
Overall				4,075.0

Table 11. Economics of high-input green water experiment.

Farmer's Name	Cost (Baht)							Fish Yield (kg)	Gross Return (Baht)	Gross Margin (Baht)
	Feed Cost (During Nursing)	*Pond Maintenance*	*Fry Cost*[1]	*Feed Cost (Supplementary)*	*Fertilizers and Manure*	*Marketing Costs*	*Total Variable Costs*			
Mr. Tongsoon	361.0	64.0	1,200.0	1,184.0	3,844.0	50.0	6,704.0	743	22,290	15,586
Mr. Phai	635.0		960.0		3,970.0		5,566.0	358	10,740	5,174
Mr. Chairat	156.0	30.0	480.0	1,440.0	1,785.0		3,891.0			-3,891
Mr. Sopar	220.0	180.0	960.0	3,240.0	2,792.0	30.0	7,422.0	780	23,400	15,978
Mr. Boonsong	92.0	90.0	240.0	270.0	654.0		1,346.0	180	5,400	4,054
Mr. Kampong[2]	91.5	150.0	700.0	360.0	856.0		2,157.5	260	7,800	5,642.5
Mr. Sunan[3]	92.5	140.0	560.0	360.0	784.0		1,936.0	285	8,550	6,614
Mr. Prasobchai	96.0	43.0	300.0	381.0	336.0		1,156.0	90	2,700	1,544
Mr. Wantamid	159.0	100.0	1,200.0	226.5	1,16.0		1,801.5	510	15,300	13,498.5
Mr. Sagnuansak	187.5	600.0	900.0	2.4	4,840.0		6,530.0	490	14,700	8,170
Mr. Surin	367.0	236.0	900.0	1,354.0	1,237.0		4,094.0	300	9,000	4,906
Mr. Tawatchai	239.0		900.0	995.0	907.0		2,741.0	244	7,320	4,579
Mean	224.7	163.3	775	892	1,843.4	40	3,778.7	385.4	11,563.64	6,821.25
(SD)	(161.6)	(166)	(320)	(925.8)	(1,607.4)	(14)	(2,266.6)	(222)	(6,663.42)	(5,801.04)

[1] Fry cost includes sex-reversed tilapia as well as other fish (if any).
[2] In addition to sex-reversed tilapia, Mr. Kampong added other fish fry at the time of stocking.
[3] Mr. Sunan had to buy all new seed at the time of stocking because all fry in his hapa died from pig fat fed during nursing.

pond water was estimated to be Baht 4,075 (Table 10). Given an expected fish production of 600 kg rai^{-1} in a six-month culture period and a market price of Baht 30 kg^{-1}, the extrapolated gross return was expected to be Baht 18,000. Therefore, a gross margin of nearly Baht 14,000 was expected from a one-rai pond.

The gross margin analysis on the basis of this on-farm trial is presented in Figure 5. The average estimated gross margin (Baht 17,000 rai^{-1} for a 7.5-month culture period) in this trial was higher than expected. Gross margin per rai was estimated to be > Baht 20,000 in the case of four participant farmers, namely Sunan, Tawatchai, Wantamid, and Kampong. These four farmers all raised fish for nine months. Prasobchai had the lowest gross margin (Baht 5,000 rai^{-1}). For others, it ranged from Baht 10,000 to 20,000 rai^{-1} (Figure 5).

Assessment of the labor used for different activities, particularly for the day-to-day activities (e.g., fertilizer application and feeding) was not practicable because these activities involved negligible time and farmers were not able to maintain a record of such activities. Therefore, labor cost has not been considered in cost benefit analyses of the high-input on-farm trial. Economic analysis (Table 11) is based on the input costs (fertilizers, feed, seed, and lime) and total output estimated on the basis of total harvest (cumulative or single) and fish price (Baht 30 kg^{-1}) in the local market.

The average cost of production was estimated to be Baht 10.1 kg^{-1} of fish. In general, production cost was associated with the quantity of inputs, particularly urea and TSP, applied. Despite very high total yield, cost per kilogram of fish production was also quite high in the case of Mr. Phai. In his case, excessive application of urea and TSP substantially increased production costs, which were estimated to be Baht 15 kg^{-1} of production. Four other farmers—Mr. Prasobchai, Mr. Sagnuansak, Mr. Surin, and Mr. Tawatchai—also had high production costs (> Baht 10 kg^{-1} of fish). For the rest, the input cost was estimated at < Baht 10 kg^{-1} of fish production. Mr. Wantamid had the lowest production costs. Though production cost in his farm was approximately Baht 4 kg^{-1} of fish, total production in his pond was also low due to an inadequate input supply. Mr. Kampong and Mr. Sunan obtained higher yields with relatively low investments. The extrapolated yields from both of their farms was higher than the average, i.e., 1,200 and 1,300 kg rai^{-1}, respectively. Meanwhile, their cost per kilogram of fish production (approximately Baht 8 and 7, respectively) was significantly less than the average cost of production (Figure 6).

A comparison between the recommended fertilizer rate and farmer practice reveals additional methods to minimize production cost for some farmers. For example, had Mr. Phai applied fertilizers at the recommended rate, assuming the production was unchanged by additional inputs, the production cost would have been lower since he applied urea and TSP at rates higher than recommended (Table 8). The economic analysis revealed that virtually all the project farmers were successful in producing adequate yields with relatively low production costs. Moreover, it also indicates a way to maintain high production by further minimizing production costs, i.e. by the application of fertilizers within the range of recommended rates.

Nonetheless, before introducing high-input green water technology to a wide range of farm families, a detailed assessment is necessary. Since high-input green water technology involves cash expenses to buy inorganic fertilizers, recommendations need to be tailored to the socioeconomic situations of the farmers. A couple of farmers in this trial, despite their satisfaction with the production technology, reported that application of urea and TSP as pond inputs caused them an additional financial burden. Inorganic fertilizers are relatively inexpensive external inputs for fertilizing a fish pond. Therefore, it is expected that a substantial increase in fish production with a small investment would allow small-scale farmers to sell fish and earn cash income. Most of the project farmers in this on-farm trial were successful in selling fish in the local market, which in general was surplus over household consumption.

Environmental Concerns

A pond is used not only for fish culture in most of the small-scale farms of Northeast Thailand. Pond water is widely used for irrigating fruits and vegetables. Additionally, ponds are a source of water for farm animals for many households. Sometimes ponds are the only source of water for household purposes (e.g. cleaning and cooking) as well. Thus, a farmer with a single pond in a relatively dry area always makes multiple uses of pond water. An environmental impact assessment of high-input green water technology on-farm was beyond the scope of this trial. Therefore, despite its tremendous potential to increase fish production, the impact of the high-input inorganic fertilization system must be assessed in order to understand whether it has negative effects on other sub-systems within the farm. The use of fertilized pond water for different purposes (e.g., household and agricultural) needs to be assessed. In general, most of the ponds are closed and there is little chance to pollute the surrounding environment unless pond water is pumped and drained.

ANTICIPATED BENEFITS

Culturists throughout southeast Asia and other tropical countries who are remote from CRSP research sites and to whom the CRSP experiments have not been extended. Also, CRSP participants will benefit by receiving more directly the critical needs of fish farmers throughout the region. Finally, regional biologists will benefit from the training and experimental work designed and overseen by CRSP researchers.

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POND© SOFTWARE DEVELOPMENT AND REFINEMENT

Eighth Work Plan, Decision Support Systems Research 1A, 1B, and 1C (DSSR1A, 1B, and 1C)
Final Report

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ABSTRACT

The POND© software has undergone continued development during the Eighth Work Plan. In addition to the model and user interface improvements accomplished during the first year of the work plan, additional work on the development of wizards for automating and completing specific frequently used tasks, model refinement and development, and economic decisionmaking was accomplished. Wizards were refined to improve their usability, and new wizards were developed to assist in determining water balances and water requirements and to interpret simulation results. Models of fish production were refined and calibrated. The ability to schedule tasks of fixed and period duration was incorporated into POND© and the associated enterprise budgeter. An economic module estimating production cycle costs and returns was developed to assist in determining optimal harvest points based on the value of different fish sizes.

INTRODUCTION

The POND© software is in the third phase of iterative refinement (Nath et al., 1995; Nath, 1996). The first phase of development resulted in Version 2.0, which was subsequently improved in Versions 3.0 and 3.5 to include consideration of water budgets, preliminary assessment of feed quality and of nutrient fluxes in pond sediments, improved routine fertilization guidelines, and parameter estimation techniques. Documentation of improvements that have been made to POND© in terms of model refinements and enhanced capabilities for decision support are the focus of this report.

POND© DEVELOPMENT

The development of prototype "wizards" in POND© was initiated in 1997. The intent of the wizard development was to provide an enhanced user interface for accomplishing frequently used, predefined tasks within POND©. The wizards were set up to prompt the user for specific information needed to accomplish the task under consideration, and step the user through the task sequentially, explaining the requirements of each step along the way. The first iteration of wizard development was initiated in the first half of the Eighth Work Plan. The discussion here describes the wizards that have been refined and developed during the second half of the Eighth Work Plan.

The development of specific wizards was driven by: 1) identifying frequently used application areas within POND© and 2) identifying areas which were sufficiently complex to warrant additional user support. This resulted in the development of the following wizards:

- A *pond setup* wizard to enable users to define new ponds at their facility;
- A *lot setup* wizard to enable users to define new lots that are associated with specific ponds;
- A *fertilizer* wizard to generate routine pond fertilization recommendations;
- A *liming* wizard to estimate lime requirements for ponds associated with specific soil types;
- A *feed optimizer* wizard to generate feed schedules that minimize the amount of feed needed to reach a specified fish target weight;
- A *water balance* wizard to conduct water balance calculations and estimate water requirements;
- An *economics* wizard to assist in calculating enterprise budgets and optimizing economic performance; and
- A *simulation* wizard to conduct facility-level simulations at a given site and view simulation results in graphical and tabular formats.

The primary focus of development this past year was on the water balance and economic wizards. The water budget model has been incorporated into POND©. The complete details of the water budget model are presented in Nath and Bolte (1998) and are summarized below.

Water Budget Model

The water budget simulation model is used for forecasting water requirements for aquaculture ponds. Water sources considered in the model include regulated inflow (Q_i), precipitation (P), and runoff (R). For many levee ponds, the latter source is negligible. Water losses include evaporation, seepage, effluent discharge, and overflow. Water sinks include regulated water discharge (Q_o), overflow (O), and evaporation (E). Water seepage (S) may occasionally be a source of water (e.g., for ponds constructed in areas with a high water table), although it is typically considered to be a sink.

Pond water inflow may be either intermittent (e.g., when water is added to maintain a desired pond depth) or continuous (e.g., a flow-through pond). Water gain from rainfall falling on the pond surface is calculated from precipitation data for a given location. The *curve number method* developed by the US Resource Conservation Service (NRCS) offers a simple procedure for estimating runoff from ungauged watersheds (USSCS, 1972). The method involves assessment of the antecedent soil moisture, hydrologic soil group, land use, and hydrologic condition for a given location. The NRCS developed a series of curves that relate combinations of the above factors with the expected runoff given the amount of rainfall produced by a storm. Curve numbers (CN) for different combinations of soil, land use, and hydrologic conditions have been tabulated by the NRCS.

Pond water may be discharged continually (e.g., in a flow-through pond) or intermittently (e.g., at harvest time or to alleviate poor water quality). The latter situation is difficult to assess *a priori* and is therefore not considered in the present model. Pond water overflow is set to zero unless the water level exceeds a maximum depth, a situation that typically depends on the depth of the drain pipe. Pond water loss or gain by seepage depends primarily on the soil porosity, methods used for pond construction, structural changes that have occurred to the pond basin over time, and pond management practices (Boyd, 1982; Teichert-Coddington et al., 1989). Pond water evaporative loss is estimated as a function of ambient air temperature, relative humidity, and wind velocity.

The model has been validated for ponds located at the Asian Institute of Technology (AIT), Thailand, and at El Carao, Honduras, which are respectively located in the humid and dry tropics. Simulation results indicated that precipitation accounted for 69.8% of the total water gains for AIT and 43.2% for El Carao. Regulated inflow provided 27% of the gains for AIT and 52.8% for El Carao. Runoff gains were minimal at both locations due to small watershed areas. Evaporation accounted for 54.9% and 40.1% of the overall water loss predicted for the AIT and El Carao locations, respectively, with seepage accounting for the remaining loss. Predicted water requirements at AIT over a five-month period exceeded actual amounts by 14.9%, apparently because seepage loss was overestimated. For El Carao, however, predicted water requirements were only 78.2% of the amount actually added, apparently due to poor estimates of evaporative water loss which averaged 0.32 cm d^{-1}, compared to pan evaporative measurements of 0.43 cm d^{-1}. In contrast, the predicted evaporative water loss for the AIT pond (0.47 cm d^{-1}) closely matched pan evaporation measurements (0.45 cm d^{-1}). The availability of relative humidity and cloud cover data for AIT explain the higher accuracy in evaporative water loss estimates, and therefore water requirements, compared to El Carao. If comprehensive weather datasets are available, the water budget model developed herein is a useful tool for estimating pond water requirements at individual facilities located in different geographical regions.

The Economist

One area where we have received considerable interest in further developing POND© deals with its enterprise budget capabilities. The economic analysis module currently is handled by an Economist object which manages economic calculations and enterprise budget generation. The Economist is capable of handling a number of different types of cost and income items, including fixed, variable, and depreciable costs. Enterprise budgeting involves summing all cost and income items, accounting for interest cost and depreciation costs. Within POND©, certain costs and income items are automatically generated based on the results of a facility simulation, e.g., income from produced fish.

Additions to the Economist module accomplished during the second half of the Eighth Work Plan include: 1) the ability to manage time-variant costs and 2) capabilities for optimizing facility management as a function of production cycle length. The ability to manage time-variant costs is important in addressing scheduling issues and costs which are tied directly to a production cycle; they also allow the Economist to generate multiyear budget scenarios tied to extended facility dynamics. This capability also relates to the capability for optimizing facility production based on production cycle lengths. To accomplish this, income values associated with different size classes of produced fish are required. Using this information, the Economist can calculate and present total enterprise costs and income based on the cumulative fixed, variable, and depreciable cost and the value of the produced fish. Optimal harvest, where the marginal cost of increased production is equal to the marginal return in produced income, is readily determined from this information.

ANTICIPATED BENEFITS

The anticipated benefits of this research include improved simulation of production facility dynamics and improved model usability via the wizard interfaces. Also, the incorporation of an extensive water balance module improves POND©s ability to provide reasonable forecasts of water requirements at different sites under different water management regimes. Finally, the enhancements to the POND© Economist to allow consideration of scheduled costs and estimate within-cycle production costs and returns will allow users to determine optimal harvest points during the production cycle.

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MACRO-LEVEL AGROECOLOGICAL SYSTEMS ANALYSIS AND SOCIOECONOMICS OF POND AQUACULTURE

Eighth Work Plan, Decision Support Systems Research (DSSR1D)
Final Report

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ABSTRACT

Recent work has been completed relating climatic and geographic factors to assess the suitability of particular agroecologic regions to aquaculture production. These studies were unable to compare the suitability of alternative land uses with aquacultural production. A study was therefore initiated to explore methods of generating terrestrial crop production estimates that: a) involve minimal use of complex simulation models and b) enable the use of biophysical input data likely to be available at the regional scale (e.g., monthly weather datasets). Such estimates are expected to assist regional-level decision makers to compare pond aquaculture with other types of farming systems. This work involved developing a framework to analyze and prioritize international development needs, and identifying and classifying indicators relating to sustainable development. Artificial neural networks were used to relate crop production to agricultural drivers. The Concurrent Decision-Making methodology appears to be a successful approach to facilitate stakeholder input into decision making and evaluation of alternatives intended to be used within group decision support tools. Development of a framework to assess international development needs and concomitant use of sustainable development indicators (SDI) should provide the target audience (i.e., international donor agencies, government organizations, and local groups) with a tool to examine where intervention would likely result in the greatest benefits. More specifically, such a tool can help to identify appropriate roles for aquaculture as well as other farming systems in disadvantaged communities.

INTRODUCTION

Our recent investigations that have focused on issues confronting regional-scale planners suggest the urgent need for tools that can facilitate holistic planning. In this context, personnel from Oregon State University have collaborated with the FAO to use models from the POND© software for regional-scale analysis. This has resulted in two detailed studies of inland aquaculture for Latin America (Kapetsky and Nath, 1997) and for Africa (Aguilar-Manjarrez and Nath, 1998). One of the limitations of both of these studies is that they provide only areal estimates of the suitability of land/water resources for inland (pond) aquaculture. No attempt was made to assess whether land/water resources are perhaps more *suitable* for other types of agriculture (e.g., terrestrial crop production and integrated farming systems).

Assessing alternate types of farming practices at the level of a strategic decision maker (e.g., policy planner) is not a trivial task because suitability of land/water resources for farming is a function of technical viability, availability of physical resources, and socioeconomic conditions, among other factors. From an analytical standpoint, simulation tools that relate biophysical and production variables can generate information which is useful for comparing farming systems in terms of technical viability. Currently available simulation models that can potentially be used for such analyses of terrestrial crop production are relatively complex (e.g., the DSSAT software; IBSNAT, 1994) and require daily weather data which is often unavailable. In this respect, the hierarchical structure of simulation models in the POND© software has provided a level of modeling (i.e., Level 1) that generates adequately accurate estimates of fish yield potential and associated resource needs for regional-scale analysis, as evidenced by their use in the studies cited above. One of the objectives of the current study was to explore methods of generating terrestrial crop production estimates that: a) involve minimal use of complex simulation models and b) enable the use of biophysical input data likely to be available at the regional scale (e.g., monthly weather datasets). Output from such methods is expected to assist regional-level decision makers to compare pond aquaculture with other types of farming systems.

Our recent work in the area of computer tools for holistic, regional-scale planning also suggests that the following areas merit attention: a) a framework to analyze and prioritize international development needs and b) identification and classification of indicators relating to sustainable development. Development of a framework to assess international development needs and concomitant use of sustainable development indicators (SDI) should provide the target audience (i.e., international donor agencies, government organizations, and local groups) with a tool to examine where intervention would likely result in the greatest benefits. More specifically, such a tool can help to identify appropriate roles for aquaculture as well as other farming systems in disadvantaged communities. Thus, additional objectives of the work reported herein were to develop a framework for assessing international development needs, and to arrive at appropriate indicators of sustainable development that can be used for planning purposes. Work conducted to date in these two areas (*Terrestrial Crop Performance Evaluation* and *Frameworks for Planning Sustainable Development*) is presented below.

TERRESTRIAL CROP PERFORMANCE EVALUATION

In this study we are investigating the use of artificial neural networks (ANN) to estimate crop yields (CY), water requirements (WR), fertilizer requirements (FR), and grow-out period or time to harvest (TH). These variables represent output analogous to predicted data from simulation models. ANN is a relatively recent artificial intelligence technique well suited for pattern recognition problems. A major advantage of ANN is the speed at which predictions are arrived at, typically several orders of magnitude faster than multiple simulation model runs.

Essentially, neural networks map input datasets (e.g., weather, soil, water, and management variables) to output data patterns (e.g., CY, WR, FR, and TH) such that if a "trained" ANN is presented with a new set of input data, it is able to accurately reproduce output variables. For evaluating crop performance by the use of ANN, one would ideally prefer to use measured input datasets together with output variables of interest from actual crop trials. Such data are difficult to come by—the alternate approach tested in this study was to use DSSAT (which has been extensively tested worldwide) as a means of generating synthetic output data with actual input weather, soil, and water datasets, together with likely management variable settings. Pilot runs have been made with DSSAT using soybeans as a test crop. The analysis used input datasets from locations in the state of Georgia.

As previously indicated, a primary objective of this effort is to reduce the amount of input data because in most real world instances, it is necessary to work with sparse datasets. Consequently, input datasets for training the ANNs were substantially reduced by summarizing the daily weather datasets (min/max temperature, precipitation, and solar radiation) used in DSSAT in the form of monthly means. An additional variable included in the monthly summaries is photoperiod (day length) because this parameter strongly influences physiological responses of the different crops, particularly soybean cultivars.

The approach of using monthly weather summaries is consistent with datasets that are typically used in regional-scale analysis by GIS (e.g., FAO, 1995). Other input variables used in the ANN included soil type, irrigation thresholds, photosensitivity coefficients, and planting dates. All of these inputs were used to train the ANN against desired outputs (i.e., CY, WR, FR, and TH) extracted from DSSATs summary output files. Preliminary results obtained using trained ANNs for a soybean cultivar planted either early or late in the season (Figure 1) suggest that predictions reasonably comparable to those obtained from DSSAT are possible, but with substantially reduced weather datasets. Relative errors were on average less than 10%. Following more extensive experimentation with several years of weather data, we plan to embed the trained neural networks in an expert system and apply it for estimating performance of different crops in a range of agroecological zones. Results from such analyses may be useful for regional decision makers to compare alternate farming systems, and to ultimately develop guidelines for land and water use management in different agroecological zones.

FRAMEWORKS FOR PLANNING SUSTAINABLE DEVELOPMENT

Strategic planning of development activities requires a systematic decision-making approach. One such approach, Concurrent Decision-Making methodology (CDM), intended to be used within group Decision Support System (DSS-decision tools for group meetings) has been outlined by Nath et al. (1998). The term "concurrent" indicates that all stakeholders present are actively involved in the phases of decision making.

Concurrent Decision-Making Methodology

CDM includes the following phases:

1. Identification and Selection of the Problem
2. Identification of Stakeholders
3. Problem Analysis
4. Goal Identification, Evaluation, and Specification
5. Generation of Solutions
6. Evaluation of Solutions
7. Selection of the Decision
8. Implementation and Monitoring

These phases are briefly described below. The decision phases are listed numerically suggesting the approach is constrained by the need to move from one phase to the next in a linear manner. In reality, however, the process is iterative and somewhat fluid in that one is encouraged to step back to any of the earlier phases (or steps within a given phase) as needed. However, skipping to a future phase is strongly discouraged.

1. Identification and Selection of the Problem
The first phase of the Concurrent Decision-Making methodology identifies and establishes problem objectives, which are stated in the form of a fairly general statement (e.g., degradation of the quality of life in a given region). This statement essentially provides some boundaries for the problem(s) to be addressed.

2. Identification of Stakeholders
The second phase involves identification of stakeholders because diverse individuals and groups are potentially

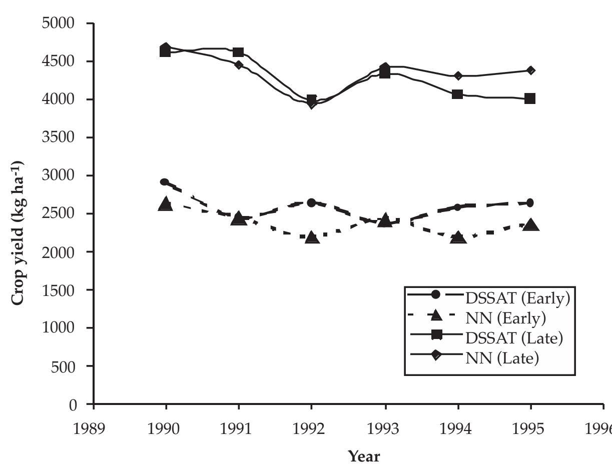

Figure 1. Preliminary results comparing crop yields for soybean from the DSSAT software and trained neural networks (NN) for the years 1990-1995. Early and late, respectively, refer to early and late planting dates for the crop as determined by DSSAT.

impacted by the selected problem or have an interest in seeing a solution to the problem. Each stakeholder may have a specific perspective, but all stakeholders share an identical (higher-level) goal that is represented in the objective statement of the problem.

3. Problem Analysis
This phase involves identification of causal factors, which affect the selected system in such a way that if they are changed, the state of the system will also change. Problem analysis can be systematically approached by adopting a hierarchical structure, with causal factor groups defined and listed at higher (more abstract) levels and sub-factors identified and listed within an appropriate group at lower (less abstract) levels. Direct and indirect relationships among factors/sub-factors should also be identified, because they provide a means for prioritizing intervention efforts. This phase involves considerable use of data and knowledge available for the system, as well as brainstorming among representative stakeholders and experts to ensure a full appreciation of complex and often conflicting factors and sub-factors.

This phase will also involve examination of the current state of the causal factors. At this stage, it is typically necessary to identify measurement units (metrics) for the factors. Note that metrics are usually assigned at the sub-factor level rather than at the factor group level, because the former is less abstract and can therefore be more precisely defined.

4. Goal Identification, Evaluation and Specification
This phase will involve identification of appropriate causal factors/sub-factors in the system that need to be changed in order to address the problems identified in Phase 3 above. The identified causal factors/sub-factors constitute goals, which have the following properties:

- a direction (e.g., increase, decrease, hold constant);
- a numerical value;
- a time frame within which the desired change is to occur;
- an assigned priority; and
- a higher-level context within which the goal resides.

An important step in this phase of CDM is to assign appropriate target values or desired future conditions (DFCs) for the first three of the above properties. It may not always be possible to specify a numerical value and time frame for a goal at the level of a factor group because, as previously indicated, this level is more abstract. However, as part of DFC specifications, sub-factors will always be assigned a desired direction of change in addition to a numerical value and a time frame.

Specifying priorities provides stakeholders with an objective means of weighing different goals and is a critical part of multi-objective decision making. It also provides stakeholders with a more objective basis of understanding the importance each of them assigns to different goals.

With regard to the context of a goal, it is necessary for stakeholders to realize that goals are essentially a means of achieving a higher end. Thus, meeting the DFC for a certain sub-factor is a means of achieving a higher-level goal (specified for the associated factor group). This hierarchical scheme extends all the way up to individual and/or organizational levels.

An additional step in this phase is to evaluate the assigned DFCs in relation to the current state of the causal factors (i.e., calculating the distance between the current and desired future states). This can provide a basis to judge whether assigned DFCs are realistic and if they need to be re-specified. Thus, evaluation and specification of goals occurs in an iterative rather than a sequential manner.

5. Generation of Solutions
This is a brainstorming and creative phase to generate as many concept solutions/decisions as possible with little judgment as to their suitability for the problem. During this phase, it may be necessary to conduct preliminary "what-if" scenarios (e.g., using models and/or other knowledge-based systems) to explore and understand relationships among causal factors and how they may change in response to different intervention schemes.

6. Evaluation of Solutions
In this phase the concept solutions are combined and reduced to a reasonable number, which can be fully explored and subjected to multi-objective optimization analysis, if necessary. It may be necessary to revisit causal factors that were previously identified that may create conflicts among participants.

7. Selection of the Decision
In this phase the focus returns to the individual(s) as the decision maker. It is expected that stakeholders will use both the objective information provided by the above phases as well as their intuition/experience to arrive at a reasoned decision.

8. Implementation and Monitoring
In the final phase of CDM, the decision is committed to action(s), but must be accompanied by appropriate implementation measures and monitoring schemes agreed to by the stakeholders. Often determinations of a detailed procedure of actions, responsibilities of individuals, and timelines are needed, activities that will use knowledge gained from the above phases. Implementation and monitoring schemes are required to continually evaluate consequences of the decisions against DFCs and to acquire new data and knowledge for use in the future. This phase is particularly important for strategic planning activities that are designed to be fully adaptive (responsive) from the outset.

Sustainable Development Indicators

A number of international development organizations (CSD, 1996) have been involved in an integrated effort to develop a framework for sustainable development indicators (SDI). This framework is primarily intended for use in decision making at the national level (CSD, 1996). Because it is to be used as a guide for all the member countries of the UN, the framework is understandably very comprehensive and provides an exhaustive list of development indicators (approximately 130) with associated descriptions. These indicators are categorized within a number of broad categories that address social, economic, environmental, and institutional issues. Within each of these categories, a number of thematic areas are addressed. Thus, social issues that are addressed include:

- combatting poverty;
- demographic dynamics and sustainability;
- promoting education, public awareness, and training; and
- protecting and promoting human health.

Table 1. Examples of higher-, intermediate-, and operational-level goals identified for two of the seven security areas recognized by CARE within an overall mission of sustainable improvement of livelihood security (adapted from CARE, 1998). Operational-level goals have not been assigned specific target levels in these examples because the framework is intended to be a generic one to be adapted by decision-makers in specific locations. In other words, targets for operational goals are site-specific.

Higher-Level Goals	Intermediate-Level Goals	Operational-Level Goals
1. Increase in % of families with nutritional and food security	1.1. Increase in % of families with better access to food	1.1.1. % of families with a target number of meals per day 1.1.2. % of families according to quality (e.g., protein, energy, and micro-nutrients) of meals consumed 1.1.3. % of families according to number of months per year that are scarce in food
	1.2. Increase in % of children with adequate nutrition and growth trends	1.2.1. % of children under 2 years old with less than two standard deviations (weight/height, height/age, weight/age) 1.2.2. % of children under two years old with adequate growth trends
	1.3. Increase in % of families with availability and diversity of food	1.3.1. % of families with higher yields than the regional average for basic crops 1.3.2. % of families implementing more than two non-traditional crops[1] 1.3.3. % of families with agricultural products cultivated in an improved family garden[2]
2. Increase in % of population with environmental security	2.1. Increase in % of population using sustainable practices and appropriate management of natural resources	2.1.1. Increase in % of watersheds under sustainable management 2.1.2. Increase in % of land area under sustainable management 2.1.3. Increase in % of forest area under sustainable management

[1] Farmed fish is often a non-traditional crop that provides diversity in food choices and has substantial nutritional value.
[2] Family gardens for subsistence farmers also increases food diversity, potentially provides better overall nutrition and has other indirect benefits (e.g., increased opportunities for women to both improve family conditions and sell/barter extra produce).

Similarly, environmental issues addressed include:
- protecting freshwater resources;
- protecting ocean resources; and
- promoting sustainable agriculture and rural development.

The above two lists constitute a very small subset of those documented in the SDI framework (CSD, 1996) but serve to illustrate the range of issues addressed. Further, the SDI framework uses a systems approach organized around the following concepts:

1. *Driving Force Indicators*: These represent human activities, processes, and patterns that influence sustainable development;
2. *State Indicators*: These indicate the (current) "state" of sustainable development; and
3. *Response Indicators*: These indicate policy options and other strategies that reflect attempts to change state indicators such that they move towards a more sustainable state.

For example, with respect to promoting sustainable agriculture and rural development, representative indicators identified by CSD (1996) are as follows:

- *Driving Force Indicators*: a) Use of agricultural pesticides; b) use of fertilizers; c) irrigation percent of arable land; and d) energy use in agriculture.
- *State Indicators*: a) Arable land per capita; and b) area affected by salinization and waterlogging.
- *Response Indicators*: a) Agricultural education.

It may be argued that these indicators are somewhat simplistic and even incomplete in some regards, but as stressed in the CSD document, the SDI framework is a work in progress. It is intended to provide a forum where the issues can be discussed and indicators can be expanded or reduced and modified according to the needs and priorities of individual countries/ organizations.

A second argument that can be made against the SDI framework is that it is far too detailed for practical decision making, particularly within individual organizations or small groups of organizations dealing with aspects of social, economic, environmental, and institutional issues (such as those affiliated with the PD/A CRSP). Moreover, it does not lend itself well to an analytical framework for implementation in a decision support system.

Consultations with representatives of CARE, the non-governmental international development organization based in Atlanta, suggest that the strategic planning framework they use is more appropriate for the above situations. This framework is being put into place for Honduras (CARE, 1998) and also approaches sustainable development ("adequate quality of life for all the members of the present generation, leaving the same or better options for future generations") in a systems manner. The framework recognizes social, economic, and ecological sub-systems and focuses on sustainable improvement of livelihood security as an overall mission.

Within the mission of livelihood security, certain higher-level goals can be defined. These goals seek to increase the percentage of the population that has:

1. Nutritional and food security;
2. Health security;
3. Educational security;
4. Participation in civil society deliberations;
5. Housing security;
6. Economic security; and
7. Environmental security.

Within each of the above security areas, CARE has identified intermediate- and operational-level goals. Examples of these for food and environmental security are provided in Table 1. Clearly, the SDI framework developed by CARE is conceptually very compatible with the CDM process described above, particularly with regard to a hierarchical goal structure where higher-level goals are more abstract and lower-level ones more operational in the sense that DFCs can be developed for them.

The next phase in this project should focus primarily on implementation of the above SDI framework in a regional-scale DSS, together with an expert system for estimating crop performance (based on the neural network approach previously discussed) and other knowledge-based tools (e.g., models). We will also integrate GIS functionality into the regional-scale DSS primarily for the purpose of data manipulation, visualization, and analysis. It is expected that the overall tool will be used to explore alternate land/water use strategies in relation to different crops (including fish farming) for the inland regions of Honduras.

ANTICIPATED BENEFITS

The study has two primary benefits to the aquaculture community. First, the identification of geographic sites which show potential for successful aquaculture development is critical in determining how to allocate development resources and identifying opportunities for economic development in a biologically suitable manner. The work accomplished under this study identifies such areas based on important biological parameters. Further, the development of datasets and methodologies supporting this analysis are general and can be applied to other areas and development opportunities. Second, the incorporation of more explicit analysis of land use decisionmaking and alternative uses for particular land forms and resources will allow planners and policymakers to more successfully identify areas where compatible land use patterns can be implemented.

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