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RESEARCH FINAL REPORT

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The Role of a Silage-Microbe Mat in Conjunction with the Detrital Trophic Level as a Complete Natural Fish Feeds System for Tilapia Aquaculture in the Dominican Republic

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I. EXECUTIVE SUMMARY

Tilapia, Oreochromis niloticus, feeding on a microbial mat ecosystem dominated by the cyanobacterium, Oscillatoria, grew faster than control tilapia fed at 3% of their body weight per day. This has been shown in previous experiments where ensiled grass stimulated a bacterial and cyanobacterial (blue-green algae) bloom on the water surface. The objective here was to develop a management system using a novel laboratory tank and field pond design which permits the microbial mat ecosystem to develop in the presences of grazing tilapia.

The laboratory tank design included a deep-water rearing chamber of 50 cm and four "feeding lanes" of approximately 550 cm^2 surface area each in the tanks. These shallow feeding lanes permit light penetration to the bottom sediment.

Feeding lanes included a sluice gate to isolate them from the rearing area. In the laboratory tanks, mature feeding lanes were opened in a sequential arrangement to permit tilapia grazing. As the mat was consumed in one lane, that one was closed and the adjacent was opened. The former lane was re-ensiled. Tilapia were allowed to consume one lane's mat for two days.

The major constraint in this research was the rapid depletion of microbial mat biomass. Microbial mats, in the laboratory, require approximately one week to mature. Tilapia were allowed to consume one lane's mat for two days, or, in other words, test tilapia were presented with approximately 550 (546.25) cm^2 of microbial mat biomass every two days (= 275 cm^2/day). Using the second laboratory trial, tilapia will grow rapidly on microbial mat until their biomass reaches the density of 1 gram of tilapia/50 cm^2 of mat. If tilapia are loaded into the system at a greater rate, then the mat is depleted more rapidly than it can be replaced and the tilapia growth rate will begin to decrease. With this estimation, it is important to consider the rapid growth rate of young tilapia and the numbers involved, not only tilapia biomass. Therefore, this laboratory calculation is only an first approximation.

For the Dominican Republic (DR) field ponds, the entire pond measured 10 x 5 M, with one-half of the surface area dedicated to a rearing area and one-half was four feeding lanes. The rearing area depth was 80 cm to 1 M and each 10-cm depth feeding lane had a surface area of 6.25 M^2. There were no significant differences in weight or length between the three treatments, nor in the percentage increase in weight or length during the 42-day feeding trial. Nevertheless, given the low labor costs in the Dominican Republic, the use of the microbial mat feed system may be economically superior to commercial feed use.

Applicability for Rural Development: This simple technology may provide a viable option to the high costs of commercial fish feeds, thus encouraging peasant farmers to engage in aquaculture. The low-cost inputs (grass clippings) are locally available and the entire operation is environmentally benign. Most significantly, field results initially indicate that the algal mat feed is competitive with commercial feeds.

Cyanobacteria, Toxins and Off-flavor: The *Oscillatoria* strains used in our research dominate other genera of blue-green algae. Only some species of blue-greens produce toxins. Blue-greens also produce geosmin, lending an off-flavor to the fish. This problem may be solved by holding the fish in a blue-green algae-free environment for several days prior to consumption.

Spinoff Activities: Research results were presented at three international fisheries and aquaculture conferences. A. Russell attended both World Aquaculture Society conferences in 1991 and 1992, P. Phillips attended the 1991 World Aquaculture Society conference and J. Bender attended the World Fisheries Congress in 1992.

In September - October 1990, Michigan State University's Consortium for Inter-Institutional Collaboration in African and Latin American Studies invited A. Russell, P. Phillips and J. Bender to present papers at their Conference on Environment and Development in Africa and Latin America. A. Russell's paper was subsequently published in MSU's The Centennial Review Spring 1991, "Environmental Crises: Africa and Latin America".

CNN filmed the microbial mat research in CAU's Environmental Biology Laboratory in August 1991 for airing in September 1991. The use of the microbial mat as a fish feed and footage of the Dominican field ponds were included.

As a corollary to the research activities between Clark Atlanta University and the Catholic University of Santiago, in May - June 1990, P. Phillips began to lead a small group of Atlanta University Center students to the Dominican Republic. The goal was to expose Atlanta University Center (AUC) students to the array of environmental problems facing a typical tropical developing country. To accomplish this, a special "Natural Resources and Energy Use" team-taught course was developed at the Catholic University. The course is coordinated by Phillips at AUC and by A. Russell in the Dominican Republic. This is a multidisciplinary team-taught course in English is based on a successful model of a course taught yearly for Dominican students.

All student participants have returned with a heightened awareness of environmental problems facing a developing country. This exposure, in addition to the enhancement of their Spanish language and cross-cultural skills, will certainly aid their career choices and make them more marketable in their graduate school programs or in their job searching.

This student program is now being advertised in other Atlanta-area colleges and universities, as well as institutions outside of Georgia.

Because of these "spinoff" activities emerging from this research, funding was obtained which actually permitted additional trips to the Dominican Republic and trips by A. Russell to the US. A CAU agricultural economist, Dr. Mesfin Bezuneh, was added to the research team of Phillips and Bender to begin to examine the cost-benefit aspect of this type of fish culture activity. The following sources of additional funding were obtained: 1) Consortium for Inter-Institutional Collaboration in African and Latin American Studies, Michigan State University; 2) Lucille and David Packard Foundation; 3) American Airlines; 3) US Environmental Protection Agency; 5) National Science Foundation.

II. OBJECTIVE

Tilapia, Oreochromis niloticus, feeding in a microbial mat ecosystem dominated by the cyanobacterium, Oscillatoria, grew faster than control tilapia fed at 3% of their body weight per day. This has been shown in previous experiments (Bender et al., 1989a). The objective herein was to design a laboratory tank and field pond and develop a management scheme which would permit the microbial mat ecosystem to develop in the presence of grazing tilapia, thus providing a continuous supply of low-cost natural feed.

Field pond research was conducted in the Dominican Republic and laboratory tank research was conducted at Clark Atlanta University (CAU).

III. RATIONALE

Developing countries generally suffer from a deficit in local food production. This deficit is even more notable when considering nitrogen. Whereas nitrogen is abundant in the atmosphere, fixed nitrogen available for plant and animal growth is often a limiting ingredient in soil and water environments.

Microbial mats are ubiquitous in nature, commonly found over the sediment surface of quiescent water and damp soils. Cyanobacteria, within microbial mats, are nitrogen fixers. Thus, a microbial mat dominated largely by cyanobacteria has a high protein content. In aquatic environments, naturally occurring microbial mats are grazed by a wide range of organisms; bacteria, zooplankton, insects and fish. For example, tilapia, a group of African cichlids, are fishes that commonly graze bacteria, algae, and higher plants in addition to processing organisms contained in the sediment of aquatic ecosystems (Bowen, 1976). As a top consumer of a microbial-based food web, tilapia can concentrate the microbial mat protein into a palatable animal protein for human consumption. Tilapia are already the most popularly-cultured freshwater fishes in tropical developing countries (ICLARM Newsletter, January 1984).

Often, in fish culture, the purchase of commercially prepared feeds can account for more than 50% of the total cost of production (Shang, 1981). This factor effectively eliminates fish culture as a viable animal protein production activity for many peasant farmers in developing countries.

Manipulating microbial mats to grow in large quantities was considered to be one avenue for producing an inexpensive and abundant feed for tilapia. If successful, this environmentally benign technological development can contribute to the overall sustainable management of land and water resources in developing countries.

IV. INTRODUCTION AND BACKGROUND INFORMATION

A natural feed system for tilapia, based on the stimulation provided by ensiled grass clippings in the formation of a stable microbial mat, was initially developed at Morehouse College's Environmental Biology Laboratory (later moved to Clark Atlanta University) in cooperation with the Pontificia Universidad Catolica Madre y Maestra (PUCMM), Santiago, Dominican Republic (Bender, 1988, USAID Grant No. DAN-5053-G-55-5046-00). The present study expanded on the results of the original research project to systematically test the microbial mat ecosystem as a complete tilapia feed in novel laboratory tanks and field ponds.

A. MICROBIAL MATS

Naturally-occurring microbial mats, composed of stratified layers of cyanobacteria and bacteria, evolved in primordial times, occupying the most inhospitable environments on earth. Harsh environmental conditions have, during evolutionary history, selected for unique physiological characteristics in these ecosystems and have generated microbial communities with adaptive flexibility under extreme conditions. The dominant cyanobacterial component of microbial mats, while photosynthetic, are known to utilize exogenous organic substrates under both light and dark conditions (heterotrophy) as a portion of their total carbon requirement for growth (Fogg et al., 1973).

1. Physiological characteristics of mats:

The physiological flexibility of microbial mats is determined by the characteristics of the cyanobacteria. These include: (1) anoxygenic and oxygenic photosynthesis (Stahl et al., 1989; Ward et al., 1989); (2) rapid induction of nitrogen fixation after oxygen exposure (Paerl and Gallucci, 1985); (3) gliding motility (Shilo, 1989); (4) survival of periodic desiccation (Shilo, 1989); and (5) successful support of a consortium of bacteria of both aerobic and anaerobic function (Caumette, 1989). These properties contribute, in a general way, to the durability and self-maintenance of the mat community. Details of some microbial mat characteristics are:

a. Flocculation: Certain species of cyanobacteria produce flocculating macromolecules, which effectively clarify the water column. The clarification process increases the solar radiation in the sediment region and, at the same time, causes the rapid deposit of heavy metals associated with particulate matter.

b. Sulfur cycle in microbial mats: The unique microbial populations that generally constitute a mat in the oxic/anoxic zones of a pond possess physiological and ecological mechanisms for the oxidation/reduction of sulfur as well as its transport within the mat and export into the water column (Bender et al., 1989b; Caumette, 1989).

c. Slime secretion: Microbial mats attach to the underlying sediments by means of a gel matrix, which incorporates the top 1-2 mm of sediment particles into the mat matrix. Xenobiotics deposited in this region can become passively incorporated into the mat conglomerate.

d. Gliding motility: Cyanobacteria are able to emerge from silt cover by gliding reactions. This mechanism can be assumed to mobilize xenobiotics from deeper regions to the sediment surface (Shilo, 1989).

B. TILAPIA FEEDING AND GROWTH

For tilapia to remain an inexpensive aquaculture option for developing countries, inexpensive diets are required. Research on tilapia dietary requirements has often aimed to replace animal protein sources, frequently with locally available plant protein sources.

A summary of protein inclusion levels in tilapia diets indicated that a 30% protein diet gives reasonable growth in many species (Jackson et al., 1982).

Beveridge et al. (1989) found that tilapia *O. niloticus* were able to detect the presence of and ingest bacteria in suspension in the water column. Tilapia also consume particle-bound bacteria. This is bacteria associated with particulate organic matter or detritus (Bowen, 1976; Schroeder, 1978). These bacteria are lysed in the low pH of the tilapia's stomach. These findings imply that tilapia should be able to digest the contents of a microbial mat.

V. METHODOLOGY

A. ARTIFICIAL STIMULATION OF MICROBIAL MATS

Microbial mats generally attach tightly to the soil or sediment substrate below the water column. The CAU laboratory-developed microbial mats can be stimulated to form on the water surface by adding buoyant ensiled grass clippings. In this case a double mat generally forms on both sediment and water surfaces (Fig. 1).

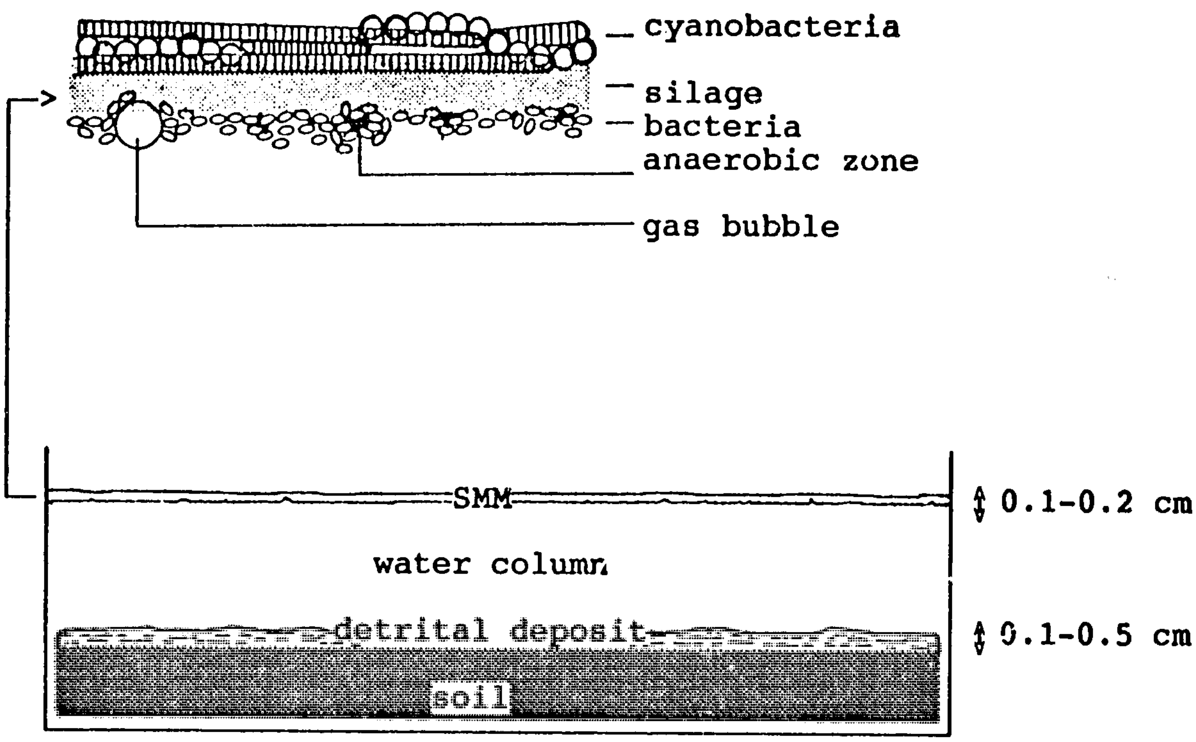

Fig. 1. Schematic diagram of a laboratory microbial mat.

Specific methods for silage production and mat generation are as follows. The tank bottom soil was initially enriched with 1.5g of $CaCO_3$, 0.3g of potash and 2.3g of phosphate. Since the Dominican field ponds were constructed with landfill transported from off-site (Fig. 2), the soil was irregularly enriched with phosphate, calcium carbonate, nitrate and potassium to stimulate the initial microbial mat (Table 1).

Fresh grass was cut and placed in an air-tight container for 15 to 20 days. Finished silage was applied to the tank, containing charcoal-filtered tap water, or field pond surface at a rate of 30 to 50 g dry weight/M^2. In the field ponds, the

Fig. 2. Dominican field pond construction in process.

Table 1. Dominican Republic field pond fertilization schedule.

May 23, 1991:	*Superphosphate*	*45 g/canal*
	Silage	*120 g/canal*
June 6, 1991:	*same as above*	
July 7, 1991:	*Superphosphate*	*45 g/canal*
	Silage	*500 g/canal*
	N-P-K, 14-6-8	*50 g/canal*
Aug 8, 1991:	*Superphosphate*	*90 g/canal*
	Silage	*1,000 g/canal*
	Lime	*50 g/canal*
Sep 9, 1991:	*Superphosphate*	*90 g/canal*
	Silage	*1,000 g/canal*
Nov 11, 1991:	*Superphosphate*	*90 g/canal*
	Lime	*125 g/canal*

corresponding wet weight of silage, calculated from the wet/dry weight relationship determined in the laboratory, was 172 g/M^2. In the laboratory, cultures were maintained at ambient temperatures (25-29 C) and under a 12-h light/12-h dark cycle provided by incandescent light placed at 25 cm over the cultures.

B. TILAPIA GROWTH PERFORMANCE IN THE CLARK ATLANTA UNIVERSITY LABORATORY TANK PHASE

Since the microbial mat biomass needs to develop and mature in isolation before the tilapia are allowed to consume it, a novel laboratory tank and Dominican field pond design was developed.

1. Laboratory Tank Design:

The design of three experimental and three control acrylic plastic tanks promoted the formation of the microbial mat and its complementary sediment layer (Fig. 3). The deeper water chamber contained a volume of water 0.5 x 0.5 x 0.4 M (depth) and served as a "grow-out" area and refuge from the adjacent shallow mat production area. This shallow area was 0.5 x 0.5 x 0.1 M (depth) and divided by a plastic barriers into four "feeding" lanes of 550 cm^2 surface area each. These shallow feeding lanes permitted light penetration to the bottom sediment and thus promoted microbial mat development. Each feeding lane included a removable barrier or sluice gate to isolate them from the grow-

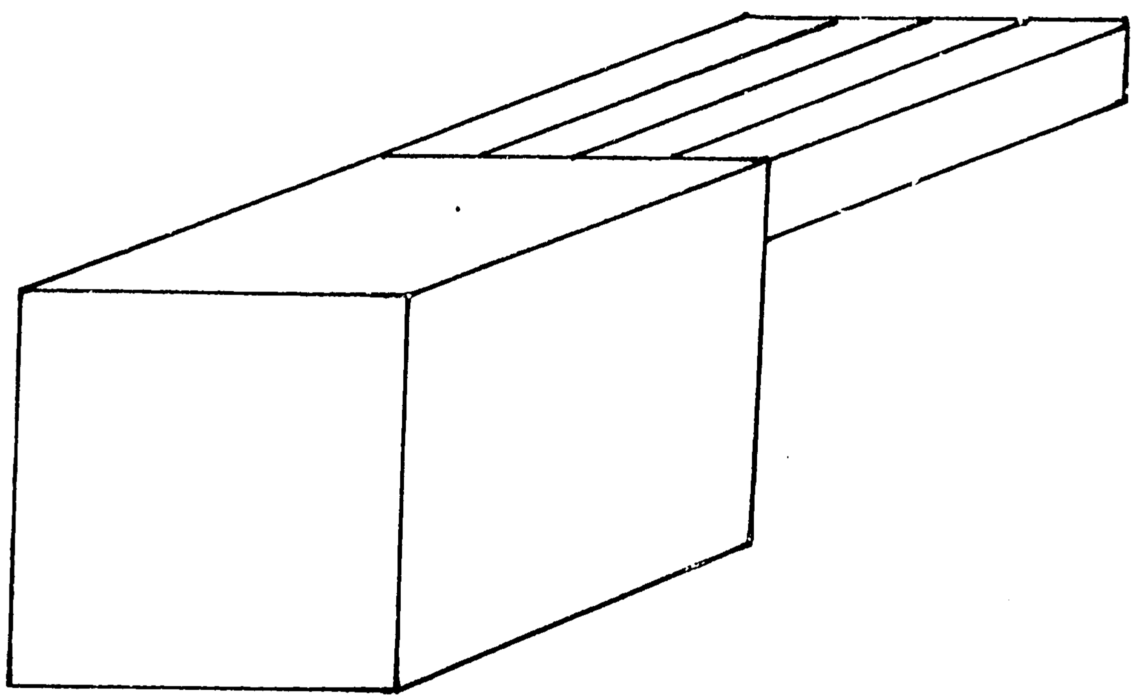

Fig. 3. Laboratory tank design which includes one "grow-out" chamber and four feeding lanes.

out area. Mature feeding lanes were opened in a sequential arrangement to permit tilapia grazing. As the mat was consumed in one lane, that one was closed and the adjacent was opened. The former lane was then re-ensiled. A 1:1 surface area ratio of feed production to grow-out chamber was arbitrarily chosen.

To remove the effect of this unusual tank design from the data analysis, three control tanks were identically constructed, though tilapia in these tanks were fed a commercial feed ration.

2. Growth Trials:

Three growth trials were conducted with: (1) 0.06 - 0.08 g; (2) 0.64 - 0.86 g; and (3) 2.0 - 2.8 g tilapia *O. niloticus* in a triplicate experimental design. Stocking levels, or number of tilapia/tank, was variable between growth trials in an attempt to maximize the number of individuals or the tilapia biomass that could be sustained per surface area of microbial mat without exhausting the mat. Therefore, the stocking levels were: (1) 12 tilapia/tank; (2) 20 tilapia/tank; (3) 6 tilapia/tank.

Experimental-tank tilapia fed on the microbial mat. Control-tank tilapia were given a 4% commercial feed ration, based on the total biomass/tank. Tilapia were generally measured and weighed on a weekly basis. The control tilapia commercial feed ration was adjusted after weighing.

3. Water Quality:

Frequent measurements of temperature, dissolved oxygen (Otterbine Sentry III meter), hydrogen ion concentration (Markson pH pen or Accumet Ph meter), and ammonia-N and nitrite-N levels (HACH kits) were taken. Partial water exchange was done when ammonia levels exceeded 1 mg/L.

C. TILAPIA GROWTH PERFORMANCE IN THE DOMINICAN REPUBLIC FIELD POND PHASE

1. Pond Design:

Nine ponds were constructed at the Research and Improvement Center for Animal Production (CIMPA) foundation farm near Santiago, Dominican Republic. The design of eight of the nine ponds promoted the formation of the mat and its complementary sediment layer (Fig. 4). The same 1:1 surface area ratio of feed production to grow-out or rearing area used in the laboratory tank design was employed in the field pond design. The entire area of each pond covered 10 x 5 M^2, half of which (5 x 5 x 1 M) served as a grow-out area and refuge from the adjacent 5 x 5 M^2 shallow mat production region. This latter was divided into four lanes. The rearing area depth was 80 cm to 1 M and each 0.1 M-depth feeding lane had a surface area of 6.25 M^2. Each lane was separated from the others by a wooden barrier. The four lanes had removable barriers to the deeper grow-out area to isolate them in a sequential manner as the mat was developing.

To remove the effect of this unusual pond design from the

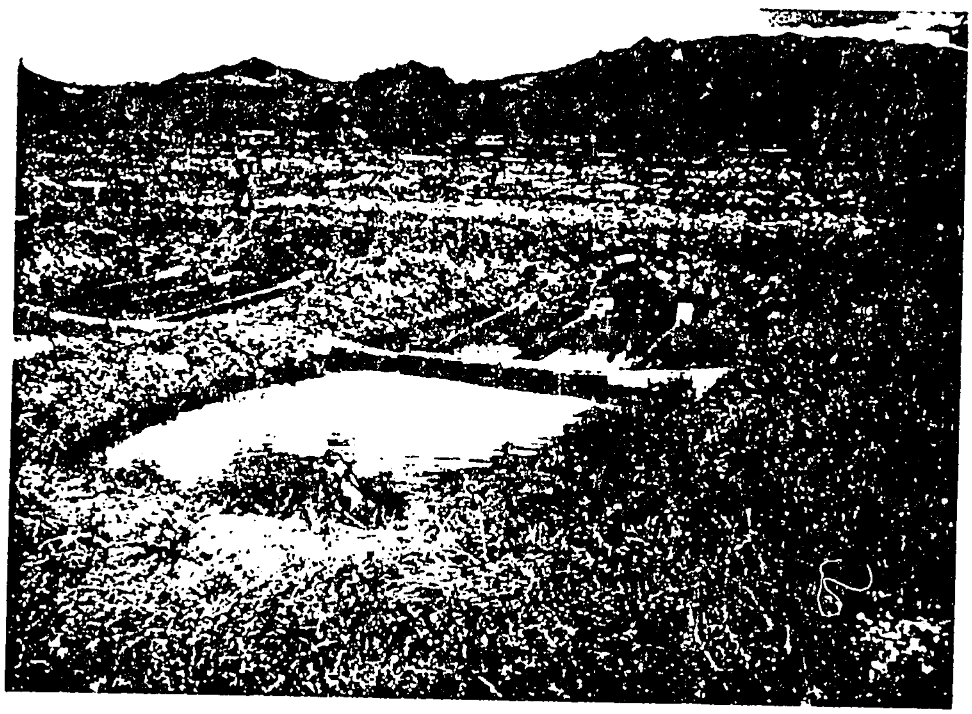

Fig. 4. Upper. Ensiling the feeding lanes in the Dominican field ponds. Lower. One of eight ponds containing four feeding lanes plus a deeper water refuge. Barriers are removed, one lane at a time, for tilapia grazing and replaced when mat is consumed. That lane is then re-ensiled.

data analysis, the eight ponds were identically constructed for all feed treatments. A ninth 10 x 5 M^2 pond was constructed without feeding lanes to mimic a more Dominican fish culture pond design.

2. Feeding Regimen and Stocking Density:

Three feeding regimens were tested in triplicate (three ponds/feeding regimen) among the nine ponds. The feeding regimen/pond was randomly assigned, except for the traditionally-designed pond. That was employed as a control pond (Fig. 5). Treatment 1 was the microbial mat. Treatment 2 was the microbial mat plus a 3% "chicken starter" commercial feed (broadcast daily at 3% of the tilapia biomass; adjusted after each weighing).

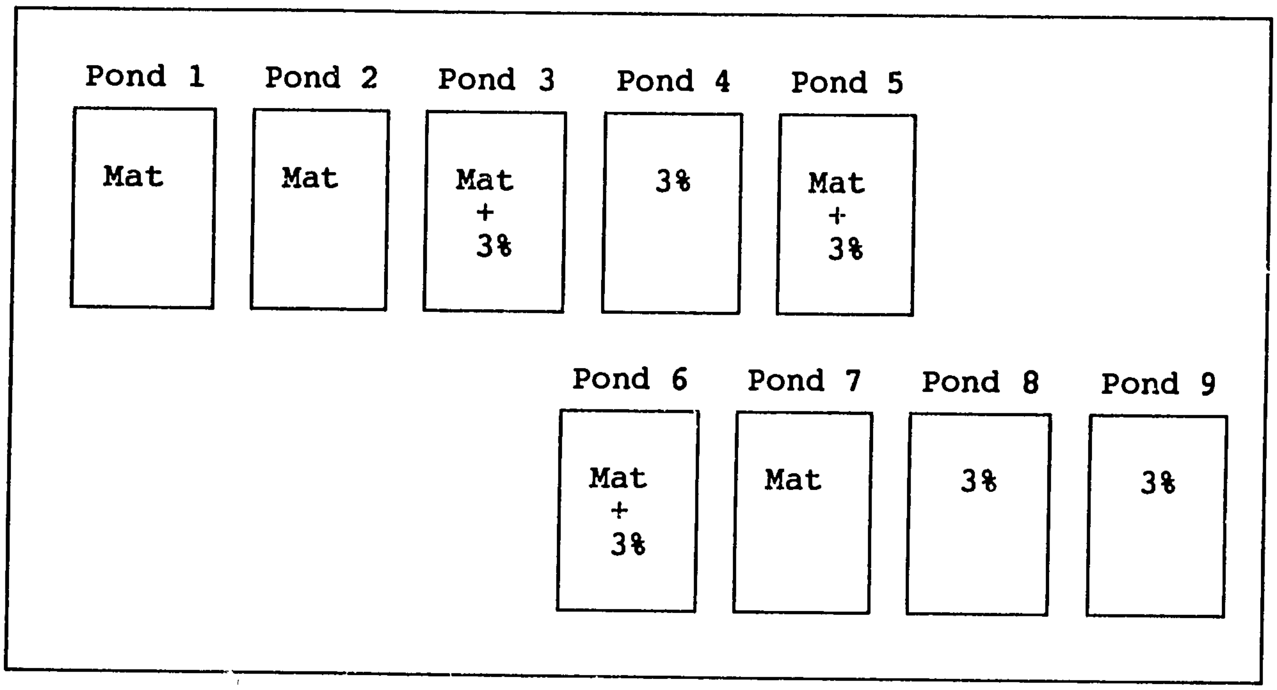

Fig. 5. Feeding regimen assignment/pond at CIMPA, Dominican Republic. Mat = microbial mat feed only, Mat + 3% = microbial mat + 3% body weight commercial feed, 3% = a 3% body weight commercial feed only.

Treatment 3, the control, was only the 3% commercial feed. The commercial feed was identical to that used in traditional fish culture research at CIMPA.

Stocking levels were 2 tilapia/M^2 grow-out surface area. This amounted to 50 tilapia in all ponds except 100 tilapia in the one traditionally-designed pond. Tilapia were measured (mm) and weighed (g) at 0, 10, 28 and 42 days. The growth trial ended at 42 days.

VI. RESULTS

A. NUTRIENT COMPARISON OF THE INPUT SILAGE TO THE FINAL MAT

Ensiled grass clippings add organic acids, principally lactic and acetic acids, to the system. In the laboratory, within days a spontaneous succession of microbial species, including nitrogen-fixing bacteria and cyanobacteria emerged spontaneously (without inoculation) and raised the protein levels to 25 to 30% of the final mat in approximately seven days (Fig. 6).

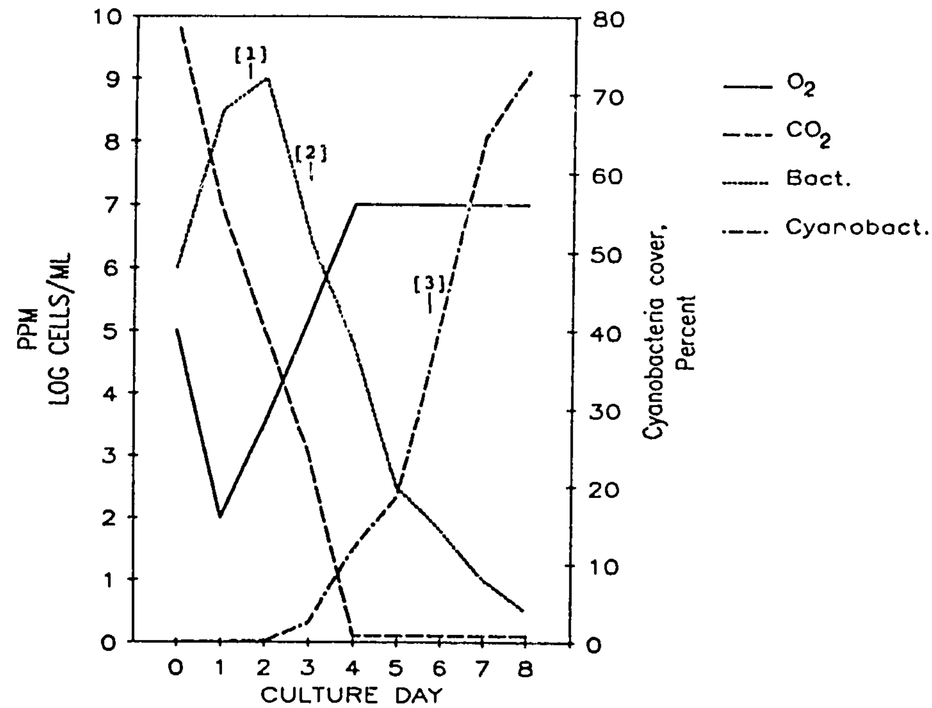

Fig. 6. Successional stages of the microbial mat community after grass silage enrichment. Bacterial measurements represent the nitrogen-fixing component only. (1) Bacterial bloom in the water column; (2) migration of the bacteria from the water column to the silage at the surface of the pond; (3) invasion of the surface mat by cyanobacteria. Profiles of oxygen and carbon dioxide signify the changing populations from bacteria to cyanobacteria.

Carbohydrate was supplied by cyanobacterial photosynthesis. Microbial biomass was ready for grazing, in the laboratory, in four to seven days (when a thick, green mat of material begins to float on the surface). The grass silage serve a secondary structural function for floating mat development. The final product was a thick floating green mat over a clear water column. A gelatinous material developed concurrently on the surface of the sediments.

This sequence was repeated in the Dominican field ponds at a slower rate. Additionally, growth of green algae was common in the ponds. These developed a periphyton-type flora of cyanobacteria.

Once established, the microbial mat becomes annealed together by a gel matrix, secreted by one or more communal members. Oxygen depletion and sulfide build up is common below the photozone of the mat and abrupt vertical redox gradients are established. In addition, gradients of decreasing mineral concentrations extend from the sediment up toward the cyanobacteria surface, while gradients of decreasing carbohydrate levels establish from the cyanobacteria region down into the sediment zone.

The rapid movement of molecules by diffusion along these gradients allows for efficient internal exchange of minerals and may account for the rapid metabolism and subsequent high rate of productivity in this ecosystem. In terms of overall productivity the microbial mats, generated at CAU by enrichment of small ponds with ensiled grass clippings, demonstrated a biomass production rate of 14.96 $g/m^2/d$. This growth level surpasses some of the most productive legume field crops (Bender et al., 1989a).

Significant increases in protein, carbohydrate and biomass were produced in seven to ten days (Fig. 7). The final product is comparable to a Purina commercial catfish ration in digestibility (measured by the difference in protein content of the feed and the protein content of the feces) by <u>O. niloticus</u> (Ekpo and Bender, 1989). Samples of microbial mat from the laboratory tanks and the field ponds were analyzed for an amino acid profile by an independent laboratory (Woodson-Tenent Laboratories, Inc., Gainesville, GA) (Table 2).

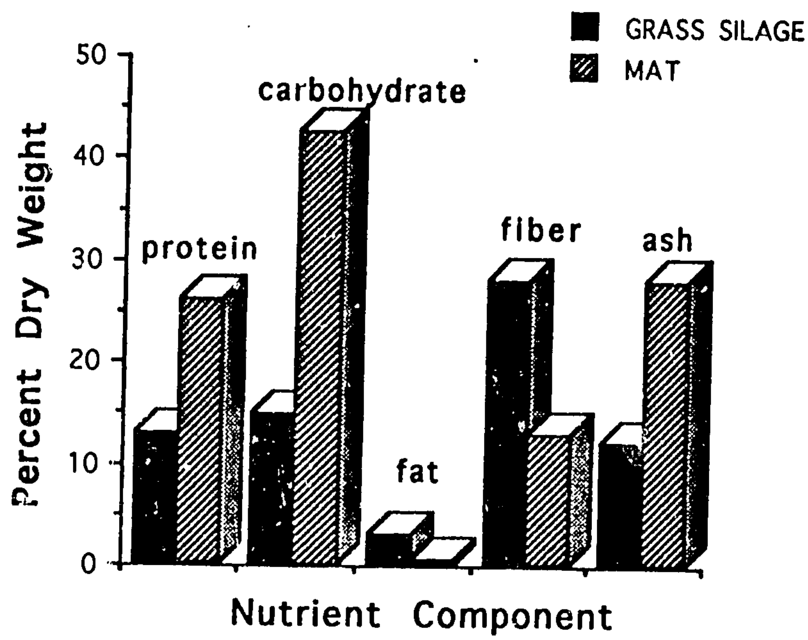

Fig. 7. Comparison of silage feed stock to final microbial mat

Table 2. Amino acid profile of laboratory-developed and Dominican field pond-developed microbial mats. The analysis was conducted by Woodson-Tenent Laboratories, Inc., Gainesville, GA.

AMINO ACID PROFILE OF DR MAT

*TRYPTOPHAN	0.18%	
ASPARTIC ACID	2.15%	
*THREONINE	1.22%	
SERINE	0.95%	
*METHIONINE	0.29%	- Sulfur-bearing
*ISOLEUCINE	1.16%	
*LEUCINE	1.78%	
TYROSINE	0.73%	
*PHENYLALANINE	0.83%	
*HISTIDINE	0.64%	
*LYSINE, TOTAL	0.99%	
*ARGININE	1.08%	
TOTAL	12.00%	

* Essential amino acids. Valine is an essential amino acid not found in the mat. Fish need at least one sulfur-bearing amino acid. They can then synthesize the remaining sulfur-bearing amino acids from this (Stickney, 1979).

AMINO ACID PROFILE OF LABORATORY MAT

*TRYPTOPHAN	0.15%	
ASPARTIC ACID	1.94%	
*THREONINE	0.88%	
SERINE	0.60%	
*METHIONINE	0.26%	- Sulfur-bearing
*ISOLEUCINE	0.87%	
*LEUCINE	1.45%	
TYROSINE	0.30%	
*PHENYLALANINE	0.71%	
*HISTIDINE	0.62%	
*LYSINE, TOTAL	0.83%	
*ARGININE	0.68%	
GLUTAMIC ACID	1.88%	
PROLINE	0.69%	
ALANINE	1.00%	
CYSTINE	0.19%	
*VALINE	0.82%	
TOTAL	14.68%	

B. GENERAL WATER QUALITY

Previous laboratory data have shown that in the presence of microbial mat, oxygen levels remain at 3 to 5 ppm during the night and total ammonia levels stabilize at approximately 0.4 mg/L at seven to ten days (Bender, 1988).

In the present laboratory tank experiments, microbial mat was only located in the feeding lanes. Therefore, water quality in the "grow-out" tanks, not in contact with microbial mat, were maintained by supplemental aeration and partial water changes when the ammonia-N levels exceeded 1 mg/L (Table 3).

Table 3. Mean water quality in laboratory tank experiments. E1-3 were experimental and C1-3 were control tanks.

EXPERIMENT 1

	Temperature	D.O.	pH	NH_3
E1	x = 24.5 s.d.=1.40	x = 7.2 s.d.=1.41	x = 7.5 s.d.=0.21	x = 1.11 s.d.=0.73
E2	x = 24.5 s.d.=1.40	x = 7.2 s.d.=1.50	x = 7.4 s.d.=0.27	x = 1.2 s.d.=0.77
E3	x = 24.4 s.d.=1.36	x = 7.4 s.d.=1.51	x = 7.5 s.d=0.22	x = 1.01 s.d.=0.70
C1	x = 24.4 s.d.=1.40	x = 7.3 s.d.=1.51	x = 7.6 s.d.=0.34	x = 1.64 s.d.=1.00
C2	x = 24.5 s.d.=1.44	x = 7.4 s.d.=1.47	x = 7.6 s.d.=0.23	x = 1.58 s.d.=0.91
C3	x = 24.5 s.d.=1.40	x = 7.6 s.d.=1.48	x = 7.6 s.d.=0.22	x = 1.60 s.d.=0.92

EXPERIMENT 2

	Temperature	D.O.	Ph	NH_3
E1	x = 25.5 s.d.=1.03	x = 7.4 s.d. 0.47	x = 8.2 s.d.=0.29	x = 0.24 s.d.=0.05
E2	x = 25.4 s.d.=1.05	x = 7.7 s.d.=0.69	x = 8.1 s.d.=0.77	x = 0.25 s.d.=0.05
E3	x = 25.4 s.d.=1.05	x = 7.3 s.d.=0.25	x = 8.1 s.d.=0.24	x = 0.25 s.d.=0.05
C1	x = 25.1 s.d.=1.27	x = 7.1 s.d.=0.94	x = 8.2 s.d.=0.27	x = 0.25 s.d.=0.05

EXPERIMENT 3

	Temperature	D.O.	pH	NH_3
E1	x = 24.6 s.d.=1.29	x = 7.9 s.d.=0.61	x = 7.6 s.d.=0.13	x = 0.55 s.d.=0.35
E2	x = 24.0 s.d.=1.32	x = 7.9 s.d.=0.62	x = 7.6 s.d.=0.12	x = 0.57 s.d.=0.30
E3	x = 24.0 s.d.=1.28	x = 7.9 s.d.=0.59	x = 7.8 s.d.=0.12	x = 0.65 s.d.=0.34
C1	x = 23.2 s.d.=1.29	x = 8.0 s.d.=0.79	x = 7.4 s.d.=0.12	x = 0.43 s.d.=0.18
C2	x = 23.0 s.d.=1.26	x = 8.0 s.d.=0.88	x = 7.5 s.d.=0.17	x = 0.50 s.d.=0.22
C3	x = 23.1 s.d.=1.22	x = 7.9 s.d.=0.86	x = 7.5 s.d.=0.16	x = 0.5 s.d.=0.22

C. CLARK ATLANTA UNIVERSITY LABORATORY TANK PHASE

Three growth trials were run:

1. EXPERIMENT 1, Eight-week trial:

The three experimental (E) and three control (C) tanks were stocked with 12 tilapia/tank. The initial average tilapia weight/tank among the six tanks ranged from 2.0-2.8 g.

During the first weekly interval, E-tilapia experienced a weight gain of 24-38% (averages among the three E-tanks), whereas C-tilapia experienced a weight gain of 11-20%. The microbial mat supply was exhausted in this time interval with this particular stocking density. Thus, during the subsequent second weekly interval, the E-tilapia experienced a dramatic decrease in percent weight gain or even a decrease in weight (negative 6-+3% change). The C-tank tilapia increased from 16-25% in average weight among the three tanks. After the second week, a supplemental 550 cm^2 tray of microbial mat plus it's respective sediment was placed into the rearing chamber of each E-tank. In addition, a commercial feed ration equivalent to 1.5% of the tilapia biomass/E-tank was added as another supplement. Therefore, with this adjustment of the E-tilapia feeding regime, this trial run's new objective was now to see if the weight loss could be recovered and if the microbial mat system would "spare" one-half of the commercial diet. The weight loss stabilized by the third weekly interval and the rate of gain was similar to the weight gain experienced by the C-tilapia. By the end of nine weeks, the average weight gain per tank was: for E-tanks, 13.4, 7.5 and 13.8%; and for C-tanks, 13.9, 14.1 and 14% (Table 4 and Figures 8 and 9).

There was no significant difference in length or weight gain among the E-tank tilapia (analysis of variance, $P>0.05$). C-3 tank grew significantly less, in both length and weight than C-1 and C-2 tank tilapia ($P<0.05$). Overall, C-tank tilapia grew significantly faster than E-tank tilapia.

This trial was terminated at the end of eight weeks because several of the larger tilapia began to breed in the feeding lanes, thus making feeding trials impossible.

Table 4. Mean length and weight of O. niloticus per sampling interval for the Eight-Week laboratory trial.

Oreochromis niloticus Mean Weight Increase (g)

EXPERIMENT 1

Mean weight at day:

	0	11	18	26	32	39	46	53	60
E1	2.5g	3.1	3.0	3.1	3.2	3.8	4.6	5.6	6.6
E2	2.8g	3.5	3.3	3.3	3.3	3.8	4.2	4.9	5.3
E3	2.1g	2.9	3.0	2.9	3.1	3.8	4.4	5.2	5.6
C1	2.7g	3.0	3.7	4.4	4.7	5.2	5.8	6.6	7.5
C2	2.6g	3.1	3.6	4.5	4.7	5.0	5.8	6.5	7.5
C3	2.0g	2.4	3.0	3.6	3.8	4.1	4.6	5.0	5.6

Oreochromis niloticus Mean Length Increase (mm)

EXPERIMENT 1

Mean length (mm) at day:

	0	11	18	26	32	39	46	53	60
E1	40.9	44.1	44.3	43.9	43.6	46.8	49.9	52.8	56.0
E2	42.2	46.3	46.5	45.2	45.0	46.9	48.4	50.8	52.6
E3	38.6	42.9	43.3	43.1	44.1	46.3	48.5	51.6	54.1
C1	41.9	42.4	43.6	47.9	50.1	52.1	54.7	56.8	59.3
C2	40.9	42.9	43.4	47.9	50.0	52.5	54.6	56.8	59.0
C3	36.8	40.3	41.3	44.4	46.5	47.7	50.0	51.9	50.6

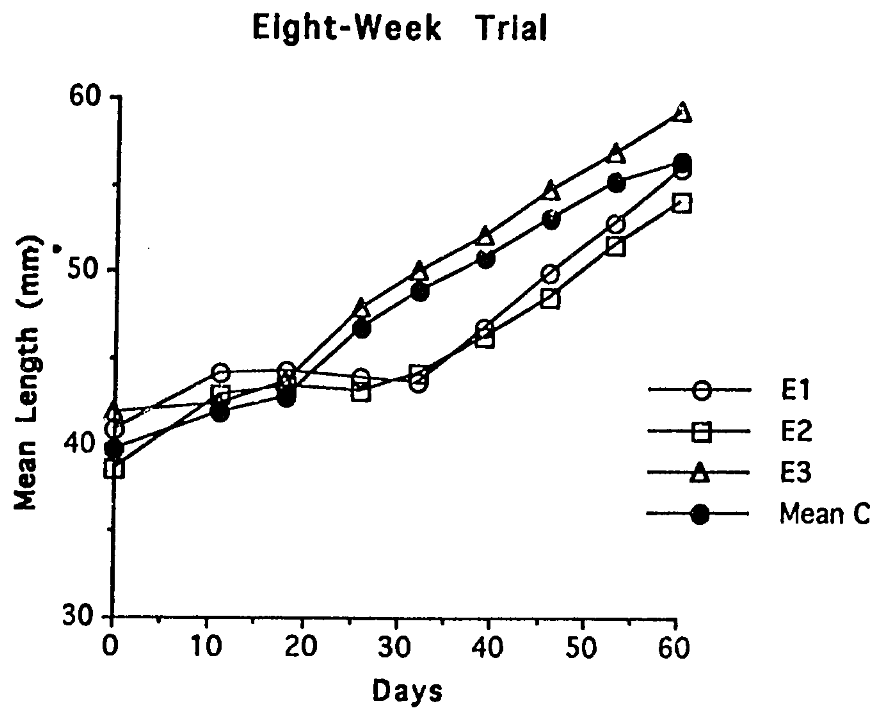

Fig. 8. Mean standard length (mm) of O. niloticus for the Eight-Week Trial. For clarity, C-tank lengths were grouped.

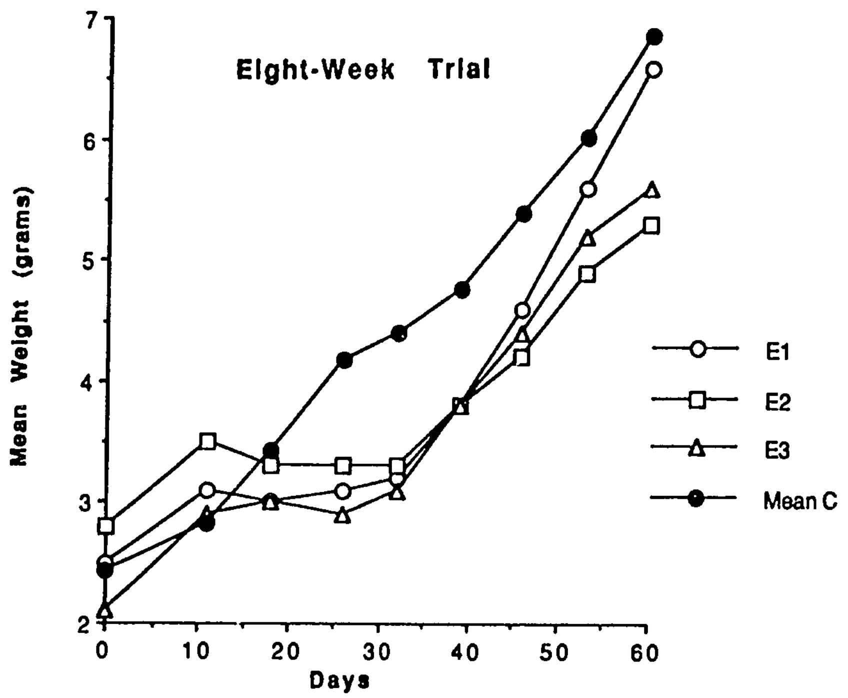

Fig. 9. Mean weight (g) of O. niloticus for the Eight-Week Trial. For clarity, C-tank lengths were grouped.

2. **EXPERIMENT 2,** Nine-week trial:

In this trial, only one C-tank was used. The three experimental (E) and one control (C) tanks were stocked with 25 tilapia/tank. The initial average tilapia weight/tank among the four tanks ranged from 0.06-0.08 g. Due to their small size, these tilapia weren't measured in length. They were weighed only infrequently.

The first weighing was at six weeks. E-tilapia experienced a weight gain of 150, 700, 733%, whereas C-tilapia experienced a weight gain of 467%. The second weighing was at 2.5 weeks. The E-tilapia increased 38, 52, 135% in mean weight/tank, whereas the C-tilapia increased 26% (Table 7).

Table 5. Mean weight of O. niloticus per sampling interval for the Nine-Week Trial.

Oreochromis niloticus Mean Weight Increase (g)

EXPERIMENT 2

Mean wgt. at day:

	0	43	65
E1	*06g*	*.50*	*.76*
E2	*.06g*	*.48*	*.66*
E3	*.08g*	*.20*	*.47*
C1	*.06g*	*.34*	*.43*

Though the growth curves for the different tanks show superior growth in microbial mat-fed E-tilapia, upon statistical treatment, there was no significant difference in weight gain among the E-tilapia tanks, nor was there a significant difference in weight gain between the C-tilapia and the three E-tilapia tanks (Figure 10).

This experiment was discontinued due to copepod competition with the E-tilapia. Copepods are voracious microbial mat consumers. Redear sunfish Lepomis microlophus were eventually used to control copepod populations and mosquitofish Gambusia affinis were used to control mosquito larvae in the E-tanks. Neither of these fish consume the microbial mat.

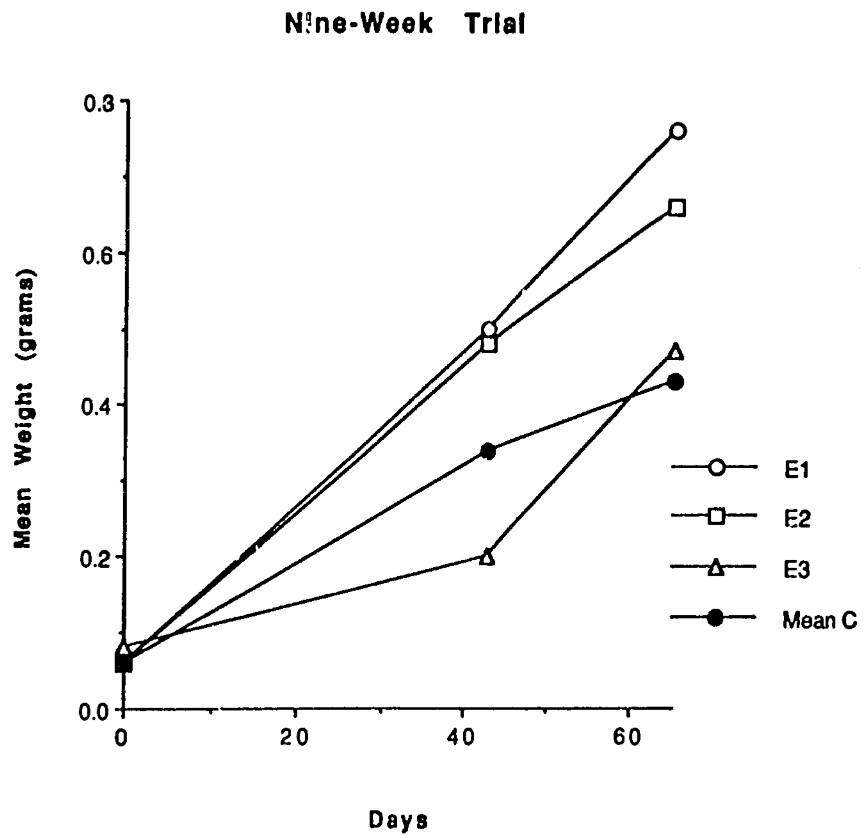

Fig. 10. Mean weight (g) of O. niloticus for the Nine-Week Trial. There was only one C-tank.

3. **EXPERIMENT 3**, Three-week trial:

The three experimental (E) and three control (C) tanks were stocked with 6 tilapia/tank. The initial average tilapia weight/tank among the six tanks ranged from 0.64-0.86 g.

During the first weekly interval, E-tilapia experienced a weight gain of 22, 39, 58%, whereas C-tilapia experienced a weight gain of 9, 10, 14% (Table 6). The increase in length and weight among E-1 and E-2 tilapia was consistently superior (significant at $P<0.05$) to that of C-tilapia (Figs. 11 and 12). The experiment was terminated at the end of three weeks because the tilapia had grown to a point at which the microbial mat supply was being exhausted.

Table 6. Mean length and weight of O. niloticus per sampling interval for the Three-Week Trial.

Oreochromis niloticus Mean Weight Increase (g)

EXPERIMENT 3

Mean weight at day:

	0	7	14	21
E1	.86g	1.36	1.50	1.92
E2	.84g	1.16	1.44	1.64
E3	.65g	.79	.90	1.02
C1	.66g	.72	.76	.81
C2	.73g	.80	.84	.84
C3	.64g	.73	.77	.81

EXPERIMENT 3

Mean length (mm) at day:

	0	7	14	21
E1	28.7	31.3	32.7	35.8
E2	27.2	29.5	35.8	34.3
E3	25.7	26.2	28.0	29.3
C1	25.2	25.8	26.5	27.0
C2	27.7	27.3	27.7	27.7
C3	27.0	26.3	26.8	27.3

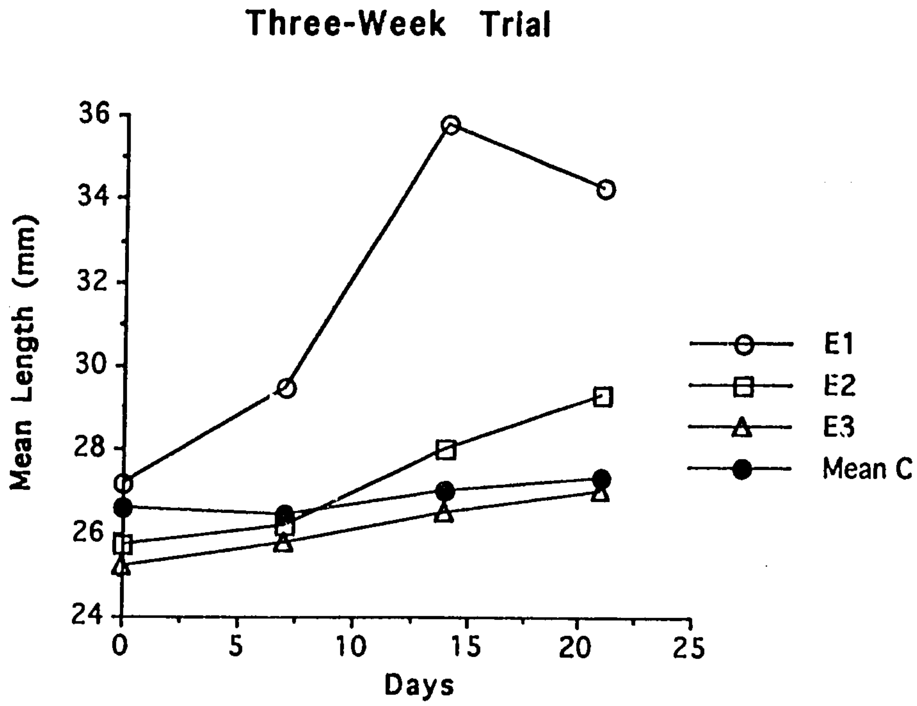

Fig. 11. Mean standard length (mm) of O. niloticus for the Three-Week Trial. For clarity, C-tank lengths were grouped.

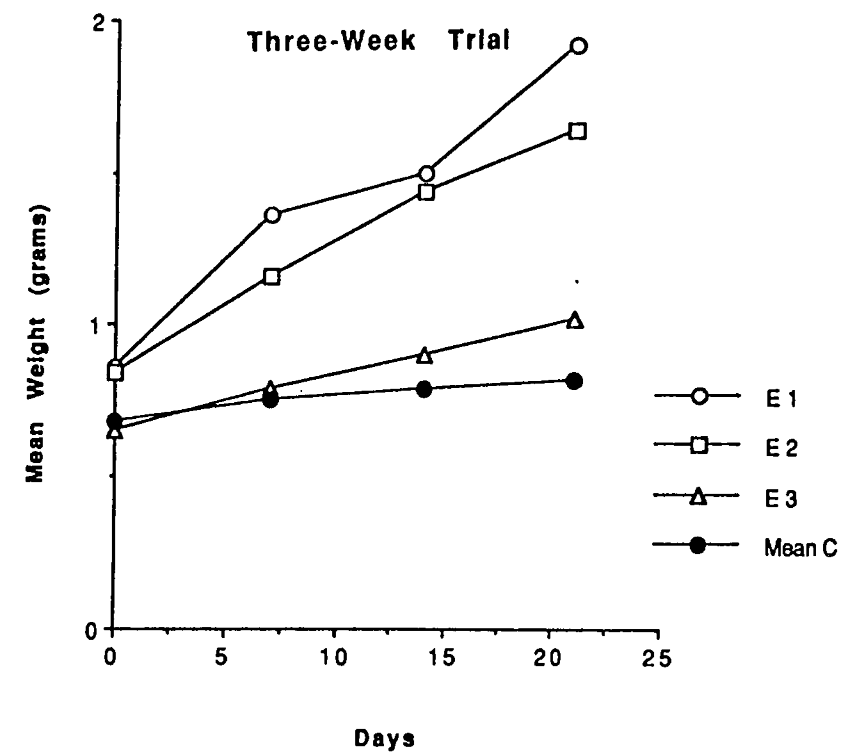

Fig. 12. Mean weight (g) of O. niloticus for the Three-Week Trial. For clarity, C-tank lengths were grouped.

Table 7. Comparison of percentage weight gain by feed treatment among the three laboratory experiments.

LABORATORY TANKS

Tank	*Exp.1*	*Exp.2*	*Exp.3*
	Mean % Wgt. Increase		
E1 mat	*13.4*	*393*	*29.3*
E2 mat	*7.5*	*369*	*25.7*
E3 mat	*13.8*	*143*	*16.3*
C1 com. feed	*13.9*	*247*	*7.3*
C2 com. feed	*14.1*		*5.0*
C3 com. feed	*14.0*		*8.0*

The major constraint in this research was the rapid depletion of microbial mat biomass. Microbial mats, in the laboratory, require approximately one week to mature. Tilapia were allowed to consume one lane's mat for two days, or, in other words, test tilapia were presented with approximately 550 cm^2 of microbial mat biomass every two days (= 275 cm^2/day). Using the third trial results, tilapia will grow rapidly on microbial mat until their biomass reaches the density of 1 gram of tilapia/50 cm^2 of mat. If tilapia are loaded into the system at a greater rate, then the mat is depleted more rapidly than it can be replaced and the tilapia growth rate will begin to decrease. With this estimation, it is important to consider the rapid growth rate of young tilapia and the numbers involved, not only tilapia biomass. Therefore, this calculation is only a first approximation.

C. DOMINICAN REPUBLIC FIELD POND PHASE

One flaw in the field pond experiment was the unavailability of a uniformly-sized tilapia, such that there was a great deal of variation in mean sizes (length and weight) among the ponds. Nevertheless, all three feed treatments received a similarly varied stock of tilapia.

Initial mean weights ranged from 6.0-17.5 g and mean lengths from 16.5-61.0 mm.

There was no significant difference in growth in length or weight among the three feed treatments during the 42-day growth period (Table 8 and Figs. 13 and 14).

Table 8. O. niloticus growth (length and weight) in the Dominican Republic field ponds. The three triplicate treatments were: Mat = microbial mat feed; Mat+3% = microbial mat + a commercial feed of 3% tilapia biomass; 3%Comm = a commercial feed of 3% tilapia biomass. The tabled results are triplicate means.

Mean length (mm) among treatments at day:

Pond	0	10	28	42
mat	35.7	56.5	70.0	101.7
mat+3%	28.8	51.0	77.3	104.7
3% comm	33.8	55.7	72.7	109.7

Mean weight (g) among treatments at day:

Pond	0	10	28	42
mat	10.9	16.5	21.9	28.9
mat+3%	7.3	13.8	21.4	29.5
3% comm	9.3	17.9	21.7	31.7

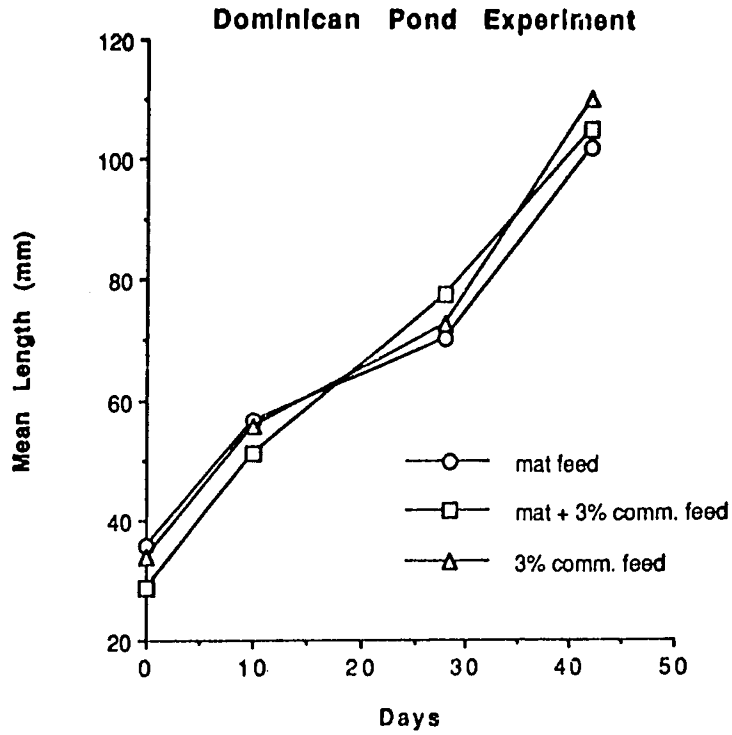

Fig. 13. Mean length (mm) of O. niloticus in the Dominican Republic field pond trial. The three triplicate treatments were: Mat = microbial mat feed; Mat+3% = microbial mat + a commercial feed of 3% tilapia biomass; 3%Comm = a commercial feed of 3% tilapia biomass. The results are triplicate means.

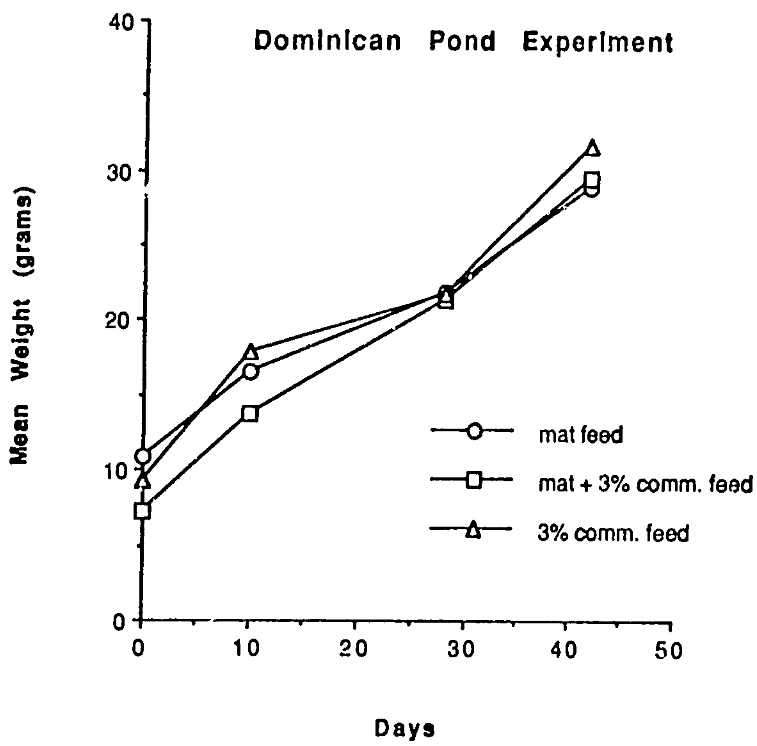

Fig. 14. Mean weight (g) of O. niloticus in the Dominican Republic field pond trial.

VII. DISCUSSION

A. WATER QUALITY

The slime layers, which are deposited at the surface around the silage, entrap bubbles of gases during the photosynthetic period. The oxygen produced at this time is apparently released to the water column during the night. In addition, since the biomass floats at the surface and the water column remains clear, little oxygen depletion occurs from algal cells that otherwise are found suspended in the water column under traditional pond manuring regimens (e.g., Stickney and Hesby, 1978). The algae population remains viable for long periods in a mixed surface mat with bacteria. For reasons yet undetermined, it does not die back even when populations are very high. Therefore, no sudden release of ammonia and oxygen depletion occurs in the water column (Bender, 1988). This system naturally solves some of the typical problems associated with aquaculture, namely depressed nighttime oxygen levels, elevated ammonia levels and fluctuating pH. Therefore, under field applications, it is possible that no energy intensive processes would ever be necessary for maintaining water quality, such as supplemental aeration.

B. MICROBIAL MATS

Microbial activities in the sediments are important to the total nutrient production, processing and storage in the pond. Several days after pond enrichment, the detrital bacteria deposit a slimy gel matrix (0.5-5 mm thick) at the pond bottom. Microbial processing of the detritus (dead cells and grass silage) generates low molecular weight products, such as free amino acids (Schroeder, 1987; Bowen, 1980), which likely become entrapped in the gelatinous layer. Such gel storage of these low molecular weight nutrients (otherwise lost in the water column), makes them available to the tilapia grazing at the pond column. In addition to the contribution of the detritivores, the shallow water column permits the growth of cyanobacteria in the sediments.

1. <u>Mat and Nitrogen Fixation</u>:

Fixed nitrogen is a valuable commodity with various competitive uses in developing countries. Microbial processes, which increase the quantities of fixed nitrogen in any land space, are significant in terms of the total field ecology and protein economy of the region. Likewise, any technology which facilitates nitrogen fixation might be considered a valuable asset in food production.

Fry (1987) and Blackburn (1987) minimize the importance of nitrogen fixation in aquatic habitats and Jones et al. (1980) point out that ponds highly enriched with sewage wastes (mineralized nitrogen) do not show nitrogen-fixation. Thus in the traditional ponds, the aquaculturist is expected to provide the protein directly or enrich the pond with mineralized nitrogen, such as animal manure, in order to generate the cellular protein within the pond. The dominant population in a mineral-enriched pond is green algae dispersed within the water column.

Unlike the traditional pond feed systems, the mat method promotes nitrogen-fixation from several perspectives: (1) the ensiling products stimulate a bloom of nitrogen fixers and apparently select for blue-green algae (nitrogen-fixing cyanobacteria), (2) the final mat establishes a community which contains anaerobic and aerobic regions (Figure 1), appropriate for fixation by aerobes, anaerobes and facultative species, (3) a spontaneous community self-organizes in such a way that photosynthesis and nitrogen fixation can occur simultaneously. In terms of the high energy requirement of nitrogen fixation and the oxygen labile character of nitrogenase, this self organization of photosynthesizing and nitrogen-fixing microbes is an unusual and a significant asset in the mat system.

2. Mat and Oxygen Economy in the Pond:

Traditional pond enrichments generally produce a population of green algae, which deplete oxygen in the water column during dark periods. In the mat system the water column remains clear because the microbial biomass is located primarily at the pond surface. Since the slimy matrix of the mat is somewhat impervious to gases, oxygen is entrapped within and below the mat during the photoperiod. After 6 hours of dark, oxygen measured 3-5 ppm in the water column (3 cm below the mat). It is assumed that oxygen, entrapped below the mat, diffused into the water column at night. In addition, since the mat remains on the pond surface, the microbes are probably supplied with respiratory oxygen directly from the atmosphere.

3. Mat and Detrital Trophic Level in the Pond Sediments:

The value of an efficient detrital processing system has been studied by a number of aquaculturists and is well documented by Moriarty and Pullin (1987). The critical factor of balance within the detrital processing system is important in terms of nutrient production, oxygen/carbon dioxide economy and minimizing the impact of oxins, such as H_2S and CH_4. Although the mat effect on the detrital processing is complex and not well understood, several assumptions can made from the nature of the mat system and observations on tilapia behavior.

In the deeper sediments regions (4-5 cm) sulfur-reducing bacteria and methanogens are present in high populations (Blackburn, 1987). These groups probably utilize acetate from the silage, producing H_2S and CH_4, shortly after silage enrichment. However, since the feed enrichment area is partitioned from the tilapia until the green mat is mature, these gases probably diffuse out early in the mat development and do not contact the tilapia. After day 3, the ecosystem changes and the cyanobacteria begins to form a mat at the pond surface. Since the mature mat system depends on photosynthesis and nitrogen fixation for nutrient production, no further outside additions are made. The environmental shock of sudden supplies of enriched material, such as commercial feeds or animal manures is avoided. Such periodic imbalances in the pond probably have significant ramifications not only in the water column but also on the anaerobic processes in pond sediments and the generation of toxic gases. In the mat system the detrital processes are fed with a continuous supply of dead bacterial cells from turnover in the mat. This supply of nutrients enters the detrital region at a slow and steady rate, thereby minimizing the sudden evolution of toxic gases. For example, if the generation of H_2S is slow and reduced iron is available, the sulfide would be precipitated as FeS, thereby limiting the evolution of H_2S into the water column (Connell and Patrick, 1969).

As the tilapia graze the mat, their mineralized waste materials are deposited in the shallow pond regions. Tilapia wastes may be converted rather efficiently to cyanobacteria cells in the shallow, sun-lit water column. Rapid tilapia growth and lack of stress behavior indicate good water quality and the presence of a positive environmental balance in the mat system.

4. Cyanobacteria and Fish Ponds:

Virtually all literature regarding blue-green algae (= cyanobacteria) in fish ponds deals with the negative impacts of blue-greens (Sevrin-Reyssac and Pletikosic, 1990). These are: 1) oxygen depletion; 2) off-flavor; and 3) toxins.

A major part of a fish pond's abundant phytoplankton may be blue-greens. With a huge blue-green bloom, a population collapse and subsequent oxygen depletion are a possible scenario. Since the microbial mat supports an entire ecosystem of blue-green algae and bacteria, a steady state of day-time oxygen production and night-time diffusion into the water column promotes satisfactory levels of water column dissolved oxygen.

Blue-green algae may contain geosmin, 2-methylisoborneol, hexanal and heptanal. These can lend a muddy taste to fish flesh (Tabachek and Yuzkowski, 1976). Nevertheless, this muddy flavor can be eliminated by holding fish in clean water for a few days (Lovell, 1976).

Though it has not been absolutely proved in the field that cyanobacteria toxins cause fish deaths (Sevrin-Reyssac and Pletikosic, 1990), Barthelmes (1984) and Seymour (1980) reported the intoxication or mass mortality of fish due to blue-green algae's cellular exudates or cell contents. These substances have been identified as polypeptides (Gorham, 1960). The major cause of mortality may actually be oxygen depletion. Additionally, an increase NH_3 concentration may accompany the decrease in oxygen.

C. TILAPIA FEED DEVELOPMENT

Feed is often the single largest operating cost in aquaculture (DeSilva, 1989). In tropical developing countries, where feed costs must be low for fish culture to be considered for rural small-scale farmers, feed development requires the following: 1) the nutrient requirements of the fish must be known; 2) agricultural byproducts, to be incorporated into the feed, must be available at a reasonable cost; 3) the fish must be able to digest the feed ingredients; 4) the feeds must be stable; 5) the feeds must be readily accepted by the fish and efficiently utilized.

The microbial mat fits the above requirements. Due to the fermentation process, silage is stable for an indefinite period of time. Silage is available locally, generally around the periphery of a pond. Cyanobacteria occur naturally in the environment and can be stimulated to bloom under the appropriate environmental conditions. The cost involved in microbial mat feed development is the labor involved in its preparation.

DeSilva (1989) also states that the "economically-optimal" dietary protein level for tilapia was approximately 25% whereas the "biologically-optimal" dietary protein level was approximately 34%. What this means is that in developing countries, where labor costs are low, it is more economical to feed fish for a longer period of time with a lower protein feed (which implies slower growth). This significant to this research because the microbial mat has a protein level of approximately 26%.

Abundant laboratory data exists to confirm that the microbial mat assists in maintaining a steady-state water chemistry.

Our laboratory observations confirm that the microbial mat is readily accepted by tilapia. We have VHS cassette footage of tilapia consuming the mat. Ekpo and Bender (1989) determined that the microbial mat was 81% digestible by _O. niloticus_ in a previous study.

D. TILAPIA PRODUCTION

The major constraint in this research was the rapid depletion of microbial mat biomass. Microbial mats, in the laboratory, require approximately one week to mature. Tilapia were allowed to consume one lane's mat for two days, or, in other words, test tilapia were presented with approximately 550 (546.25) cm^2 of microbial mat biomass every two days (= 275 cm^2/day).

Since the first trial began with relatively large tilapia, the second with very small (offspring of the first trial tilapia) and the third trial with fewer intermediate-sized tilapia (also offspring of the first trial tilapia), this is the point at which the quantity of microbial mat biomass needed to sustain a particular tilapia biomass may be estimated. Using the third trial run data from tanks E-1 and E-2 (E-3 biomass was not fully depleted by the test tilapia), tilapia will grow rapidly on microbial mat until the tilapia biomass reaches the density of 1 gram of tilapia/50 cm^2 of mat. If tilapia are loaded into the system at a greater rate, then the mat is depleted more rapidly than it can be replaced and the tilapia growth rate will begin to decrease. With this estimation, it is important to consider the rapid growth rate of young tilapia and the numbers involved, not only tilapia biomass. Therefore, this calculation is only an first approximation.

A curious observation from these experiments is that the growth rate and final weight gain in those tilapia located in the E- and C-tanks adjacent to the laboratory window were less (often significantly so) than the other tanks. For example, in both the second and third trials, the E-3 (next to the window) tilapia did not perform significantly different than control tilapia (even though their growth on the graph can be seen to be greater).

VIII. CONCLUSION

Initial laboratory trials with tilapia given unlimited access to the floating cyanobacterial mat + bottom sediment (Bender's prior research results) indicated that the entire ecosystem results in superior growth of O. niloticus. Under that design, tilapia cannot be separated from the developing mat ecosystem. Therefore, we attempted to define a laboratory and field production system that permitted mat development in a shallow water pond section and incorporated a deeper water refuge. The novel laboratory aquarium and field pond design was intended to compensate for this deficiency and to separate feeding areas from a deep water rearing refuge.

The Dominican Republic field pond trial indicated that the mat is competitive, in terms of tilapia production, when compared to commercial feeds. When comparing the cost of the prepared commercial feeds versus the cost of the additional labor involved to manage a microbial mat feed system in a low-wage economy, the savings may be very significant.

A. SUMMARY OF THE MAT FEED SYSTEM

The mat system of fish feeds has the following unique features:

1. Low-protein grass clippings, pre-processed by ensiling, provide the initial pond fertilization. The silage enriches the pond with molecular products distinct from either animal manures or commercial fertilizers.

2. The ensiling-enriched pond system follows a unique pattern of microbial succession.

3. The central microbial process, generating a protein rich product, is nitrogen-fixation.

4. The feeds are produced in the shallow regions of a pond, where the incident radiation reaches the sediment region.

5. The entire pond environment, including the detritus processing system in the sediments, becomes involved in the generation of the fish feed.

6. The system is self-maintained in a balanced ecology.

Each microbial process prepares the grass for the next step, until a final biomass, rich in protein and carbohydrate, is produced. All microbial activities occur naturally and are easily managed in a tropical environment. The mat system is designed particularly for regions having few natural resources. Although animal manuring of ponds is successful in many countries, it is impractical in some of the poorest regions where animals are either not available or the dung has competitive uses. In addition, in some developing countries (e.g., Costa Rica) fish raised in manured ponds has created a negative attitude toward fish consumption by consumers (J.A. Rodriguez, Universidad Nacional, Costa Rica, personal communication, 1989).

When considering food production in terms of the total environment (pond plus surrounding field) it is important to review the entire protein economy. Animal manure production is essentially a process of concentrating the fixed nitrogen from a field of grass. In contrast, the mat system produces protein, thereby increasing the nutritional value of the total field environment. This feed system can be applied in regions lacking the typical sources of natural or commercial fertilizers. Although additional field testing remains to be done, laboratory data and preliminary field tests in the Dominican Republic suggest that simple, vegetative materials can be used to generate a high-quality protein for O. niloticus. Since this system is solar-driven and relies on spontaneous microbial processes, it has important potential for low-cost protein production in areas with few resources.

Additionally, the mat system has potential for being integrated into US Peace Corps efforts to promote low-cost fish culture in tropical developing countries.

Results from this project will provide information of potentially broad application in the area of natural fish feeds. Although natural feed production has been a priority in many developing countries, the research efforts have generally not integrated a study of the transfer of nutrients in the total ecosystem with investigation of pond design and fish management strategies. Since our system is basically solar-driven, employing nitrogen fixation for protein production, and anaerobic bacteria for nutrient processing, it is inherently a low-cost system. The only inputs are ensiled grass clippings and sun light. Since commercial fish feeds often comprise over 50% of aquaculture costs (Shang, 1981), this method should have important economic advantages in both large- and small-scale aquaculture systems of developing countries.

B. NEW RESEARCH DIRECTIONS

1. Wastewater treatment:

Wastewater has long been considered for a multiplicity of lower-grade (other than drinking water) reuse options such as in recharging of underground aquifers, industry, agriculture, green-space irrigation and aquaculture (World Health Organization, 1973, 1989). For unrestricted irrigation of all crops, the World Health Organization (WHO) recommends an output water quality of 1,000 fecal coliform cells per 100 ml of water. Additionally, WHO recommends input water quality of less than or equal to 10,000 cells/100 ml for fish-culture water, whereas Edwards

(1985) recommends not exceeding 100,000 cells/100 ml. At these levels, there is little evidence of penetration of bacteria into fish muscle and bacterial contamination of fish should only be external.

Tilapia and carp grow rapidly in wastewater stabilization ponds. In particular, tilapia graze on sediment and surface-bound material, a well as free-living bacteria in the water column (Beveridge et al., 1989; Pullin and Lowe-(McConnell), 1982). In any aquatic system the addition of bacteria promotes phytoplankton development. Presence of phytoplankton, in turn, promotes the development of zooplankton communities. These are all food sources for different species of fish. This extended food chain concentrates wastewater phosphates and nitrates, and these are removed when fish are harvested. The presence of fish enhances the overall water quality by removing bacteria and eutrophying minerals. The result is a lower biological oxygen demand and a consequent increase in oxygen and Ph levels.

Brown et al. (1987), in reviewing the common practice of sewage-fed aquaculture throughout the world, reported that China, India, Thailand and Vietnam are leaders in wastewater aquaculture. For example, fish ponds in Calcutta provide 20 tons of fish per day to city markets.

Many US universities conduct research on fish aquaculture utilizing wastewater plant effluent, or even more commonly, by manuring culture ponds with animal wastes in an integrated agriculture-aquaculture system. In an Arkansas wastewater treatment plant, Henderson (1978) controlled excessive plankton blooms and converted nutrients from wastewater into useable protein by culturing the filter-feeding silver and bighead carps. Under that system, remarkably, no supplemental feeding was necessary, as all nutritional requirements were met by the effluent. Most significantly, he found that fecal coliform levels were reduced by the presence of the fish and recommended fish culture in oxidation ponds or wastewater lagoons.

Tilapia feed on the cyanobacterial, or microbial, mat. During mat development, there is a significant decrease in water column bacterial populations. That coliform bacteria may be removed from the water column during mat development was confirmed at the University of Maiduguri, Nigeria and Morehouse College (Archibold, 1989) and at Clark Atlanta University (Phillips, unpublished data). Since tilapia will feed on the mat, the presence of internalized coliform bacteria may be another concern. Yet one tilapia, Oreochromis niloticus, with gastric pH generally below 2.0, has evolved a mechanism for lysing bacteria (Bowen, 1976) and blue-green algae (Edwards, 1985). In this manner, bacterial cell contents are made available to satisfy nutritional requirements, at the same time rendering the pathogens harmless.

The implication is to recycle valuable nutrients present in wastewater through production of edible fishery products.

2. Crayfish Production

An new direction of this research involves the use of crayfish (*Procambarus clarkii*) with microbial mat and household waste as food sources. Expanding urbanization, affecting 80% of the world's population, has created an increased separation between food production systems and neediest human consumers. At the same time the build-up of unprocessed organic wastes in cities has compounded the associated economic strain and health risks to urban populations. This research will examine a simple waste-based method of urban crayfish aquaculture near downtown Atlanta, Georgia, USA (field test) versus controlled laboratory tests at CAU. [See Appendix A.3, Bender and Phillips (1992)].

The results of these feeding trials with crayfish and microbial mat may also have importance in the previously mentioned St. Vincent pesticide project. St. Vincent rivers have been depopulated and small-scale crayfish culture may be possible with microbial mat as the feedstock.

IX. LIMITATIONS

There were two major impediments in this research: 1) a 1990 - 1991 gasoline shortage in the Dominican Republic and; 2) the Dominican bank closure during five months in 1991.

In addition to chronic electricity and water shortages, the Dominican Republic experienced a serious petroleum shortfall in 1990 - 1991. This resulted in gasoline and diesel shortages which significantly slowed the timetable for pond construction completion. Specifically, work could not be conducted during November 1990. Due to the high water table at CIMPA, the ponds were built up rather than excavated. This required contracting with truckers to deliver soil. Subsequently, heavy rains of December 1990 delayed progress.

Due to the high Dominican government foreign debt and consequent demands of the International Monetary Fund, several Dominican banks were temporarily closed during their reorganization. One half of the $7,000 for pond construction, which had been exchanged into Dominican pesos, was placed in Unibanco of Santiago in September 1990. This bank was closed by the government in November 1990 until May 1991, whereupon the funds were released.

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XI. APPENDICES

Appendix A. Conference Posters/Presentations:

Research results were presented at three international fisheries and aquaculture conferences. A. Russell attended both World Aquaculture Society conferences in 1991 and 1992, P. Phillips attended the 1991 World Aquaculture Society conference and J. Bender attended the World Fisheries Congress in 1992. The abstracts follow:

1. World Aquaculture Society 22nd Annual Conference and Exposition, San Juan, PR, June 16-20, 1991.

2. Aquaculture '92 Conference and Exposition, Orlando, FL, May 21-25, 1992.

3. World Fisheries Congress, Athens, Greece, May 3-8, 1992.

Comparison of tilapia (*Oreochromis niloticus*) growth feeding on a cyanobacterial mat plus detrital deposits versus a commercial feed.

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A mixed matrix of silaged grass, bacteria and cyanobacteria, containing 26% protein and 43% carbohydrate, was produced in shallow enriched laboratory ponds in 7–10 days. The final silage-cyanobacterial mat showed increases of over 300% in biomass and 100% in protein content over the silage feedstock. This system is significantly different than using a system of animal waste enrichment, which is based on nitrogen concentration and conversion, rather than fixation.

Oreochromis niloticus grazing on the cyanobacterial mat and detrital layer grew significantly faster than those feeding on either the mat alone, the detrital layer alone or a Purina catfish ration. The results of feeding experiments identify the nutritional value of the mat system and signify the importance of the detrital trophic level in tilapia growth. Low-level additions of silage to shallow ponds rapidly generated nutrient-rich biomass at the pond surface and stimulated a bloom of slime-producing bacteria within the sediment region. Cell turnover in the heavy microbial biomass at the pond surface presumably contributed a continuous supply of cell debris for anaerobic processing in the sediments. Gelatinous deposits at the bottom of the pond may have provided an appropriate matrix for the sequester and storage of these nutritious products, thereby making them available for fish grazing. Since this system is based on simple and available biomass (grass) and is driven by natural microbial processes, it may hold important potential for cost-effective feed production in developing countries.

Tests are being conducted in the Dominican Republic to determine the applicability of this feeding system to a field situation.

LABORATORY TANK AND FIELD POND DESIGN FOR TILAPIA OREOCHROMIS NILOTICUS FEEDING ON A MICROBIAL MAT DOMINATED BY THE CYANOBACTERIUM OSCILLATORIA

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Tilapia *Oreochromis niloticus* feeding on a microbial mat ecosystem dominated by the cyanobacterium, *Oscillatoria*, grows faster than control tilapia fed at 3% of their body weight per day. The objective here was to develop a management system using a novel laboratory tank and field pond design which permitted the microbial mat ecosystem stimulated by ensiled grasses to develop in the presence of grazing tilapia. Laboratory tank and field pond design included a deep-water rearing chamber and four "feeding lanes". Sluice gates isolated the feeding lanes. Mature feeding lanes were opened in a sequential arrangement to permit tilapia grazing. Tilapia were allowed to consume one lane's mat for two days. Three growth trials were conducted with: (1) 0.06 - 0.08 g; (2) 0.64 - 0.86 g; and (3) 2.0 - 2.8 g tilapia in a triplicate experimental design. With the intermediate-sized tilapia, increase in weight among experimental tilapia was consistently and significantly superior to that of controls (ANOVA, $P<0.05$) due to the ratio of mat biomass to tilapia biomass. Tilapia grew until their biomass reached a density of 1 gram of tilapia/50 cm^2 of mat. This calculation is a first approximation. Cost benefit analysis of using the microbial mat system as a fish feed is being analyzed for the Dominican Republic pond experiment. This will take into account the target population for this type of fish pond culture, the small-scale farmer.

Keyword (1): Tilapia nutrition Keyword (2): Microbial mats

P0069

AN INTEGRATED SYSTEM OF WASTE DISPOSAL WITH CRAWFISH PRODUCTION IN AN URBAN ENVIRONMENT

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ABSTRACT: Expanding urbanization *has* affected 80% of the world's population *and* created an increased separation between food production systems and *the* neediest human consumers. At the same time the build-up of unprocessed organic wastes in cities has compounded the associated economic strain and health risks to urban populations. This research examines a simple waste-based method of urban crawfish aquaculture near downtown Atlanta, Georgia, USA (field test) versus controlled laboratory tests.

In an attached greenhouse built for home solar space heating, several ponds were recessed into the earthen floor. *Procambrus clarkii* brood stock were placed in a 1 m diameter x 0.3 m depth pond. As reproduction and juvenile growth progressed, approximately one-third of the crawfish were moved to a larger (5.6 m x 2.4 m x 0.8 m) greenhouse pond. During warm months crawfish were moved to a backyard (10 m diameter x 1.5 m depth) pond for maturation. Populations were continuously moved through the pond series, with adults harvested at the end-point outdoor pond for home consumption. Ponds were flushed with water collected from roof run-off, stored in a cistern, and delivered by gravity flow to the ponds. Low-cost feed production included two methods of processing available waste plant materials into microbial biomass *with a* high protein content. The first method involved ensiling yard grass clippings and using these as feed stock for cyanobacteria culture. The resulting grass/cyanobacteria mat had a protein content approximately 100% greater than protein in grass clippings. In the second method, all kitchen wastes and yard leaf-fall were recycled into an earthworm/compost production bin. Finished compost was layered at the edges of the three ponds to provide a continuous supply of grazing material.

Replicated laboratory tests comparing cyanobacterial mat versus household compost as a crawfish nutrient source are in progress.

Appendix B. Conference on Environment and Development in Africa and Latin America, Michigan State University, 1990:

In September - October 1990, Michigan State University's Consortium for Inter-Institutional Collaboration in African and Latin American Studies invited A. Russell, P. Phillips and J. Bender to present papers at their Conference on Environment and Development in Africa and Latin America. A. Russell's paper was subsequently published in MSU's The Centennial Review Spring 1991, "Environmental Crises: Africa and Latin America". A copy of the publication is included:

Hecht, S., R. Norgaard, and G. Possio. 1988. "The Economics of Cattle Ranching in Eastern Amazonia." *Interciencia* 13: 233-40.
Hecht, S. 1985. "Environment, Development and Politics: Capital Accumulation and Livestock Sector in Eastern Amazonia." *World Development* 13: 663-84.
Mahar, D. 1989. *Government Policies and Deforestation in Brazil's Amazon Region.* Washington, DC: The World Bank.
Myers, N. 1986. "Tropical Forests: Patterns of Depletion." *Tropical Forests and the World Atmosphere.* Ed. G. T. Prance. Boulder: Westview Press.
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Stavin, R. and A. Jaffe. 1990. "Unintended Impact of Public Investment on Private Decisions: The Depletion of Forested Wetlands." *American Economic Review* 80: 337-52.

LAND USE: EROSION AND POVERTY IN THE DOMINICAN REPUBLIC

By Fernando Arturo Russell

Introduction

AROUND FIVE HUNDRED YEARS AGO, when Christopher Columbus discovered La Hispaniola, the second largest island in the Caribbean, he recorded in his logbook that this was "the most beautiful land that human eyes had ever gazed upon." The whole island was nearly 100 percent covered with forests with abundant rivers, some of which were navigable.

The situation five centuries later is troublesome: according to some estimates, forest cover is down to 10 percent; an alarming number of rivers have dried up or are in the process of drying up; soil erosion has become a major problem throughout the island, and living conditions, specially in the rural areas have seriously worsened in the last few decades.

The Dominican Republic occupies the eastern two thirds of La Hispaniola, with Haiti as its western next-door neighbor. Around 60 percent of the 48,442 square kilometers of Dominican territory is mountainous, with some peaks reaching as high as 3,000 meters. In fact, we have the highest peak of, all the Antilles, Pico Duarte, which stands 3,087 meters high.

The main problem affecting the natural resources today is soil erosion, which is a consequence of deforestation and inadequate agricultural techniques. Slash and burn agriculture is largely practiced by landless small farmers throughout the country. Commercial exploitation of the forest also takes place in some remote areas even though there is a law that bans cutting trees except by special permit.

Land Use

Table 1 shows a classification of land use capabilities in the Dominican Republic. These land use capabilities have been established according to the physical and chemical characteristics of the different soils, their fertility, fragility, as well as the topography of the terrain. According to this classification, about 20 percent of the land could be dedicated to agricultural use. Land suitable for grazing is estimated in 24.5 percent of the territory,

Table 1. Classification of Land Use Capabilities in the Dominican Republic (From Hartshorn et al. 1981)			
Class	Km²	%	Production capability
I	537	1.1	Excellent for agriculture
II	2,350	4.9	Very good for agriculture
III	3,122	6.6	Good for agriculture
IV	3,639	7.7	Limited or marginal for agriculture
V	6,071	12.7	Pasture; no danger of erosion
VI	5,611	11.8	Pasture; danger of erosion
VII	25,161	52.7	Forests
VIII	1,202	2.5	Wildlife areas
Total*	47,693	100.0	

*Does not include the 588 km² in islands, lakes and other non-classified areas.

while 53 percent is considered to be of forestal capacity. This 53 percent, as well as the 2.5 percent classified as wildlife conservation areas, are all in the mountains throughout the country.

Table 2 shows the actual kinds of land use in practice in 1980 (CRIES 1980). Agricultural land covers 40 percent of the territory, about twice the area classified as suitable for such use; grazing land takes another 43 percent of the territorial extension, almost twice the area classified as adequate for such use; forest cover is estimated at 14.4 percent based on a classification requiring at least 75 percent tree crown cover which therefore ex-

Table 2. Main Types of Land Cover Use in the Dominican Republic (Adapted from CRIES 1980)		
Land Cover Use	Km²	%
Agriculture (extensive + intensive)	17,102	39.8
Grazing land (pasture, rangeland, and limited rangeland)	20,91	42.8
Forest (broadleaf and conifers)	6,829	14.4
Urban	292	0.6

cludes nearly all pine forests. Other estimates of the remaining forests in the country that require only 50 percent tree crown cover include most pine forests and come up with higher figures. One such study carried out by FAO in 1980, estimated forest cover to be 38 percent.

Regardless of the criteria used to define forests, one thing we can be sure of is that deforestation is still going on at an alarming rate and that we are nowhere near the 53 percent estimated as necessary forest cover in the classification of land use capabilities shown above.

The fertile lowlands throughout the country are dedicated mainly to the production of cash crops for exportation: tobacco, sugar cane, citrus, watermelons, etc. Some of these crops are produced on plantations owned by large companies which in many cases have forced the small farmer, principal supplier of food crops, to move to the fragile uplands. This fact, coupled with the demands of a growing population that requires more foodstuff every year, and the high costs of importing produce from abroad, sets the conditions for expanding the agricultural frontiers into the forests and causes their degradation. Hillside agriculture is carried out in the same fashion as it is practiced in the lowlands, and generally does not incorporate soil conservation measures.

The steep lands in the Dominican Republic provide 75 percent of the peanuts, 50 percent of the potatoes, cassava, and legumes, 40 percent of the corn, 100 percent of the coffee, and 50 percent of the beef produced in the country (Tables 3 and 4).

Table 3. Food Production in the Dominican Republic (Adapted from Morel 1986)		
Crop	Cultivated area (000 tn/yr)	% in slopes
Black beans	133.5	50
Red beans	789.8	50
Peanuts	710.3	75
Corn	538.5	40
Potatoes	21.7	50
Cassava	270.8	50

Table 4. Cultivated Land in Mountainous Areas (type VII) (From Gellfus 1986)

Area	Coffee and Cocoa (ha)	Annual Crops (ha)
Cordillera Central	26,600	136,000
Sierra de Neyba	1,800	24,400
Sierra de Bahoruco	6,700	9,300
Sierra de Yamasá	9,200	26,600
Cordillera Septentrional	50,700	41,200
Los Haitises	——	17,000
Cordillera Oriental	3,100	12,400
Península Samaná	——	17,000
	98,100	283,900

The small farmer who works on these marginal lands generally does not own his plot, has no access to fertilizers or pesticides, and does not qualify for bank loans. His crop yields are significantly lower than the national averages (Table 5).

Table 5. Average Crop Yield in Río Verde, Sierra de Yamasá, Compared with National Averages (From IICA, 1984)

Crop	Average Yield (In quintales/tarea)* Río Verde	National
Rice	1.02	3.83
Corn	0.72	1.80
Red Beans	0.54	0.93
Green peas	0.80	1.26
Peanuts	0.70	1.40
Cassava	2.32	6.77
Sweet potatoes	1.15	6.93
Pumpkins	4.40	3.84
Yautía	1.36	7.84
Ñame	0.82	8.08
Coffee	0.66	0.31

*1 quintal = 100 lbs.; 1 tarea = 629 m2.

The slopes where these crops are grown are incapable of supporting crops in a sustainable way (the exception being coffee, a perennial grown in combination with large trees that provide it with a necessary shade). With the removal of the forest cover that precedes the cultivation of annual or short-cycle crops, or the establishment of pasture, soils are left unprotected from the heavy rainfall and are easily eroded (Table 6 [next page]).

Erosion and Deforestation

Soil erosion is indeed occurring at an alarming rate. The Ocoa watershed, in the southern part of the country, is losing 500 tons per hectare per year, that is, a layer of 3.4 centimeters of topsoil per year (Table 7).

Table 7. Loss of Topsoil per Watershed (From Hartshorn et al. 1981)

Watershed	Area (ha)	Erosion (tons/ha/yr)	Topsoil Erosion (cm/yr)
Las Cuevas	5,690	275	1.8
Tavera	7,370	275	1.8
Bao	9,330	346	2.3
Nizao	9,920	125	0.8
Ocoa	5,630	507	3.4
Guayubín	7,340	111	0.7
Chacuey	3,860	95	0.6

Besides reducing soil fertility and crop productivity on-site, soil erosion in the uplands causes siltation of the river beds, irrigation canals, and hydroelectric reservoirs, as well as flooding in the lowlands. The Tavera hydroelectric reservoir, completed in 1973 at the cost of $141 million, has lost already 50 percent of its dead storage capacity and around 15 percent of its active storage capacity due to the accumulation of 20 meters of sediment behind the dam. These reductions in storage capacity have cut down the expected useful life of this reservoir to half of what was originally designed. Hydropower accounts for about 15 percent of the country's electricity generation.

Table 6. Land Use and Total Areas of Seven Important Watersheds in the Dominican Republic (measured in hectares) (From Olson et al. 1984)

Watershed	Land Use						
	Forest	Perennial Agricultural Crops	Annual Cultivated Crops	Pasture	Mixed Pasture and Annual Cultivated Crops	Mining	Total
Hatillo	24,550	56,120	—	1,620	36,900	2,910	122,100
Bao	34,430	—	7,870	650	42,850	—	85,800
Sabaneta	21,650	230	1,210	9,240	13,170	—	45,500
Sabana Yegua	76,380	7,580	9,580	15,050	49,000	—	157,590
Rincón	3,070	8,150	540	—	5,550	—	17,310
Tavera	18,440	—	7,970	4,220	46,980	—	77,610
Valdesia	13,630	1,410	620	—	70,550	—	86,250
	192,190	73,490	27,790	30,780	265,000	2,910	592,160

Extensive cattle rearing in forest areas is another important cause of environmental degradation. Besides the compaction of the soil caused by animal traffic, quite often grazing is closely associated with deforestation. The small farmer practicing slash and burn agriculture does not own the land under cultivation. The landowner allows the small farmer to cut and burn a small plot of forest and to grow some crops for a couple of years. Upon experiencing a loss of productivity due to competition from weeds and erosion, the farmer grows pasture and later abandons the plot, which will be used by the landowner as grazing. The small farmer moves on to a new plot and repeats the procedure once again.

It is estimated that we are losing 20,000 hectares of forest per year, while reforestation reaches around 3,000 hectares per year. Deforestation is worst in the western half of the country, where most of the mountains are located. A study carried out at the Catholic University in Santiago, using satellite images, aerial photography, and field inspections of this area of the dominican territory, calculates that the loss of broadleaf and pine forest is 14,100 hectares per year. The same study indicates that from 1972 to 1986, grazing land has increased in 42 percent, cultivated land has increased in 34 percent, and forests have decreased in 32 percent (Tables 8 and 9).

From the previous data shown here, it is clear that land mismanagement in the Dominican Republic is a problem reaching catastrophic proportions.

Land Tenure

The uneven distribution of land is one of the main factors underlying land mismanagement in the Dominican Republic. According to the country's 1981 agricultural census, 55.24 percent of all farmland is made up of holdings larger than 50 hectares and is owned by 1.83 percent of all landowners. On the other hand, 12.18 percent of the farmland is made up of small holdings with less than 5 hectares and is owned by 81.72 percent of all landowners. Not surprisingly, this skewed pattern of land distribution has been considered one of the worst in the world (FAO 1988). The larger estates occupy most of the lowlands suitable for agricultural use, whereas the smaller holdings typically occupy lands that are considered marginal or unsuitable for agriculture.

Table 8. Global Land Use Area Modifications Between 1972/1973 and 1985/1986 West Part of the Dominican Republic (From Fournier et al. 1987)

CLASS	Area Km² 72/73	1979	85/86	72/73/79 Km²	Δ%	79/85-86 Km²	Δ%	72/73-85/86 Km²	Δ%
Agriculture	2,686	3,377	3,605	+691	+26%	+ 228	+ 7%	+ 919	+34%
Pasture	6,760	7,136	9,622	+376	+ 6%	+2,486	+35%	+2,862	+42%
Shrubland*	7,229	6,786	5,627	-443	- 6%	-1,159	-17%	-1,602	-22%
Forest**	6,658	5,914	4,543	-744	-11%	-1,371	-23%	-2,115	-32%

* Dry forest, thorny vegetation and cactus.
** Pine and broadleaf.

Table 9. Deforestation Rates, Western Part of the Dominican Republic 1972/1973 to 1985/1986 (From Fournier et al. 1987)

Cover Type	Remaining Forest (ha) 72/73	79	85/86	Deforestation Rates Δ 72/73 to 79	Δ 79 to 85/86	Δ 72/73 to 85/86
Forest*	665,800 28%	591,400 25%	454,300 19%	74,400 ha -11% 4,960 ha/yr	137,100 ha -23% 9,140 ha/yr	211,500 ha -32% 14,100 ha/yr
Shrubland**	722,900 30%	678,600 25%	562,700 23%	44,300 ha 9,953 ha/yr	115 900 ha 7,227 ha/yr	160 200 ha 10,680 ha/yr

* Pine and broadleaf
** Mostly dry forest

The above situation is aggravated by the high number of landless small farmers, an estimated 400 thousand (Rodríguez 1987). Out of a total dominican population of 7 million, of which 3 million inhabit the rural areas, this is a significantly high proportion.

Impacts of Land Mismanagement On Society

Land mismanagement is a major cause of both environmental and social degradation. It has some direct and indirect impacts on the socioeconomic dynamics that determine, to a certain degree, the quality of life.

Bremer et al. (1984), in an excellent paper on the fragile lands of Latin America and the Caribbean, list what they consider to be the main impacts of fragile land mismanagement on society:

1. *Declining Agricultural Incomes.*
   As the degradation of the soils progresses (erosion, soil compaction, loss of fertility), productivity declines accompanied with a possible increase in costs. This implies reduction in agricultural income (including income from crops, silviculture and animal husbandry). The small farmer finds himself progressively impoverished and quite often abandons all agricultural activities and either migrates to the city or tries to find new and more profitable ways of making a living. The ones that continue to engage in agricultural activities must extend their operations to new marginal lands only to find themselves trapped in an regressive spiral that leads them to more poverty and more land degradation.
2. *Deteriorating Quality of Life.*
   Land degradation can reduce the supply and/or the quality of other consumer goods associated with it:
   - It can reduce the quantity and the quality of the water for domestic use; erosion can damage roads, houses and livestock through flooding and landslides;
   - Deforestation and erosion reduce the availability of wood used as fuel, increasing the time and effort invested in gathering such resources.
   - Nutrition levels decline as food production and income go down.
3. *Downstream Economic Effects.*
   The economic impacts of land mismanagement in the uplands are felt downstream as well:

   - The supply of raw materials for processing may be reduced.
   - The costs of some basic services, such as electricity may increase (due to the decrease in hydropower).
   - Productivity will decrease and crops will be lost in the lowlands due to flooding during the rainy season and lack of water for irrigation during the dry season.
   - Because of low crop productivity and an increasing demand of foodstuff from the population, the country will need to import greater amounts of food from abroad.

Conclusion

Land degradation is both a cause and a consequence of social degradation in the rural areas of the Dominican Republic. It causes social degradation in the sense that the overall quality of life decreases in terms of income, nutrition levels, health standards (such as lack of domestic water) etc., as we have already seen. It is a consequence of social degradation from the standpoint of the lack of socially fair and ecologically sound alternatives available to the small farmer to make a living. Having very small holdings, quite often in areas not suitable for agriculture, or worse yet, having no land at all, the small farmer has no other choice but to engage in ecologically degrading activities to survive.

There have been some attempts to improve rural living conditions through programs such as the Agrarian Reform. However, the results have been somewhat frustrating. Most of the time, the distributed land does not end up in the hands of the landless small farmer, but rather is assigned to members of the ruling political party.

Decisions taken at the political level, put into action by the government itself and by the agribusiness sector regarding how to use the agricultural lowlands, have a definite effect on what happens in the uplands. The fact that 9 percent of all dominican land is occupied by sugar cane plantations, in areas that at the beginning of the century were mostly dedicated to food production helps explain why there are so many small farmers cultivating food crops in the hills.

In order to implement policies that really get to the roots of the problem of land degradation, actions have to be taken at several levels, all the way from the government to the small farmer himself. Government actions may include the creation of off-farm employment in the rural areas, the intensification in the use of fertile agricultural land, the implementation of effective programs of Agrarian Reform, a modification of the landholding system and careful land use planning. It is unlikely that a farmer will apply land conservation techniques if he has no incentives and moreover, if the land is not his own. At the small farmer level, some measures can be taken to help revert the accelerated degradation of the soils. These may include soil conservation programs and alternative farming systems, such as agroforestry. These new strategies will have to be both ecologically sustainable and socially accepted in order for them to have the necessary impact towards the reversal of the trends in land mismanagement that presently contribute to erosion and poverty in the rural areas of the Dominican Republic.

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HUMAN SETTLEMENT, POLITICAL INSTABILITY, AND ENVIRONMENTAL DETERIORATION IN UGANDA, 1972-1989[1]

By Richard Fusch

Introduction

AS THE POPULATION of Uganda has grown and human settlements have become more complex, the environmental impact of human settlement dynamics has become greater and greater. However, from 1972 to 1986, Uganda witnessed an intense period of political instability which included "on-again, off-again" civil war and massive human rights abuses. The political instability during this period lead to the collapse of the agricultural export sector of the economy, and regional population dislocation occurred as many people left the countryside seeking safety in the cities, or migrated to other rural regions to avoid conflict, or moved into heretofore unsettled forested areas or legally gazetted game reserves. Concomitantly, changes took place within the rural settlement systems as housing quality declined, general deforestation and rural wood lot deforestation occurred, and food and nutritional imbalances intensified as a result of a rural fuel wood crisis. Local custom, which often acted to permit both settlement and development while conserving the environment, disintegrated in many rural areas. Furthermore, enforcement of national legislation which aided environmental protection collapsed in the period 1972-86, or was ignored or dramatically altered to serve short-term political gains. As a direct result of this long-term political instability and the problems it created in the human settlement systems of Uganda, the country faces a series of rural environmental crises which pose serious problems for the future development potential of the country.

The history of Uganda's political instability is generally well known.[2] In brief, from 1971-86 Uganda was administered by several politically and morally corrupt governments, the most prominent of which were the Idi Amin government (1971-79), and the Milton Obote government (1980 to December 1985). In 1986, the government of Yoweri Museveni was formed; it is attempting to restore a government of national unity, the economy, and a national sense of purpose. Although most of the southern portion of

Appendix C. Cable Network News Presentation of Clark Atlanta University's Microbial Mat Research, 1991:

CNN filmed the microbial mat research in CAU's Environmental Biology Laboratory in August 1991 for airing in September 1991. The use of the microbial mat as a fish feed and footage of the Dominican field ponds were included. A copy of the VHS tape is included in this report.

Appendix D. Atlanta University Center Student Participation in Environmental Issues Studies in the Dominican Republic:

According to a study by the non-profit environmental group CEIF-Fund (CEIF-Fund, 1989), African Americans have been essentially excluded from environmental careers. Much of this problem is attributed to lack of exposure to environmental issues in minority communities, in addition to poor effort by environmental groups and companies in recruiting minority employees. This is very significant when considering international issues, since most developing country environmental problems involve non-white populations. Active participation of minority populations in global environmental problems is an urgent need and must begin with an active participation of undergraduates in a program that inspires and motivates, as well as provides theoretical classroom information.

As a corollary to the research activities between Clark Atlanta University and the Catholic University of Santiago, in May - June 1990 P. Phillips began to lead a small group of Atlanta University Center students to the Dominican Republic. The goal was to expose AUC students to the array of environmental problems facing a typical tropical developing country. To accomplish this, a special "Natural Resources and Energy Use" team-taught course was developed at the Catholic University. The course is coordinated by Phillips at AUC and by A. Russell in the Dominican Republic. This is a multidisciplinary team-taught course in English is based on a successful model of a course taught yearly for Dominican students. PUCMM has the capability of also offering Spanish at different levels simultaneously through their Spanish for Foreigners program. The thrust of the program is to demonstrate the impact of deforestation and the subsequent effect on the ecology of the landscape and the social welfare of the Dominican population.

This program is offered immediately after the Spring Semester and lasts four weeks. The entire program is equivalent to six-credit hours and is transferrable to the student's home institution. Attached is a copy of the "Natural Resources and Energy Use" syllabus. Additionally, included is a copy of the CAU student production of a promotional tape that illustrates the scope of the entire program.

All student participants have returned with a heightened awareness of environmental problems facing a developing country. This exposure, in addition to the enhancement of their Spanish language and cross-cultural skills, will certainly aid their career choices and make them more marketable in their graduate school programs or in their job searching. For example, one student postponed his entrance into medical school and returned on his own to the Dominican Republic to improve his Spanish. He felt that Spanish fluency would enhance his professional skills. Another student gained summer employment for two years in a Washington, DC-based consulting firm specializing in international development issues. This same student has decided to enter the Peace Corps after graduation and eventually begin a graduate program in natural resource management. A third student is exploring the possibility of combining graduate studies with field research in the Dominican Republic in the area of public health.

This student program is now being advertised in other Atlanta-area colleges and universities, as well as institutions outside of Georgia.

Fig. 8. Field trip to Los Haitses National Park, May 1991.

Appendix E. Additional Funding to Enhance and Expand the Research Activities:

Because of these "spinoff" activities emerging from this research, funding was obtained which actually permitted additional trips to the Dominican Republic and trips by A. Russell to the US. A CAU agricultural economist, Dr. Mesfin Bezuneh, was added to the research team of Phillips and Bender to begin to examine the cost-benefit aspect of this type of fish culture activity.

The following sources of additional funding were obtained:

1. Consortium for Inter-Institutional Collaboration in African and Latin American Studies, Michigan State University.

2. Lucille and David Packard Foundation.

3. American Airlines.

4. US Environmental Protection Agency.

5. National Science Foundation.