Title XII
Collaborative Research Support Program

Tenth Annual Administrative Report

(1 September 1991 to 31 August 1992)

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This administrative report addresses the management and technical accomplishments of the Pond Dynamics/Aquaculture Collaborative Research Support Program during the reporting period of 1 September 1991 to 31 August 1992. Program activities are funded in part by the United States Agency for International Development under Grant: DAN-4023-G-00-0031-00.

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Disclaimer

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Table of Contents

I. INTRODUCTION

The Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) is an international effort to develop aquacultural technology as a means of confronting food and nutritional problems in developing countries, and to help people learn management skills and earn income. The program is funded by the U.S. Agency for International Development (USAID), under authority of the International Development and Food Assistance Act of 1975 (P.L. 94-161), and by the universities and institutions that participate in the CRSP. Oregon State University (OSU) is the Management Entity (ME) for the CRSP and has technical, administrative, and fiscal responsibility for the performance of grant provisions.

The CRSP is a cohesive program of research that is carried out in selected developing countries and the United States by teams of U.S. and Host Country scientists. The U.S. institutions participating in the program are Auburn University, the University of California at Davis, and the Consortium for International Fisheries and Aquaculture Development (CIFAD). CIFAD members include the University of Arkansas at Pine Bluff, the University of Hawaii, the University of Michigan, Michigan State University, and Oregon State University.

CRSP activities were formally initiated on 1 September 1982 after several years of planning. From 1982 to 1987, CRSP projects involved the participation of government agencies and educational institutions in six host countries: Honduras, Indonesia, Panama, the Philippines, Rwanda, and Thailand. Funding constraints during 1986 and 1987 forced a reduction in operations. A reorganization plan was submitted in December 1986 to the Joint Committee on Agricultural Research and Development (JCARD) Panel on CRSP's and the AID Agricultural Sector Council Subcommittee. The plan, which went into effect on 1 September 1987, called for maintaining a presence in each of the USAID geographical areas originally selected. Country sites were reduced to three: Rwanda, Thailand, and Panama. However, political initiatives in Panama in 1987 made it necessary for the CRSP to relocate to Honduras. Largely through the efforts of Auburn University and through continuing financial commitments of the USAID Mission, the CRSP was welcomed back into Honduras in April 1988 and began experiments with the assistance of the Honduran Department of Renewable Natural Resources (RENARE) in August 1988.

The end of this reporting period marked another change for the Honduras project—the start of a new brackish water site in Choluteca. In accordance with the goals of the USAID Mission in Honduras, the CRSP has opened another station near the Gulf of Fonseca to evaluate environmental impacts and alternative production strategies associated with shrimp farming in that region. Closer collaboration between the PD/A CRSP and Honduran organizations, other CRSPs, and private aquaculture farms will be facilitated through the CRSP's involvement in this new site. CRSP research at the freshwater station in Comayágua, which continues to operate under host country supervision, now focuses on on-farm trials of CRSP global technologies, including the popular "El Carao" method developed in Honduras.

With the completion of the first three cycles of standardized global experiments (1982-1987), the CRSP began focusing on the statistical interpretation of data that were collected at the six project sites. The research program was successfully modified to reflect the reduction in sites without changing the overall emphasis of the CRSP. The global nature of the program therefore remained intact. Experimental protocol, as described in subsequent work plans, conforms to that of the original three cycles to allow comparison between sites over time. Field experiments blend program-oriented and project-oriented (site-specific) considerations in response to the results of the earlier experiments.

After years of discussion, the CRSP is moving ahead with plans to incorporate much of the CRSP global database into the International Center for Living Aquatic Resource Management (ICLARM) FISHBASE. This will further ensure safekeeping of the important data that have been collected through nine years of CRSP experiments. In an effort to transfer the CRSP Central Data Base from its present home in the Management Entity to a research project, the technical committee undertook a rigorous evaluation of the data base. The committee suggested that in addition to the administrative and maintenance functions now performed by the data base manager, new data base activities should optimally include statistical analyses.

Another milestone in the CRSP was met with the completion of PONDCLASS, the expert system on pond management guidelines. PONDCLASS is now being tested at several field locations, including CRSP sites in Rwanda and new sites in northeast Thailand and the Philippines. PONDCLASS provides not only new technology for fish culturists but also serves as an excellent teaching tool for simulating pond responses to a variety of fertilizing inputs.

In the past few years the CRSP has actively pursued new funding opportunities to support project activities. The CRSP expanded its geographic representation with the inclusion of a temperate freshwater site in Egypt—made possible through the new bilateral Egypt project. The CRSP has also been successful in attracting funding in four target areas: economics research, gender studies, on-farm studies, and outreach. Projects in these new focus areas are showing their first results, and are successfully adding a broader dimension to the CRSP experience. Natural resources management has always been a cornerstone of the CRSP; therefore, the continued efforts in this area are not new. What is new is the integration of natural resources work with socio-cultural and economic dimensions of aquaculture.

Last year's economics study initiated in Thailand by researchers from the University of Arkansas at Pine Bluff and Michigan State University culminated in a technical report that described profit-making fish culture enterprises in the impoverished Northeast region. This study complements the economics study currently underway in Rwanda– funded primarily through a buy-in from USAID's Historic Black Colleges and Universities (HBCU) Program– and the ongoing private sector research for commercial shrimp and tilapia farms in Honduras. The HBCU grant also enables the University of Arkansas at Pine Bluff to augment core CRSP biological research in Rwanda through much needed experiments on temperature tolerance of tilapia. CRSP researchers in Rwanda regularly assist the USAID Mission in their natural resources projects and have helped transfer CRSP technologies to Rwandan farmers, who are now experiencing widespread success with fish culture. A gender study of women in fish farming and a workshop in Rwanda, funded by Women in Development/Policy & Project Coordination (USAID), the USAID Mission in Kigali, and other sources including the CRSP, provided insights into improving the design of CRSP research through the incorporation of socio-cultural variables. The CRSP was pleased with this opportunity for enrichment and regrets only that it does not have a larger financial commitment from USAID to support long-term research in Women in Development. In addition to the many grants and cooperators affiliated with the CRSP project in Rwanda, the European Economic Community recently contributed funds to improve and expand the pond facilities at the research station at the National University of Rwanda.

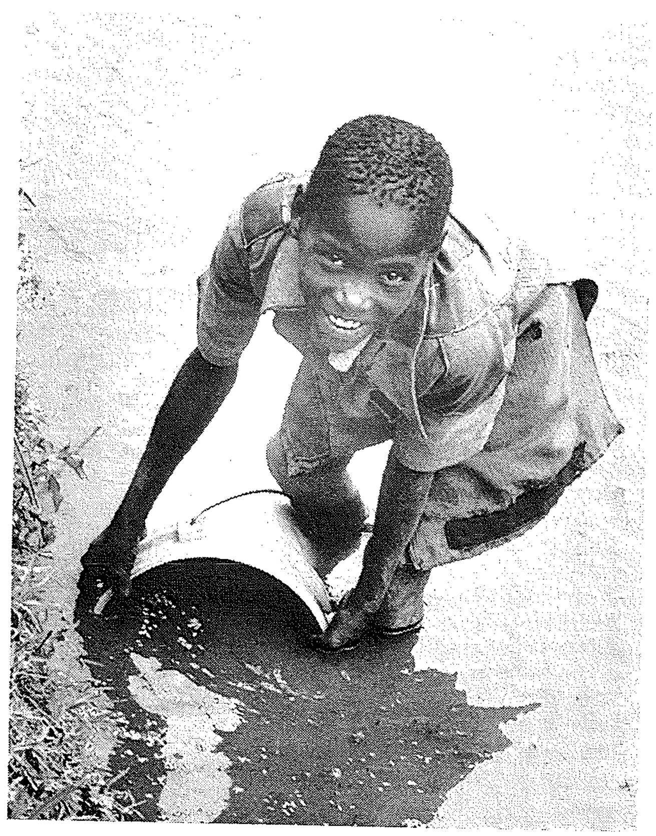
During the current reporting period, many new members have been added to the CRSP through informal buy-ins. For example, the recently initiated Egypt project involves new researchers from long-time CRSP institutions– including the University of Hawaii at Manoa and Oregon State University– and adds a new U.S. institution (the University of Oklahoma at Norman) and a new host country institution (the Agricultural Research Center of Egypt) to the CRSP technical committee.

Other on-going "buy-in" activities include: expanding traditional pond dynamics work to encompass a broader analysis of the effects of aquaculture on the environment, and a proposal to collaborate with the International Center for Living Aquatic Resources Management (ICLARM) on an aquaculture methods manual. The CRSP continues to be one of the principal players in the CRSP Council's efforts to attract funding for a large-scale agroecological study in Honduras involving their two most important export products, shrimp and melons.

The twenty percent increase in funding that the CRSP received in May 1991 funded projects addressing the critical needs defined by JCARD, BIFADEC, the External Evaluation Panel, and the CRSP Technical Committee. Part of the funding was used as seed money to leverage support from other sources. The funds allocated to a Women in Development study helped to leverage funds from a number of sources (see above); the funds for testing CRSP models on farms in the Philippines were matched by University of Hawaii and Central Luzon State University. The small grant to Auburn University to conduct field trials and workshops in Panama was rendered infeasible due to US travel restrictions, yet the allocation was turned to good use by making possible a ten-year compendium of CRSP research in Honduras. Other new studies included investigations in tropical pond soils, which has allowed us to facilitate linkages with other soils projects such as the TropSoils CRSP; a workshop in Rwanda for East Central African fish farmers, extensionists, and Peace Corps Volunteers; polyculture research using native species; and research on ecologically sound alternatives to therapeutic drugs used in fish culture. An additional annual 9% budgetary increase, which was received at the end of this reporting period, was devoted to a comprehensive external review of the CRSP. The final evaluation will be completed during the next reporting period.

The CRSP has benefited from its involvement in the CRSP Council, a group composed of the eight USAID-funded Collaborative Research Support Programs, although full participation in this group extracts a high cost in terms of time and capital from the smaller CRSPs such as ourselves. Through the Council, the PD/A CRSP has over the years participated in presentations to Congress, the World Bank, USDA, USAID, JCARD, and environmental groups. One impact of this effort was to increase public awareness of CRSP programs. The Council plans another series of presentations in 1993.

Many other technical and programmatic accomplishments are described in detail in this Tenth Annual Administrative Report, which covers the period from 1 September 1991 to 31 August 1992.



II. SUMMARY OF ACTIVITIES AND ACCOMPLISHMENTS: 1 SEPTEMBER 1991 TO 31 AUGUST 1992

This year marks the eighth year of active research by the Pond Dynamics/ Aquaculture CRSP. Major accomplishments during the reporting period include the completion of a number of the activities scheduled under the Fifth and Sixth Work Plans, refinement of several important CRSP aquaculture pond models, and field testing and refinements to the CRSP pond management expert system, PONDCLASS. In addition, the Technical Committee completed the CRSP Handbook of Analytical Methods during the year. A number of Special Topics Research activities were completed, and other research activities of the Sixth Work Plan continue. As always, efforts to disseminate research results continued through a variety of avenues.

Data Analysis and Synthesis

The Data Analysis and Synthesis Team (DAST) at the University of California, Davis (UCD) continued to develop and refine several pond dynamics models reported on previously (PD/A CRSP Eighth Annual Report). Primary production models were updated by incorporating the results of work done on changes in the sensitivity of phytoplankton to light and reformulating portions of the models dealing with the effects of pond turbidity and depth on primary productivity. Dissolved oxygen and temperature simulation models were simplified so that they are now suitable for execution with CRSP data.

During this reporting period Version 1.1 of the CRSP expert system PONDCLASS was completed by the Oregon State University (OSU) DAST team. Efforts leading to the completion of this version included a formal peer review of the previous version, (undertaken by the Management Entity), incorporation of the appropriate changes and suggestions into the program, and preparation and editing of the PONDCLASS *User's Guide* by the Management Entity. The OSU DAST team also investigated the dry matter-nutrient relationships of several types of manures and factors affecting nutrient availability in chicken manure. The results of these research efforts are useful in determining suitable manure input rates for ponds; the information can also be incorporated into pond simulation and management models and computer programs, e.g., PONDCLASS, for improving the estimates of fertilization rates that the models generate. These efforts are detailed in the DAST reports in Section V, United States Research Component of the Global Experiment.

In addition, the UCD DAST team collaborated with researchers from the University of Hawaii (UH) to develop methods for assessing diel cycles of planktonic respiration rates. A report on this research is included in Section VI, Special Topics Research in the Host Countries and the United States.

Central Data Base

The Management Entity continues to maintain the CRSP Central Data Base for the storage and retrieval of standardized records from the research sites. At the individual sites, data on physical variables (e.g., solar radiation, temperature, and rainfall) and chemical variables (e.g., water and soil chemical characteristics) are collected concurrently with biological measurements (e.g., primary productivity, fish growth, and fish production). Whereas the resulting data sets are useful for *site-specific* studies, the compilation of all the individual data sets into the Central Data Base provides opportunities for many kinds of *global* analyses. Detailed standardized records such as those found in the Central Data Base are rare in the aquaculture literature. The Central Data Base has continued to grow through the inclusion of new data, generated under the Fourth and Fifth Work Plans, which have been transmitted from the research sites. All data from the Fourth Work Plan are now in the Central Data Base, whereas data generated by research from the Fifth and Sixth Work Plans are still being received and entered.

The utility of the Central Data Base extends beyond the PD/A CRSP. The Central Data Base was designed to facilitate communication with other large databases, such as the Tropsoils CRSP data base and ICLARM's FISHBASE, thereby creating opportunities for collaboration. It can also serve as a storage and retrieval center for standardized data from *any* research site. CRSP scientists as well as scientists in the aquaculture community at large may contribute to and access the data base. Data are available on computer diskettes or in print as PD/A *Collaborative Research Data Reports*. Additionally, the PD/A CRSP and ICLARM (International Center for Living Aquatic Resources Management) have tentatively agreed to incorporate CRSP data into ICLARM's FISHBASE.

This year the Technical Committee voted to continue to maintain the Central Data Base after evaluating its usefulness to researchers both within and outside the CRSP. Although maintenance of the Central Data Base remains a function of the Management Entity at present, it will be maintained elsewhere after Spring 1993.

Field Sites

Honduras

Workers at the El Carao research facility in Honduras tested the possibility of substituting inorganic nitrogen and phosphorus fertilizers for a portion of the standard application of chicken litter in tilapia production ponds. The studies were repeated during the cold and the hot seasons. Ponds that were fertilized weekly with chicken litter at various rates were supplemented with urea to maintain weekly total N inputs at about 25 kg/ha and diammonium phosphate was added to maintain N:P ratios at 4:1. The results of the study indicate that some substitution of inorganic N and P for chicken litter can be done without a significant reduction in yields. The use of inorganic inputs in place of organic fertilizers can lower biological oxygen demand in the ponds, thus reducing possible incidences of hypoxia, fish stress, and reduced yields. Preliminary financial analyses suggest that the partial substitution may also increase the profitability of pond operation. The pond fertilization recommendations given to producers in Honduras have already been modified to reflect the findings of this study.

Rwanda
The hypothesis that cassava meal can be used as a supplemental feed to increase fish growth in fertilized tilapia ponds was tested in experiments conducted at the Rwasave Fish Culture Research Station. Results indicated that fish growth was indeed enhanced by the supplemental feeding. The use of the energy-rich cassava meal apparently frees dietary protein for fish growth. The cost of using cassava meal in the experiments was exceeded by the value of the increased fish yield under existing market conditions in Rwanda, suggesting that farmers can use this approach to increase both yields and income from their ponds. These results also suggest that it may be appropriate to use commercial feeds produced for other animals in fertilized tilapia ponds. In the past such feeds have been considered to contain energy in excess of that required by fish.

The effects of temperature and treatment duration on the production of all-male tilapia fry by hormonal sex-reversal were tested in Rwanda. Treatment durations were 20, 30, and 40 days, and treatment temperatures were either ambient (20±2°C) or elevated (27±2°C). In general, more males were produced when the treatment was maintained for longer periods of time. It was concluded that the 30-day treatments are adequate for success at elevated temperatures (around 27°C), but that 40-day treatments are preferable when temperatures are closer to 20°C. This type of information is of particular relevance in a country like Rwanda, where much of the country's fish farming activity takes place at cooler high-elevation locations.

Other CRSP activities in Rwanda included a study of the factors influencing infestations of black spot disease in tilapia, a survey to determine the socioeconomic factors that affect the transfer and sustainability of aquaculture technology, a conference on high-altitude tilapia culture, and the implementation of a project to promote the inclusion of gender issues into aquaculture planning, training, extension activities, and research in Rwanda.

Thailand
Research completed in Thailand during the year included a study of supplemental feeding in fertilized ponds, tilapia-*Clarias* polyculture trials, and an investigation of the role of urea in pond systems. In the supplemental feeding experiments, ponds provided only with fertilizers (chicken manure supplemented with nitrogen and phosphorus) were compared with ponds provided with feed only and ponds provided with manure, N and P supplements, and feed. Fish in ponds receiving feed only had significantly higher final weights than fish in ponds that received only fertilizer, but never reached the preferred market size of 500 g. The growth of fish in ponds that were fertilized and fed was not significantly different from that of fish in fed-

only ponds, indicating that there is value to be gained through fertilization, even in fed ponds. Based on feed and fertilizer costs in Thailand at the time the experiments were conducted, however, it was concluded that the most efficient system was that in which ponds received only fertilizers.

The tilapia-*Clarias* trials enabled researchers to further refine a polyculture system that was worked on in earlier experiments. They concluded that if supplemental feed is to be added to a system in which *Clarias* are raised in tilapia ponds, the *Clarias* should be caged, and that the best stocking density for the *Clarias* is probably about six to seven caged fish per square meter of pond surface.

Laboratory studies were conducted to determine urea hydrolysis and decomposition rates and to evaluate the toxicity of urea to two species of fish. Although urea decomposition rates were found to be slow under the conditions of these experiments, it was felt that actual decomposition rates in ponds may be greater. Decomposition rates based on this study and others may be useful in estimating efficient pond fertilization schedules. With regard to urea toxicity, these tests showed that there should be little concern when tilapia or silver barb are the culture species. Urea concentrations far in excess of those that would result from normal pond fertilization resulted in no mortalities in either species after 96-hour exposures.

New Collaborative Efforts

A final significant development of the past year was the culmination of efforts to bring a new collaborative project into the program. During this year a new temperate site in Egypt was added to the CRSP project portfolio, and new universities and scientists in the United States and Egypt were welcomed to the CRSP Technical Committee. Research activities on the Egypt project, which will run through September 1994, include studies on polyculture, bioconversion, and biotechnology.

Other Activities

Information Dissemination and Technology Transfer
As in previous years, CRSP participants have made efforts to share the information gained through our research efforts with other interested parties. Such efforts include participation in conferences, publication of research results in journals, participation in workshops, and conducting farmer visits, research station tours, and demonstrations.

Real gains in on-farm production are achieved through two-way communication—not only from researcher to farmer, but also from farmer to researcher. CRSP workers have demonstrated an awareness of this important principle by conducting on-farm trials at various locations and by including a number of different types of farmer surveys in their activities, particularly in Rwanda. A major effort of this type was the "Colloquium on Rwanda Women in Aquaculture," held at the National Fish Culture Research Station at Kigembe, Rwanda. This colloquium was jointly organized by the OSU Women in Development (WID) office, the CRSP project at Rwasave, the Ministry of Agriculture, Livestock, and Environment (Government of Rwanda), and the National Fish Culture Service based at Kigembe. The Colloquium was notable in that it recognized the important role played by women in fish culture activities in Rwanda. It offered a unique opportunity for a number of women fish farmers to sit down with researchers, planners, and extension agents to discuss the problems and constraints they face when operating fish ponds, and to hold a constructive dialogue with the other participants regarding ways of improving communications and the transfer of fish production technologies to the private farms.

Also in Rwanda, a conference on high-elevation tilapia culture was held at the Rwasave Station in Butare from 1 to 7 September 1991. Participants from Rwanda, Burundi, and Zaire attended the conference, including university professors and students, aquaculture station managers, FAO personnel, Peace Corps volunteers, model farmers, extension and training specialists, some trainees, and government ministry personnel. Technical papers were presented on rice-fish culture, rabbit-fish culture, composting regimes, elevation-related tilapia production, tilapia-*Clarias* polyculture, and the Zaire Peace Corps sustainable fish culture extension service. A volume of conference proceedings is being compiled.

In Thailand, field testing of low-intensity aquaculture techniques on small-scale integrated farms was begun. This project will test fertilization and stocking practices developed at CRSP research sites as well as pond management guidelines developed by the DAST (i.e. PONDCLASS) in ponds at selected private farms. One of the methods tested will be the algal bioassay technique developed by CRSP workers in Thailand.

On-farm testing of production techniques developed by the CRSP was also carried out in Honduras. CRSP researchers worked with three groups of farmer-cooperators, either directly or through cooperation with Land Use Productivity Enhancement Project or Peace Corps volunteers in Honduras. Whereas farmers who adhered to the guidelines given by the CRSP were able to significantly improve production, the production of those who deviated from CRSP guidelines was similar to that of ponds managed as traditional production systems.

Annual Technical Committee Meeting

The annual meeting of the Technical Committee was held in Orlando, Florida in May. A number of reports on work completed or in progress were given by the participants, who represented all collaborating institutions and field sites. New officers were elected and decisions were made regarding the management of the CRSP Central Data Base and the procedures for the development of the Seventh CRSP Work Plan. In addition, plans for carrying out the External Evaluation Panel's review were made. Homer Buck, the EEP member in attendance, prepared the Annual EEP review of the CRSP from information gathered at this meeting. Technical accomplishments are described in Section IV.

III. CRSP RESEARCH PROGRAM BACKGROUND

At its inception, the Pond Dynamics/Aquaculture CRSP had a single, main theme—that of a common set of experiments to be implemented globally, following a standard experimental protocol at a number of research sites around the world. The Global Experiment, as it came to be called, was intended as a comparative study of aquaculture pond dynamics; one which would help us begin to understand how and why ponds at different geographic locations function differently, and how the management of those ponds might be tuned or adapted to different sets of environmental conditions to optimize production.

As CRSP research progressed, it became apparent that there were important additional needs to be addressed. To meet these additional needs, research components were added, so that in the past few years the main core of the program has included three components:

- Global Experiment,
- Special Topics Research in Host Countries, and
- Data Analysis and Synthesis.

During this reporting period the main core of CRSP activities has been augmented by a set of supplemental activities that are associated with one or more of the main components, but complement them in unique ways. These supplemental activities have included experiments aimed at improved understanding of specific dynamic processes in ponds, field testing of CRSP pond management guidelines (e.g., PONDCLASS), and efforts to address the special needs and concerns of women fish farmers in Rwanda. Most of these activities were carried out at the primary CRSP research locations (Host Countries and in the U.S.), but at least one was begun at a new site, the Freshwater Aquaculture Center in the Philippines.

The Global CRSP Experiment

The long-range goal of the CRSP is to increase the availability of animal protein in less-developed countries through pond aquaculture. The strategy adopted by the CRSP in pursuit of this goal is to undertake the basic research required to improve the efficiency of pond culture systems. A technical plan consistent with this strategy was developed under a planning study funded by USAID (Specific Support Grant AID/DSAN-G-0264). The technical plan reviewed and synthesized literature on state-of-the-art pond aquaculture. Overseas sites were surveyed to determine research needs and availability of local support in less-developed countries. The findings from these surveys were then translated into planning guidelines.

In the course of the planning activities it became apparent that there were two important aspects of improving the efficiency of pond culture systems: the need to improve the technological reliability of pond management systems, and the need for economic optimization consistent with local conditions.

The wide variation observed in the productivity of different pond systems illustrated the need for improved management technologies. Pond aquaculture had been practiced for centuries as a highly developed art form, and the literature was replete with reports about practices that had produced high yields. However, the results were often not reproducible when these same practices were applied to other ponds. It was clear that there were subtle differences regulating productivity from pond to pond and from site to site, but the nature of these differences remained obscure.

Rigorous economic analyses of pond aquaculture systems must be part of the aquaculture development strategy in both the U.S. and developing countries. In order to determine if contemporary pond management practices are the most efficient approach to fish production, it became necessary to develop quantitative production functions to facilitate analyses of the various strategies or combinations thereof. It was not possible to develop these functions without making numerous and often tenuous assumptions, because the dynamic mechanisms regulating the productivity of the ponds were poorly understood and the existing data base, until now, had been inadequate. Therefore, the common denominator in improving production technologies and facilitating economic analyses is an improved understanding of pond dynamics.

The Pond Dynamics/Aquaculture CRSP is unique relative to other CRSP's in several ways. The most visible difference is that it is funded at a substantially lower level than some CRSP's. A less obvious difference is that whereas other CRSP's are composed of a cluster of related projects organized on disciplinary or geographical bases, this CRSP is fundamentally organized around a single global experiment that involves all of its participants. Additionally, this CRSP is one of the few that was planned by the participating institutions.

Experimental Design

During the planning of this CRSP, it became apparent that the inadequacy of the existing pond aquaculture data base was a major constraint to improving the efficiency of pond culture systems. The abundant technical literature about pond aquaculture can provide general guidelines for the operation of pond systems; however, reports found in the literature cannot be statistically compared to one another because of the lack of standardization in experimental design, data collection, and analysis. Consequently, they are of limited utility for predicting the performance of other pond culture systems. The CRSP approach, therefore, is to develop quantitative expressions for improving production technologies and facilitating economic analyses by conducting standardized experiments and developing a standardized data base for use in evaluating pond performance quantitatively over a broad range of environments.

The initial statistical design for the experiment involved monitoring environmental and fish production variables at seven geographical locations. The project sites were carefully selected to include a geographical cross-section of the world where advances in pond aquaculture would be most beneficial and most apt to succeed. From 1987 to 1991 the program conducted experiments at three of the sites originally selected; these sites represent the three major regions of the tropics—Southeast Asia, Africa, and Latin America. All of the sites lie within a zone 15 degrees north or south of the equator. Another site in S.E. Asia was added in 1991. Observations specified in biannual (originally annual) work plans are made on twelve or more ponds of similar size at each location. The variables observed, frequency of observation, and materials and methods are uniform for all locations.

Observations at each location are analyzed by the research team involved at that location. Data from all sites are also filed in the CRSP Central Data Base, where they are accessible to the Data Analysis and Synthesis Team for analysis. Standard statistical methods are used to test hypotheses about correlations between variables and to evaluate the sources of variation within ponds, between ponds within locations, and between locations. Because of the relatively large number of locations and ponds at each location, the experimental design has substantial statistical power. Data in the Central Data Base are also available to *any* researcher—whether or not directly associated with the CRSP.

Since 1987, CRSP Work Plans have been designed to be more flexible, with respect to the Global Experiment, than was originally the case. Although the global aspects of CRSP research are maintained by conducting similar experiments at the various sites and by conducting these experiments in a standardized manner, certain aspects of the experiments may be adjusted to more directly address the needs of the country or region in which the work is taking place. Site-specific studies, not necessarily carried out at any other site, have also been included in CRSP work plans to address the needs and concerns of workers in the host countries.

CRSP Work Plans

From the program's beginning, the Technical Committee of the PD/A CRSP has had the responsibility for developing technical plans to guide the research efforts of each experimental cycle. During the first three cycles of the program, when global experiments were the main emphasis, CRSP work plans were developed annually. Each annual cycle consisted of two culture periods (wet and dry seasons) of four to five months duration, together with their associated sets of observations and data records. The First Work Plan specified a standard protocol for the preparation and stocking of ponds at all locations. Although the research program has evolved so that many different experiments are carried out at the various sites, the concept of a standard protocol for research at all sites has been maintained. The standard protocol initially introduced as a part of the First Work Plan has been improved with each subsequent work plan and has finally evolved into the PD/A CRSP's

Handbook of Analytical Methods, compiled by the Materials and Methods Subcommittee of the Technical Committee and distributed to CRSP participants in 1992.

As mentioned previously, the first three work plans were annual plans. In response to the recommendations of the External Review Panel during the first Triennial Review, a biennial approach to Work Plan development and execution was adopted beginning with the Fourth Work Plan, which was in effect from 1 September 1987 through 31 August 1989. Two-year operating cycles allow more time for completion and evaluation of experiments before plans for the next cycle must be completed. The Fourth Work Plan included tests of specific hypotheses formulated after review of the first three cycles of CRSP research.

The Fifth Work Plan was developed by the Technical Committee in May 1989, and encompassed research efforts carried out between 1 September 1989 and 31 August 1991. As with the Fourth Work Plan, the specific aquaculture needs of the host countries were more directly addressed in the experiments. In addition, during the period covered by the Fifth Work Plan, field experiments with farmer-cooperators were initiated.

This reporting period constitutes the first of two years of activities covered under the Sixth Work Plan, which began on 1 September 1991 and will be in effect through 31 August 1993. In addition to the set of experiments originally planned and approved at the Ninth Annual Meeting in May of 1991, a group of nine supplemental projects, funded by a 20% budget increase, was included in the Work Plan. Preliminary proposals for the Seventh Work Plan are now being reviewed prior to approval for implementation from 1 September 1993 through 31 August 1995.

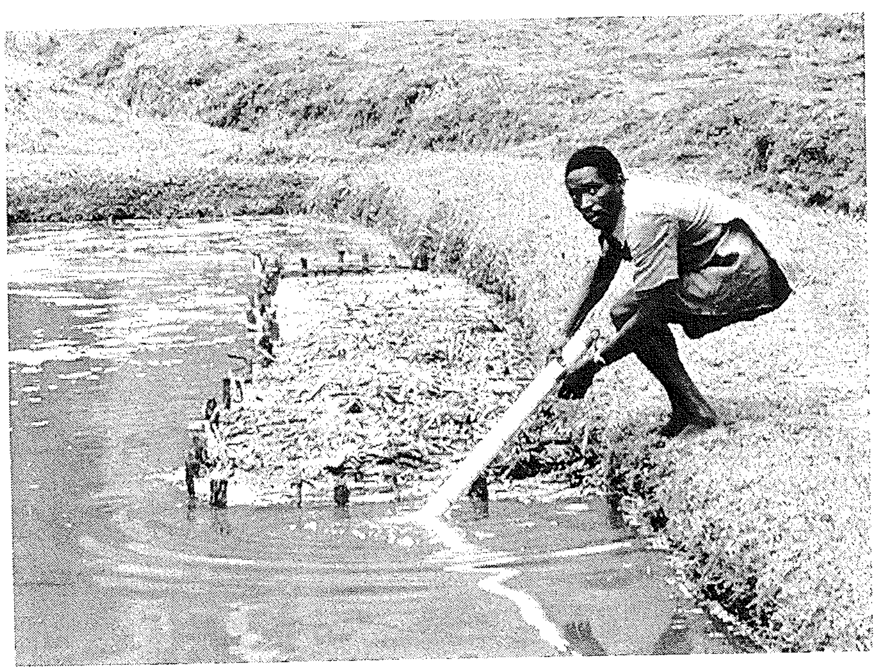
Data Management

Consistent with its long-term goal, the CRSP continues to develop practical pond management models to improve the efficiency of pond culture systems. The development of quantitative models depends upon the efficient management of standardized data.

Standardized data are tabulated at each research location in accordance with CRSP work plans. Project teams may conduct independent analyses of their data and publish results if they so desire. However, in all cases the data are transmitted to a centralized CRSP Data Base maintained by the Management Entity. In this way, the entire data set is available to all CRSP participants, but especially to the CRSP Data Analysis and Synthesis Team (DAST). The DAST was appointed by the CRSP Board of Directors to accomplish data analysis, synthesis, and model development. The various activities of Team members are supported as part of the U.S. Research Component of the CRSP.

The CRSP Central Data Base is kept continually up-to-date by the data base manager at the Program Management Office (PMO). All data generated by the experiments of the First through Third Work Plans were translated, entered, and verified prior to the beginning of activities under the Fifth Work Plan. This included data from the seven sites that were part of the Program during the first three experimental cycles. During that time, each site made approximately 90,000 observations per year, including information on 164 physical, chemical, and biological variables. This amounted to a half-million observations that were compiled and translated into standardized formats. During this reporting period, all data from the Fourth Work Plan have been added to the data base and data generated by the activities of the Fifth Work Plan have been added as they have been received from the field sites.

The format and current status of the data base facilitates communication with other large agricultural data bases. More importantly, it allows researchers worldwide ready access to data from the Global Experiment. Upcoming collaboration with researchers at the International Center for Living Aquatic Resources Management (ICLARM), with the possible inclusion of CRSP data in ICLARM's FISHBASE data base, will widen the accessibility of data generated by this program to researchers elsewhere. The data contained in the CRSP Central Data Base are already available to other researchers through the U.S. National Aquaculture Library.



The Global Experiment and Beyond

Prior to this reporting period, the CRSP grant was renewed through August 1995. Under the terms of the continuation plan, research continues at three sites, in Rwanda, Honduras, and Thailand. These sites are representative of the three USAID geographical areas in which the CRSP conducts overseas research: Africa, Latin America, and Southeast Asia. In addition, sites in the Philippines and Egypt have recently been added.

The continuation plan builds on the experience and knowledge gained through previous cycles of the CRSP Global Experiment. The focus during the first three years of the continuation plan is on refining the global models and on field testing. The final two years will focus on the verification of the models through continued on-farm trials and field testing. Research will emphasize oxygen dynamics, aeration, sediment-water interactions, influences of temperature on productivity at high altitudes, use of supplemental feeds, effects of pond size and nutrient addition schedules on fish production, and effects of density on intraspecific competition and maturation schedules of tilapia. Intensive sampling of pond variables, using standardized sampling protocols, will continue during the course of field experiments and the standardized data will be added to the CRSP Central Data Base. In addition to these variables, CRSP researchers will study the interaction of fish culture with existing socioeconomic systems at all research sites.

IV. RESEARCH PROGRAM ACCOMPLISHMENTS

The Global Experiment

The global nature of the Pond Dynamics/Aquaculture CRSP is evident in the interrelationships among projects. The program consists of tightly knit research projects that share the long-term goal of increasing the availability of animal protein in less developed countries through pond aquaculture.

Project emphasis is placed on standardized experimental design and data collection. Standardization permits the comparison of data from diverse geographical locations. The experimental design involves monitoring environmental and fish production variables in twelve or more ponds at each of three geographical locations in accordance with standardized work plans.

The five cycles of the original Global Experiment (1982 to 1987) followed one another logically. Although the main objective changed from cycle to cycle, consistency in experimental design allowed the comparison of results between cycles. The global nature of the program has been preserved in the experimental cycles as described in the Fourth, Fifth, and Sixth Work Plans. The Sixth Work Plan, which was finalized in early 1991, went into effect at the beginning of this reporting period (1 September 1991). The experimental protocol for all studies in the Plan remains consistent with that used in the Global Experiment, thereby enhancing the statistical accuracy of the data base and allowing standardized comparisons to continue to be made. The research described in this annual report is the result of activities carried out under both the Fifth and Sixth CRSP Work Plans.

Results of the Global Experiment

Major Global Experiment research topics presently include stocking density studies, studies on the manipulation of fertilizer N:P ratios to maximize primary production and fish production, polyculture studies, experiments dealing with the use of supplemental feeds in fertilized ponds, and on-farm trials of the results of CRSP research at the primary research sites. *Oreochromis niloticus* (tilapia) remains the primary species used in CRSP research at the overseas sites, but studies continue in which other species are cultured in polyculture systems with tilapia. Species used in polyculture trials include *Clarias gariepinus* in Rwanda, *Clarias batrachus* in Thailand and *Colossoma macropomum* in Honduras. Results of both of these polyculture studies are included in this annual report. Thailand project members also report a study on the supplemental feeding of fertilized ponds and on stocking strategies for the production of Nile tilapia. Workers in Honduras report an experiment to determine whether the standard rates of organic fertilizer additions used in that country can be reduced by substituting sources of inorganic nitrogen and phosphorus. Other Global Experiment studies planned as a part of the Sixth Work Plan are either ongoing or were completed too recently to be reported here. These include the CRSP fertilizer guideline verification studies being conducted in the

Philippines, a set of experiments to determine the effects of pond size on production (Thailand), a stocking density experiment conducted in Thailand, and field testing of low-intensity aquaculture techniques on small-scale integrated farms in Thailand.

The Fourth, Fifth, and Sixth Work Plans differ from the first three Work Plans in that hypotheses about pond dynamics are tested in different field experiments at each research location. This procedure allows the CRSP to proceed rapidly through the testing process. The Global Experiment was further enhanced by addition of intensive sampling periods and diel studies. *Standard Methods* (Standard Methods for the Examination of Water and Wastewater, APHA 1985) continued to be used as the primary reference for water quality analytical methods during this period; however, the Technical Committee of the CRSP completed the *Handbook of Analytical Methods* during this reporting period. This is a more comprehensive collection of methods than has, until this time, appeared in the "Summary of Accepted Analytical Methods" section of CRSP Work Plans; it will serve as the primary reference for CRSP research in the future.

Substitution of Inorganic Nitrogen and Phosphorus for Chicken Litter in Production of Tilapia

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Introduction

Supplementation of chicken litter with inorganic nitrogen has increased primary productivity (Teichert-Coddington et al. 1990). Work with various C:N ratios of organic inputs allowed for an appropriate rate of supplemental nitrogen to be established for El Carao that would increase fish production without wasting nitrogen (Teichert-Coddington et al. 1991). It remained to be seen if organic inputs could be decreased by substituting inorganic N and P. The studies reported herein demonstrate that moderate decreases in organic inputs can be achieved, but that reduced fish yields will accompany sharp decreases.

Materials and Methods

Ponds of 0.1 ha at the El Carao National Fish Culture Research Center, Comayagua, Honduras, were selected for this study. The study was repeated during cold and hot seasons of the year. The methodology was the same during both seasons except where indicated. Ponds were randomly assigned to treatments. Treatments were replicated three times. Ponds were fertilized weekly with chicken litter (CL) at rates of 750, 500, 250, or 0 kg total solids/ha during the cold season, and 500, 250, or 0 kg total solids/ha during the hot season. Urea was applied to maintain weekly total N inputs at about 25 kg/ha. Diammonium phosphate was added as needed to maintain N:P ratios of at least 4:1. Mean weekly inputs of inorganic fertilizer during the cold and hot seasons are summarized in Table 1. Manure was frequently analyzed for nitrogen and phosphorus. It was assumed that 55 and 100% of the N and P, respectively, in chicken litter was available for plankton use during the cold season. During the hot season, 50% of N and P in manure was assumed to be available for phytoplankton. Knud-Hanson et al. (1991) determined that 40% of N in chicken litter was "evolved"during two weeks of incubation in pond water. We assumed that additional N would be released from decomposition of less labile materials incubated for longer periods.

Ponds were maintained at approximately 0.9 m depth. Ponds were stocked with sex-reversed *Oreochromis niloticus* fingerlings at 20,000 fish/ha. During the cold season, half of the tilapia were *O. niloticus* and half were red tilapia that had been crossed repeatedly with *O. niloticus*. Guapote tigre (*Cichlasoma* *managuense*) fingerlings were stocked at 500/ha to control unwanted tilapia reproduction. Fish growth was monitored monthly. At harvest, ponds were completely drained and fish were counted and weighed. The growing season for cold and hot seasons was 5 September 1991 to 4 February 1992, and 12 March 1992 to 11 August 1992, respectively.

Table 1. Mean weekly inputs of urea and diammonium phosphate (DAP).

Treatment	Cold season Urea (kg/ha)	DAP (kg/ha)	Hot season Urea (kg/ha)	DAP (kg/ha)
750	29.7	0	-	-
500	37.5	0	33.5	9.5
250	41.3	9.9	37.6	15.4
0	40.6	31.0	39.5	26.8

Water was obtained for analyses by pooling subsamples taken with a 90-cm column sampler while traversing the pond. Samples were taken between 0700 and 0800 hours. Chlorophyll *a*, Secchi disk visibility, primary productivity, total solids, volatile solids, and zooplankton counts were determined once a week. Zooplankton were filtered from 14 liters of water using an 80-µ mesh net, and enumerated by group (copepoda, cladocera, rotifera, and nauplii). Total ammonia-nitrogen, organic-nitrogen, pH, filterable orthophosphate, and total phosphorus were determined every two weeks. Total alkalinity and total hardness were measured three times during the study. Daily wind speed, solar radiation, evaporation, and rainfall were recorded. Data were analyzed by regression analyses and ANOVA. Linear response to a reduction in CL input was tested by orthogonal contrasts. Significant differences among means were determined with S-N-K *post hoc* tests ($P \leq 0.05$).

Results

Nitrogen and phosphorus constituted 2.40 and 1.69%, respectively, of chicken litter dry matter during the cold season, and 2.35 and 1.34% during the hot season.

Cold season (September 1991 - February 1992)
Mean fish yields and average weights were not significantly different among treatments (Table 2). Mean weights of *O. niloticus* (Nile or "black" tilapia) and red tilapia were similar, but mean total yields of the black tilapia (1353 kg/ha) were 75% greater than yields of the red tilapia (772 kg/ha). Yield differences between the two types of tilapia were related to survival differences. Mean survival of the black tilapia (90.9%) was 79% greater than that of the red tilapia (50.8%). The red tilapia suffered a greater rate of predation by ospreys as witnessed repeatedly by field workers, and our experience is that red tilapia does not survive handling and environmental stress as well as black tilapia.

Table 2. Summary of fish harvest results during the cold season (September 1991 - February 1992) at El Carao.

Pond	Treatment	*Oreochromis niloticus* Yield (kg/ha)	*Oreochromis niloticus* MeanWt (g)	*Oreochromis niloticus* Survival (%)	Red tilapia Yield (kg/ha)	Red tilapia MeanWt (g)	Red tilapia Survival (%)	*Cichlasoma managuense* Yield (kg/ha)	*Cichlasoma managuense* MeanWt (g)	*Cichlasoma managuense* Survival (%)	Total adult yield (kg/ha)	Reprod. (kg/ha)	Total fish yield (kg/ha)	Mean survival (%)	Mean tilapia wt. (g)
1	CL0	611	83	73.90	613	89	68.7	2.3	18.9	24.0	1226	2.3	1228	71.3	85.8
2	CL500	1729	189	91.40	973	191	50.9	17.4	42.5	82.0	2719	2.3	2722	71.2	189.9
3	CL750	1308	149	87.80	473	150	31.6	7.1	39.4	36.0	1788	61.8	1850	59.7	149.2
4	CL250	1583	183	86.50	682	199	34.3	0.0		0.0	2265	0.0	2265	60.4	187.5
5	CL750	1286	138	92.90	884	154	57.3	7.2	29.9	48.0	2177	7.7	2184	75.1	144.4
6	CL0	1494	153	97.50	965	167	57.7	10.8	56.7	38.0	2471	52.7	2523	77.6	158.5
7	CL500	1639	169	97.20	843	176	47.9	0.0	0.0	16.0	2482	0.0	2482	72.6	171.0
8	CL750	1341	134	100.40	472	140	33.8	0.0		0.0	1813	4.5	1817	67.1	135.1
9	CL0	1067	118	90.70	771	126	61.3	2.3	17.4	26.0	1841	2.6	1843	76.0	120.9
10	CL250	1673	194	86.40	869	171	50.8	3.4	37.8	18.0	2545	0.0	2545	68.6	185.3
11	CL500	1333	141	94.50	760	155	49.1	5.1	46.4	22.0	2098	2.6	2100	71.8	145.7
12	CL250	1265	139	91.20	963	147	65.7	10.8	30.8	70.0	2239	2.8	2241	78.5	142.0
	CL750	1312a	140a	93.7a	609a	148a	40.9a	4.8	34.6	28.0	1926a	24.6	1950a	67.3a	143a
MEAN	CL500	1567a	166a	94.4a	859a	174a	49.3a	7.5	29.6	40.0	2433a	1.6	2435a	71.8a	169a
	CL250	1507a	172a	88.0a	838a	172a	50.3a	4.7	34.3	29.3	2349a	0.9	2350a	69.2a	172a
	CL0	1057a	118a	87.4a	783a	127a	62.6a	5.1	31.0	29.3	1846a	19.2	1865a	75.0a	122a

Means in columns followed by the same letter are not different (P > 0.05).

Table 3. Means of water quality variables determined during the cold season of 1991 (August 1991 - February 1992) at El Carao in ponds fertilized weekly with chicken litter (CL) at 0 to 750 kg TS/ha, and urea and diammonium phosphate to maintain total N inputs of 25 kg/ha and a ratio of 4N:1P.

Treatment	pH	Total alkalinity (mg $CaCO_3$/l)	Total hardness (mg $CaCO_3$/l)	Organic N (mg/l)	Total ammonia (mg/l)	Total P (mg/l)	Filterable PO_4 (mg/l)	Secchi disk (cm)	Chlorophyll *a* (mg/m^3)	Total volatile solids (mg/l)	Net primary production (mg O_2/l/d)
CL750	9.45a	77.8a	90.2a	4.42a	0.153a	3.70a	1.80a	10.6a	888a	219a	12.6a
CL500	9.50a	62.2b	68.4bc	4.12b	0.199ab	2.85b	1.45a	11.4a	812a	181a	12.9a
CL250	9.64a	57.2bc	57.9cd	3.95bc	0.311c	2.67b	1.38a	12.2a	703a	158a	11.3a
CL0	9.58a	42.6d	45.6d	3.44d	0.403c	2.64b	1.69a	13.6a	495a	138a	9.6b
Linear contrast	ns	hs	hs	hs	hs	hs	ns	s	s	hs	hs

Means in columns followed by the same letter are not different (P > 0.05).
ns = not significant; s = significant (P ≤ 0.05); hs = highly significant (P ≤ 0.01).

Covariant analyses of fish growth curves indicated significant differences among treatments (Figure 1). Growth was curvilinear for both black and red tilapia in all treatments except CL250, where it was linear. Growth stopped after the fourth month in the CL0 treatment.

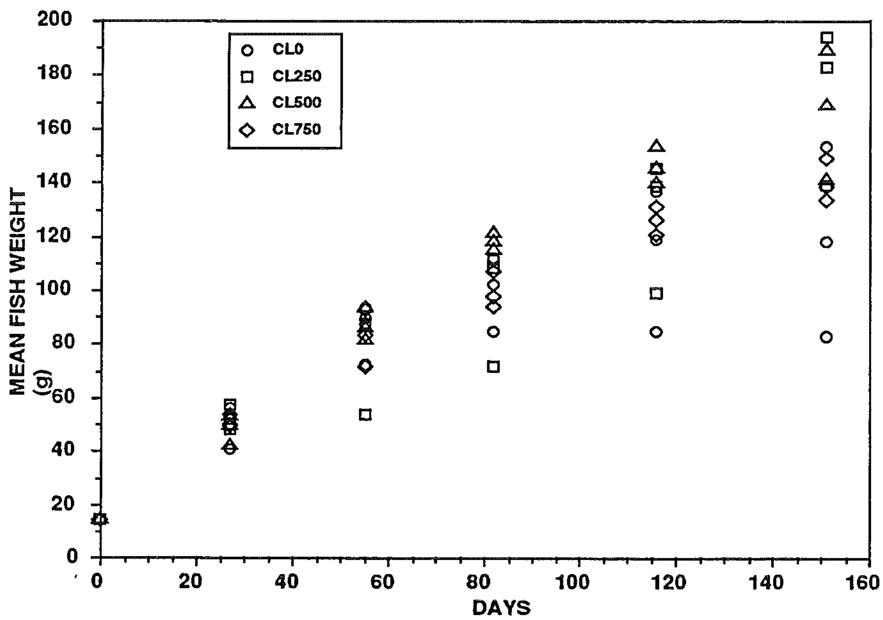

Figure 1. Growth of *Oreochromis niloticus* in ponds fertilized weekly with chicken litter (CL) at 0 to 750 kg total solids/ha, and urea and diammonium phosphate to maintain N inputs of 25 kg and a ratio of 4N:1P during the hot season of 1992 at El Carao.

Net primary productivity, chlorophyll *a*, total-P, organic-N, total alkalinity, and total hardness significantly decreased with decreasing litter input; total ammonia and Secchi disk visibility significantly increased with decreasing litter input (Table 3). There were no significant differences among treatments for pH, filterable orthophosphate, or zooplankton concentrations (Table 4).

Hot season (March - August 1992)

Mean weight of tilapia in CL 500 was significantly greater than weight of fish in CL250 and CL0 (Table 5). Fish yields at the highest level of organic fertilization were 53 and 72% greater than at the intermediate and lowest levels, respectively. However, the differences were not significantly different, because of high coefficients of variation at the intermediate (42%) and lowest (48%) organic fertilization levels. Mean yield of the CL250 treatment was lowered by 55% mortality in one replicate.

Analysis of covariance indicated that the slopes of mean fish growth curves were significantly different among the three treatments ($P \leq 0.0001$) (Figure 2). The growth of fish in ponds receiving no chicken litter practically stopped after three months. Growth of fish in the other two treatments was linear, although fish in the treatment receiving intermediate levels of chicken litter tended to slow during the last six weeks.

Table 4. Mean zooplankton concentrations during the cold season of 1991 (September 1991 - February 1992), and the hot season of 1992 (March - August).

	Cold season (No./l)				Hot season (No./l)			
Treatment	Rotifera (No./l)	Cladocera (No./l)	Copepoda (No./l)	Nauplii (No./l)	Rotifera (No./l)	Cladocera (No./l)	Copepoda (No./l)	Nauplii (No./l)
CL750	450a	26a	333a	230a	-	-	-	-
CL500	436a	46a	349a	202a	760a	176a	237a	99a
CL250	225a	76a	390a	142a	192a	128a	169a	85a
CL0	353a	23a	281a	154a	174a	178a	228a	58a
Linear contrast	ns	ns	ns	ns	s	ns	ns	ns

Means in columns followed by the same letter are not significantly different ($P > 0.05$).
ns = not significant; s = significant ($P \leq 0.05$); hs = highly significant ($P \leq 0.01$).

Table 5. Summary of fish harvest results during the hot season of 1992 at El Carao.

		Oreochromis niloticus			*Cichlasoma managuense*				Total
Pond	Treat	Yield (kg/ha)	MeanWt (g)	Survival (%)	Yield (kg/ha)	MeanWt (g)	Survival (%)	Reproduction (kg/ha)	fish yield (kg/ha)
1	CL0	3126	170.0	92.0	8.2	21.0	78	56	3189
2	CL500	3223	206.9	77.9	6.0	49.6	24	16	3245
3	CL500	3995	248.5	80.4	6.0	54.1	22	27	4028
4	CL0	1224	80.0	76.5	0.0		0	12	1236
5	CL0	1786	103.0	86.7	7.1	20.8	68	19	1812
8	CL250	3333	197.2	84.5	9.9	47.2	42	20	3363
9	CL500	3463	238.0	72.8	1.4	70.9	4	16	3480
10	CL250	1375	152.7	45.0	0.2	20.0	2	15	1390
11	CL250	2243	135.7	82.7	9.1	28.3	64	12	2264
MEAN	CL500	3560a	231a	77a	4	58	17	20	3584a
	CL250	2317a	162ab	71a	6	32	36	16	2339a
	CL0	2045a	118b	85a	5	21	49	29	2079a

a,b; Means in a column followed by the same letters are not different ($P > 0.05$).

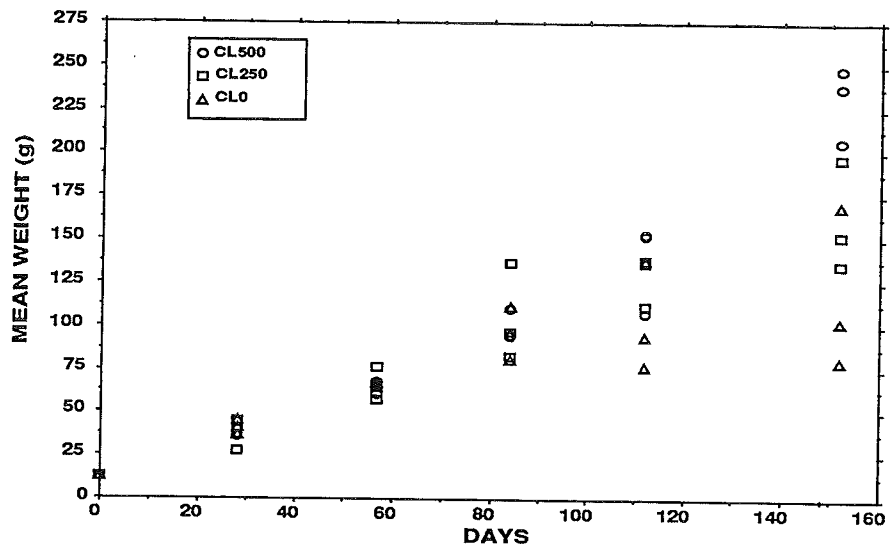

Figure 2. Growth of *Oreochromis niloticus* in ponds fertilized weekly with chicken litter (CL) at 0 to 500 kg total solids/ha, and urea and diammonium phosphate to maintain N inputs of 25 kg and a ratio of 4N:1P during the hot season of 1992 at El Carao.

Net primary production, chlorophyll *a*, total-P, organic-N, total alkalinity, and total hardness significantly decreased with decreasing litter input; total ammonia and Secchi disk visibility significantly increased with decreasing litter input (Table 6). There were no significant differences among treatments for pH or filterable orthophosphate.

Zooplankton numbers were not different among treatments, except for a linear decrease in rotifer concentrations with a decrease in CL input (Table 4). Mean rotifer concentrations in CL500 were high because of a short-lived spike in one of the replicate ponds.

Discussion

Except for CL0, fish yields were generally lower during the cold season than the hot season. The mean yield of CL250 during the hot season would have been greater (2788 kg/ha) if a replicate pond that suffered 55% mortality was not included in the mean. Poorer yields in the cold season can be attributed to lower survival and colder temperatures. Yields for the treatment receiving no CL were similar during both seasons; a cessation of fish growth before harvest indicated that carrying capacity had been reached. Lower temperatures during the cold season delayed achievement of carrying capacity until the fourth month, whereas it was reached in three months during the hot season.

Primary productivity for each level of CL input was similar during both seasons. In each season, primary productivity decreased with decreasing CL

Table 6. Means of water quality variables determined during the hot season of 1992 at El Carao in ponds fertilized weekly with chicken litter (CL) at 0 to 500 kg TS/ha, and urea and diammonium phosphate to maintain total N inputs of 25 kg/ha and a ratio of 4N:1P.

Treatment	pH	Total alkalinity (mg $CaCO_3$/l)	Total hardness (mg $CaCO_3$/l)	Organic N (mg/l)	Total ammonia (mg/l)	Total P (mg/l)	Filterable PO_4 (mg/l)	Secchi disk (cm)	Chlorophyll *a* (mg/m^3)	Total volatile solids (mg/l)	Net primary production (mg O_2/l/d)
CL500	9.61a	103.6a	70.4a	3.90a	0.169a	2.77a	1.30a	12.2a	705a	205a	12.3a
CL250	9.45a	92.0a	60.1ab	3.59b	0.280a	2.69a	1.37a	13.5a	613a	172a	11.4a
CL0	9.85a	80.7a	44.6b	3.14c	0.323a	1.99b	1.16a	19.5b	333b	127b	8.1b
Linear contrast	ns	s	hs	hs	s	s	ns	hs	hs	hs	hs

Means in columns followed by the same letter are not different ($P > 0.05$).
ns = not significant; s = significant ($P \leq 0.05$); hs = highly significant ($P \leq 0.01$).

inputs. The reduction in productivity was not related to a lack of N and P, however. Total ammonia nitrogen actually increased with a decrease in CL input, because of a lack of absorption by phytoplankton. Filterable orthophosphate was not different among treatments; furthermore, orthophosphate levels were very high in all ponds and were therefore not limiting production. Chicken litter may have contributed a micronutrient that was limiting phytoplankton growth, but it is more likely that the decomposition of chicken litter made more CO_2 available for phytoplankton use. The correlation of alkalinity and hardness levels with increasing CL inputs supports this hypothesis. Carbon dioxide increases the dissolution of calcite and dolomite, thereby forming bicarbonate (alkalinity) and Ca and Mg ions (hardness). Higher CL inputs produced more CO_2, which increased total alkalinity and total hardness. Phytoplankton had more CO_2 available to them, either directly or indirectly, through the carbonate-bicarbontate system. Availability of CO_2 through the alkalinity system decreases drastically, however, at the high pH levels measured during these trials. Problems caused by low CO_2 levels were thereby accentuated in the non-organically fertilized ponds. At a pH of 9.5, only about 22% of the alkalinity would have been available as CO_2 (Boyd 1990). The pH at El Carao rose while urea was being used as a supplemental nitrogen fertilizer.

It was expected that zooplankton would be more concentrated in organically fertilized ponds, thereby providing an additional source of nutrition for tilapia. During both seasons of study, there was no relationship between zooplankton populations and CL input. It may be that observed zooplankton concentrations were a standing stock that had escaped predation, and that their numbers would have been higher in organically fertilized ponds if they were not consumed by tilapia.

Primary productivity was clearly increased by organic fertilization during both seasons. It appears from the cold season study that weekly CL inputs beyond 500 kg/ha were not correlated with higher increases of primary productivity. Fish yield was not increased by higher primary productivity during the cold season, because colder temperatures and reduced fish densities prevented fish from taking advantage of higher nutrient availability. However, the fish clearly benefited from higher natural productivity during the hot season.

Anticipated Benefits

Substitution of inorganic N for organic inputs has allowed weekly chicken litter fertilizer rates to be reduced from 750 to 500 kg/ha without a decrease in fish production. Less organic input implies less biological oxygen demand, which in turn may decrease community respiration rates that have resulted in nocturnal hypoxia. Prior studies have shown that hypoxia can decrease tilapia yields. The standard El Carao fertilization rate that is extended to producers in Honduras has been modified to reflect results of these studies. Preliminary financial evaluation indicates that profitability is significantly increased by using the modified methodology.

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On-Farm Testing of PD/A CRSP Fish Production Systems in Honduras

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Introduction

The Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) was established at El Carao National Fish Culture Research Center, Comayagua, Honduras in 1983. Since that time, research has been conducted on fish stocking rates, the use of inorganic and organic fertilizer, supplemental feeding, and combinations of fertilization and supplemental feeding for fish production. The goal of this work has been to increase fish production and profitability by small- and medium-scale commercial producers using a technology that relies heavily on enhancement of natural pond productivity using locally available nutrient inputs.

PD/A CRSP research results have been disseminated at local, regional, and international scientific meetings, in regular lectures at local vocational-agricultural schools, at technology-transfer days at El Carao, through formulation of pond management plans for producers who buy fingerlings at El Carao, and in scientific publications. The next step is to transfer the production technologies developed through PD/A CRSP research to the farmer. Testing of these production systems under on-farm conditions will validate research findings and the PD/A CRSP Pond Management Guidelines, as well as serve as a teaching tool for extensionists and producers.

Another program of technology transfer, the USAID/Honduras and Ministry of Natural Resources Land Use and Productivity Enhancement (LUPE) program, expressed interest in collaborating with the PD/A CRSP in order to promote aquacultural development as part of its overall effort. The LUPE program worked with hillside farmers in the southern and central regions of Honduras to promote watershed conservation and sustainable agriculture. Many of the farmers that participated in the LUPE project had few resources such as fertilizers available to them. However, the use of compost as a fish pond nutrient input, as developed by the Rwanda PD/A CRSP, could be tested in these hillside ponds.

In early 1991, the Honduran PD/A CRSP principal investigator, Marco Iván Rodríguez, developed a program that linked producers in the northern and central regions of Honduras to El Carao. These small- to medium-scale commercial producers were interested in maximizing their profitability by refining their production technology. This group of farmers participated in field trials of the PD/A CRSP production systems developed in Honduras and Thailand.

Peace Corps/Honduras had an on-going fish culture project which placed Peace Corps volunteers (PCV's) primarily with the MNR. The goal of the Peace Corps/Honduras Fish Culture Project plan for 1991 to 1998 (Blenker and Thompson undated) was to improve the economic and nutritional status of the resource-limited rural population in Honduras through the introduction of sustainable fish culture production systems. The Associate Peace Corps Director for the fish culture project expressed an interest in having PCV's test appropriate PD/A CRSP fish production systems on farms where PCV's provided technical assistance; however, implementation of such trials depended solely on farmer interest and access to factors of production.

The Honduras PD/A CRSP developed a progam to conduct on-farm trials with resource-limited and small- and medium-scale commercial fish farmers in the southern, central, and northern regions of Honduras. The proposed program included three sets of on-farm trials, a set to be administered directly out of El Carao, a set to be administered by LUPE, and a third set to be administered by PCV's. The program was presented to the PD/A CRSP Board of Directors (BOD) for approval and funding in April 1991. The PD/A CRSP BOD approved the project and allocated $25,000 for project implementation. The project was begun in May 1991.

Project Design

The two components of this project were on-farm trials and short courses in aquaculture for extensionists and the farmers participating in the trials. An initial short course would be given before beginning farm trials, and a follow-up seminar would be given upon completion of the trials to summarize and discuss trial results.

Small to Medium-Scale Farmers
Honduran PD/A CRSP personnel were responsible for identification and selection of small- and medium-scale commercial fish farmers to participate in the on-farm trials managed out of El Carao. Participant farmers should have two ponds for use in trials, to allow the comparison of two production systems. Each prospective farmer would be interviewed prior to selection. Upon selection, the farmer and a PD/A CRSP representative would sign a contract that stipulated the responsibilities of each party during the on-farm trials. MNR extension personnel associated with PD/A CRSP would make monthly visits to participating farmers to collect data and water samples and to provide technical assistance as necessary.

Land Use and Productivity Enhancement Farmers
In mid-1991 the General Directorate of Fisheries and Aquaculture (DIGEPESCA) and LUPE directors met to discuss the implementation of

on-farm trials of fish culture systems that would be appropriate for LUPE-assisted farmers. Both directors agreed that such a program would be beneficial. LUPE extension personnel that were selected by the LUPE project director to implement on-farm trials were responsible for the initial selection of candidate farmers. Only one pond per farm would be used for the trials. Candidate farmers were then interviewed and briefed by Honduran PD/A CRSP personnel as to farmer's responsibilities during the on-farm trials, however, no contract between the farmer and LUPE was signed. LUPE extension personnel were responsible for supervising data collection by and providing regular technical assistance to participant farmers. A Honduran PD/A CRSP aquaculture specialist was assigned to accompany participating LUPE extension agents on farm visits at least once each month. During each visit, the PD/A CRSP aquaculture specialist would collect data and water samples and provide technical assistance. LUPE was responsible for transporting the aquaculture specialist from the Tegucigalpa headquarters to the field sites.

Peace Corps Farmers
Peace Corps/Honduras was only collaterally involved in testing PD/A CRSP production systems on farms. PCV's were responsible for collecting production data at each of their sites, but they were not obliged to test PD/A CRSP fish production systems. In practice, greatly different situations made it difficult to standardize inputs and management systems.

Implementation

In July 1991, a one week short course in aquaculture was presented. The course was held at the Training Center for Agricultural Development, CEDA, a joint Ministry of Natural Resources/Government of Japan project for training in agriculture. This center, located adjacent to the El Carao station, has classroom, dormitory, and cafeteria facilities, and is located about five km from Comayagua. All course participants stayed at the CEDA. The course was designed for fish farmers and extensionists that were participating in the on-farm trials in order to provide them with a more thorough understanding of aquaculture and the on-farm trials in which they were about to participate. Certain topics were not covered because they were not critical to the successful implementation and completion of the on-farm trials. For example, pond construction was not reviewed because participants already had functioning ponds. The course schedule was as follows:

Monday	Principles of aquaculture.
Tuesday	Requirements of aquaculture, water quality, field work in fertilization, Secchi disk use, on-going CRSP experiments, fertilizer calculations.
Wednesday	Tilapia reproduction, fish transport, field work in tilapia reproduction,sexing, and transport of fish.
Thursday	Production systems and economics, the field trials, and field data collection.
Friday	Chinese carp and tambaquí reproduction, production system enterprise budgets, and field practice sexing.

There were 17 full-time participants in the course (Appendix 1). In addition, a producer from La Villa, Comayagua, and four RENARE employees from Comayagua attended the Thursday session on production systems, economics, and the field trials. Course participants were provided with reference materials and a Secchi disk.

The four production systems to be tested on-farm were:

1. Compost

Compost should be corralled along one pond bank and should occupy 10% of the pond surface area. The corral was constructed by driving stakes into the pond bottom at 10-15 cm intervals. A long stake was placed horizontally and tied to each of the vertical stakes just above the water's surface. A second horizontal stake could be tied at mid-stake level to provide additional structural support. The top of the corral should not be greater than 5 cm above the water surface in order to discourage birds from roosting.

Prior to stocking the pond, an initial application of 1,000 kg/ha green matter (grasses, leaves, weeds, etc., excluding plants with a high tannin content, e.g., *Eucalyptus)* was made. Household kitchen scraps and ash could also be added to the compost pile. Additional applications of green matter were made weekly at a rate of 500 kg/ha; all applications were made on a dry matter basis. Pond productivity could be increased by substituting up to 20% of the green matter with fresh animal manure, as long as the 500 kg/ha weekly application rate was not exceeded. If manure was not available, urea could be added at a rate of 25 kg/ha per week. The compost pile should be mixed daily. Ponds were stocked with male *Oreochromis niloticus* fingerlings at $1/m^2$ and fingerling guapote tigre (*Cichlasoma managuense)* at $0.05/m^2$ to control tilapia reproduction.

2. Chemical Fertilization

Nitrogen and phosphorus, as inorganic fertilizers, were the only nutrient inputs to ponds. Nitrogen and phosphorus were applied weekly at 30 kg/ha and 8 kg/ha, respectively. Ammonium phosphate (18-46-0) and urea (46-0-0) are the commonly available chemical fertilizers; therefore the weekly fertilization rates were 40 kg/ha and 49.5 kg/ha, respectively. The weekly fertilizer dose was divided in half, with a three-day interval between the application of each half dose. The fertilizer should be dissolved in bucket of pond water, which will then be dispersed over the pond surface. Ponds were stocked with male *Oreochromis niloticus* fingerlings at $2/m^2$ and fingerling *Cichlasoma managuense* at $0.05/m^2$ to control tilapia reproduction.

3. Organic Fertilization

Animal manure was the only pond nutrient input. Fresh manure, e.g., cow or pig, was mixed with pond water and the manure slurry applied to ponds; chicken litter was broadcast over the pond surface. The manure application rate was 500 kg/ha/week on a dry matter basis. Ponds were stocked with male *Oreochromis niloticus* fingerlings at $1/m^2$ and fingerling *Cichlasoma managuense* at $0.05/m^2$ to control tilapia reproduction.

An alternative fertilization regime increased weekly manure applications to 750 kg/ha and included an urea (25 kg/ha weekly) application. The urea dose should be divided in half, with a three-day interval between the application of each half dose. Tilapia stocking rate was increased to 2 fish/m^2.

4. Fertilization Followed by Feed
Chicken litter was applied to ponds at a rate of 750 kg dry matter/ha/week. Urea was also applied weekly at 25 kg/ha; the weekly dose should be divided in half, with a three-day interval between the application of each half dose. Both fertilizers were applied during the first 12 weeks of grow-out. Beginning with week 13, fertilization was suspended and fish feeding was initiated. Fish were fed a commercial, pelleted fish feed (25% protein) daily at a rate of 3% of the fish biomass. The daily feeding rate was adjusted monthly based on average fish weight, determined by seine sample, and 100% survival of the fish was assumed. The daily feed allowance did not exceed 100 kg/ha. Ponds were stocked with male *Oreochromis niloticus* fingerlings at 2/m^2, and fingerling *Cichlasoma managuense* at 0.05/m^2 to control tilapia reproduction.

The PD/A CRSP, through the El Carao National Fish Culture Research Center, provided the tilapia and guapote fingerlings necessary for stocking. All other production costs were borne by the farmer. Field data was collated and analyzed by PD/A CRSP personnel at El Carao. Production trials were to last 150 days. Total alkalinity in pond water was analyzed prior to stocking to determine the need for lime; liming was considered unnecessary if total alkalinity exceeded 20 mg/L as $CaCO_3$ PD/A CRSP personnel provided technical assistance to participant farmers.

During each monthly visit, the PD/A CRSP representative sampled the fish population to quantify fish growth and collected water samples from each pond. The PD/A CRSP aquaculture specialist was also present for pond stocking and harvesting. Water samples were analyzed at El Carao for total ammonia nitrogen according to methodology given in *Standard Methods* (APHA 1989). Total alkalinity and pH were measured onsite using HACH kit methodologies. Participant farmers or visiting extensionists were asked to measure and record Secchi disk visibility in their ponds weekly.

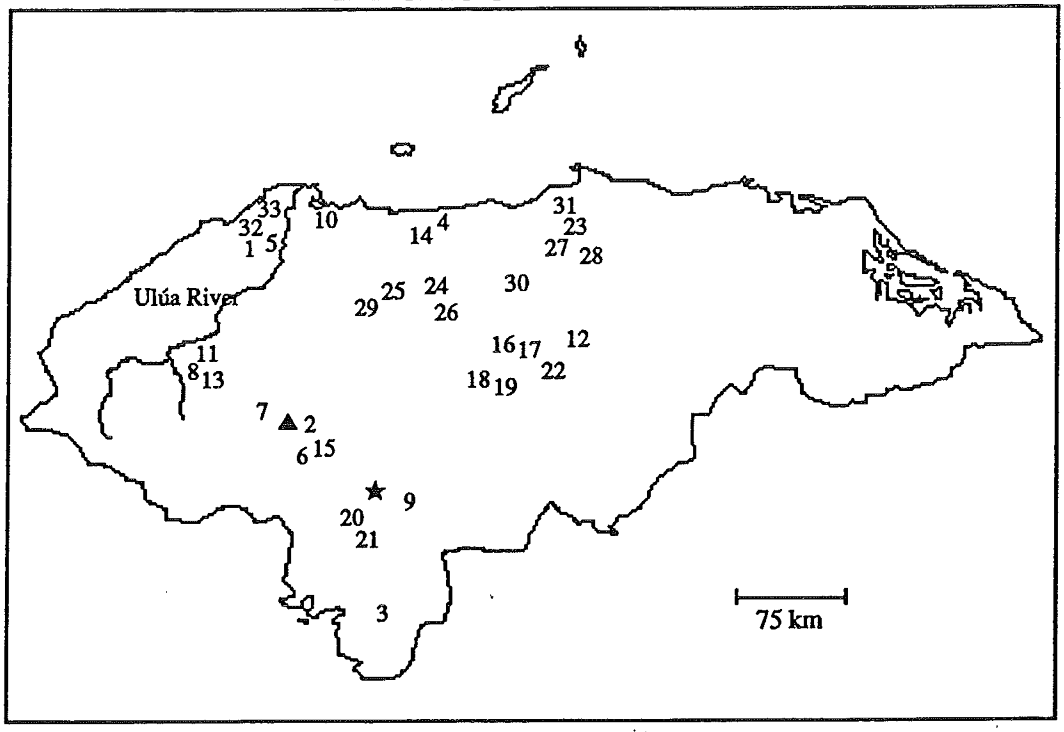
A total of 13 small- and medium-scale commercial fish farmers were selected to participate in the on-farm trials (Table 1 and Figure 1). All but one producer tested two production systems: *chemical fertilization* and *fertilization followed by feed.* One farmer was only able to test one system. Ten farmers completed the trials and only 70% of them adhered to the management system. Two farmers initiated a second series of trials upon completion of the initial trial. Both farmers repeated the *fertilization followed by feed* system, but stocked 2 or 3 fish/m^2.

LUPE extension personnel selected seven farmers to participate in the trials in September 1991 (Table 2 and Figure 1). One pond per farm was utilized in these trials. It was originally planned that participant farmers would use the

Table 1. Small- and medium-scale commercial fish farmers that participated in on-farm trials of PD/A CRSP production systems.

Producer	Location	Comments
Constantino Barleta	Jucutuma, Cortéz	Successfully completed; began second cycle.
Marcio Castellon	San Benito, Comayagua	Successfully completed.
DIGEPESCA station	Jesús de Otoro, Intibucá	Fish stolen during fourth month of culture.
DIGEPESCA station	Santa Bárbara, Santa Bárbara	Successfully completed.
Escuela Agrícola Panamericana (EAP)	Zamorano, Francisco Morazán	Successfully completed; 180-day cycle.
Escuela Agrícola John F. Kennedy (JFK)	San Francisco, Atlántida	Prolonged student strike prevented project implementation.
Efrain Ferrera	Paujiles, Atlántida	Successfully completed, but 176-d cycle; began second cycle.
Carmen Alicia Funez	Santa Rosita, Santa Bárbara	Cycle completed, but management plan not followed.
Santos Arnulfo Garcia	El Real, Olancho	Successfully completed; began second cycle.
Instituto Nacional Agrario (INA) station	Santa Rosita, Santa Bárbara	Cycle completed, but management plan not followed.
Carlos Lobo	San Francisco, Atlántida	Cycle completed, but management plan not followed.
Manuel Murillo	Las Metalias, Atlántida	Farmer was murdered; cycle not completed.
Marco Iván Rodríguez	Los Palillos, Comayagua	Successfully completed.

REPUBIC OF HONDURAS



Participant Farmers

Principal Cities
- ★ Tegucigalpa
- 1 San Pedro Sula
- 2 Comayagua
- 3 Choluteca
- 4 La Ceiba
- ▲ El Carao Station

El Carao Station
- 5 Barleta
- 6 Castellon
- 7 DIGEPESCA/Otoro
- 8 DIGEPESCA/Sta. Bárbara
- 9 EAP
- 10 Ferrera
- 11 Funez
- 12 Garcia
- 13 INA
- 14 Lobo
- 15 Rodríguez

LUPE
- 16 Zuñiga
- 17 Zelaya
- 18 Amijo
- 19 Escoto
- 20 Rodas
- 21 JFK School
- 22 Leal

Peace Corps
- 23 Escobar
- 24 La Escuela
- 25 Miranda
- 26 Hernandez
- 27 Villa Nueva
- 28 Mercado
- 29 Leba
- 30 Rosa Urbana
- 31 Zelaya
- 32 Exito Campesino
- 33 Canahuati

Figure 1. Map of Honduras showing locations of major cities and approximate locations of farms that participated in the PD/A CRSP on-farm trials.

compost system. No farmers were interested in such a system, however. They preferred to collect animal manures for pond nutrient input. Two LUPE coordinators were assigned to supervise extensionists involved with the trials. One coordinator suffered two consecutive car accidents, and later, after recovery, suffered a series of heart attacks; as of May 1992 he was still convalescing. The other supervisor resigned from LUPE in late 1991. All of the extensionists who had attended the training course and were involved with the trials, were transferred to other sites shortly after the trials began and were not replaced. Severe administrative problems that crippled LUPE throughout the latter part of 1991 and into 1992 have all but paralyzed project activities. Consequently, supervision and data collection at all farms suffered, and only one farmer completed the trial.

Peace Corps volunteers who had been at their sites for about one year worked with 13 client farmers (Table 3 and Figure 1). No farmer chose to test any of the PD/A CRSP production systems, but rather used a variety of fish culture practices. Nutrient inputs into ponds were varied and sporadic, ranging from termite nests to manure collected nearby to agricultural by-products such as wheat bran, rice-polishing waste, or cracked corn. Ponds were often stocked with additional fish species, the most common being tambaqui *(Colossoma macropomum). Cichlasoma managuense,* to control tilapia reproduction, was stocked by less than 20% of the farmers.

Project Results

Small to Medium Scale Farmers

Mean fish yields after 157 days were 2413 and 1785 kg/ha for the *fertilization followed by feed* and *chemical fertilization* systems, respectively (Table 4).

These means included data from producers who were known to have deviated significantly from the workplan; deviation from the workplan was suspected when results of water quality measurements, e.g., ammonia and Secchi disk visibility, were below expected values for the management system being tested. The producer was then questioned regarding adherence to the workplan, and responses generally confirmed noncompliance with the workplan. The predominant reason for noncompliance appeared to be that the farm owner was not directly involved in daily management, but rather relied on a farm manager who obviously did not share the owner's commitment to the trials.

Mean yields increased to 2890 and 2180 kg/ha for the *fertilization followed by feed* and *chemical fertilization* systems, respectively, when data from non-complying farmers was excluded from the analysis (Table 4). Mean final tilapia weight also increased slightly (Table 4); tilapia of this size were readily marketable in Honduras. The minimum size fish Honduran consumers appeared to accept ranged from 100 to 125 g. Fish smaller than this can be difficult to market in urban areas, although reports from rural areas indicated that it was possible to sell fish as small as 50 g.

Table 2. LUPE project farmers that participated in on-farm trials of PD/A CRSP production systems.

Producer	Location	Comments
Juan Zuñiga	Salamá, Olancho	Excessive vegetation on pond bottom prevented sampling.
Hector Zelaya	Salamá, Olancho	Pond water level not properly maintained.
Carlos Amijo	San Marcos de Guaimaca, Francisco Morazán	Ponds too deep to sample.
Jimmy Escoto	San Marcos de Guaimaca, Francisco Morazán	Pond could not be sampled because of excessive debris.
Bernardino Rodas	Surcos de Caña, Ojojona, Francisco Morazán	Fertilized at 20% of recommended rate. Ran out of urea during last 6 to 8 weeks of trial. LUPE extensionist had not visited site in three months.
John F. Kennedy public school	Surcos de Caña, Ojojona, Francisco Morazán	Lack of water to properly maintain pond water levels. LUPE extensionist had not visited site in three months. Fish stolen before harvest.
Marcos Leal	Campamento, Olancho	LUPE extensionist accidently stocked fish in Army Major's instead of farmer's pond.

Table 3. Farmer that received technical assistance from Peace Corps volunteers.

Producer	Location	Comments
Aquilino Escobar	Potrerillos, Yoro	High reproduction; does not want to use guapote.
La Escuela	El Coco, Colón	Pond overstocked with guapote; poaching suspected.
Lacho Miranda	Enancaya, Yoro	
Miguel Hernandez	Jalapa, Yoro	Pond originally stocked in 1984 and not drained since.
Jose Santos de Villa Nueva	Las Mangas, Colón	Pond stocked with mixed-sex tilapia, poorly managed, and impossible to completely drain.
Humberto Mercado	Rigores, Colón	Unable to maintain pond water levels because of lack of water; poaching suspected.
Juan Leba	Buenos Aires, Colón	Pond dike broke or overflowed on a couple of occassions.
Jose de la Rosa Urbana	El Zarzal, Yoro	Poaching suspected.
Fermin Zelaya	Ilanga, Colón	
Exito Campesino	San Lorenzo, Cortés	Poaching suspected.
Jose Canahuati	El Caracol, Cortés	Poaching suspected.

Table 4. On-farm trial production results for small to medium scale tilapia farmers.

Producer	Treatment[1]	Pond area (m^2)	Date stocked	Stocking rate (fish/ha)	Duration (days)	Mean final weight (g/fish)	Gross yield (kg/ha)	Survival (%)
Barleta	Fert. + feed	2,400	16 Apr 91	30,000	163	154	2,373	51
Castellon	Fert. + feed	2,400	23 Aug 91	20,000	152	153	2,429	79
EAP	Fert. + feed	900	4 Oct 91	18,000	180	215	3,173	82
Ferrera	Fert. + feed	230	21 May 91	30,000	176	108	3,149	98
Funez [2]	Fert. + feed	234	15 May 91	20,000	146	75	1,457	97
Garcia	Fert. + feed	650	4 Jun 91	20,000	148	204	3,838	94
INA [2]	Fert. + feed	875	15 May 91	20,000	146	108	2,163	85
Lobo [2]	Fert. + feed	200	18 Jun 91	20,000	153	64	756	59
Rodriguez	Fert. + feed	800	7 Jun 91	20,000	161	192	2,381	62
MEANS	*all farmers*	965		22,000	158	141	2,413	79
	compliant farmers	1,230		23,000	163	171	2,890	78
Barleta	Chemical	2,400	16 Apr 91	30,000	163	58	1,591	91
Castellon	Chemical	2,500	23 Aug 91	20,000	152	117	2,153	92
EAP	Chemical	900	4 Oct 91	18,000	180	182	3,054	93
Funez [2]	Chemical	234	15 May 91	20,000	146	97	1,531	79
Garcia	Chemical	1,250	4 Jun 91	20,000	148	154	1,511	49
INA [2]	Chemical	875	15 May 91	20,000	146	59	1,060	86
Lobo [2]	Chemical	200	18 Jun 91	20,000	153	63	790	63
Rodriguez	Chemical	4,837	7 May 91	17,000	161	170	2,588	80
MEANS	*all farmers*	1,650		20,625	156	113	1,785	79
	compliant farmers	2,377		21,000	161	136	2,180	81

1 Fertilization followed by feed or chemical fertilization; see text for details.
2 Producers known to have deviated sharply from standardized workplans.

In each treatment, tilapia mean weight at each sampling was regressed against time to obtain a general indication of growth across farms (Figure 2).The regression equations were:

$Y = 0.803X + 5.859$, $R^2 = 0.661$, for *fertilization followed by feed*, and
$Y = 0.639 X + 9.949$, $R^2 = 0.626$, for *chemical fertilization*,

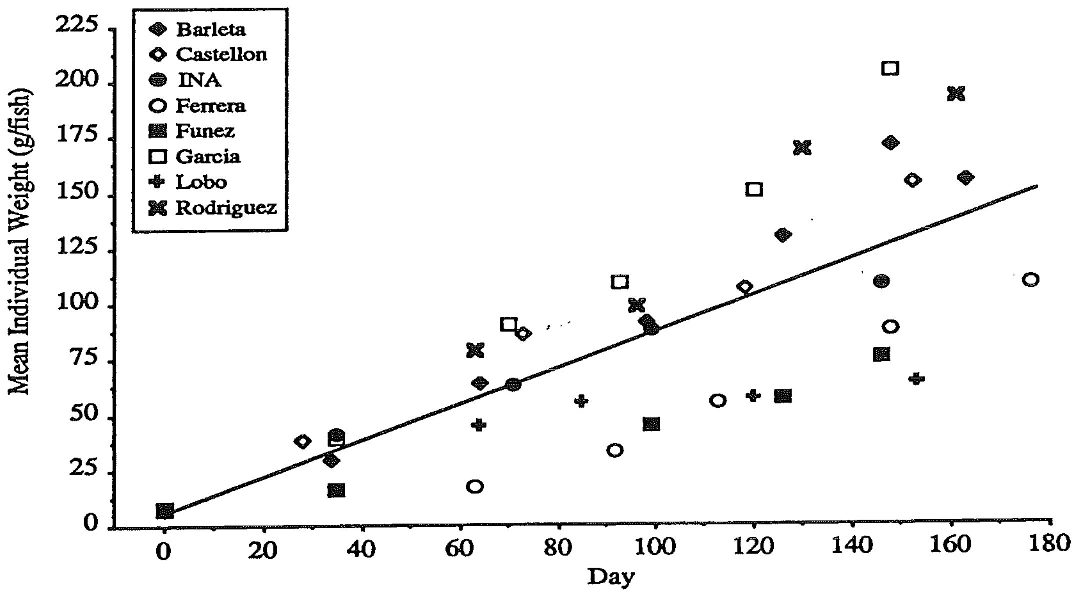
where Y equals mean individual weight (g/fish) and X equals day number. Observed fish growth was about 25% higher in the *fertilization followed by feed* system. The variability observed in the data can be attributed to noncompliance with the workplan, stocking rate differences, and site differences.The results of water quality analyses are shown in Table 5. Mean total ammonia concentrations and pH values were similar in both treatments. Observed mean total alkalinity was greater in the *fertilization followed by feed* system.

Table 5. Mean water quality variables in ponds on small- to medium-scale tilapia farms during on-farm trials.

	Total alkalinity (mg/L as $CaCO_3$)		pH		Total ammonia (mg/L NH_3-N)	
Farmer	Feed & fert.	Chemical	Feed & fert.	Chemical	Feed & fert.	Chemical
Barleta	68	145	10.0	9.0	0.20	0.38
Castellon	56	82	9.5	10.0	0.42	0.12
Ferrera	-	56	-	8.3	-	0.07
Funez	86	120	8.5	8.0	0.02	0.16
Garcia	103	120	8.7	8.0	0.67	0.44
INA	95	112	10.0	8.0	0.16	0.07
Lobo	39	47	7.0	6.8	0.07	0.05
Rodriguez	86	137	9.0	8.5	0.47	0.43
Mean	76	102	7.8	7.6	0.29	0.21

Research on similar production systems was conducted at the El Carao station prior to initiation of the on-farm trials. Teichert-Coddington et al. (1991) reported tilapia yields after 147 days of 2349, 2196 and 2223 kg/ha, when feeding was initiated after 1, 2, and 3 months, respectively, of organic fertilization only. Fish were stocked at $1/m^2$. When fish were stocked at $2/m^2$, tilapia yield was 4794 kg/ha/151 days where ponds were fertilized with manure during the first 60 days, after which fish were offered a pelleted feed (Green 1992). In a study where 14 kg N and 12.6 kg P per hectare were applied weekly to ponds stocked with 1 $fish/m^2$, tilapia yield after 150 days was 1513 kg/ha (Green et al.1989). In Thailand, ponds stocked with 1.6 $tilapia/m^2$ were fertilized weekly with chemical fertilizer (28 kg N and 7 kg P/ha) and chicken litter (25 kg/ha) (Knud-Hansen et al.1991). After 147 days, tilapia yield was 2570 kg/ha.

Fertilization Followed by Feed



Chemical Fertilization

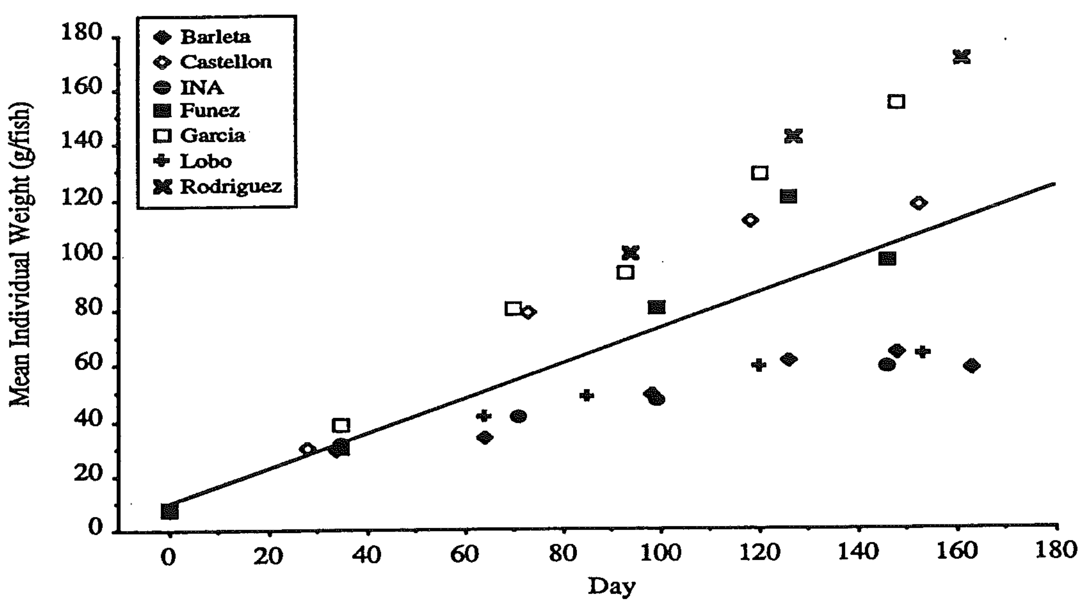


Figure 2. Growth of tilapia during on-farm trials conducted in collaboration with small- to medium-scale commercial tilapia farmers in Honduras. Management systems used: fertilization followed by feed (above) and chemical fertilization (below).

Table 6. Inputs used during on-farm trials by small- to medium-scale tilapia farmers.

Producer	Treatment[1]	Chemical fertilizer urea (kg)	Chemical fertilizer 18-46-0 (kg)	Chicken litter (kg)	Feed (kg)
Barleta	Fert. + feed	60	0	2,422	196
Castellon	Fert. + feed	60	0	1,995	635
EAP	Fert. + feed	23	0	1,640	574
Ferrera	Fert. + feed	9	0	234	72
Funez[2]	Fert. + feed				
Garcia	Fert. + feed	16	0	1,097	218
INA[2]	Fert. + feed				
Lobo[2]	Fert. + feed			592	0
Rodríguez	Fert. + feed	24	0	738	340
MEANS		28	0	1,180	243
		34	0	1,297	292
Barleta	Chemical	337	250	0	0
Castellon	Chemical	290	218	0	0
EAP	Chemical	156	*206	0	0
Funez[2]	Chemical				
Garcia	Chemical	145	109	0	0
INA[2]	Chemical				
Lobo[2]	Chemical	27	0	0	0
Rodríguez	Chemical	610	448	0	0
MEANS		282	205	0	0
		345	256	0	0

[1] *Fertilization followed by feed* or *chemical fertilization*; see text for details
[2] Producers known to have deviated sharply from the standardized work plans.
* Fertilizer 0-20-0.

The range of yields obtained by farmers (Table 4) was comparable to the range of yields obtained on the experiment station. The total quantity of inputs used by each farmer during the trials is shown in Table 6. Our observation was that farmers who adhered strictly to the workplan obtained the greatest yields, unless they experienced unexpected fish mortality.

Partial enterprise budgets were developed for each production system based on mean data from farmers who complied with the workplan (Table 7). Average income above input costs was $930 and $407/ha/162 day grow-out cycle (US$1 = Lempiras 5.40, July 1992) for the *fertilization followed by feed* and *chemical fertilization* systems, respectively. Total variable costs were, on average, 17% higher for the *fertilization followed by feed* system than for the *chemical fertilization* system. A farmer that utilized the fertilization followed

Table 7. Partial enterprise budgets, in Lempiras, for the fertilization followed by feed and the chemical fertilization production systems used during on-farm trials in Honduras. Values used for budget development were means from farms where farmers complied with the workplan. Budgets were based on 1-ha pond and a 162-day production cycle. July 1992 exchange rate: US$1.00 = Lempira 5.40.

			Fertilization plus feed		Chemical fertilization	
Description	Unit cost	Unit	Quantity	Cash	Quantity	Cash
INCOME						
• adult tilapia	7.17	kg	2,890		2,180	
TOTAL INCOME				20,721		15,631
VARIABLE COSTS						
• fingerlings						
tilapia	0.10	each	23,000	2,300	21,000	2,100
guapote	0.15	each	500	75	500	75
• plastic bags	6.00	each	47	282	43	258
• feed (20% protein)	76.70	45-kg sack	53	4,065	0	0
• fertilizer						
chicken litter	2.28	27-kg sack	400	912	0	0
urea	69.00	45-kg sack	7	483	33	2,277
18-46-0	82.00	45-kg sack	0	0	24	1,968
• transport						
fingerlings	200.00	60-km trip	1	200	1	200
feed	200.00	60-km trip	1	200	0	0
chicken litter	200.00	60-km trip	2	400	0	0
fertilizer	200.00	60-km trip	0	0	1	200
• field labor						
day	14.00	day	87	1,218	72.5	1,015
night	24.50	night	162	3,969	162	3,962
• irrigation water	25.00	ha-m	2	50	2	50
• interest on variable capital	0.23	year	0.5	1,544	0.5	1,321
TOTAL VARIABLE COSTS				15,698		13,433
INCOME ABOVE VARIABLE COSTS				5,024		2,198

by feed system would need to have a greater amount of available capital, and would have more capital at risk during the culture period.

Results of the second trials showed that increasing the fish stocking rate from 2 to 3/m^2 did not increase total yields at either of the two farms where this was tested. Gross tilapia yield at Ferrera's farm was 2866 kg/ha in 122 days. After 167 days, tilapia yields at Garcia's farm were 3779 and 3259 kg/ha for ponds stocked at 2 or 3 fish/m^2, respectively. Feed conversion efficiency at one of the farms indicated that increased density was not accompanied by a proportionate feed increase. Efficiency was 1.03 for the higher density and 1.50 at the lower density at Garcia's farm. A reluctance to increase feed inputs to the levels necessary for good growth resulted in small, marginally marketable fish at the higher density. Net income was less at the higher density because of higher fingerling costs and lower yields.

LUPE Farmers
The one LUPE farmer who completed the farm trial harvested 1048 kg/ha of tilapia after 207 days. This farmer's management plan called for weekly applications of fresh cow manure (500 kg/ha total solids) and urea (20kg/ha); however, actual cow manure applications were 20% of the specified quantity and he ran out of urea about 6 weeks prior to harvest.

Peace Corps Farmers
The mean tilapia yield was 1343 kg/ha after an average grow-out period of 211 days; other fish yield averaged 117 kg/ha, for a gross fish yield of 1484 kg/ha (Table 8). Fish yield varied from 315 to 3163 kg/ha. In discussions with the PCV's it became apparent that fish yield varied in relation to the level of inputs used, i. e., adherence to a management plan. Such a response is expected, and is what we observed with the small/medium scale commercial farmers. However, farmers that consistently provided nutrient inputs to the pond obtained yields that approximated those achieved by the small- and medium-scale commercial farmers. Tilapia size at harvest averaged 122 g, which is similar to sizes obtained by small/medium scale farmers, and is easily marketable. Lack of data did not allow tilapia growth to be characterized, but experience suggests that the grow-out period was too long, i.e., that significant fish growth had ceased long before fish were harvested. Thus, factors of production (ponds, inputs, farmer's labor, etc.) were underutilized.

Very little economic data was available for this group of farmers. Data was collected sporadically and only for a few farmers. Very few inputs were purchased, and it was not possible to assign an accurate economic value to inputs collected from the field, e. g., manure, termite nests, etc. Thus, it was impossible to conduct an economic evaluation of the traditional fish production system.

Comparison of Production Systems

In Honduras, systems characterized by varied and sporadic nutrient inputs (ranging from termite nests to manure collected nearby to agricultural

Table 9. Comparison of selected production parameters between the traditonal system and the *fertilization followed by feed* and *chemical fertilization* systems used by fish culturists during on-farm trials in Honduras.

Production System	Stocking rate (fish/m^2)	% Difference relative to traditional system	Grow-out duration (d)	% Difference relative to traditional system	Annual tilapia yield (kg/ha/yr)	% Difference relative to traditional system
Traditional system	1.9	---	189	---	2,579	---
Fert. followed by feed compliant farmers	2.3	+ 21	163	- 14	6,496	+ 152
Chemical fertilization compliant farmers	2.1	+ 11	161	- 15	4,904	+ 90

by-products such as wheat bran, rice-polishing waste or cracked corn), and grow-out cycles that are considerably longer than 150 days can be collectively considered as the "traditional production system." This system is practiced by the non-compliant small- and medium-scale commercial farmers and the farmers assisted by PCV's, and provides a basis against which to compare the impact of the PD/A CRSP production systems tested during the on-farm trials. Many of thesmall to medium scale commercial farmers historically used production systems similar to the traditional system. Significant increases in tilapia yield relative to the traditional system were obtained by farmers using PD/A CRSP production systems (Table 9). Other important differences between the traditional and PD/A CRSP systems were that with the traditional system stocking rate was about 16% lower and the grow-out duration was about 15% longer (Table 9).

Summary

The results of the on-farm trials with the small- and medium-scale tilapia farmers demonstrated that the PD/A CRSP production systems were more productive than the traditional tilapia production system used in Honduras. The limited enterprise budget analysis indicated that both PD/A CRSP systems resulted in significant income above variable costs, an indicator of the economic viability of the systems. It should be noted that the PD/A CRSP production systems tested in this trial were not developed for subsistence fish farmers, but rather for small- to medium-scale commercial fish farmers who have the capability of purchasing the necessary factors of production. It is this group of fish farmers who we feel will have the greatest impact on freshwater aquaculture in Honduras.

The one PD/A CRSP production system included in the trials for subsistence farmers (the compost system) was not tested. No farmer felt sufficiently resource-limited to test the compost system that was developed by the Rwanda PD/A CRSP; there were sufficient resources available, e. g., manure in fields, agricultural by-products, and termite nests, etc., that farmers did not feel compelled to use compost. Any production system is only as good as the farmer who implements it; we observed that farmers who complied with the workplan obtained consistently high yields that approximated those attained on the experiment station, whereas non- or variably-compliant farmers obtained proportionally lower yields. This observation applies equally to all fish farmers associated with the on-farm trials.

To develop and implement an on-farm testing program is an ambitious endeavor. The program of on-farm trials just completed was the first such activity undertaken as part of the Honduras PD/A CRSP, and there were a few lessons learned. We attempted to involve participants from all of the sectors active in fish culture in Honduras, and as result the on-farm trial activities were dispersed country-wide (Figure 1).

However, this involved interaction with a number of agencies other than the PD/A CRSP host country counterpart, effectively limiting our direct control over the trials. Cooperating agencies always expressed interest and commitment to the trials, but because the trials were not specific activities of

Table 8. Production results from Peace Corps Volunteer assisted traditionally-managed fish ponds.

Producer	Pond area (m^2)	Date stocked	Stocking rate (fish/ha)	Duration (days)	Mean tilapia weight (g/fish)	Tilapia yield (kg/ha)	Other fish yield (kg/ha)	Gross yield (kg/ha)	Tilapia survival (%)
Canahuati	600	27 Aug 91	22,500	*	*	*	*	*	*
Canahuati	600	27 Aug 91	22,500	*	*	*	*	*	*
Escobar	235	20 Nov 91	4,468	145	90	314	0	314	78
Exito Campesino	1,500	23 Oct 91	23,300	*	*	*	*	*	86
Hernandez	150	*	*	*	55	1,093	0	1,093	*
La Escuela	330	*	*	145	104	523	41	564	*
Leba	395	11 May 91	8,481	339	168	1,382	0	1,382	97
Miranda	325	5 Nov 91	12,308	162	80	862	0	862	87
Mercado	350	*	*	*	109	785	441	1,226	34
Rosa Urbana	480	22 Aug 91	20,167	234	183	2,249	229	2,479	61
Villa Nueva	80	*	*	*	93	1,116	0	1,116	*
Zelaya	1,000	22 Aug 91	25,000	235	146	2,321	319	2,640	64
Zelaya	350	Mar 91	20,000	237	195	2,785	377	3,163	71
MEANS	492		17,636	214	122	1,343	117	1,484	72

* No data available.

the agencies' annual workplans, field-level execution of the trials often suffered. It is important that the researchers have direct input into the execution of the field trials to ensure that the protocol is adhered to and that proper, complete data is collected. These shortcomings must be rectified if future on-farm trials are to be conducted in collaboration with other agencies in Honduras.

The trials conducted directly by El Carao and PD/A CRSP personnel also involved farmers located in diverse geographic regions of Honduras. As a result, much time and expense were expended on travel; time spent on travel was time not available to work directly with participant farmers. Future trials should be limited to one to two geographic zones at a time (e. g., the Comayagua Valley). This would allow greater contact with the farmers in each zone and a more efficient transfer of technology. Subsequent trials would then be conducted in different geographic zones.

Acknowledgements

We thank Gary L. Thompson, APCD, and the PCV's of the U.S. Peace Corps/ Honduras Fish Culture Program for their collaboration and support, and the personnel of the Land Use Productivity Enhancement Project, Ministry of Natural Resources for their participation in the on-farm trials.

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List of attendees at one-week short course on aquaculture, CEDA, Comayagua, Honduras, July 1991.

Name	Work Site	Agency
Edmundo Morales	Ojojona, Francisco Morazan	LUPE
Victor Flores Agalteca,	Francisco Morazan	LUPE
Allan Rodd Moss	Salama, Olancho	LUPE
Carlos Oqueli	Soledad, Paraiso	LUPE
Miguel Mercado	Concepción de María, Choluteca	LUPE
Daniel A. Casasola	Guaymaca, Francisco Morazan	LUPE
Sarah ten Bensel	El Progreso, Yoro	PCV/RENARE
Arnulfo Garcia Rodríguez	Sta. María del Real, Olancho	Producer
Efrain Ferrera	Tela, Atlantida	Producer
Armando Muñoz	Santa Bárbara	INA
Mardoqueo Ferrrera	Tela, Atlantida	Producer
Claudia L. Sosa	Tegucigalpa	Rotary Club
Adrian Arnoldo Vidal P.	San Francisco, Atlantida	JFK Ag School
Gustavo Adolfo Hernandez	San Francisco, Atlantida	JFK Ag School
Mario Danilo Ponce	Comayagua	RENARE
Steve Marma	Toyos, Yoro	PCV/RENARE
Lourdes Moncada	Choluteca	RENARE

Supplemental Dietary Energy to Enhance Utilization of Natural Food Organisms for Growth by Tilapia

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Introduction

Supplemental feeding of tilapia with inexpensive, energy-rich feedstuffs may spare scarce protein for growth rather than for energy, thereby increasing the efficient use of protein in naturally occurring food organisms in fertilized ponds. In controlled environments the addition of non-protein digestible energy to the diet of tilapia improved conversion of dietary protein to fish flesh (Shiau and Huang 1991, El-Sayed and Teshima 1992). Results of an earlier experiment (Work Plan 5, Experiment 6) indicated that some types of natural tilapia food occurring in fertilized ponds were somewhat deficient in digestible energy.

Objectives

The objective of this experiment was to test the hypothesis that an energy-deficient natural diet produces greater tilapia growth in enriched ponds if a low-protein, high-energy feedstuff such as cassava meal is added as supplemental feed.

Materials and Methods

Eighteen 7-are ponds were fertilized with freshly cut grasses at 350 kg/ha/wk as dry weight (1 are = 100 m^2). Twelve of the ponds (four ponds per treatment) also received cassava meal at 437, 875, and 1750 g per pond per day. The six remaining ponds received only grasses. Treatments were calculated to give 0, 0.75, 1.5, and 3.0 kcal digestible energy (DE) per m^2 per day. Feed was applied once daily at noon.

Fish were sampled monthly to determine average weight by sex. The dissolved oxygen concentration was monitored once weekly, morning and afternoon. Chlorophyll *a* concentrations and Secchi disk visibility were measured every two weeks. Ponds were drained 133 days after stocking.

Results

Fish receiving the highest amount of digestible energy weighed significantly more at harvest (P=0.05) than fish receiving no additional digestible energy (Table 1). The average weight at harvest was strongly correlated to the quantity of supplemental dietary energy added to the ponds (Figure 1). Production of adult fish was significantly greater at the 0.75 and 3.0 kcal DE input rates than at the 0-kcal DE input rate (Table 1). Total net production, including reproduction, in cassava-enriched ponds was 29 to 37% higher than in control ponds without supplemental energy, but these differences were not statistically significant. The degree of nutritional benefit from additional dietary energy may have been partially masked by stress from low dissolved oxygen levels associated with the highest input level of cassava (Figure 2). Researchers at the PD/A CRSP in Honduras reported improved

Table 1. Net fish production, percent fish survival, and dissolved oxygen data.

	Treatment (kcal DE/m^2/d)			
	0	0.75	1.5	3.0
Net Production, adult fish (kg/are/day)	9.4 a[1]	15.5 b	14.8 ab	17.5 b
Kg fingerlings/are	1.6 b	1.3 b	1.2 b	0.2 a
Average weight males (g)	96 a	109 ab	119 ab	126 b
Average weight females (g)	50 a	55 a	56 a	71 b
Overall average weight (g)	71 a	84 ab	90 b	99 b
Survival (%)	77 a	91 a	81 a	83 a
Net production(kg/are/yr) (including fingerlings)	13.9 a	19.1 a	18.3 a	17.9 a
Average AM DO (mg/L)	2.6 c	1.4 b	1.3 b	0.6 a
Average PM DO (mg/L)	7.8 b	6.4 b	6.6 b	4.2 a
PM DO minus AM DO (mg/L)	5.2 ab	5.0 ab	5.3 b	3.5 a

[1]Numbers followed by the same letter are not significantly different.

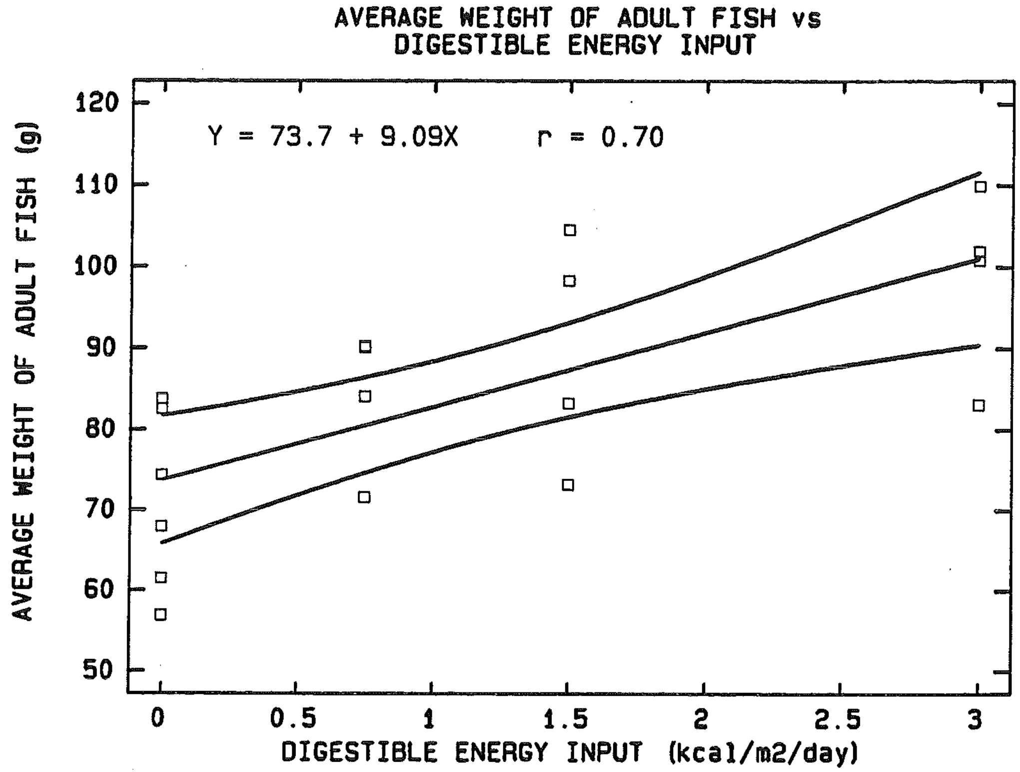

Figure 1. Relationship between the average weight of adult tilapia at harvest and the input rate of supplemental digestible energy.

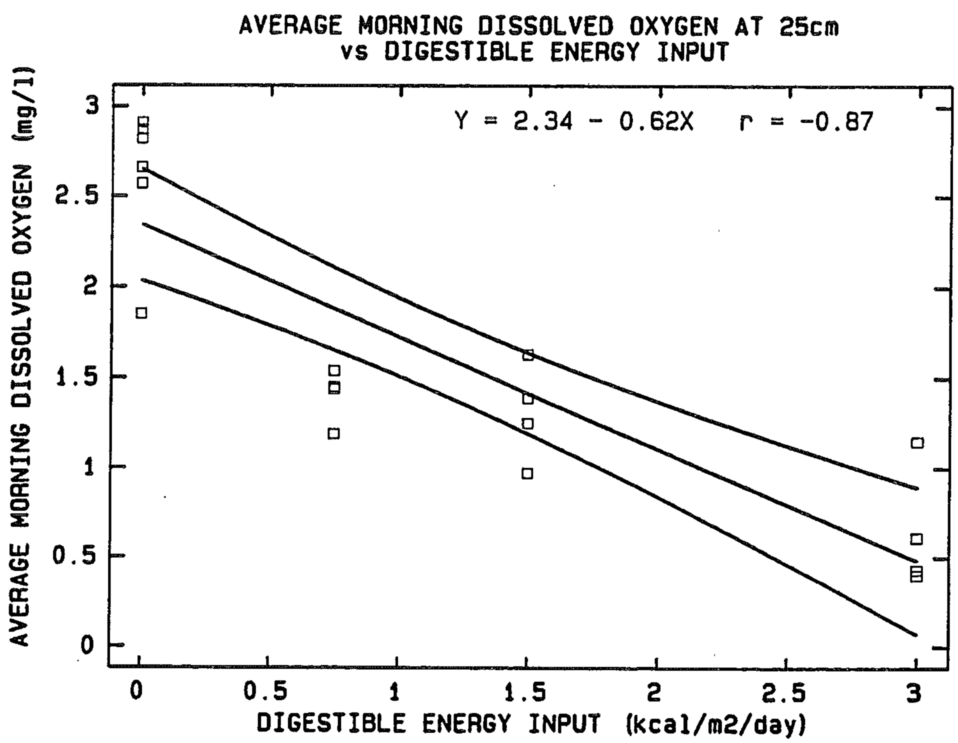

Figure 2. Relationship between the average morning dissolved oxygen concentration taken at 25 cm and the input rate of supplemental digestible energy.

tilapia growth when aerators were used to maintain dissolved oxygen concentrations of at least 10% saturation (Green, personal communication).

Fingerling recruitment at the highest level of DE/m^2 was significantly lower (0.2 kg/are) than in the other treatments (1.2 to 1.6 kg/are). Average morning dissolved oxygen concentrations of 0.6 mg/L 25 cm below the water surface probably reduced fry survival at the highest cassava input. Few nests were observed in ponds receiving the highest DE treatment.

Chlorophyll *a* levels were low for most ponds during the experiment. Differences were not associated with treatment, nor was there any apparent correlation of chlorophyll with fish production.

Although the grass applied had a very high C:N ratio (32:1), additional carbon in the form of digestible energy appeared to enhance fish growth, thus suggesting that the natural diet resulting from fertilization with grass is energy deficient for tilapia. The additional energy could have directly benefitted the fish through consumption or indirectly through increased availability of natural food organisms, such as bacteria and zooplankton, that fed on the cassava. A future experiment will attempt to separate direct and indirect nutritional benefits of supplemental dietary energy.

Anticipated Benefits

Supplemental dietary energy may increase the amount of fish flesh produced per unit weight of nitrogen added to fertilized ponds. The results of this experiment suggest that farmers can spare protein in natural food organisms for growth of tilapia by adding energy-rich feedstuffs such as cassava meal. In Rwanda the value of the additional fish produced exceeded the cost of the cassava meal. The results also suggest that commercial feeds such as poultry or swine rations, traditionally considered to contain excess digestible energy for fish, may be highly appropriate for tilapia in heavily fertilized ponds.

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Tilapia and *Clarias* Polyculture

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Introduction

Clarias are commonly cultured in Thailand using earthen ponds and supplemental feed. Nutrients from such ponds, as well as surplus feeds that remain uneaten, are wasted in this culture. In an earlier experiment, we found that *Clarias* could be stocked in cages in tilapia ponds, and in such a system the *Clarias* can eat supplemental feed, while their waste products can increase primary production and tilapia growth. In 1990, we further detailed this aquaculture system (reported in the CRSP Ninth Annual Administrative Report), but were unable to complete the experiment satisfactorily because of unavailability of *Clarias* fry and uneven mortality of *Clarias* and tilapia. The development of tilapia and *Clarias* polyculture can substantially increase yields and use nutrients more efficiently than monoculture of either species. The purpose of this study was to further refine the polyculture system.

Clarias are also used in polyculture systems as a predator to limit natural reproduction in ponds. Restraining *Clarias* in cages negates such an effect, but allows for more efficient use of supplemental feed. This experiment also compared growth of caged and uncaged *Clarias* to evaluate their predatory effect. This study was originally proposed as Study 3 in Work Plan 5.

Objectives

The purpose of this study was to examine the roles of *Clarias* and tilapia in polyculture systems. To accomplish this, four treatments were tested:

- (A) Tilapia (2/m^2) alone in fertilized ponds;
- (B) *Clarias* (0.5/m^2) and tilapia (2/m^2) at large in ponds, with supplemental fertilization only;
- (C) *Clarias* in cages (4 cages at 220 fish/cage) and tilapia in ponds, with supplemental feed for the caged fish and no fertilization;
- (D) *Clarias* (8 cages) and tilapia (2/m^2) at large in ponds with feed for the caged fish.

Materials and Methods

The experiments were conducted at Bang Sai. Each pond treatment was triplicated. Tilapia and *Clarias* were stocked on 10 May 1991. Stocking and harvest data are given in Tables 1 and 2. *Clarias* in caged treatments were stocked into one cubic meter cages at 220 fish per cage. Treatment C included 4 cages and treatment D included 8 cages per pond. Treatments A and B had weekly fertilizer inputs of 2 kg nitrogen (91 kg urea/ha/wk) and 1 kg phosphorus per pond (46 kg TSP/ha/wk). Supplemental feeding in treatments B, C, and D was initially done at 10% BW/d for *Clarias* and gradually reduced to 3%/day by harvest. Water chemistry analyses were conducted weekly. Ponds were harvested on 9 September 1991 (122 days).

Results

Growth, survival, and yield in each treatment are summarized in Table 3. For tilapia, there were significant differences in growth among treatments, with the highest growth occuring in the high density *Clarias* treatment ($p \leq 0.05$). There were no significant differences in survival or yield of tilapia among treatments. These results were compromised by mortality in one

Table 1. The biomass, number, and size of *Clarias* and tilapia stocked into ponds of each treatment.

Treatment	Species	Biomass (kg)	Number	Size (g)
A1	Tilapia	3.2	440	7.2
A2	Tilapia	3.2	440	7.3
A3	Tilapia	3.2	440	7.2
B1	*Clarias*	1.8	110	16.7
	Tilapia	3.2	440	7.2
B2	*Clarias*	1.8	110	16.5
	Tilapia	3.8	440	8.6
B3	*Clarias*	1.4	110	12.6
	Tilapia	3.1	440	7.1
C1	*Clarias*	11.6	880	13.2
	Tilapia	3.0	440	6.8
C2	*Clarias*	12.7	880	14.5
	Tilapia	3.1	440	7.1
C3	*Clarias*	13.4	880	15.3
	Tilapia	3.1	440	7.2
D1	*Clarias*	29.9	1760	17.0
	Tilapia	3.1	440	7.0
D2	*Clarias*	26.6	1760	15.1
	Tilapia	3.2	440	7.4
D3	*Clarias*	22.6	1760	12.8
	Tilapia	2.6	440	6.0

pond (D3) at the highest *Clarias* density. When growth data for that pond were removed from the analysis, there was no significant difference in tilapia growth among treatments.

Clarias results differed considerably among treatments (Table 3). Growth was significantly lower in the at-large treatment (B) ($p \leq 0.001$), but did not differ between the caged treatments. Survival showed a similar relationship, with significantly lower survival in the at-large treatment and no difference in the caged treatments. Net yield differed significantly in all three treatments, with increased density resulting in higher yield ($p \leq 0.001$).

Because tilapia and *Clarias* mortality occurred in at least one pond (D3) at high loading, relationships between growth, survival, and yield of *Clarias* or tilapia and various pond water or input variables were analyzed. By simple correlation, tilapia yield was significantly correlated to Secchi disk depth ($r^2 = 0.836$, $p \leq 0.05$), while tilapia growth was correlated to chlorophyll *a* concentration ($r^2 = 0.746$). *Clarias* growth and yield were strongly correlated to low DO because *Clarias* density and feeding caused the low DO. Multiple stepwise regressions of various input variables (Table 4) on growth of *Clarias*

Table 2. The biomass, number, and size of *Clarias* and tilapia harvested from each pond.

Treatment	Species	Biomass (kg)	Number	Size (g)
A1	Tilapia	76.0	338	225
A2	Tilapia	70.6	374	189
A3	Tilapia	42.2	365	116
B1	*Clarias*	7.2	70	103
	Tilapia	96.6	378	256
B2	*Clarias*	7.0	75	93
	Tilapia	88.8	445	199
B3	*Clarias*	5.6	42	133
	Tilapia	60.7	357	170
C1	*Clarias*	201.6	864	233
	Tilapia	55.4	408	136
C2	*Clarias*	256.1	857	298
	Tilapia	80.0	408	196
C3	*Clarias*	234.0	809	289
	Tilapia	78.0	379	206
D1	*Clarias*	473.2	1723	274
	Tilapia	97.6	354	276
D2	*Clarias*	467.8	1687	277
	Tilapia	111.1	394	282
D3	*Clarias*	312.5	1208	259
	Tilapia	58.1	174	334

Table 3. Growth, survival, and net yield for *Clarias* and tilapia in each pond.

Pond	Growth (g)	Survival (%)	Yield (kg/ha)
	Clarias		
B1	86.3	63.6	245
B2	76.5	68.2	236
B3	120.4	38.2	191
C1	219.8	98.2	8636
C2	283.5	97.4	11063
C3	273.7	91.9	10027
D1	257.0	97.9	20150
D2	261.9	95.9	20055
D3	246.2	68.6	13177
	tilapia		
A1	217.8	76.8	3309
A2	181.7	85.0	3064
A3	108.8	83.0	1773
B1	248.8	85.9	4245
B2	190.4	101.1	3863
B3	162.9	81.1	2618
C1	129.2	92.7	2382
C2	188.9	92.7	3495
C3	198.8	86.1	3405
D1	269.0	80.5	4295
D2	274.6	89.5	4905
D3	328.0	39.5	2523

and tilapia indicated that tilapia growth was significantly correlated to chlorophyll *a* and dissolved oxygen concentrations ($r^2 = 0.79$, $p \leq 0.001$), while *Clarias* growth was correlated to the number of days with low dissolved oxygen ($r^2 = 0.75$, $p \leq 0.01$). Survival was not significantly correlated to any of these variables for either species.

Anticipated Benefits

This project, coupled with two earlier experiments, clarified many of the potential problems in *Clarias*-tilapia polyculture. If supplemental feed is to be added for *Clarias*, the fish should be caged. *Clarias* growth and yield increased when density was increased from 110 to 1760 fish per 220 m^2 pond. Yield of tilapia and *Clarias* was compromised at the highest density, however, due to tilapia mortality. It appears that the highest loading rate for *Clarias* in such a system is 6-7 caged fish per m^2 of pond.

Table 4. Pond water quality variables used in the multiple regressions. Low D.O. events = number of mornings with D.O. < 2 in mid water column.

Pond	Low D.O. events	D.O.	Alkalinity	NH_3	Total Kjeldahl Nitrogen	Total Phosphorous	Secchi Disk Depth	Chlorophyll A
A1	3	3.9	106.6	0.42	4.1	0.90	14.94	151.4
A2	0	4.1	153.5	0.50	3.4	0.70	27.6	103.6
A3	3	3.5	58.6	0.80	4.5	0.30	21.7	43.1
B1	0	4.7	120.7	0.38	4.2	0.80	20.0	132.7
B2	1	4.0	120.4	0.47	5.5	0.57	19.3	142.4
B3	0	4.4	91.8	0.60	3.8	0.46	22.4	55.6
C1	3	3.5	70.6	0.77	5.0	0.28	23.4	69.1
C2	4	3.3	169.8	0.33	4.5	0.46	22.1	194.0
C3	3	3.8	111.5	0.29	3.0	0.37	22.8	81.8
D1	5	2.7	163.1	0.61	6.7	0.91	20.5	428.5
D2	3	3.6	171.3	1.00	6.4	0.68	20.4	265.0
D3	5	3.4	152.0	0.65	5.6	0.56	23.8	277.6

The feeding of *Clarias* in treatment D led to low dissolved oxygen and other conditions that limited growth of both *Clarias* and tilapia. Mortality also occurred in pond D3, although our data indicated no correlation between survival and either average DO values or number of days with low DO. One dramatic low oxygen event probably caused the mortality, but was not recorded due to the frequency and timing of our water sampling.

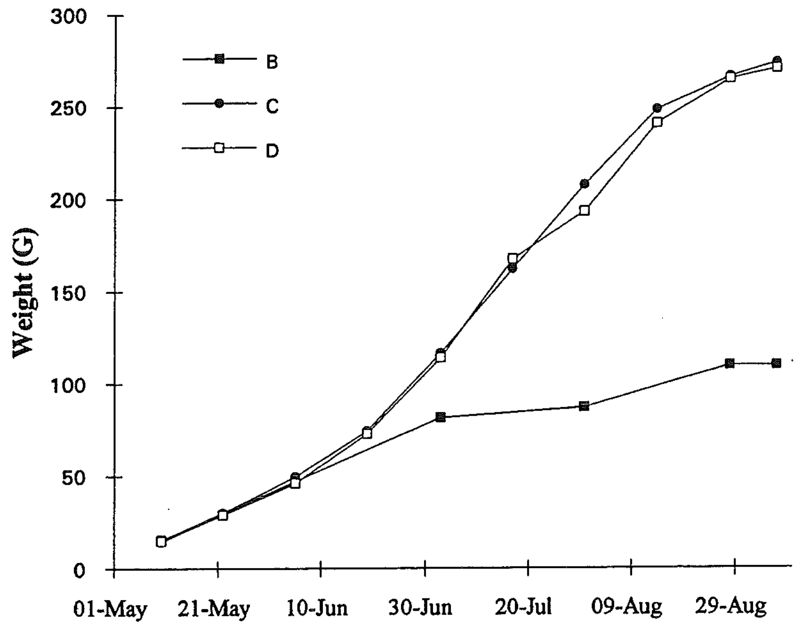

Figure 1. Growth of tilapia in each treatment.

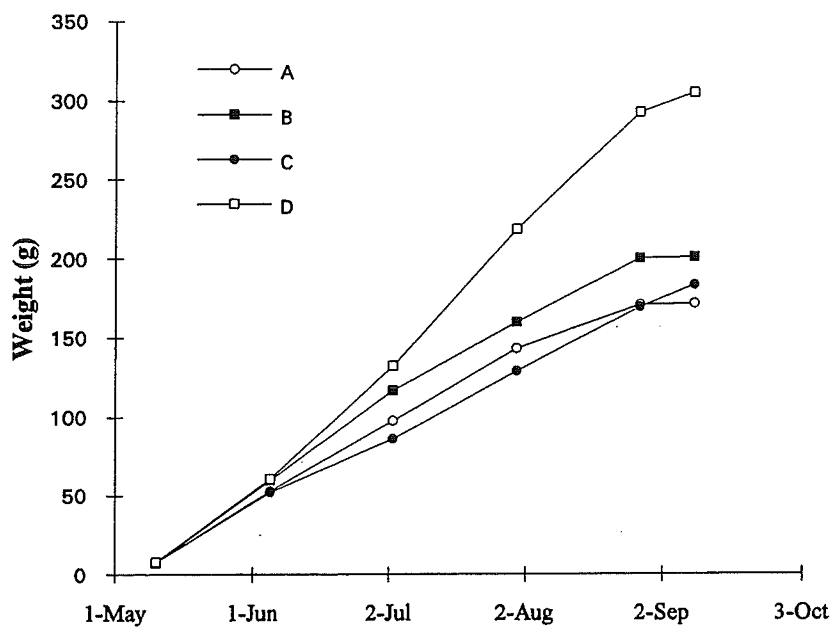

Figure 2. Growth of *Clarias* in each treatment.

Supplemental Feeding of Tilapia in Fertilized Ponds

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Introduction

Tilapia are commonly grown in semi-intensive culture using fertilization to increase primary production and fish food. However, size at harvest under such systems usually averages 250 g in five months, and it may take as long as five more months to rear the fish to 500 g under semi-intensive culture. In Thailand and many other areas the market price is much higher for large tilapia than small ones, and the demand for larger tilapia can be met either by extending the growout or by adding feed to the ponds. The purpose of this study was to evaluate the addition of feed to already-fertilized fish ponds, in order to increase the growth of tilapia to a larger market size without lengthening the growout period. Since the ponds were already fertilized and contained natural food, this addition of feed would be considered supplemental feeding rather than complete feeding. This study was originally proposed as Study 8 in Work Plan 5.

Objectives

The purpose of this study was to evaluate the role of supplemental feeding in the production of large tilapia for market. To accomplish this, three treatments were tested:

1. Ponds with triple superphosphate and urea fertilization only,
2. Ponds with feed only and no fertilizer, and
3. Ponds with feed and fertilizer.

Materials and Methods

The experiments were conducted at Bang Sai. Each treatment was triplicated. Ponds were originally fertilized on 9 October 1991. Sex reversed *Oreochromis niloticus*, averaging 1 g per fish, were stocked at 2 fish per m^2 (500 fish per pond) on 9 October 1991. Stocking and harvest data for each pond are given in Table 1. Treatment 1 included inorganic fertilization at rates of 80 kg urea/ha/wk and 40 kg TSP/ha/wk.

Table 1. Stocking and harvest data for the experimental ponds.

	At Stocking			At Harvest		
Pond	Number	Size (g)	Biomass (kg)	Number	Size (g)	Biomass (kg)
Fert 1	500	0.70	0.37	398	253	101
Fert 2	500	0.87	0.40	372	112	42
Fert 3	500	0.80	0.39	360	187	67
Feed 1	500	0.60	0.32	394	348	138
Feed 2	500	1.00	0.38	346	280	97
Feed 3	500	0.90	0.38	436	347	152
Both 1	500	0.60	0.45	373	299	112
Both 2	500	0.70	0.31	316	282	89
Both 3	500	0.80	0.38	241	323	78

Treatment 2 included feeding of tilapia to satiation. The satiation ration was determined weekly by using a floating feed at controlled rates and determining the total amount of feed taken in one feeding. Initial feeding rates were 25 g per day (5% BW/d) and these rates were gradually changed to 2400 g per day (2% BW/d) by harvest. Water chemistry analyses were conducted weekly. Ponds were harvested after 162 days on 19 March 1992. Treatment effects were tested statistically by analysis of variance and multiple regression. Results were considered significant at $p \leq 0.05$. For multiple regression, values were included in the regression when $p \leq 0.10$.

Results

Growth, survival, and yield data for each pond are shown in Table 2. Growth differed significantly between treatments (ANOVA, $p \leq 0.05$). Fed ponds had the highest growth rate, fertilized-and-fed ponds were intermediate, and fertilized ponds had the least growth (Figure 1). The mean weight of fish increased steadily in each treatment except during the last month (Figure 1). The apparent decline in the last month was probably due to sampling bias when seined subsamples were compared to the entire population sampled at draining. Also, the average weight of a subset of fish at harvest was considerably different than the mean weight determined by weighing the entire fish biomass and dividing by the total number of fish. Due to better precision, the latter estimate was used for final weight of fish in each pond. The final net yield (kg/ha) in each pond did not differ significantly among treatments (ANOVA), due

Table 2. Growth, survival, and yield of fish from each of nine experimental ponds.

Pond	Growth (g)	Survival (%)	Yield (kg/ha)
Fert 1	252.3	79.6	4013
Fert 2	110.8	74.4	1646
Fert 3	185.9	72.0	2672
Feed 1	348.4	78.8	5487
Feed 2	279.6	69.2	3868
Feed 3	346.6	87.2	6044
Both 1	298.9	74.6	4449
Both 2	281.7	63.2	3558
Both 3	322.3	48.2	3100

mainly to large inter-pond variation in survival. Survival was also not significantly different among treatments (ANOVA).

The results of this experiment for fish growth, survival, and yield were somewhat clouded by variations within treatments. This was particularly noticeable in the unfed treatment, where growth was particularly low in one pond (FERT 2) which developed low alkalinity as the experiment progressed. Also, several of the ponds with high loading of feed or feed and fertilizer developed low oxygen. High ammonia levels also occurred in ponds receiving only fertilizer. Multiple regression between total fish growth and several other pond measures (Table 3) indicated that growth was significantly correlated with feeding rate, frequency of low dissolved oxygen, and alkalinity (r^2=0.978, $p \leq 0.001$, Table 4). The development of low alkalinity during our experiments in Thailand has occurred only in the inorganically fertilized ponds in this experiment, suggesting that organic fertilizers (in previous experiments) or feeds provide additional carbon to the ponds, preventing low alkalinity from occuring as photosynthesis progresses. Low dissolved oxygen (<2 mg/L) occurred in the morning in all of the treatments, but particularly in the fed ponds. High ammonia levels (>2 mg/L) occurred in ponds treated only with fertilizers. Since these ponds were also the low growth treatment, NH_3 levels were not included in the multiple regression. Combinations of fertilizers and feeds produced consistent alkalinity but variable feeding rates among replicates. The variation in feeding rates was probably due to variable natural food production in each pond. Phytoplankton densities (estimated by chlorophyll *a* concentrations) also varied considerably within treatments, probably reflecting the variation in natural food production between ponds.

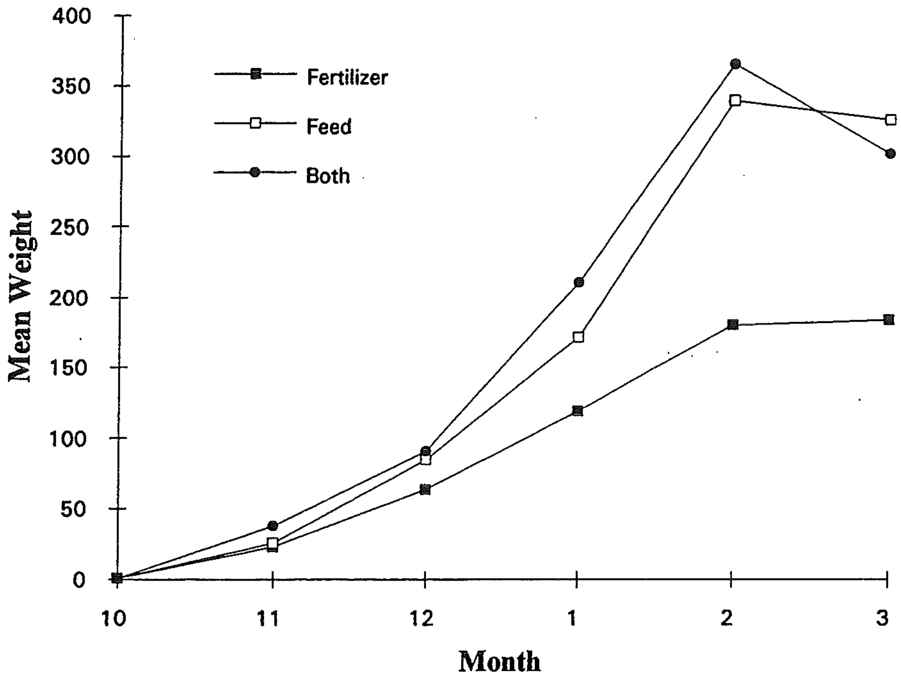


Figure 1. Monthly changes in average weight of tilapia from fertilized ponds, fed ponds, and ponds receiving both inputs.

Anticipated Benefits

Input of feed resulted in more rapid growth of tilapia, particularly in the last two months of culture, and in significant increases in final weight (from 180 to 320 g). However, final weight never approached 500 g, which produces a much higher market price. There were no significant differences in fish growth between fed ponds (receiving about 152 kg of feed each) and fertilized and fed ponds (receiving only 43 kg of feed each), indicating that fertilization may still be effective in producing natural feeds in intensive tilapia ponds. Conversion ratios in fertilized ponds (0.867), fed ponds (1.17), and ponds receiving both inputs (1.10) were all fairly similar. The most efficient system therefore depends largely on feed and fertilizer costs; for our present example, this would be fertilizer alone.

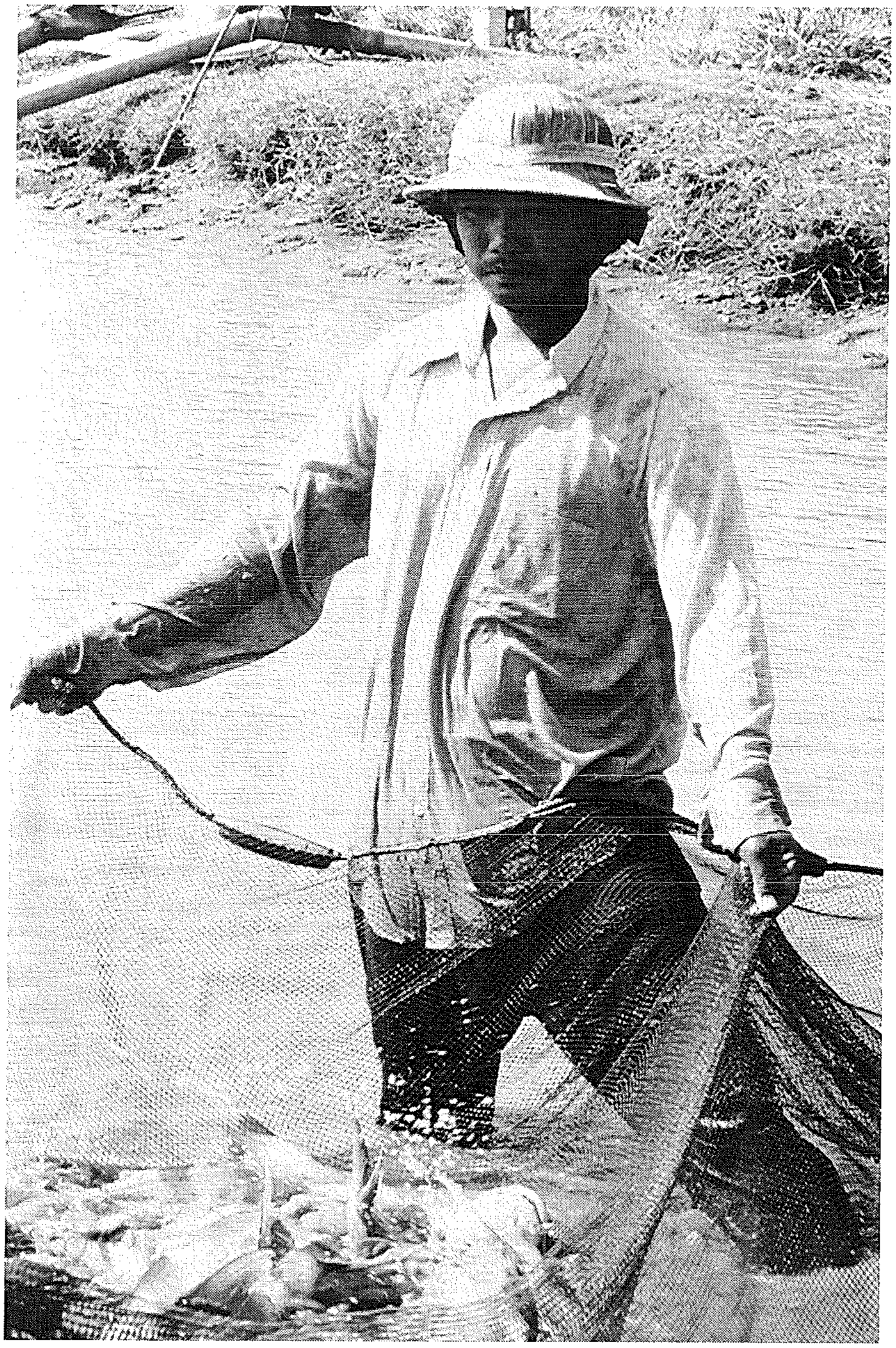
Between-pond variation was again considerable, and the best pond in the fertilizer treatment achieved similar growth, survival, and yield as the fed ponds. All ponds had considerable variation, indicating that natural feed alone may not explain this variation. The causes of such variation are unknown, but remain important.

Table 3. Selected chemical and biological characteristics of the nine experimental ponds used in multiple regression analysis with fish growth, survival, and yield.

Pond	Total Food (mg/m³)	Average Chlorophyll *a*	Average Alkalinity (mg $CaCO_3$/L)	Low D.O Events	High Ammonia Events
Fert 1	0	123	160	0	0
Fert 2	0	95	45	0	2
Fert 3	0	157	102	1	1
Feed 1	159.5	124	147	1	0
Feed 2	148.1	67	71	3	0
Feed 3	149.7	98	87	3	0
Both 1	61.2	114	135	2	0
Both 2	45.4	162	155	2	1
Both 3	23.2	122	157	3	0

Table 4. Multiple regression values for the relationship between growth and the variables in Table 3.

Variable	Coefficient	Partial r	P
Feed	0.671	0.680	0.003
D.O	20.520	0.651	0.032
Alkalinity	1.139	0.553	0.001
Constant	57.500		0.059



V. UNITED STATES RESEARCH COMPONENT OF THE GLOBAL EXPERIMENT

Introduction

Title XII of the International Development and Food Assistance Act of 1975 implies that CRSP research activities should be mutually beneficial to developing countries and the United States. In planning this CRSP, the consensus among CRSP participants was that this requirement would be met through collaborative research involving both U.S. and developing country institutions. However, subsequent to awarding the CRSP grant, USAID interpreted "mutually beneficial" to mean that the CRSP should fund research activities both in the developing countries and in the U.S., and instructed the CRSP to support research activities at the U.S. institutions.

The U.S. Research Component was also established in response to the needs of the CRSP participants themselves. CRSP planners recognized at the outset that aquaculture ponds are extremely complex ecosystems. This complexity has been reflected in the number of variables and frequency of observations required by the experimental protocols specified by the Technical Committee in all the CRSP Work Plans. Further, although researchers at each of the overseas field sites were free to analyze their own data and publish their findings, it was recognized that the management and analysis of the global data set (i.e., the data generated by all the field sites) would require the establishment of a central data storage and retrieval system. Therefore, provisions were made for the establishment and maintenance of a central data base, to be administered by the Program Management Office at Oregon State University.

It also became clear that the comprehensive analysis and interpretation of global data could only be achieved through the formation of an independent team, composed of researchers who could devote their efforts to this type of analysis, as opposed to the analysis of the results of individual experiments. The Data Analysis and Synthesis Team (DAST) was established in September 1985 to perform this function. The U.S. Research Component, then, is composed of the Data Analysis and Synthesis Team (DAST) and a number of Special Topics Research Studies that have developed in conjunction with the activities of the DAST. Although the Central Data Base is not a part of the U.S. Research Component, it is described in this section because its output provides the foundation for many of the activities conducted by the DAST.

The CRSP Central Data Base

The CRSP Central Data Base is maintained by the Program Management Office (PMO). Field personnel send data to the principal investigators at their collaborating U.S. universities, who check the data sets and forward them to the Data Base Manager at the PMO. The data sets are then electronically translated into a standardized format and sent back to the principal investigators for verification. (Data entry is already standardized through the use of templates developed by the Data Base manager and approved by the Technical Committee) Verified files are entered into the Central Data Base for use by the Data Analysis and Synthesis Team or other interested researchers. Specific sets of data requested for analysis may be retrieved in virtually any format desired. All project teams also independently analyze their data and many of their results have been published in journals or in the proceedings of scientific meetings (see Appendix A).

A significant feature of the CRSP Central Data Base is its comprehensiveness. In contrast with the data collection practices of most aquacultural research projects, the biological and chemical data collected by the CRSP are complemented with records of important physical parameters that significantly affect the dynamics of aquaculture systems, including data on photosynthetically active radiation, rainfall, evaporation, air temperature, and wind speed. Detailed records such as these are rare in the aquaculture literature, and they allow for more complete analyses of the dynamic processes occurring in ponds.

At the present time, the data records for all activities conducted through the Fourth Work Plan have been verified and entered into the CRSP Central Data Base. Additional data generated by research conducted under the Fifth Work Plan have been added to the data base during this reporting period.

The Data Analysis and Synthesis Team

The analysis and modeling of data by the DAST is critical to unifying the research conducted at the overseas CRSP sites into a global experiment. The activities of the DAST are decentralized; members of the Team operate from offices at the University of California at Davis and Oregon State University. Through their involvement on the Technical Committee, the members of the DAST interact with scientists from the field-based research component of the Global Experiment. The specific feedback from the DAST to the Technical Committee made possible through this interaction is particularly valuable, not only because work plans occasionally need to be modified to provide additional data required for model development by the DAST, but also because field testing of the models and management tools developed by the DAST must be a part of CRSP research. The DAST also works in concert with the Data Base Manager to translate and verify the large amount of data that are being compiled in the CRSP Central Data Base.

The primary objectives of the Data Analysis and Synthesis Team include:

- the development of data management techniques,
- the definition of site-specific as well as global relationships, and
- the development of computer models that make optimum use of the CRSP Central Data Base and are suitable for diverse applications such as simulation studies, prediction, management, teaching, planning, and other research.

The initial efforts of the DAST included basic statistical testing of the global data, including the development of models of fish growth. A limitation imposed on these initial analyses was that not all of the data from the early experimental cycles of the CRSP had been fully verified and entered into the Central Data Base. Therefore, although the initial DAST analyses did reveal some significant relationships, those relationships could not be assumed to be applicable across the full range of geographical locations covered by CRSP research. Analyses of the data continue to be conducted, using a variety of statistical approaches, with the advantage that the Central Data Base is now complete through the activities of the Fourth Work Plan.

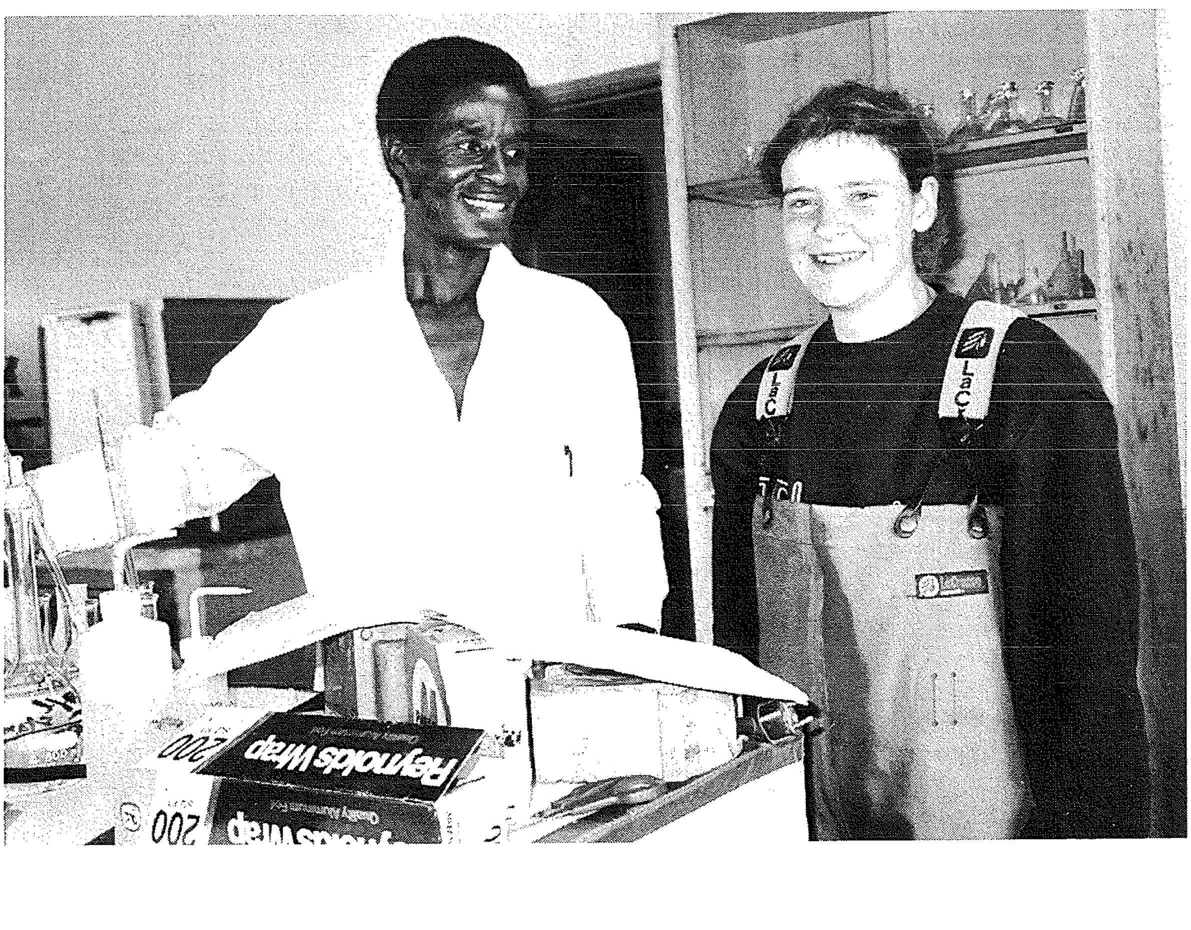
Subsequent DAST work has also included the development of a number of sophisticated aquaculture pond models designed to meet the objectives specified above. This work has been conducted primarily by DAST members at the University of California at Davis. These models, which have been reported on in several previous Annual Reports, include dissolved oxygen models, temperature stratification models, and whole ecosystem models. Much of the work is based on a generalized descriptive model of pond ecosystems developed by CRSP participants during the early phases of the program (Figure 1). Included in this annual report are papers documenting progress made in refining some of these models during the past year. In addition, ideas for new research activities are disseminated by the DAST in their quarterly newsletter.

Another major effort of the DAST, at Oregon State University, has been the development of PONDCLASS, a computer-based expert system for pond management. This program provides suggested rates of liming and fertilization for ponds, based on information provided by the user and default information contained in the program for each of several classes of earthen aquaculture ponds. The PONDCLASS program has gone through several revisions, the most recent of which incorporates suggestions for improvement received from non-CRSP reviewers of the program. PONDCLASS is available for use with both IBM-compatible and Macintosh personal computers. Current CRSP Work Plans call for continued field testing of the management guidelines provided by the program.

Special Topics Research Studies

A number of ancillary studies have been conducted by DAST members and workers associated with them during the course of the program. Among these were a study on the effects of unionized ammonia on tilapia in fertilized fish ponds, an evaluation of sex steroid concentrations in relation to the gonadal development of carp, work on the development of automated data collection instrumentation, efforts to develop procedures for estimating water column respiration rates, studies on nutrient availability from various types and forms of animal manures, and the development of a pond classification system for identifying the characteristics, potential problems, and appropriate management practices of ponds at various sites. Many of these studies have been reported on in previous annual reports or were incorporated into DAST modeling or expert system efforts; studies conducted during the past year are included in this annual report.

The benefits of performing analyses of the global data and developing computer models that simulate pond conditions will occur on several levels-production management, design, and planning. The quantification of relationships between variables and the effects of different treatments will allow farmers to adapt general management techniques to the specific local constraints of climate, water, feed, and fertilizer availability in order to optimize production. The design of production systems will be improved by matching production facilities and costs with production goals. As the Data Analysis and Synthesis Team moves closer to meeting its objectives, the CRSP will begin to realize its goal of combating food and nutritional problems through improved aquaculture technologies that can be made available to fish farmers both in the U.S. and abroad. The efforts of the DAST members toward this goal during the past year are detailed in the reports that follow.



Data Base Management

Hilary Berkman
Oregon State University
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All data from CRSP experiments are maintained in a centralized data base located in the Program Management Office. This facilitates data analysis by the CRSP Data Analysis and Synthesis Team (DAST), and also provides access to CRSP data by outside researchers. The Central Data Base allows for comparisons between CRSP sites because many variables are required to be reported and data from all sites are standardized. Also, the Central Data Base helps preserve the global nature of the CRSP.

The Data Base is complete through the Fourth Work Plan. For the first three cycles of experiments there are 128,406 rows of data. For the Fourth and Fifth Work Plans there are 41,432 and 35,217 rows of data, respectively. Data from the Fifth Work Plan are still being received in the Data Base Management Office. There are data for 164 variables for the first three cycles of experiments and 147 variables for the Fourth and Fifth Work Plans, excluding identifying columns, date columns, and extra data columns. Data are reported and stored by category; for example, soil data, fish data, and weather data are all stored in separate tables within the data base. These are referred to as templates. All tables have identifying columns in common with all other tables. Identifying columns include the site, cycle or work plan, season or experiment, and dates and pond numbers where appropriate. Data which are reported by a research site but are not required by the Work Plan are added to an appropriate table and are included in the Data Base.

Altogether the CRSP Data Base currently utilizes 30 megabytes of memory; the first three cycles account for 15 megabytes, the Fourth Work Plan data use 7 megabytes, and the Fifth Work Plan data presently use 8 megabytes. These numbers represent both the quantity of data stored in the data base and the R:Base operating environment.

Data for the first three cycles of experiments are stored in R:Base for DOS (R:Base version 2.2) and data from the Fourth and Fifth Work Plans are stored in R:Base version 3.1. Both versions of R:Base allow data to be exported and imported from the following types of files: ASCII delimited, ASCII fixed field, Lotus 1-2-3™ (all versions), Symphony™, DBase II™, dBase III™, DBase II PLUS™, pfs:FILE™, VisiCalc™, and Multiplan™. The ASCII options make R:Base usable with any other program with ASCII capability. Further, data received by the Data Base Management Office in a Macintosh format can be translated to an IBM format and imported into the Data Base. R:Base allows easy access to the CRSP data either in whole or in part. Data can be retrieved by any of the identifying columns or by values within the variable columns. R:Base also has a few descriptive statistic functions (average, maximum, minimum, standard deviation, and variance) which can be applied to columns to identify outlying values or errors in data entry. Data are provided to CRSP researchers and the public in any format requested; the most commonly used is Lotus 1-2-3 files on 5.25- or 3.5-inch diskettes for IBM and compatible users, and in Excel™ files for Macintosh users. Data can be sent through electronic mail networks as well, although this option has not been used.

The CRSP Data Base is constantly being refined. Errors in the data are reported to the Data Base Management Office by members of the DAST, other users of the Data Base, or individuals at the research sites as they discover errors. The Data Base Manager makes needed corrections, thus continuously improving the CRSP Data Base.

During the reporting period initial steps have been taken to incorporate data in the CRSP Data Base into FISHBASE, a large data base which summarizes global information on living aquatic resources maintained by the International Center for Living Aquatic Resources Management (ICLARM).

DATA ANALYSIS AND SYNTHESIS TEAM ANNUAL REPORT 1991-92

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The Data Analysis and Synthesis Team (DAST) currently consists of only two members, and their efforts are focused on the following areas of activity:

1. Improvement of pond management guidelines (Lannan).
2. Development of improved methods for modeling and optimizing oxygen regime in ponds (Piedrahita).
3. Development of models for stratified ponds (Piedrahita).

During this period, the computer expert system for pond management (PONDCLASS) was revised and updated. The revision process incorporated information from CRSP field trials and from tests to measure amounts of available nutrients in different animal manures under laboratory conditions. This latter information complements field measurements of nutrient content of manures and serves to improve the efficiency of nutrient utilization in fertilization practices. Models to simulate dissolved oxygen in ponds were revised to incorporate new findings on the diurnal fluctuations of respiration rates in ponds. The models were also used to determine conditions conducive to optimum oxygen production in the ponds. Lastly, models were developed for predicting temperature and dissolved oxygen concentration at three depths in stratified ponds.

Analysis and Modeling of Water Quality in Ponds

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Introduction

Work at UC Davis during the 1991-92 year has concentrated on developing, testing, and validating computer models of pond processes. Successes with the models and associated work have resulted in considerable progress being made toward the fulfillment of two of the research goals specified for the DAST in the Sixth Work Plan:

- To develop improved computer models and field procedures for monitoring and optimizing the oxygen regime in pond systems, and to use this information in the formulation of objective criteria for comparing pond performance.
- To develop and test models of temperature and dissolved oxygen stratification in CRSP ponds.

General descriptions of the findings and progress of the DAST studies carried out by the UC Davis team are presented below; they are based largely on the quarterly DAST Newsletters and on papers that have been submitted for publication.

1. Modeling Primary Production in Aquaculture Ponds

Models of primary production that had been developed previously (as reported in the Eighth Annual Administrative Report, Egna et al., 1990) were updated and thoroughly revised, and the results of that work are presented here. There were two distinct areas in which the work was focused. One was an analysis of changes in light sensitivity in phytoplankton. The other was a reformulation of a model to be used to analyze the effects of pond turbidity and pond depth on overall primary production. The two projects address directly the following objective for DAST Study 2 in the Sixth Work Plan: To use the new information to provide improved measurements of the pond primary production systems for use in the CRSP Pond Efficiency and Optimization Models.

1.a. Light Sensitivity Changes

Introduction

It is well known that environmental and adaptive changes in phytoplankton populations over diel periods can affect oxygen production rates in natural waters (Giovannini 1989, Harding et al. 1982(a) and 1982(b), Harris 1978, Stross et al. 1973, Newhouse et al. 1967, Lorenzen 1963, Doty and Oguri 1957, Yentsch and Ryther 1957). Our purpose in the work described here was to develop a modeling approach to explore the hypothesis that changes in the sensitivity of phytoplankton to light, as measured by the light saturation intensity, can account for diurnal variations in production rates. This is accomplished by developing a model to calculate the change, over time, of the saturating light intensity that would account for the variations in the production rates observed in the field.

Materials and Methods

The work consists of the analysis of measurements of dissolved oxygen concentration in ponds using a model based on a mass balance. The model was formulated to permit the calculation of the light sensitivity of phytoplankton that would be required to achieve a given primary production rate. The rate of oxygen production by phytoplankton can be expressed as the product of the maximum specific production rate under non-limiting conditions and the estimated biomass, scaled by the degree of relative limitation due to light, nutrients, and temperature:

$$PP = U_{max} * CB * LL * NL * TL \qquad (1a.1)$$

Where: PP = Rate of photosynthetic oxygen production (mg O_2/L/h)
U_{max} = Maximum specific primary production rate (mg O_2/mg C/h)
CB = Biomass of photosynthetically active organisms (mg C/L)
LL = Depth-integrated relative light limitation, the ratio of actual photosynthetic production to maximum production at optimum conditions (0-1)
NL = Relative nutrient limitation, the ratio of actual nutrient availability to optimum nutrient supply (0-1)
TL = Relative temperature limitation (0-1)

The mechanistic determination of the rate of phytoplankton oxygen production over a diurnal period in Equation 1a.1 is written in terms of environmental variables that affect phytoplankton production: light, temperature, and nutrient conditions. Of these, continuous diel data for light and temperature are commonly available. In situations where nutrient availability is non-limiting and temperature effects are known, a model can be written to calculate the relative photosynthetic response to light as a variable quantity, by attributing the differences between observed and calculated primary productivity to changes in light response:

$$LL_{Calc} = \frac{PP_{Obs}}{(U_{max} * TL * CB)} \qquad (1a.2)$$

Where: LL_{Calc} = Calculated relative light limitation (0-1)
PP_{Obs} = Observed rate of photosynthetic oxygen production (mg O_2/L/h)

In production models, the sensitivity of phytoplankton to light is commonly expressed in terms of the light saturation parameter (I_{sat}) which is defined as the light intensity at which maximum photosynthetic production occurs (Jorgensen 1976, Steele 1962). In previous aquaculture models, the light saturation parameter (I_{sat}) has been assumed to be constant over the diel period (Losordo 1988, Piedrahita 1984, Meyer and Brune 1982). The use of a constant light saturation value implies that during the course of the simulation, there are no adaptive changes being made in the physiology of the phytoplankton as a result of changing temperature, light, or nutrient conditions that would affect their sensitivity to light, and thus the optimum light intensity for photosynthetic production. The photosynthetic response to a given light intensity is then assumed to be the same in the morning as in the afternoon. This restrictive assumption could be eliminated if the pattern of diurnal light adaptation were known.

The analytical model of photosynthetic production given in Equation 1a.2 can be used to estimate the change in phytoplankton diel light sensitivity from pond DO data by establishing the relationship between relative photosynthetic production (LL) and light sensitivity. The relative photosynthesis as a function of light in an optically thin section is described in production equations such as that presented by Steele (1962), in which relative photosynthetic production is given in terms of two parameters, light intensity (I) and light saturation intensity (I_{sat}):

$$P_{rel} = \frac{I}{I_{sat}} \exp\left(1 - \frac{I}{I_{sat}}\right) \qquad (1a.3)$$

Where: P_{rel} = Relative photosynthetic production in an optically thin layer (0-1)
I = Photosynthetically active light radiation (Einst/m²/h)
I_{sat} = Optimum light intensity, saturation (Einst/m²/h)

The average (over depth) relative photosynthesis can be expressed with an equation derived from the production function proposed by Steele (1962), yielding:

$$LL = \frac{e}{\varepsilon}\left[\exp\left(-\frac{I_o}{I_{sat}}\exp(-\varepsilon z)\right) - \exp\left(-\frac{I_o}{I_{sat}}\right)\right]\frac{1}{z} \qquad (1a.4)$$

Where: I_z = Light intensity at any depth (Einst/m²/h)
I_o = Surface light intensity (Einst/m²/h)
z = Pond depth (m)
ε = Light extinction coefficient (m^{-1})

When all parameters except I_{sat} are known, and the calculated average relative photosynthesis (LL_{Calc}) (Equation 1a.2) has been obtained from pond data, it is possible to obtain an approximate solution to this transcendental equation in terms of I_{sat} by letting:

$$\exp\left(- \frac{I_0}{I_{sat}} \exp(-\varepsilon z) \right) = 1 \qquad (1a.5)$$

This simplification is valid for typical values of light extinction and depth in shallow aquaculture ponds with high turbidity. The term exp(- ε z) in Equation 1a.5 represents the fraction of incident light transmitted through the water column to the bottom (Bannister 1974), and is effectively zero in typical aquaculture ponds (eg. 0.0002 for e = 8.5 m^{-1}, and z = 1 m). The simplified form of Equation 1a.4 can then be solved for I_{sat}:

$$I_{sat} \cong \frac{-I_0}{Ln\left(1 - \frac{LL\ \varepsilon\ z}{e}\right)} \qquad (1a.6)$$

By replacing the light term (LL) in Equation 1a.6 with the expression for LL_{Calc} from Equation 1a.2, we obtain an expression that can be used to calculate the level of phytoplankton light saturation over the pond depth, from pond DO data:

$$I_{sat} \cong \frac{-I_0}{Ln\left(1 - \frac{PP_{Obs}\ \varepsilon\ z}{U_{max}\ TL\ CB\ e}\right)} \qquad (1a.7)$$

Equation 1a.7 is not intended as a descriptive model, but rather employs a descriptive model (Equation 1a.1) in an analytical context to test the hypothesis that the diurnal asymmetry of primary production with respect to light is primarily a function of light adaptation by phytoplankton. This report investigates the feasibility of short term light adaptation to account for diel production asymmetry by using field data to calculate I_{sat} from Equation 1a.7, and then correlating the calculated I_{sat} with a measured indicator of the change in light sensitivity (chlorophyll *a* fluorescence).

The analytical model of light adaptation (Equation 1a.7) is evaluated here with data taken from experimental shrimp ponds at the Mariculture Research and Training Center (MRTC) of the Hawaii Institute of Marine Biology in the Fall of 1989. The data were taken from a shallow (0.8 m) difficulty in directly measuring actual gross primary production rates under field conditions, these data are estimated from an analysis of net primary productivity adjusted for estimated respiration and diffusion rates. These processes, as well as parameter values for maximum specific production (U_{max}) and the temperature limitation function (TL), were calculated with empirical equations covering a range of values to test the response of the model.

The rate of diffusion of oxygen into the system from the atmosphere was estimated from the empirical equation of Banks and Herrera (1977). The maximum specific production rate (U_{max}) was estimated with a function developed by Eppley (1972) that describes an envelope curve of nutrient and light saturated growth rates from extensive literature data. The value of the maximum specific production rate was based on an optimum production temperature estimated at approximately 30°C. This temperature value is in the middle to upper range of water temperatures recorded in the pond, and assumes the adaptive capability of the algae to adjust their optimum growth rates to the prevalent temperature environment (Groden 1977, Brock 1967, Aruga 1965). The temperature limitation function for production was estimated using the equation described by Zison et al. (1978). Daytime water-column respiration rates were estimated by a linear extrapolation from nighttime respiration rates before dawn on Julian Date 285 to nighttime respiration rates just after dusk on Julian Date 286, following the method of Hall and Moll (1975).

The model was solved using STELLA™, a dynamic programming language, for a 24-hr period from 0600 hours on Julian Date 286 to 1800 hr on Julian Date 287 with a time increment of 0.5 hr.

Results

The relative depth-integrated photosynthetic production (LL_{Calc}) estimated over the diel period shows a close correlation with surface photosynthetically active radiation (PAR) except during midday (when photosynthetic production is reduced) and just before dusk (when photosynthetic production with respect to light increased briefly) (Figure 1a.1). The changing light saturation level or light sensitivity of phytoplankton over time that would account for the variability in the response observed in Figure 1a.1 was calculated with Equation 1a.7. The results, illustrated in Figure 1a.2, show that the light saturation level of the phytoplankton follows a diurnal cycle which increases from dawn to noon and then decreases again from noon until dusk. In terms of light adaptation, this would indicate that the phytoplankton became progressively less sensitive to light as light intensity increased, and then regained light sensitivity as light intensity decreased. This result is consistent with the rapid cellular response to photoinhibition, in which the reduction of photosynthetic rates occurs rapidly after exposure to higher levels of irradiance (Reynolds 1984). Upper-layer fluorometric chlorophyll *a* data (Figure 1a.3) also show a diurnal cycle, in which values at dusk return approximately to the levels observed at dawn after a significant midday decrease. These changes appear to indicate a short term adaptive response of

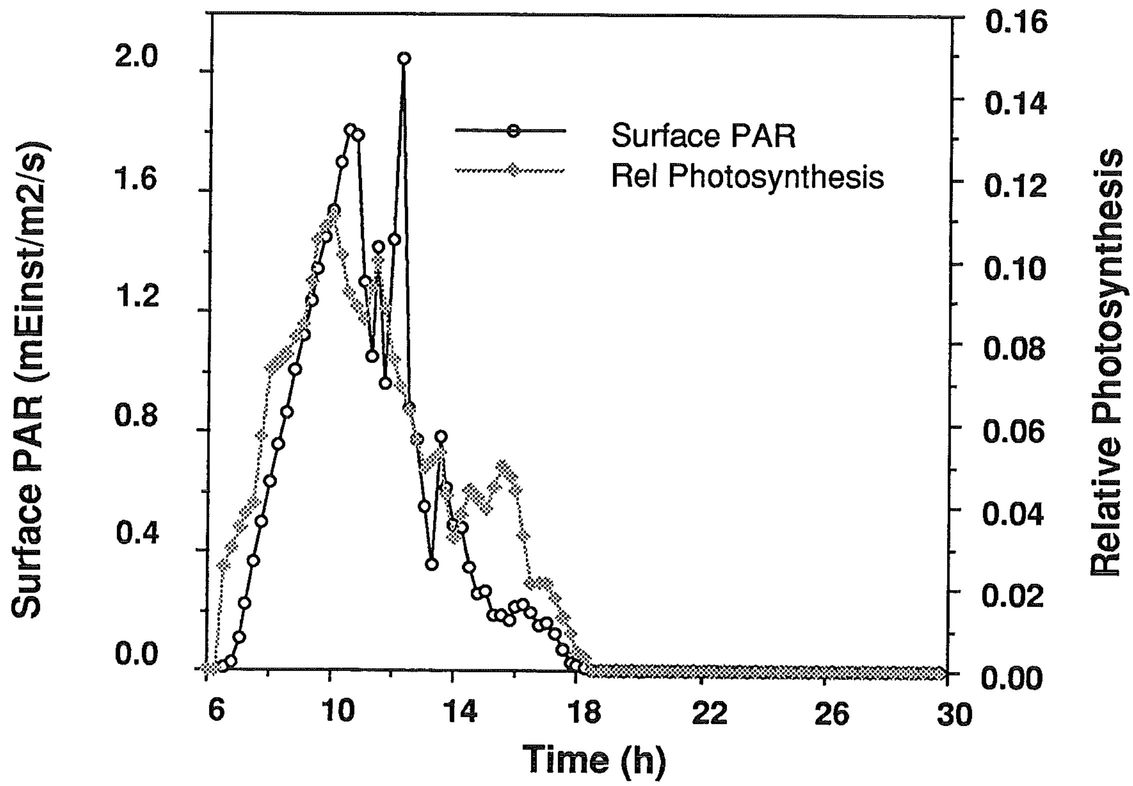


Figure 1a.1. Phytoplankton depth-integrated relative photosynthetic production (LL_{Calc}) estimated from rate of change of dissolved oxygen concentration less diffusion and respiration processes, plotted against diurnal photosynthetically active radiation (I_o) recorded over the diel cycle, Julian Date 286.

phytoplankton that is distinct from the process generally described as shade- or light-adapted, as this process is reported to occur over time periods of at least several hours to several days (Prezelin et al. 1991, Laws and Malecha 1981).

Anticipated Benefits

By modeling the light saturation value used in Steele's production equation (1962) as a dependent variable, it is possible to plot the diurnal curve of light saturation intensity. It is also possible to evaluate the validity of changes in light sensitivity as an explanation of diurnal changes in phytoplankton productivity with respect to light. The model developed serves to analyze the dynamics of photosynthetic light optimization in aquaculture ponds, and provides an estimation of the diurnal dynamics of the light saturation curve. More importantly, the methodology presented can be applied to more sophisticated mechanistic equations and more detailed field experiments to determine more accurate estimates of light sensitivity dynamics. As noted by Jassby and Platt (1976), one of the most compelling reasons motivating the search for a mathematical relationship between photosynthesis and light, aside from the need for estimating and predicting biomass and productivity, aside from the need for estimating and predicting biomass and productivity, is that it allows determination of the physiological parameters of photosynthesis operationally by choosing parameter values which provide the best fit between the equation and the experimental data. This work supports the hypothesis that short-term light adaptation is a major factor in the diurnal fluctuations of photosynthetic production and suggests that the use of production models for determining photosynthetic parameters may be justified. The model has applications for evaluating photosynthesis/ irradiance relationships to obtain diurnal curves of light sensitivity.

1.b. Production Optimization

Introduction

Ongoing research at UCD has focused on developing a systems approach to the design and operation of aquaculture ponds. In any production system, a goal of the system designers is to achieve consistent, predictable production levels. This goal is accomplished by minimizing variability and instability in the production process, and improving the scientific and engineering basis on which management decisions are made.

A critical component of pond operation is the management of the primary

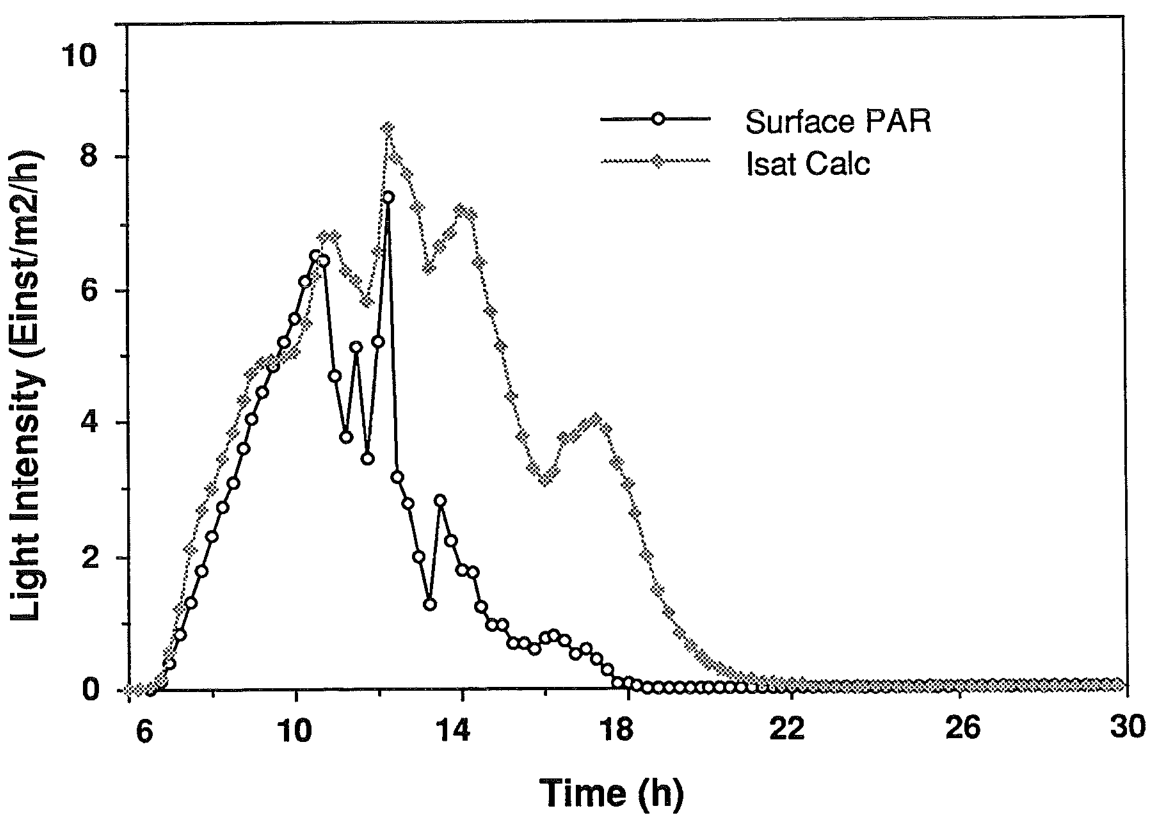


Figure 1a.2. Photosynthetically active radiation (PAR) and calculated light saturation ($I_{sat\ Calc}$) over diel period Julian Date 286.

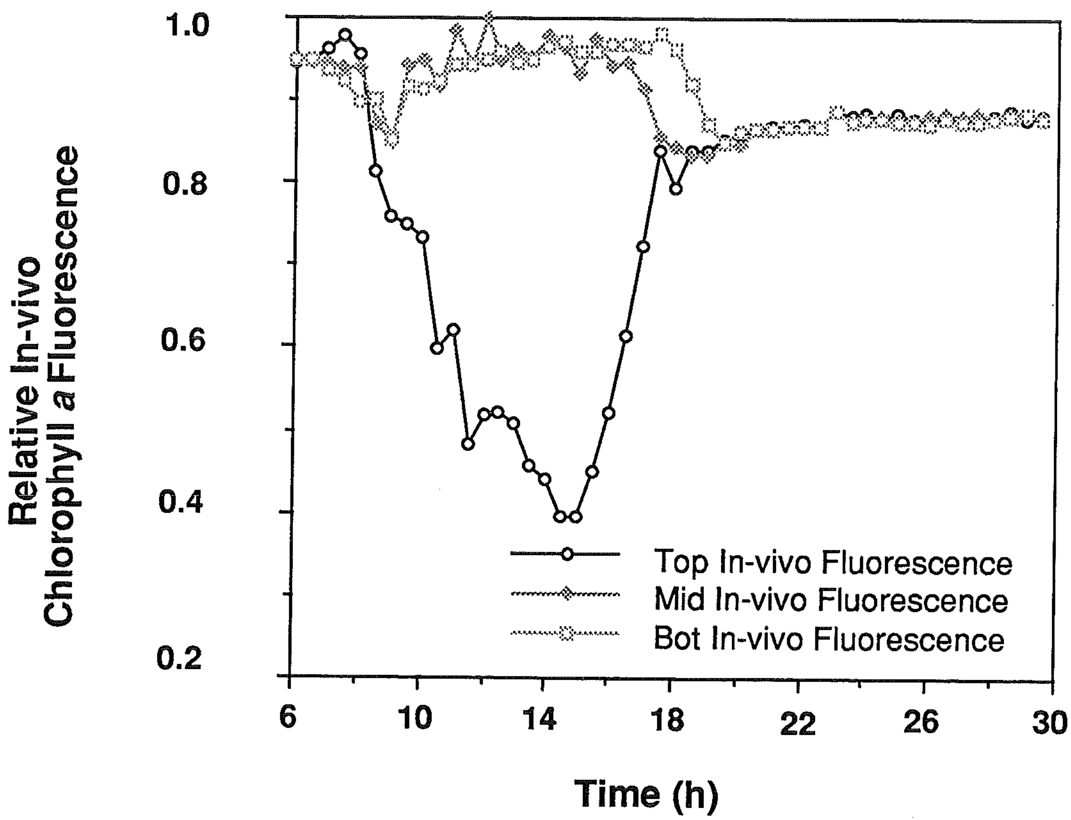


Figure 1a.3. Chlorophyll *a* fluorescence data recorded at three depths through the diel cycle on 13 Oct. 1989 (Julian Date 286). Data are shown on a scale relative to the maximum fluorometer reading.

short-term chemical, physical, and biological changes that occur in a pond. As the productivity of the pond system and the standing crop of phytoplankton increase, so do the degree of fluctuation in diel DO concentrations, the degree of vertical stratifications of the water column, and the temporal fluctuations in water quality. In highly turbid pond systems the rapid extinction of incident light in the surface layers results in a large area close to the bottom of the pond acting only as a net oxygen sink. This zone of high oxygen consumption, combined with the high production zone in the surface layers during the day, causes instability in the diel dissolved oxygen concentration. As the standing phytoplankton crop is reduced, stability of the system increases but total food availability and gross production of oxygen tend to decrease. Therefore, the trade off in balancing the pond system is in terms of gross productive potential vs. stability.

Balancing the productivity and stability of a pond can be based on the analytical determination of the optimum design of the pond system in terms of the physical characteristics of the pond and on the biological parameters of the phytoplankton crop. The biological parameters are: specific production, specific respiration, and sensitivity to light. The physical parameters are:

specific respiration, and sensitivity to light. The physical parameters are: depth, turbidity, and light intensity. Of the three physical parameters (depth, turbidity, and solar radiation) only depth and turbidity are readily controllable in practical situations. Therefore, the purpose of this research was to determine the relationships between the physical and biological parameters for maximum net production and to develop expressions for the optimum depth and turbidity for these conditions.

Materials and Methods

The model described here is based on derivations of Steele's (1962) production equation. Steele's equation expresses production in terms of three basic variables: light, phytoplankton light saturation, and maximum production. The procedure followed in our work with Steele's equation can be used with other production equations subject to the limitations of the mathematical complexity involved. Steele's equation is the most commonly used production equation, although it will not be universally applicable to all production systems (Field and Effler 1982). The applicability of any production model to a particular system must be determined by experimentation. Steele's equation can be written as:

$$\mathrm{Prod} = P_{max} \frac{I}{I_{sat}} \exp\left(1 - \frac{I}{I_{sat}}\right) \tag{1b.1}$$

Where:

- Prod = Photosynthetic production in an optically thin section (mg $O_2/m^3/h$)
- P_{max} = Maximum photosynthetic production rate (mg $O_2/m^3/h$)
- I = Photosynthetically active light radiation (Einst/m^2/h)
- I_{sat} = Optimum light intensity, saturation (Einst/m^2/h)

The gross production rate throughout the water column is given by Steele's equation (1962) integrated over pond depth, with light intensity at any depth given by Beer's law. Net production rate can be estimated by adding water-column respiration to gross production rates. If water-column respiration is assumed to be a function of algal concentration, the net production equation can be written as (details of this derivation are available in Giovannini and Piedrahita 1992):

$$NP_Z = \frac{\Phi_{max}\, I_{sat}\,(\varepsilon_{total} - \varepsilon_{other})}{\varepsilon_{total}} \left[\exp\left(\frac{-I_o \exp(-\varepsilon_{total}\, z)}{I_{sat}}\right) - \exp\left(\frac{-I_o}{I_{sat}}\right)\right] - \frac{(\varepsilon_{total} - \varepsilon_{other})\, R\, z}{K_c} \tag{1b.2}$$

Where: NP_Z = Total net primary production of water column ($mgO_2/m^2/h$)

$$P_{max(c)} = \frac{\Phi_{max}\, K_c\, I_{sat}}{e} = \frac{P_{max}}{Chlor\text{-}a}$$

I_o = Surface light intensity (Einst/m^2/h)
z = Pond depth (m)

$P_{max(c)}$ = Maximum specific production rate (mg O_2/mg Chlor-*a*/h)
F_{max} = Maximum quantum yield (mg O_2/Einst absorbed)
K_c = Light absorption coefficient of chlorophyll-*a* (m^2/mg Chlor-*a*)
e = Base of natural logarithm (exp(1) = 2.718...)
ε_{total} = Total light extinction coefficient (m^{-1})
= $\varepsilon_{chlor} + \varepsilon_{other}$
ε_{chlor} = Light extinction coefficient due to chlorophyll-*a* (m^{-1}).
ε_{other} = Sum of all sources of light attenuation other than chlorophyll including water, and suspended and dissolved solids (m^{-1}).
R = Specific respiration rate (mg O_2/mg Chlor-*a*/h)

The process of deriving optimum values for either depth or light extinction coefficient from Equation 1b.2 can be carried out by differentiating the net production function with respect to depth or turbidity, solving for the corresponding optimum value at the peak, and obtaining an expression for optimum depth or turbidity. The resulting equations are transcendental, but can be simplified to provide solvable expressions that yield approximate values for optimum depth and turbidity. The simplification is based on the assumption that the light reaching the bottom of the pond is effectively zero, a condition which is common in aquaculture ponds.

The simplified expressionfor optimum depth (z_{opt}) given a particular turbidity becomes:

$$z_{opt} \cong -\,Ln\left(\frac{R}{P_{max(c)}\, e}\,\frac{I_{sat}}{I_o}\right)\frac{1}{\varepsilon_{total}} \quad (1b.3)$$

and the optimum total turbidity ($\varepsilon_{T(opt)}$) for a particular pond depth is:

$$\varepsilon_{T(opt)} \cong \left(\frac{P_{max(c)}\, e\, \varepsilon_{other}}{R\, z}\left(1 - exp\left(\frac{-I_o}{I_{sat}}\right)\right)\right)^{\frac{1}{2}} \quad (1b.4)$$

Results

A sample graph of the net production rate per unit area (mg $O_2/m^2/h$), given by Equation 1b.2 as a function of depth and turbidity, is shown in Figure 1b.1 for the given set of parameters indicated. The maximum net production for this production equation is an asymptotic value as depth approaches zero and turbidity approaches infinity. Therefore, it is not possible to determine a simultaneous optimum combination of values for depth and turbidity that would yield the maximum net production of oxygen. However, at any particular depth, there is an optimum turbidity where net production is maximized. Similarly, at a given turbidity, there is an optimum depth that can be derived from Equation 1b.2, as seen from Figure 1b.1.

The theoretical equations for estimating optimum depth and turbidity can be examined for feasibility and sensitivity to changes in system parameters by utilizing sample data representative of a range of conditions found in aquaculture ponds. The results of this analysis are shown in Table 1b.1 for four sets of parameter values. Table 1b.1 shows the calculated and actual optimum light extinction coefficients and the associated calculated and actual net production for a range of depths. The "calculated" light extinction coefficient values are approximations obtained from Equation 1b.4, while the "actual" values are obtained from a numerical solution of Equation 1b.2. Net production rates are obtained from Equation 1b.2 in both cases. The difference between the calculated and actual net production indicates the loss in net production that would occur (estimated from Equation 1b.2) if the "calculated" light extinction coefficient were used instead of the "actual" value.

In all cases, the net production increases as depth is reduced and turbidity increased. This is due to the asymptotic nature of the production function (Equation 1b.2), but is consistent with the results obtained from other studies. Grobbelaar (1989) noted that the relationship between the aphotic and photic zones in a water column is critical to the efficiency of light utilization in the water column and concluded that the larger the ratio, the lower the overall net productivity of the system. In addition, Murphy (1962), in a similar analysis of the effects of depth and turbidity on net productivity, observed that "fish ponds should be constructed as shallow as is compatible with the ecological requirements of the fish species."

A similar analysis can be made to determine the estimated optimum depth for a given light extinction coefficient (Equation 1b.3) and the associated net production.The optimum values of depth obtained with Equation 1b.3 are in close agreement with the actual optimum depth values obtained from an analysis of Equation 1b.2.

Anticipated Benefits

The results presented here should provide an analytical basis for the determination of optimum net primary production in aquaculture ponds.

Table 1b.1 Sensitivity analysis of estimated optimum light extinction coefficient (Equation 1b.4) for a range of depths, with 4 different sets of parameter values. Units: R and P_{max}: (mg O_2/mg Chlor-*a*/h); I_o and I_{sat}: (Einst/m²/h); Net Prod terms: (mg O_2/m²/h); ε_{other} and $\varepsilon_{T(opt)}$ terms: (m⁻¹); Z: (m).

Run #1: R = 1, I_o = 7.2, I_{sat} = 3.6, ε_{other} = 1, P_{max} = 11

Z	ε_{Topt} Calc	ε_{Topt} Act	Net Prod Calc	Net Prod Act	Error: NP Act-Calc
0.52	7.04	9.2	1111.93	1148.54	36.61
0.73	5.94	7	1080.55	1094.41	13.87
0.94	5.23	5.8	1038.62	1044.35	5.72
1.16	4.7	5.1	993.42	995.93	2.50
1.37	4.3	4.6	951.74	953.16	1.42
1.58	4	4.2	912.69	913.52	0.83
1.79	3.8	3.9	876.38	876.59	0.21
2	3.6	3.7	842.01	842.01	0.00

Run #2: R = 1, I_o = 10.8, I_{sat} = 3.6, ε_{other} = 1, P_{max} = 11

Z	ε_{Topt} Calc	ε_{Topt} Act	Net Prod Calc	Net Prod Act	Error: NP Act-Calc
0.52	7.4	9.9	1230.10	1280.79	50.69
0.73	6.2	7.5	1204.48	1224.80	20.31
0.94	5.5	6.2	1165.11	1172.59	7.48
1.16	4.95	5.3	1118.76	1121.72	2.96
1.37	4.56	4.8	1075.42	1076.66	1.24
1.58	4.24	4.4	1034.04	1034.63	0.59
1.79	3.98	4.1	995.09	995.38	0.28
2	3.77	3.8	958.53	958.62	0.10

Run #3: R = 2, I_o = 7.2, I_{sat} = 3.6, ε_{other} = 1, P_{max} = 11

Z	ε_{Topt} Calc	ε_{Topt} Act	Net Prod Calc	Net Prod Act	Error: NP Act-Calc
0.52	5	7.3	828.19	916.45	88.26
0.73	4.2	5.5	814.32	859.44	45.12
0.94	3.7	4.5	782.14	805.94	23.79
1.16	3.34	3.8	741.37	753.50	12.13
1.37	3.1	3.4	701.11	706.75	5.64
1.58	2.9	3.1	660.40	662.97	2.58
1.79	2.7	2.8	620.15	621.89	1.74
2	2.5	2.7	581.16	583.55	2.40

Run #4: R = 1, I_o = 7.2, I_{sat} = 3.6, ε_{other} = 2, P_{max} = 11

Z	ε_{Topt} Calc	ε_{Topt} Act	Net Prod Calc	Net Prod Act	Error: NP Act-Calc
0.52	9.96	10.9	1018.16	1021.88	3.71
0.73	8.41	8.8	935.12	935.84	0.72
0.94	7.41	7.5	861.35	861.51	0.15
1.16	6.68	6.7	793.60	793.62	0.02
1.37	6.15	6.2	736.36	736.36	0.00
1.58	5.7	5.7	685.03	685.03	0.00
1.79	5.38	5.4	638.63	638.63	0.00
2	5.09	5.1	596.30	596.30	0.00

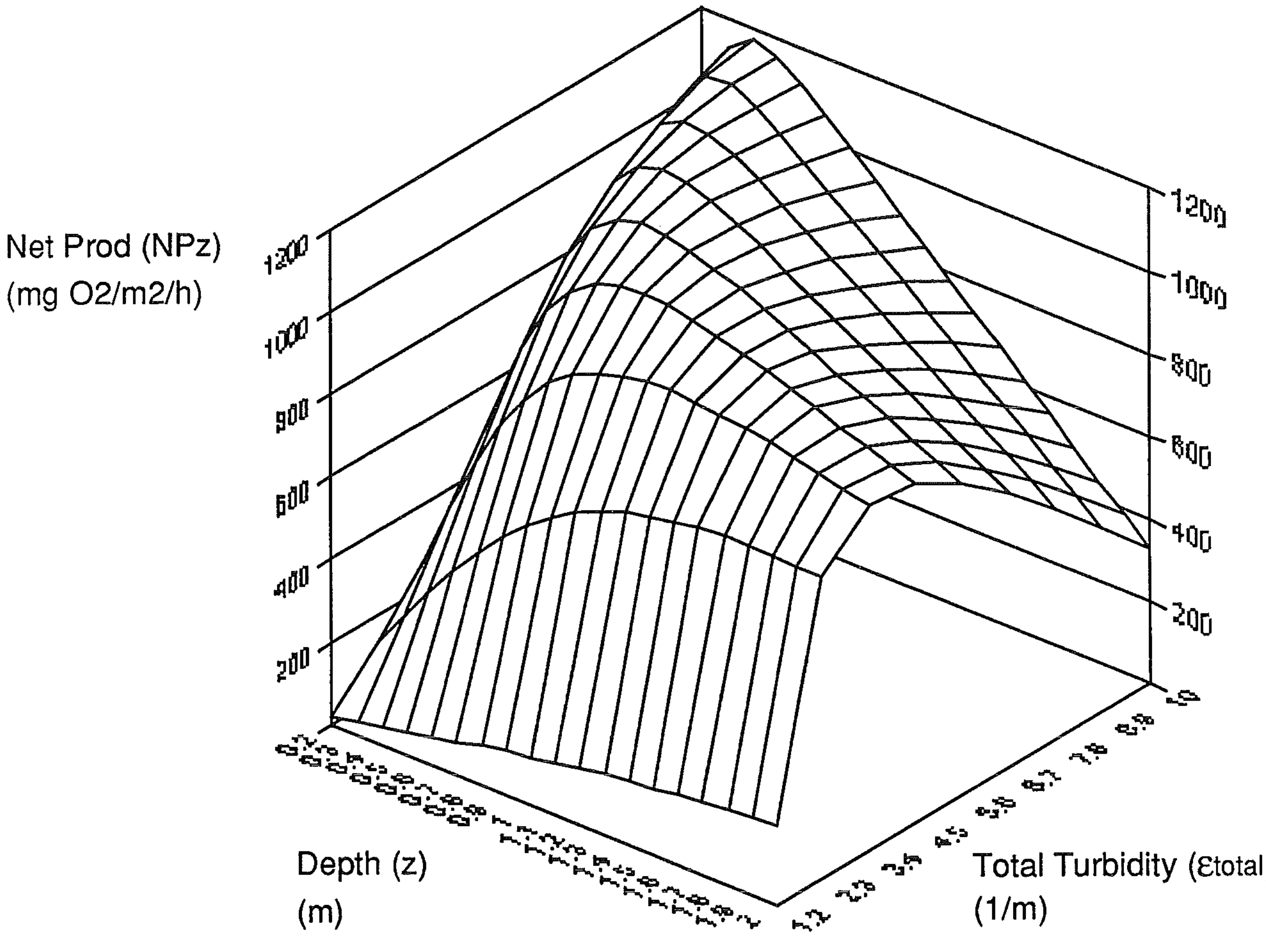


Figure 1b.1. Plot of net production function (Equation 1b.2) with respect to depth (z) and total turbidity (ε_{total}), using parameter values (Run #1): R = 1 (mg O_2/mg Chlor/h); K_c = 0.016 (m^2/mg Chlor); Φ_{max} = 520 (mg O_2/Einst absorbed); ε_{other} = 1 (m^{-1}); I_o = 7.2 (Einst/m^2/h); and I_{sat} = 3.6 (Einst/m^2/h).

determination of optimum net primary production in aquaculture ponds. These relationships may be helpful for a pond manager seeking to strike a balance between the conflicting goals of production and stability. The model developed for this analysis can be used to provide baseline values for pond configuration, which can be adjusted based on the overriding physical and biological requirements of the cultured animals.

The expressions for optimum depth and turbidity are written in terms of three physical and three biological parameters. These parameters represent the minimum information about a primary production system that is needed to characterize that system. As expected, the biological parameters are the most difficult to quantify, and are subject to change over time, as adaptation and succession occur in the phytoplankton population. This is characteristic of any biological process, and points to the importance of developing efficient measurement techniques for routinely determining these parameters.

2. Simulation of Water Quality in Stratified CRSP Ponds:

The effort to develop models to simulate temperature and dissolved oxygen concentration in stratified ponds has resulted in simplified models that are suitable for execution with CRSP data. The development of these models addresses the following objectives, as stated in the Sixth Work Plan (Study 3).

- To simplify the data requirements of existing temperature and dissolved oxygen stratification models and test the models with non-CRSP and CRSP data sets.
- To incorporate into existing models the more accurate characterization of primary production and respiration rates identified in Study 2.
- To calibrate and verify the modified/simplified models with CRSP data.

The two models (one for temperature and one for dissolved oxygen simulation) are described in detail below.

2.a. Temperature

Introduction

A model previously developed for simulating temperature and dissolved oxygen in stratified ponds (the Losordo Model: Losordo 1988, Losordo and Piedrahita 1991) is being revised for use with CRSP data. At the present time, the temperature revision is complete, and simulations have been carried out with CRSP data. A detailed description of the model and of the simulation results has been presented by Culberson and Piedrahita (1992). Of primary concern in the current revisions are the reduction of data inputs required to execute the model, and the tailoring of the data input requirements to reflect more closely those data commonly available to (or easily collectible by) an aquaculturist.

Temperatures are calculated at three different depths in a simulated pond by doing an energy balance for layers of water centered around the three depths selected. There have been few changes in the general form of the energy balances used in the revised model, but data input and flexibility of the model has been improved to facilitate execution with new data sets and use of the model for analysis of different "questions." Substantial changes had to be made to deal with the estimation of some heat exchange rates, because some data critical to these calculations were not available in the CRSP data sets. Given the extent of reduction in data requirements, the model has a surprisingly high predictive accuracy.

The model has been used to predict water temperatures for both fully-mixed and stratified ponds for a variety of study sites. In most simulations, the correlation coefficients between measured and predicted temperatures are greater than 0.90 over the range of simulation depths. Where correlation coefficients are below 0.90, differences with measured temperatures could not be attributed to erroneous energy balance considerations. As an example, the model cannot predict situations where surface waters are warming while bottom waters are cooling, and differences will occur between measured and predicted values. A situation such as the one described is difficult to explain since it could only be caused by the presence of a temporary "heat sink" in contact with the deeper waters.

Materials and Methods

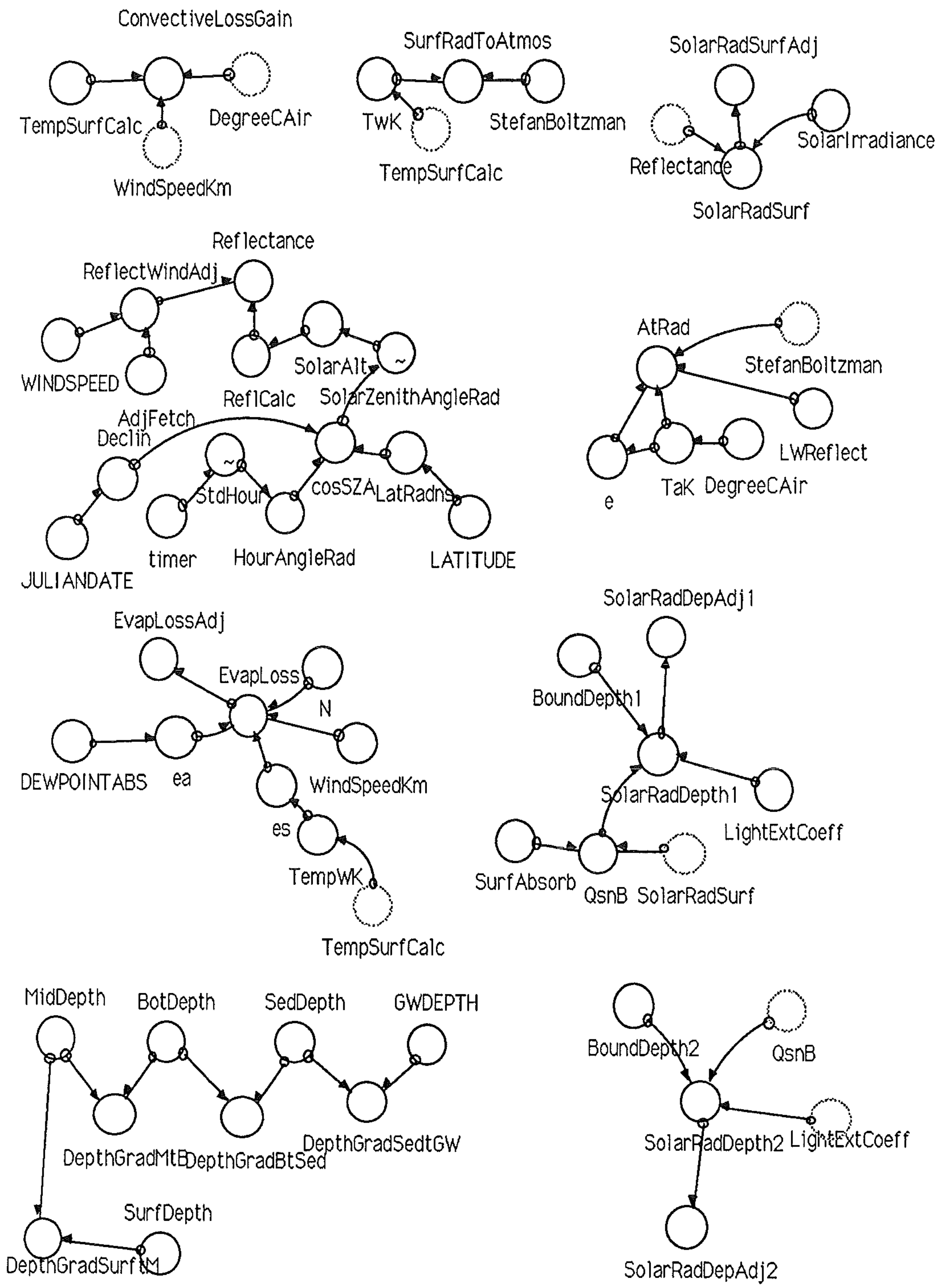
The basis for the construction of the model described here is a three-layer volume element taken to be representative of a water column in a generalized aquaculture pond This three-layer volume element is identical to those volume elements described in Losordo's model, except that the Losordo model breaks a 90 cm-deep pond into five water volume elements (there is an additional sediment volume element in both models). The reduction in the number of volume elements and the allowance for variable pond depths represents perhaps the most fundamental change to the structure of the Losordo model. For example, heat transfer rates and wind-generated shear forces are transferred through the water column based on gradient differences in energies over depth:

$$dH/dt = \rho w * cpw * Av * Ez,z * (dT/dz) \qquad (2a.1)$$

Where:

dH/dt	=	the rate of heat transfer between volume elements (kJ/hr)
ρw	=	density of water (kg/m^3)
cpw	=	heat capacity of water (4.1816 cal/g/°C)
Av	=	volume element surface area (m^2)
Ez,z	=	effective diffusion coefficient at depth z (m^2/hr)
dt/dz	=	difference in temperature between centers of adjacent volume elements

In the Losordo model, the depth of the volume elements are fixed; that is, the Losordo model was developed for ponds of 90 cm depth, and verification of the model was conducted using measurements from ponds of this given depth. While it would have been possible to revise the Losordo model to any particular depth, changes in as many as forty-one separate model elements (those dependent upon depth inputs) would have been required for each possible pond depth to be studied. The current model adjusts its volume elements as a function of a single PONDBOTTOMDEPTH input depth, and calculations such as those shown in Equation 2a.1 are revised automatically as a function of this input. Other minor differences include gathering all the input nodes to one area on the model diagram for the current model, facilitating data inputs, and consolidation of icon-based characterizations based on energy-balance groupings (Figure 2a.1).



Figuer 2a.1. STELLA II diagram of energy-balance sub-groupings, detailing elements used in characterizing energy inputs and losses.

There are, however, important differences in several of the energy-balance characterizations between the Losordo model and the model described here. In several cases, certain types of data inputs were required for the Losordo model which were not available from the PD/A CRSP research sites. These cases will be discussed below, and revisions to the energy-balance characterizations which resulted from this lack of data will be presented.

1. *Light Extinction Coefficient Estimations*
The Losordo model uses an expression from Lind (1979) combined with an adjustment for angle of incident radiation from Rabl and Neilson (1975) to calculate a bulk light extinction coefficient. This calculation requires underwater light data (usually in the form of photosynthetically active radiation, or PAR measurements) as follows:

$$\varepsilon = (\ln Iz_1 - \ln Iz_2)/(z_2 - z_1) * 1/\cos \theta r \qquad (2a.2)$$

Where:
ε = light extinction coefficient (m^{-1})
Iz_1 = light intensity at depth z1
Iz_2 = light intensity at depth z2
θr = angle of refraction

Inasmuch as measurements of underwater light intensity are not routinely available from PD/A CRSP experimental sites, nor are farmers apt to have these measurements available on-site, it was decided a substitute measure would be needed. Poole and Atkins (1929) and more recently Boyd (1990) have demonstrated that Secchi disk depth can be used to estimate the bulk light extinction coefficient as follows:

$$\varepsilon = 1.7/SDD \qquad (2a.3)$$

Where: SDD = Secchi disk depth (m)

Because Secchi disk measurements are easily obtainable and are currently part of PD/A CRSP measurement protocols, it is felt Secchi disk measurements are ideal substitutes for estimating light extinction coefficients. Consequently, underwater PAR values at two depths taken at noon local time for the Losordo model are replaced with a Secchi disk measurement at a time convenient to local conditions and data collection protocols. Indeed, using the Secchi disk method for estimating the light extinction coefficient results in some inherent inaccuracy, since the procedure does not differentiate between the types of solids which may contribute to light attenuation in the water column (Losordo 1988). However, owing to the widespread use of Secchi disk measurements as an indicator of water column light extinction and the relative accuracy of the extinction coefficient generated therefrom, values of ε for the revised model are calculated as in equation 2a.3.

2. *Relative Humidity Measurements*
Measurements of the moisture content of the air above the pond water surface are important when estimating the amount of energy lost from the pond over a diel cycle due to evaporation. In evaluating the energy-balance

equations in the models under discussion, it was found that up to one third of the total energy loss from the pond surface was due to evaporative heat flux. The Losordo model utilizes an estimation from Fritz and Middleton (1980) to calculate the evaporative heat flux for small waste stabilization ponds:

$$\phi_e = N * W_2 * (es - ea) \quad (2a.4)$$

Where:

N	=	empirical coefficient (5.0593) (kJ/m²/km/mm Hg)
W_2	=	wind speed at a reference height 2 m above the water surface (km/hr)
es	=	saturated vapor pressure at surface water temperature (mm Hg)
ea	=	water vapor pressure just above the pond surface (mm Hg)

and where es and ea can be approximated as:

$$es = 25.374 \exp (17.62 - 5271/T_{wc}) \quad (2a.5)$$

$$ea = Rh * 25.374 \exp (17.62 - 5271/T_{ac}) \quad (2a.6)$$

Where:

T_{wc}	=	temperature of the surface water (°C)
T_{ac}	=	temperature of the air above the surface (°C)
Rh	=	relative humidity measured at 2m above pond surface.

As was the case for underwater PAR measurements, relative humidity values are not routinely reported from PD/A CRSP experimental sites. However, Henderson-Sellers (1984) offers a slightly different equation for calculating the water vapor pressure just above the pond surface (ea) which does not rely on relative humidity measurements–rather, water vapor pressure is calculated using dew-point temperature:

$$ea = 610.78 \exp [17.2694 * (T_d - 273.16)/(T_d - 35.86)] \quad (N/m^2) \quad (2a.7)$$

Where: T_d = dew-point temperature (°K)

Similarly, dew-point temperatures are not normally part of weather monitoring protocols at PD/A CRSP sites, nor of aquaculture sites in general. However, Koon et. al. (1986) suggest average daily dew-point temperatures may be estimated by subtracting 2 °C from the morning minimum dry-bulb temperature, and this estimate is used in the revised model.

3. *Air Temperature Measurements*
Currently the data reporting protocols for the PD/A CRSP experimental sites do not require continual monitoring of air temperatures; only the daily minimum and maximum air temperatures are included in the global database. Since air temperatures at the pond site are critical for calculations of convective heat exchange at the pond surface, evaporative heat loss, and atmospheric radiation into the pond, an estimation of air temperatures over the diel cycle is required. Card et al. (1976) have developed a simulation algorithm which predicts air temperatures based on sinusoids derived from long-term weather data, combined with a minimum and maximum air temperature initialization. The temperature at any given time can be calculated:

$$T = T_{mean} + \text{Temp Swing} * P \qquad (2a.8)$$

Where:

$$\text{Temp Swing} = T_{max} - T_{min} \ (°C) \qquad (2a.9)$$

$$T_{mean} = (T_{max} + T_{min})/2 \ (°C) \qquad (2a.10)$$

$$P = a[\sin(\omega_1 t_1 - \phi) + b \sin 2(\omega_1 t_1 - \phi)] \qquad (2a.11)$$

And:
ω_1 = angular frequency, $2\pi/24$ (radians/hr)
t_1 = time (in hours from midnight)
ϕ = phase angle (sets the profile correctly with respect to clock time; determined by the time at which the median temperature is expected to occur)

The coefficients a and b in Equation 2a.11 set the amplitude of the temperature swing such that $P_{max} = 0.5$, and peak-to-peak amplitude is unity. For use in the revised model minimum and maximum temperatures are assumed to occur at 0600 and 1500 hr, respectively, or a=0.4484, and b=0.2706 (see Card et. al 1976 for a detailed explanation). If T_{min} occurs at 0600, and T_{max} occurs at 1500, hr the median temperature will occur at 1030 hr and:

$$\phi = (10.5/24) * 2\pi \qquad (2a.12)$$

or:

$$\phi = 2.7489 \text{ radians}$$

Substituting in for P and adding 6 hours to the simulation start time (thereby initiating the simulation at 0600 hr as opposed to 2400 hr) yields the temperature estimation expression:

$$T = (T_{max} + T_{min})/2 + (T_{max} - T_{min}) * 0.4484 * [\sin(2 * (\pi/24) * (t + 6) - 2.7489) + 0.2706 * \sin(2 * (2 * (\pi/24) * (t + 6) - 2.7489))] \qquad (2a.13)$$

4. *Wind Vector Estimation*
Among the more difficult and sensitive data inputs to substitute for is that of wind vector, another measurement not included in PD/A CRSP protocols. Lack of concurrently recorded wind direction and wind speed also means wind vectors cannot be directly calculated for the experiment sites in question. While not used directly in calculations of the overall heat content of the water column being modeled, wind vector measurements are critical to the estimation of the amount of turbulent mixing occurring within the water column, and therefore to the extent of stratification itself. The Losordo model calculates this turbulent mixing based upon the extent of shear stress at the surface of a pond caused by the wind (Henderson-Sellers 1984):

$$t = \rho_a * Cz * (Wvz)^2 \ (N/m^2) \qquad (2a.14)$$

Where:
- t = shear stress
- ρ_a = air density (kg/m³)
- Cz = coefficient of aerodynamic resistance; 1×10^{-3}
- Wvz = wind vector magnitude at a height of z meters above the water surface (m/s)

Considerable effort was put into devising ways of estimating wind vector inputs for the model, but a suitable method of estimation was not found. It does appear, however, that for a given day at a given site the wind vector input may be calibrated as a function of wind speed. Once this calibration has been made, the model appears to predict closely temperature stratification in other ponds at the same site. The procedure used in presenting the temperature simulations in this report was to run the model using available input data, then to correct for discrepancies from observed stratification using the wind vector input to modify the effect of winds across the pond on turbulent mixing. After this correction was established, it was fixed for a given date and the model was then run for other ponds on the site for that date.

5. *Solar Radiation Inputs*
Since the entire energy/heat balance description used in both the Losordo model and the revised model under description depends on estimations of energy flux into and out of the system, the most useful solar radiation input measurement would be in units of watts per square meter (W/m^2). Indeed, where these measurements are available they are entered directly into the model as such. However, some of the PD/A CRSP sites do not have available pyranometer (readings recorded as W/m^2). More commonly, due to an emphasis at many of the research sites on phytoplankton studies, solar radiation is measured with quantum sensors (readings recorded as photons/m^2/hr). Since the photometers measure only that radiation in the photosynthetically active range of the spectrum (approximately 420 - 750 nm), it is a measurement which underestimates total radiation received by the earth in a particular location. Furthermore, varying cloud cover over a diurnal cycle will selectively filter wavelengths of the light passing through them. For these reasons, for those sites where only PAR measurements are

available, an additional calibration and correction for solar irradiance values in W/m^2 will be necessary. As in the case of the wind vector estimations, once this correction for solar irradiance has been made for a given pond at a site, the values over a diurnal cycle are fixed and then incorporated into simulation runs for other ponds at the site.

Results

Validation of the revised model was conducted by comparing the predicted temperature simulations generated with those previously produced with the Losordo model. The detailed data set gathered by Losordo (1988) for Northern California pond sites was modified to resemble those data sets generated by PD/A CRSP experiment sites. That is, where Losordo's database presents site weather data (solar irradiation, wind speed, wind direction, air temperature, relative humidity, wind vector) every twenty minutes (based upon sixty-second time intervals averaged over the twenty minutes), the PD/A CRSP database provides weather data only at those times where experimental protocols demand it–most commonly at 0600, 1000, 1400, 1600, 1800, and 2300 hours, and at 0600 hours the next day (local time), over a given diel cycle. Readings are generally cumulative readings over the time interval, from which average readings for the time interval are then calculated and reported. After Losordo's (1988) database was reduced in this way to averages for the time intervals between 0600, 1000, 1400, 1600, 1800, 2300, and 0600 hr the following day, the data were entered directly into the revised model. Figure 2a.2 shows the comparison between temperature profiles predicted by the Losordo model and those predicted by the modified model. Included in the figure are the measured temperatures at three depths within each pond. It should be noted that the revised model simulates temperatures at depths slightly different from the depths used in Losordo's model. This is due to the way the revised model calculates volume element sizes-volume element thickness is variable, but must be uniform throughout the pond depth.

After these validation runs were made between the models, the revised model was then initialized with data from PD/A CRSP experiment sites. Data from Thailand were gathered during an experimental cycle in 1988, data from Honduras were gathered during an experimental cycle in 1992, and data from Rwanda were gathered from an experimental cycle in 1989. The models were initialized in the ways described above, using a pond selected at random to calibrate for wind vector and solar radiation estimates. The model was then run using different ponds from the same experimental site for the same day. In other words, the simulation runs for the PD/A CRSP experimental sites are for novel ponds, selecting these ponds for differences in Secchi disk measurements or pond depths, or both, using site-specific calibrations made as discussed above. Predicted temperature profiles for each pond were then generated for the given diel cycle. Comparison of the revised model's predicted temperatures to the measured temperature profiles over these cycles are illustrated in Figures 2a.3 and 2a.4.

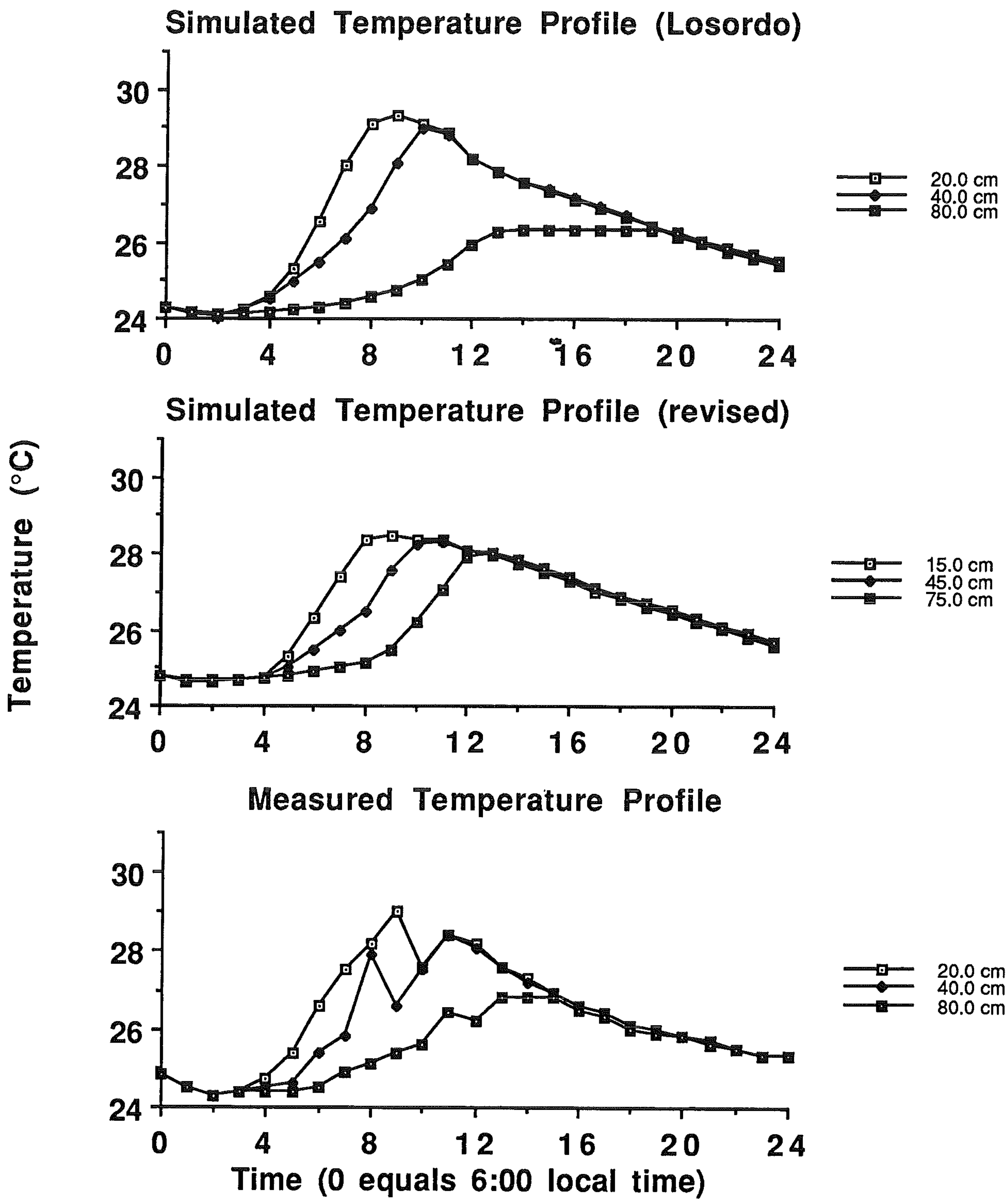


Figure 2a.2. Comparisons of Losordo's Model, Revised Model, and measured temperature profiles for a stratified pond.

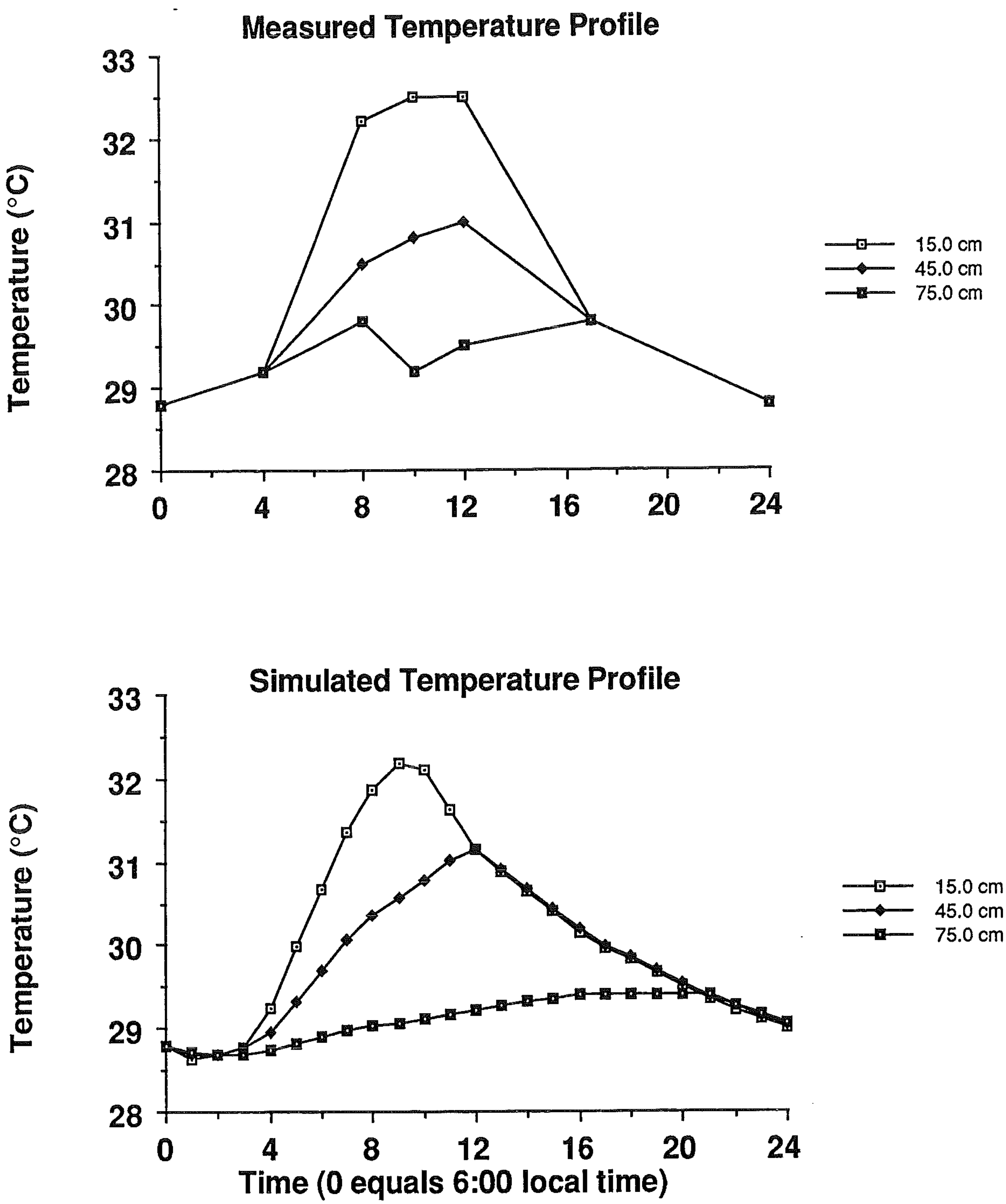


Figure 2a.3. Revised Model output and measured temperature profile for a stratified PD/A CRSP pond.

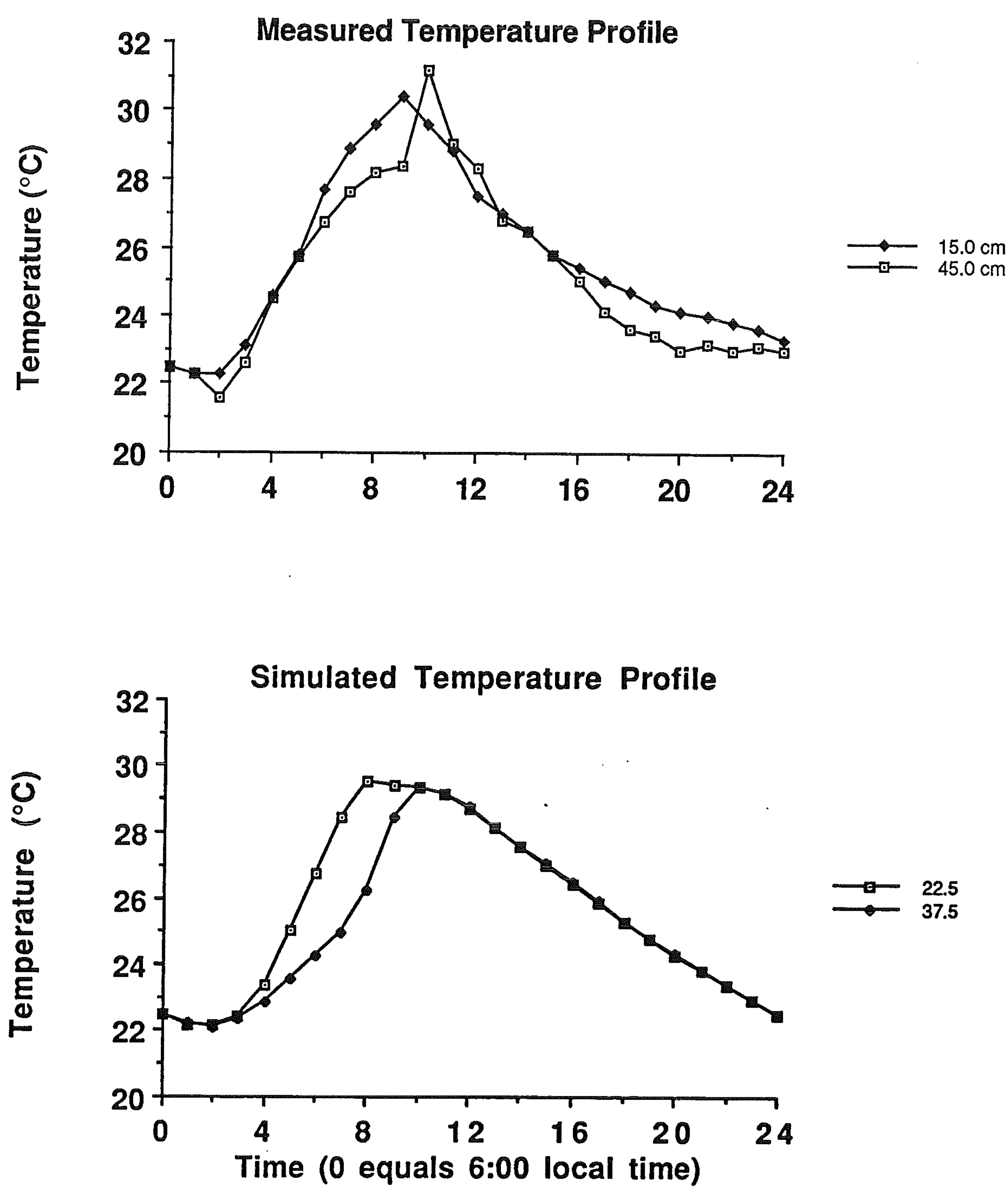


Figure 2a.4. Revised Model output and measured temperature profile for a mixed PD/A CRSP pond.

Anticipated Benefits

What is perhaps most striking about the results obtained with the modified model is the sustained accuracy of the predictions in temperature stratification (or lack thereof) across several different pond sites in several different countries. Combined with increased flexibility of use and adaptability to less intensive input data files, it is evident the energy-balance approach used in these models is an appropriate one when characterizing the overall heat content within ponds used for aquaculture. Indeed, there has been some loss of accuracy in the temperature predictions, but the onset of stratification, the degree of stratification from surface to pond bottom, the onset of mixing, and the simulation of completely mixed conditions remain remarkably accurate. Even with some resolution loss from the Losordo model, differences in instantaneous temperature predictions from measured temperature values across the pond depth rarely exceed 0.25°C.

The revisions to the model described above now allow the user to ask a variety of "what if" questions not possible with the Losordo model. The revised model has been run for simulations describing ponds of depths from 45 cm to 120 cm, for ponds of surface areas ranging from 0.30 to 4.00 hectares, for ponds in sheltered areas and in exposed ones, and for ponds in both the southern and northern hemispheres. Simulation results have generally remained as consistently accurate for all these situations as for those described in this report. Applied as either a research tool or used as an aid by extension agents or farmers themselves, the revised model can be of use when deciding where to place aquaculture ponds, how deep to build them, and what considerations might best be exploited locally to suit the needs of the particular animal to be cultured.

2.b. Dissolved Oxygen Concentration

Introduction

Following procedures similar to those used in the development of the model to simulate temperature in stratified ponds, a second model has been developed for simulating dissolved oxygen concentration. This second model is used to simulate dissolved oxygen concentrations at three depths in the pond at hourly intervals over a diel cycle. Both models are revisions and simplifications of previous models (Losordo and Piedrahita 1991, Losordo 1988). The simplifications were undertaken primarily to permit model execution with data such as those available in the PD/A CRSP data base. The revisions incorporate findings and research results derived under PD/A CRSP projects. Currently, the revised dissolved oxygen model is being verified with data inputs selected from the Fourth and Fifth Work Plans.

Materials and Methods

The dissolved oxygen model is coupled to the temperature model (Culberson and Piedrahita 1992), and simultaneous calculations of temperature and dissolved oxygen are obtained as the model is executed. Just as temperature calculations were based on energy balances, dissolved oxygen estimates are based on mass balances. In the model, rates of production, consumption, and transfer of oxygen are quantified and used to calculate dissolved oxygen concentrations as functions of time. Diffusion of oxygen between water at different depths is estimated with diffusion coefficients similar to those used for the temperature model.

Perhaps the most notable change in the dissolved oxygen model is the change in the characterization of phytoplankton respiration. In the original Losordo model (Losordo 1988), phytoplankton respiration at night was estimated as a percentage of the primary productivity value during the light period. Recent work on the characterization of diel fluctuations in phytoplankton productivity (Szyper et al. 1992) suggests that this straight percentage neglects a residual respiration component exhibited by phytoplankton in the first two or three hours following sundown. The inclusion of a time-lag element for characterizing this residual respiration in the revised model shows an improvement over the original (Losordo) characterization.

A second revision to the Losordo model includes recent information concerning the interpretation of dark-bottle respiration data as estimates of pond water column respiration rates. Teichert-Coddington and Green (1992) have outlined procedures for determining the best incubation schedule for obtaining mean daytime and nighttime water column respiration rates, and their results have been used to generate a regression equation which relates a single four-hour incubated dark-bottle measurement initiated at 0800 hr (the usual format followed in CRSP research protocols) to an estimate of average overall nighttime pond water column respiration rate. Again, as with the above-mentioned revision to phytoplankton respiration, this modification has improved the dissolved oxygen concentration predictions over those of the previous Losordo model.

Further modifications have been made to model structure and layout which have resulted in easier data input procedures for the operator, but which will not be discussed in detail here. As with the revised temperature model, the updated dissolved oxygen model can now be easily manipulated to facilitate answering "what if" questions when the operator is interested in how pond morphology, pond management, and pond placement influence diel cycles of pond water quality.

Results

For the purposes of illustrating the accuracy of the model and to discuss the changes and simplifications made to the original model (Losordo 1988), simulation runs from two sites in Northern California will be presented here. Preliminary simulations using PD/A CRSP-generated data indicate that the accuracy of the dissolved oxygen model does not differ significantly from that demonstrated in the Northern California runs, in spite of the requisite reductions in data input frequency and complexity when using the CRSP database.

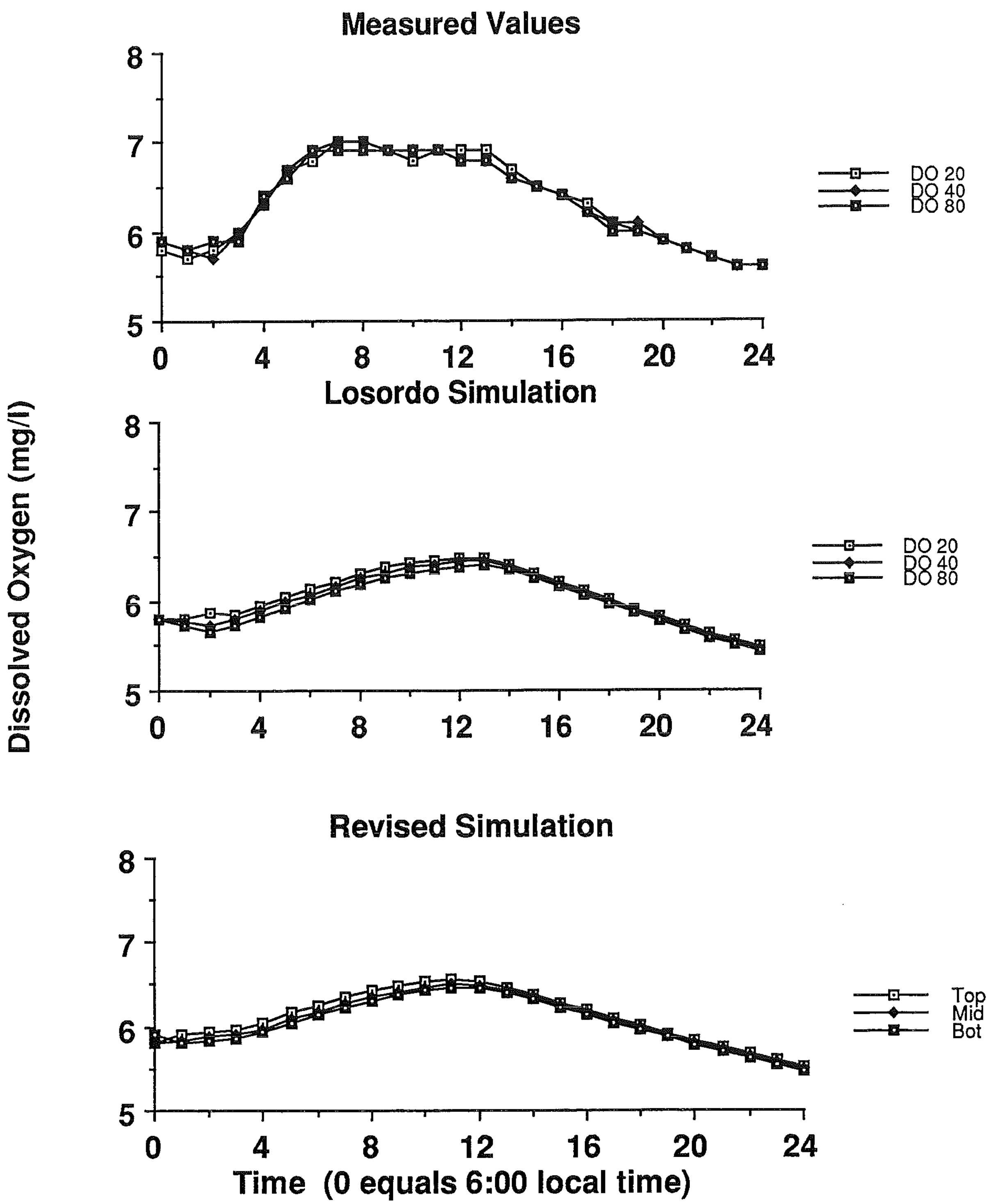


Figure 2b.1. Comparisons of Losordo's Model, Revised Model, and measured dissolved oxygen profiles for a mixed pond.

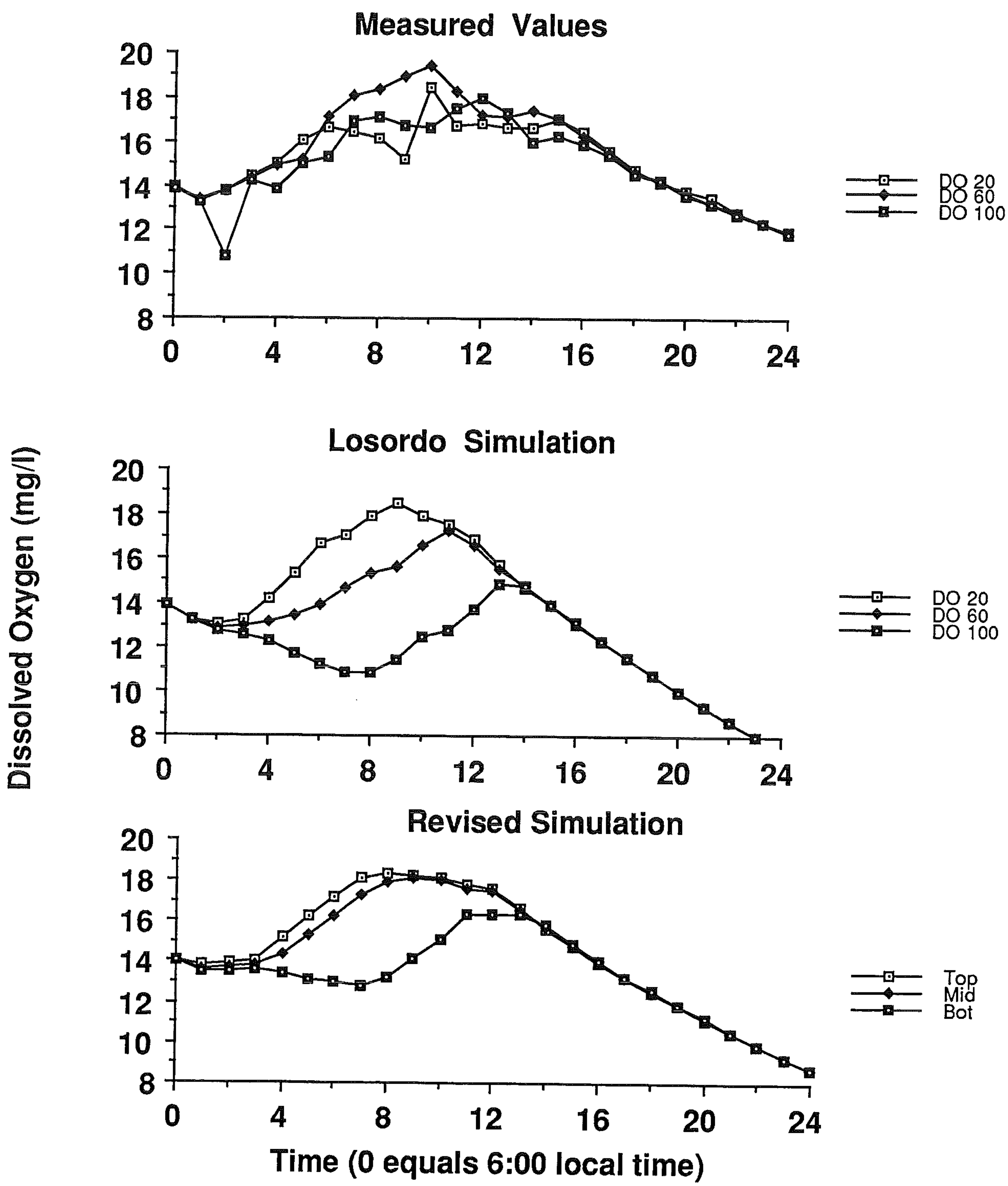


Figure 2b.2. Comparisons of Losordo's Model, Revised Model, and measured dissolved oxygen profiles for a stratified pond.

The simulation examples presented here reflect outputs generated using "CRSP-like" data inputs. As was the case in the initial testing of the temperature model, data inputs used for these simulations mimic the data collection routines currently being followed at CRSP research sites. Inputs to the model are made for 0600, 1000, 1400, 1600, 1800, 2300, and 0600 (+1 day) hr, times which reflect the current CRSP data collection schedules. Figure 2b.1 shows plots of measured values of DO, Losordo's model outputs, and the revised model's outputs for a Northern California pond under fully mixed conditions. Figure 2b.2 shows the same plots for another Northern California pond under stratified conditions.

Anticipated Benefits

The simulation results obtained with the revised dissolved oxygen model are very encouraging. The general trend in dissolved oxygen concentration changes at the various depths in a pond has been simulated with relatively modest data requirements. There are still differences between the measured and the simulated dissolved oxygen values, indicating weaknesses in our ability to model the processes of oxygen production and consumption in ponds. Continued improvements in the models are expected as results of other related CRSP research are incorporated.

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PONDCLASS: Expert System Guidelines for Fertilizing Aquaculture Ponds

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Introduction

Research by the Oregon State University component of the Data Analysis and Synthesis Team (OSU-DAST) has been aimed at translating the findings of CRSP field research projects into practical pond management guidelines that can be applied wherever pond aquaculture is practiced. During the current work plan, the OSU-DAST completed version 1.1 of PONDCLASS, the expert system guidelines for fertilizing aquaculture ponds. The principal accomplishments leading to completion of PONDCLASS version 1.1 during the current year were:

1. PONDCLASS underwent a formal external peer review, which was conducted by the Program Management Office under the Director's guidance.
2. Incorporation of reviewer's comments and suggestions into the PONDCLASS program where appropriate and practical, and
3. Preparation of the final draft of the PONDCLASS *User's Guide*.

PONDCLASS Version 1.1 for both the Macintosh and IBM PC computers are ready for distribution as soon as the *User's Guide* is printed.

PONDCLASS Review and Revision

During the current year, PONDCLASS version 1.1 was subjected to an external peer review process conducted by the PMO. The product was well received by all the reviewers, who felt that PONDCLASS is an effective medium for communicating practical pond management guidelines. Some reviewers also commented that the output was realistic and consistent with their own observations on fertilizer loadings in different countries. Minor corrections and suggestions made by the reviewers have been made to the *User's Manual*. On the basis of their comments, the chapters in the manual were reorganized. Some reviewers were of the opinion that there should be separate versions of the *User's Manual* for Macintosh and IBM-compatible versions of PONDCLASS. However, because of the added expenditure involved in printing two separate manuals, we have decided to have a common manual that has instructions for operation of both versions. The completed and revised product was delivered to the PMO for final preparation and desktop publishing in July 1992.

Some changes were made to PONDCLASS based on recent CRSP research. The version of the program that was subjected to internal review by CRSP participants assumed that all ponds require the addition of some organic material for optimal fish production. This assumption was made on the basis of early field research conducted by the CRSP. However, there is now compelling evidence, particularly from the sites in Thailand (Knud-Hansen et al. 1992), that high fish yields can be obtained using only inorganic fertilizers. These observations are consistent with the current paradigm in other countries, such as Israel (Schroeder et al. 1990), which suggests that management of algal productivity through the addition of appropriate amounts of inorganic nitrogen and phosphorus can lead to enhanced fish production. We have therefore removed the organic matter constraint in PONDCLASS; however, users can opt to add manure if so desired by specifying a BOD requirement.

The issue of whether ponds require allochthonous organic matter or not remains unresolved. Currently, we have no means of identifying ponds that may benefit from such treatment. It is possible that ponds with low alkalinity may benefit from the addition of manure, the decomposition of which supplies CO_2, thereby alleviating carbon limitation (Schroeder and Buck 1987, McNabb et al. 1989, Wohlfarth and Schroeder 1991). Research suggesting that high fish yields can be obtained by the addition of only inorganic fertilizers has been confined to highly alkaline waters in Thailand and Israel. It is not known whether these results are applicable to source waters of low alkalinity. Manure additions may also be beneficial in highly turbid ponds. Further research into the role of externally derived organic matter in pond performance is therefore urgently required.

When manure is used as a fertilizer source for ponds, PONDCLASS assumes that the total nitrogen and phosphorus contained becomes available for algal uptake. There is evidence, however, that not all of the nitrogen and phosphorus in manures added to water becomes available in forms that algae can use, at least in the short term (Lannan et al. 1990, Knud-Hansen et al. 1991). The practical implication of this situation is that PONDCLASS may tend to underestimate the actual fertilizer requirements of a pond. Estimates of nitrogen availability from poultry manure range from 40% (Knud-Hansen et al. 1991) to approximately 60% (Lannan et al. 1990) of the total nitrogen content. Similarly, nitrogen availability has been estimated to be about 50 and 30% for swine and dairy manures, respectively, and phosphorus availability to be 80, 80, and 60% of the total phosphorus contained in poultry, swine, and dairy manures, respectively (Lannan et al. 1990). Because there is likely to be considerable variation in nutrient availability from different manures, it is not possible to arrive at availability coefficients that are applicable to all situations. However, coarse estimates of nutrient availability may be obtained by suspending manure samples in water for a few days prior to their application in ponds. The total nutrient content of the manure weighted by its availability coefficient can then be entered in PONDCLASS to determine the quantity of manure required to satisfy pond nutrient demands. A discussion of one possible field method to estimate the total nutrient contents of manures and factors that may affect nutrient availability from manures is presented in a separate technical report.

In refining the latest version of PONDCLASS, every effort was made to maximize the user's control over program operation. The fertilizer and lime requirement utilities are provided only for the user's convenience; their use is strictly optional. Even if the user elects to use a particular utility, the values given by PONDCLASS can be edited. Alternately, values for different observational variables can be directly entered by the user. Further, although the internal equations are fixed, some of them can be externally calibrated by the user. Therefore, the ultimate reliability of PONDCLASS is in the hands of the user.

PONDCLASS is currently undergoing field testing in the Philippines and Thailand by other CRSP participants. We anticipate that the results of these studies will provide us with feedback on program operation and the appropriateness of algorithms currently used in the expert system. PONDCLASS has, however, been successfully used in a microcosm study designed to investigate rabbit manure use in tilapia (*Oreochromis niloticus*) culture (Franco 1991). Fish yields in the PONDCLASS treatment were the highest among fertilized tanks, and were similar to those in control tanks that received a commercial feed at 2% body weight per day. Both fish yields and primary productivity levels in the PONDCLASS treatment were much higher than two fertilizer treatments involving predetermined rabbit manure loading rates (50 and 75 kg dry wt/ha/day). Further, the amount of fertilizer required to produce 1 kg of fish was the lowest in the PONDCLASS treatment. These results suggest that the PONDCLASS rationale of supplying nutrients in quantities required by algae and based on background carbon, nitrogen, and phosphorus concentrations in water may be more efficient than the addition of predetermined quantities of fertilizers, which may result in insufficient nutrient concentrations at some times and excess levels at other times.

Relevance of PONDCLASS to the CRSP Global Experiment

Completion of PONDCLASS version 1.1 represents a point of arrival in the history of CRSP research. The original program proposal for the Pond Dynamics/Aquaculture CRSP explicitly addressed the need for data analysis and synthesis in developing transferable technologies. The intended flow of information through what is now referred to as the CRSP Global Experiment is illustrated in Figure 1, which is taken from the original Program Proposal accepted by USAID in 1982. In formulating this plan, it was anticipated that some aspects of research findings in the CRSP field experiments at different locations would be site specific, whereas other aspects would apply universally to all aquaculture ponds. Understanding these distinctions was considered essential to advancing the management of aquaculture ponds from a highly developed art form to a true production technology.

At the inception of the CRSP, it was intended that data analysis and synthesis would be done cooperatively by a committee of principal investigators of CRSP projects (Figure 1). Initial progress in synthesis of CRSP research findings was slow, largely because of heavy demands on the time of the various principal investigators in establishing and operating the field research activities at diverse geographical locations. Therefore, a standing Data Analysis and Synthesis Team (DAST) was organized within the CRSP. The DAST was specifically structured to accelerate the synthesis of CRSP research findings into predictive models and operating guidelines (Figure 1).

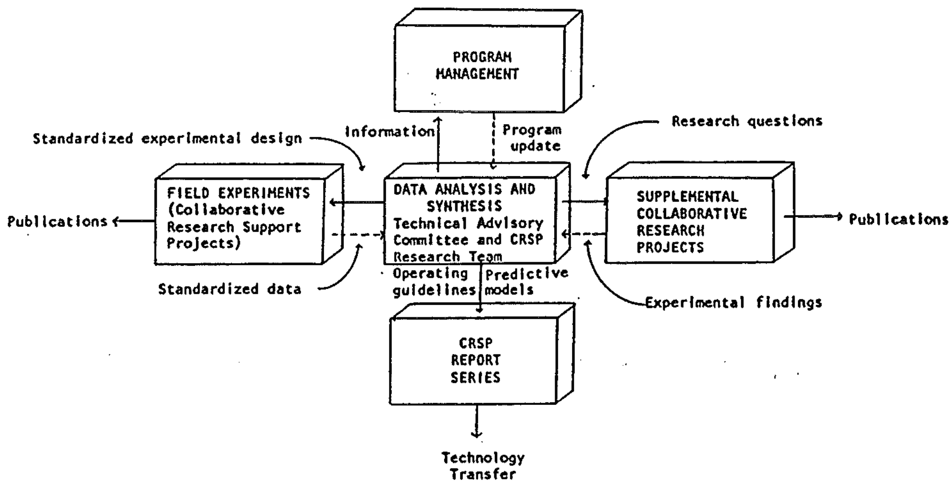

Figure 1. Interrelationships among CRSP Activities as presented in the original CRSP program proposal.

As one of its functions, the DAST mediated discussions among CRSP researchers regarding research questions to be addressed in the Global Experiment. These discussions led to the formulation of conceptual models of aquaculture ponds. The first of these conceptual models took the form of mass balance diagrams which illustrated the movement of energy and mass through aquaculture ponds (Figure 2). The conceptual models proved to be extremely useful in identifying research questions and in developing a consensus of the CRSP researchers on a paradigm of pond dynamics.

Although the conceptual models were extremely useful in research planning, and in fact advanced the level of science in the CRSP Global Experiment to a higher plane, they had one significant shortcoming. In the mass balance diagrams, the processes involved in the movement of mass and energy (as indicated by the arrows) are implicit. Thus, when the research group discussed the nature of the dynamic processes occurring in ponds, there was always a possibility that different members of the group would apply different interpretations of the implied processes.

In PONDCLASS, the functional relationships among the dynamic processes are now explicit. They may not be perfect descriptions of the processes in all cases, but they are explicit. The explicit nature of the equations in the PONDCLASS algorithms provides the opportunity for the CRSP research team to evaluate the equations and underlying assumptions, and to design experiments to test assumptions in cases where questions arise regarding their validity. The explicit nature of the equations thus provides the opportunity to advance the scientific rigor of CRSP research to the next higher plane.

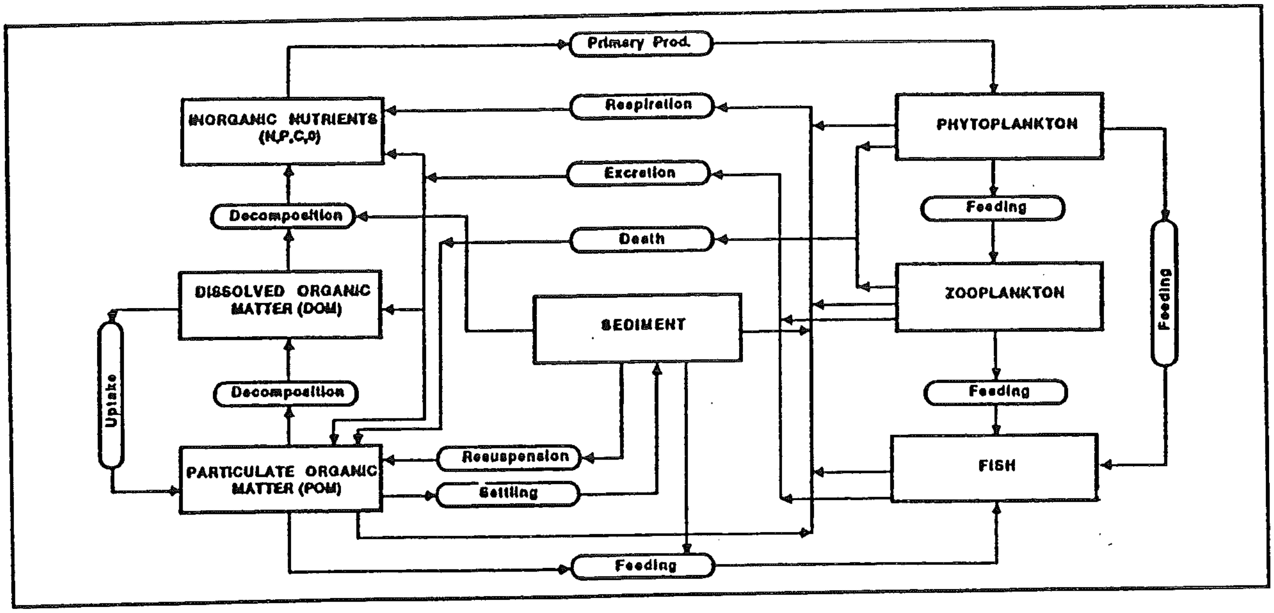

Figure 2. A conceptual model of an aquaculture pond. The arrows connecting the model's components represent the movement of mass in the system. The system includes both biological and non-biological components. The strictly biological components are phytoplankton, zooplankton, and fish, whereas the non-biological components are the inorganic nutrients that are considered likely to limit productivity. Examples of limiting nutrients are nitrogen, carbon, and phosphorus, which are possible limiting nutrients for photosynthesis, and oxygen and nitrogen (ammonia), which affect fish growth, health, and survival. Sediments include decomposing organic matter that settles from the water, the parent soil material, and benthic organisms. Particulate organic matter is a composite of dead particulate organics and bacteria that either coat the particles or are in free suspension. Most research on fertilized ponds has been based on the premise that yields and production rates are determined by primary productivity. Nutrients added to a pond must undergo transformations that include fixation by phytoplankton before they are available to fish. The importance of the heterotrophic food chain has not been recognized until recently (Source: PD/A CRSP Fifth Annual Administrative Report 1987).

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Dry Matter-Nutrient Relationships in Manures and Factors Affecting Nutrient Availability from Poultry Manure

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Introduction

Previous work by the OSU-DAST included the development of a database of typical characteristics for manure types and forms that has been built into PONDCLASS (Lannan et al. 1990, Lannan unpublished). Because manure characteristics vary widely (Loehr 1974), these typical values may not accurately reflect manure composition at a particular site. Simple field methods to estimate the nutrient content of individual waste samples offer a possible solution to this problem. One such method involves the use of a modified soil hydrometer or the 'slurry meter' (Tunney and Molloy 1975a), which is based on significant positive correlations between dry matter and specific gravity in manures and between nutrient (total nitrogen and phosphorus) and dry matter contents of manures (Tunney and Molloy 1975b).

Dry matter-nutrient regressions which provide estimates of total nitrogen and phosphorus concentrations in parts per million have previously been published (Tunney and Molloy 1975b, Chescheir et al. 1985). However, we found that these regression equations do not accurately predict nitrogen and phosphorus values when applied to an independent data set (reflecting information from several sources) published by Overcash et al. (1983). This is perhaps because the regressions were based on data from a few farms in a given locality, in which case less variation in nutrient contents due to local conditions (e.g., feedstuffs, environmental parameters, etc.) may be anticipated. Further, dry matter-nutrient relationships for some manures, if they do exist, were not available (e.g., dry matter-nitrogen relationships for poultry manure). Such relationships may be useful in estimating the fertilizer value of manures by the slurry meter method.

Some studies have indicated that not all of the nitrogen and phosphorus contained in manures become available as dissolved inorganic nitrogen and phosphorus (DIN and DIP) when manures are added to water (Lannan et al. 1990, Knud-Hansen et al. 1991). These studies suggest that fertilizer requirements calculated on the basis of the total nitrogen and phosphorus contents of manures (i.e., in McNabb et al. [1989] and Lannan unpublished) may tend to underestimate the fertilizer requirements of ponds.

Temperature is one of the factors that influence the mineralization of nitrogen from manures applied to soils (Hadas et al. 1983, Sims 1986). Studies to determine the effects of temperature on nitrogen or phosphorus release from manures in water have not been conducted. An implicit assumption in earlier studies on nitrogen and phosphorus release from manures added to soils

(Hadas et al. 1983, Sims 1986) and water (Lannan et al. 1990, Knud-Hansen et al. 1991) is that repeated manure additions result in similar nutrient release patterns, but this assumption has not been tested.

Therefore, a research project was undertaken to (i) verify and develop dry matter-nutrient relationships for various manure types and forms and (ii) examine whether nitrogen and phosphorus release from poultry manure added to water is influenced by temperature or repeated manure additions.

Materials and methods

Dry matter-nutrient relationships

Total nitrogen and phosphorus data from the comprehensive database of Overcash et al. (1983) were regressed against dry matter for possible relationships. When significant relationships could not be established for certain manure forms, all the data on different forms for a particular manure type (e.g., total nitrogen and phosphorus-dry matter relationships for poultry manures) were analyzed together to ascertain whether any relationship existed.

Temperature and repeated manure addition effects on DIN and DIP release from poultry manure

Fresh, unmodified layer-poultry manure was applied to twelve buckets containing 18 L of buffered freshwater at a rate approximating 300 kg dry matter/ha in a one-meter deep pond (1260 kg/ha on a wet weight basis). There were three replicates each for four treatments in the experiments. Three buckets were used to study the effects of repeated manure additions (held at 15°C), and nine buckets (three per treatment) to study the effects of the temperature regimes studied (15, 20, and 25°C) on DIN and DIP accumulation. The latter set will be referred to as T1, T2, and T3 buckets in this report. The buckets were maintained in the dark in a constant temperature room (15°C). The higher temperature treatments (20 and 25°C) were established using electric immersion heaters. None of the buckets were artificially aerated.

In the temperature comparison study, water samples were drawn at intervals of 1, 3, 5, 7, 10, 14, and 20 days after manure addition and analyzed for total ammoniacal and nitrate nitrogen (sum=DIN), and soluble reactive or dissolved inorganic phosphorus (DIP). Total ammoniacal nitrogen concentrations were also measured in samples drawn four hours after manure addition. Nitrite-nitrogen was not measured because a previous study (Nath 1992) indicated that its build-up is negligible when manure is added to water.

For the repeated addition study, a second dose of the original manure (kept in frozen storage) was added at the same rate as the initial dose on Day 7. Water samples were drawn from these buckets on Days 1, 3, 5, 7, 8, 10, 12, and 14 after the first dose of manure and analyzed for DIN and DIP. To compare nutrient release patterns, the entire sampling period was divided into two intervals. The first interval was after the initial addition of manure and included observations on Days 1, 3, 5, and 7. The second interval followed the second addition of manure, on Day 7, and was considered an independent set of observations (Days 8, 10, 12, and 14, or Days 1, 3, 5, and 7 after the second addition of manure).

Results

Dry matter-nutrient relationships
Regression equations that resulted in the best fit to the available data are summarized in Tables 1 and 2. The regressions indicate that the total nitrogen content (dry weight basis) was negatively correlated with dry matter for poultry, beef, and dairy manures (Figure 1). Total phosphorus content (wet weight basis) was positively correlated with dry matter for poultry and beef manures (Figure 2).

Temperature and repeated manure addition effects on DIN and DIP release from poultry manure
Manure characteristics. The total nitrogen, total phosphorus, ammonia-nitrogen, and ortho-phosphate contents of the manure used in this study were 1.26, 0.44, 0.50, and 0.18% (wet weight basis), respectively. The C/N ratio was 6.72 and the dry matter content was 23.8%.

Temperature effects. DIN concentrations reached highest levels on Day 3 in the T1 and T2 tanks, and peaked on Day 1 for T3 tanks (Figure 3). These concentrations corresponded to 57.3 ± 5.9, 51.6 ± 6.9 and 56.0 ± 2.5% (Mean ± 1 SD) of the total nitrogen supplied by poultry manure. After a period of decline to a low on Day 10, DIN concentrations began to increase again

Table 1. Relationships between dry matter and total nitrogen for different manures. All the regressions are significant at the 0.05 level (TN = total nitrogen as % dry weight).

Manure type and form	Regression equation[a]	R^2
1. Poultry manure[b]	$TN = 11.982 + 1.913\ (\ln x)$	0.49
2. Beef manure (pit stored)	$TN = 2.71 + 33.83e^{(-x/3.06)}$	0.67
3. Dairy manure (fresh)	$TN = 9.109 - 0.542\ x + 0.01\ x^2$	0.75
4. Dairy manure (gutter waste)	$\text{Log}\ (1+TN) = 1.539 - 0.0167\ x$	0.62

[a] Independent variable x = % dry matter;
[b] Includes data from fresh, medium pit, deep pit, pits with drying boards, slurry, and litter poultry manure.

Table 2. Relationships between dry matter and total phosphorus for different manures. All the regressions are significant at the 0.05 level (TP = total phosphorus as %).

Manure type and form	Regression equation[a]	R^2
1. Poultry manure[b]	$TP = -0.146 + 0.0592x - 0.0013x^2 + 0.0000098x^3$	0.66
2. Beef manure[c]	$TP = 0.01542 + 0.00976x$	0.46

[a] Independent variable x = % dry matter;
[b] Includes data from all forms of poultry manure listed below Table1;
[c] Includes data from fresh, pit stored, and wastes + bedding manures.

(Figure 3). DIN concentrations were significantly influenced by temperature and sampling day ($P \leq 0.001$). However, contrast procedures indicated that treatments T1 and T3 were not significantly different ($P=0.24$), but that T1 and T3 combined together were different from T2 ($P \leq 0.001$). Overall treatment differences were significant only on Days 1 and 5 ($P \leq 0.05$).

In general, DIP concentrations increased rapidly during the first 10 days followed by a more gradual rise thereafter (Figure 4). Concentrations on Day 20 for T1, T2, and T3 tanks were 71.4 ± 2.9, 68.2 ± 7.6, and 73.2 ± 3.1 % (Mean $\pm$ 1 SD), respectively, of the total phosphorus content added to the tanks. DIP concentrations were significantly influenced by temperature and sampling day ($P \leq 0.001$). Treatments T1 and T2 were not significantly different ($P=0.71$), but T1 and T2 combined together differed significantly from T3 ($P \leq 0.001$). Overall treatment differences were significant only on Day 5 ($P \leq 0.01$) and Day 10 ($P \leq 0.001$).

Effects of repeated manure addition. To compare nutrient release trends between the first and second intervals following manure addition, it was necessary to correct observed levels of DIN and DIP in the second interval for the expected increase due to mineralization of the first manure dose in the second week. This was because two phases of DIN and DIP build-up were evident in the T1 tanks of the temperature study, which were maintained under the same conditions as the repeated addition buckets but did not receive a second dose of manure (Figures 3 and 4). The expected increase was estimated from the T1 tanks of the temperature study. Corrected values (Figures 5 and 6) were used for statistical analyses.

DIN concentrations were significantly different between the two intervals (Figure 5) and were also influenced by the sampling day ($P \leq 0.001$). Contrast procedures showed that differences between treatments were significant on all sampling days ($P \leq 0.05$). DIP concentrations were significantly different between intervals (Figure 6), and were also affected by sampling day ($P \leq 0.001$) and day-treatment interaction ($P \leq 0.05$). Contrast procedures indicated that differences were not significant ($P=0.57$) on the first sampling day (i.e., Day 1 vs Day 8), but were significant on the next three sampling days ($P \leq 0.05$).

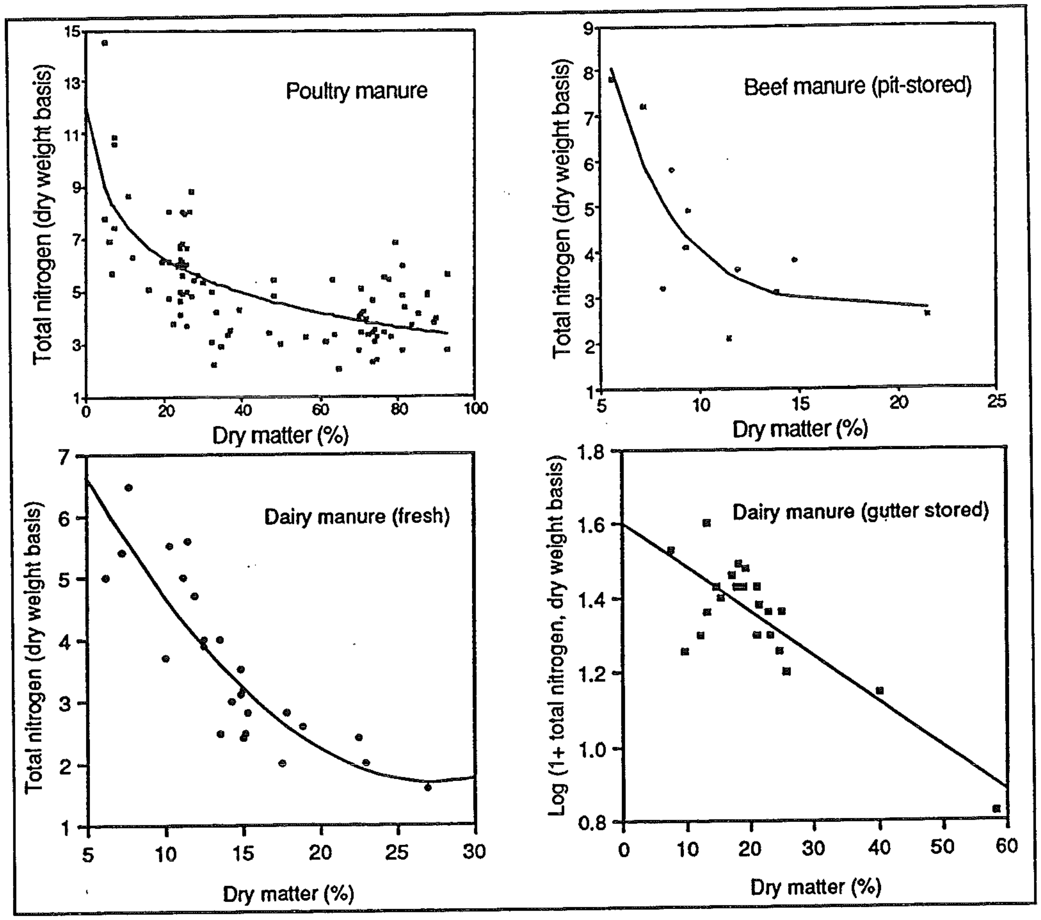


Figure 1. Regressions of total nitrogen on dry matter for different manure types. The fitted regression equations are listed in Table 1. Data source: Overcash et al. (1983).

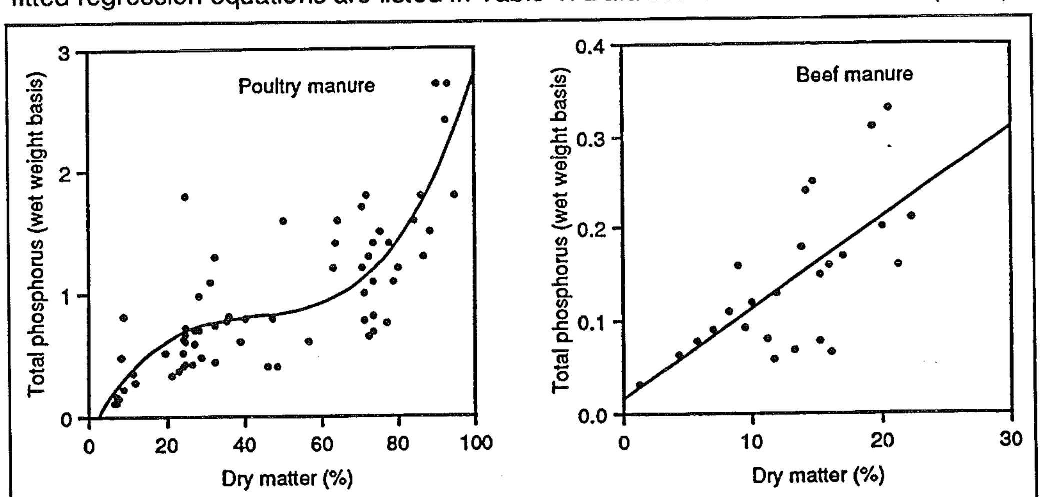
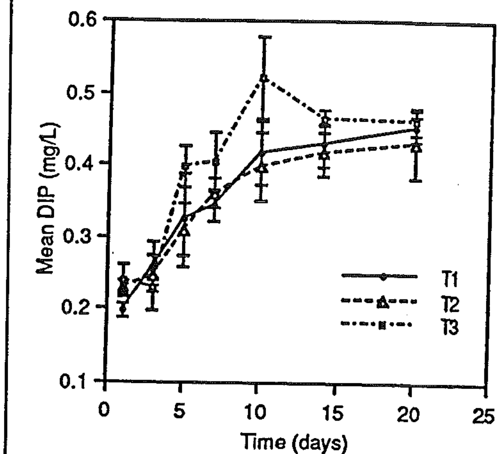


Figure 2. Regressions of total phosphorus on dry matter for different manure types. The fitted regression equations are listed in Table 2. Data source: Overcash et al. (1983).



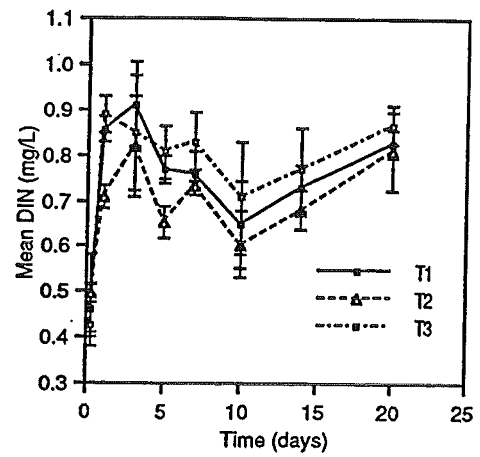
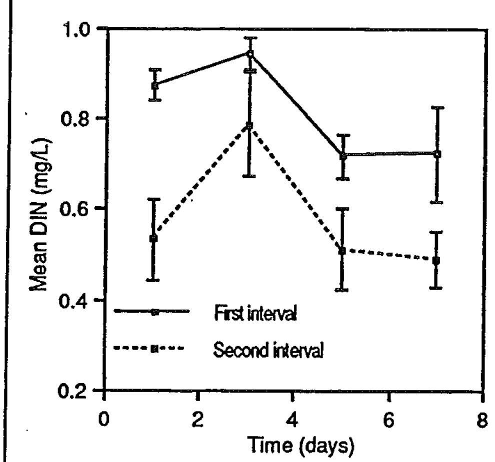


Figure 3. Mean DIN (± 1 SD) against time in the study on the effects of different temperatures on nutrient

Figure 4. Mean DIP (± 1 SD) against time in the study on the effects of different temperatures on nutrient release from poultry manure in water.



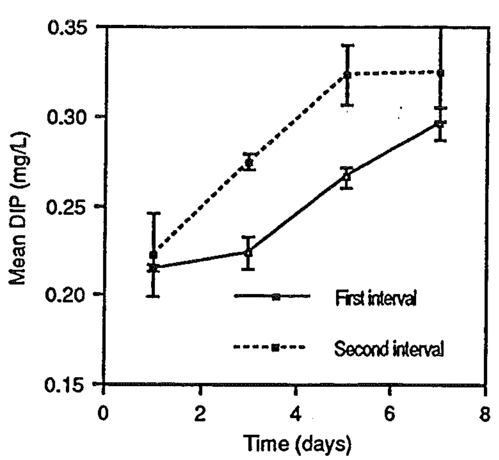


Figure 5. Mean DIN (±+ 1 SD) against time during the intervals following the first and second addition of poultry manure to water in the study on the effects of repeated manure addition on nutrient release.

Figure 6. Mean DIP (± 1 SD) against time during the intervals following the first and second addition of poultry manure to water in the study on the effects of repeated manure addition on nutrient release.

Discussion and Conclusions

Relationships between nutrient content and dry matter

The fitted regression equations (Figures 1 and 2; Tables 1 and 2) support previous observations that there is a relationship between the nutrient content and dry matter percentage of various manure types and forms (Tunney and Molloy 1975a, Chescheir et al. 1985, Tunney and Bertrand 1989). These equations can provide first approximations for the nutrient contents of manure forms for which dry matter has been estimated using a slurry meter, or in situations where analytical procedures to measure total nitrogen and phosphorus contents in a given waste sample are not available.

The slurry meter (HERKA, Postfach 1207, Kreukwertheim, Germany) or an ordinary soil hydrometer which has a specific gravity scale ranging from 1.00 to 1.06 (e.g., Fisher #14-331-15B, as used by Cheschelr et al. 1985) may prove to be useful in that they can be employed in the field to rapidly estimate the dry matter content of manures. For solid wastes or viscous slurries, appropriate dilution (ranging from 1:1 to 1:4 manure:water) is necessary before the hydrometer is used (Cheschelr et al. 1985, Tunney and Bertrand 1989). This method of estimating the nutrient content of manures may be even more effective if dry matter-nutrient relationships are developed at specific sites to more accurately reflect local conditions of manure production, handling, and storage.

Factors affecting DIN and DIP release from poultry manure

DIN concentrations were significantly influenced by temperature, but there did not appear to be a systematic trend as temperature increased from T1 to T3 (Figure 3). The treatment differences were significant only on Days 1 and 5 and appeared to be due to the lower concentrations in T2 tanks on these sampling days (Figure 3). These differences may simply be due to sampling variability or because of differences among the buckets that are not temperature related. Results from this study differ from the observations of Sims (1986), in which an increase in nitrogen mineralization accompanied an increase in temperature over a prolonged time period of 150 days. Data presented by Hadas et al. (1983), however, support our observations that temperature has little effect on inorganic nitrogen accumulation in the short term. Two phases of DIN build-up were observed (Figure 3), presumably corresponding to the rapid and intermediate periods of nitrogen mineralization in soils (Gale and Gilmour 1986, Bitzer and Sims 1988). The rapid phase has been reported to last about one week and the intermediate phase about two weeks (Gale and Gilmour 1986), which is consistent with our findings (Figure 3).

Although DIN trends are of importance in studying nitrogen pathways in water after manure addition, the actual amounts of inorganic nitrogen originating from the manure are probably better represented by total ammoniacal nitrogen. Because DIN comprises both total ammoniacal and nitrate nitrogen and the latter was not recorded in the manure samples, it must have originated from the nitrification of ammoniacal nitrogen. Mean total ammoniacal nitrogen levels recorded during the rapid phase corresponded to 57.3, 51.6, and 56.0% of the total nitrogen added to the T1, T2, and T3 buckets, respectively. The increase in total ammoniacal nitrogen from the lowest concentrations observed on Day 10 to the levels on Day 20 correspond to approximately 8.4, 9.5, and 7.0% of the total nitrogen added. Thus, the amounts of available nitrogen released after 20 days are 65.9, 61.5, and 63.0% of the total nitrogen added to T1, T2, and T3 buckets, respectively (overall mean=63.5%).

DIP concentrations were also affected by treatment; in this case, the lower temperatures together did not differ from T3, perhaps due to the higher concentrations of DIP on Days 5 and 10 in T3 buckets (Figure 4). These results do not clearly suggest a trend towards increased DIP accumulation at higher temperatures, and the observations may have been due to experimental error or non-treatment related variability, as was the case with DIN. Considering all the tanks together, about 71% of the total phosphorus added became available as DIP by Day 20, which is consistent with our previous observations (Lannan et al. 1990) although the peaks in that case were recorded on Day 5. This difference may be due to changes made in the experimental protocol (Nath 1992).

Although DIN and DIP trends in the current study differed from our initial work involving nutrient availability from poultry, swine, and cattle manures (Lannan et al. 1990), nitrogen and phosphorus availability coefficients were somewhat similar between the two studies. About 60% of the total nitrogen and 80% of the total phosphorus became available as DIN and DIP in the manure comparison study, compared to about 64 and 70%, respectively, in the current study. Nitrogen availability in both our studies was higher than the value of 40% reported by Knud-Hansen et al. (1991); this may be due to differences in the manure samples and experimental procedures (Nath 1992).

With regard to the effects of repeated manure addition on nutrient release from poultry manure, differences in DIN concentrations observed between the first and second intervals were perhaps due to the lower concentrations during the second interval (Figure 5), which in turn may be due to nitrogen loss from the manure during storage (Moore et al. 1975), or because of corrections (based on T1 values) applied to the data. Nutrient release patterns, however, appeared to be similar (Figure 5). DIP concentrations were higher during the second interval compared to the first (Figure 6), perhaps because of changes that occurred to the manure during storage (e.g., mineralization) or because of the corrections applied to the data. As with DIN, patterns of DIP accumulation were similar between the two intervals (Figure 6). The manure was not analyzed again before the second dose was applied, and it is not known whether its composition was substantially altered during the one week of frozen storage.

In summary, this study on possible factors affecting nutrient availability from poultry manure suggests that temperature does not have a pronounced effect on nutrient release, at least in the short term, and that although repeated manure addition results in similar nutrient release patterns, the actual quantities of DIN and DIP that accumulate may differ, perhaps as a result of changes that occur in manures during storage. However, the study does corroborate previous observations that not all of nutrients contained in manures becomes available for algal uptake in the short term after manure application to water.

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VI. SPECIAL TOPICS RESEARCH IN THE HOST COUNTRIES AND THE UNITED STATES

Introduction

The Special Topics component of the CRSP was created to provide opportunities for Host Country and U.S. researchers to collaborate on original research directed toward the needs and priorities of each host country. The intent is to strengthen linkages within the host country institution and to contribute to the development of research capabilities within the institution by providing opportunities for scholarly involvement of faculty and advanced students. This component also provides host country institutions and agencies with access to the human resources of the CRSP in seeking solutions to short-term local problems. Projects focus on specific aspects of the Global Experiment that would benefit from site-specific, detailed investigations. They complement the U.S.-based Special Topics Research Projects.

Proposals for these Special Topics Research Projects are developed collaboratively by the host country and U.S. scientists. The proposals are endorsed by the host country institution and are reviewed by the CRSP Board of Directors for technical merit and relevance to the general goals of the CRSP. The Board also requires that the projects be consistent with USAID and host country development strategies and priorities.

Although the Special Topics Research Projects are an important part of the CRSP, they are not a major component in terms of funding support or time expenditures. Twenty to twenty-five percent of each research associate's time typically is devoted to this activity. The CRSP places highest priority on the long-term basic research defined as the Global Experiment. Host country agencies and institutions and USAID Missions, however, often consider such basic research activities to be of low priority. Consequently, administrators in the host countries sometimes have difficulty justifying participation in the CRSP. The CRSP support for the Special Topics Research activities helps to justify this participation.

For this reporting period, Special Topics Research reports have been contributed by CRSP workers at host country sites in Honduras, Rwanda, and Thailand and at U.S. sites at Oregon State University (OSU), the University of Arkansas at Pine Bluff (UAPB), and at the University of Hawaii (UH), in collaboration with DAST team members at the University of California at Davis (UCD). A special research topic investigated in Honduras was on pond reaeration rates. Special topics projects in Rwanda dealt with factors affecting the occurrence of black spot disease in cultured tilapia, the effects of temperature and treatment duration on the success of hormonal sex reversal of tilapia fry, socioeconomic factors affecting the transfer and sustainability of aquaculture technology, and women's participation in fish culture activities. Workers in Thailand conducted studies on the role of urea in pond fertilization. One team of workers at OSU conducted laboratory studies on the effects of lime applications on soil pH and water alkalinity for a range of different soil types, and another reported on the use of rabbit excreta as a fertilizer, using Nile tilapia reared in fiberglass tanks. The UAPB group reported on a series of four experiments evaluating the effects of temperature on the growth of tilapia, and the UH/UCD DAST collaboration resulted in a report on planktonic respiration rate cycles in fertilized ponds.

Analysis and Evaluation of Reaeration Rates

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Introduction

This report documents work undertaken to complement research previously carried out by the Auburn University/Honduras group and to fill a critical void in the successful modeling of dissolved oxygen concentrations in ponds. The Honduras group previously developed a method for the evaluation of reaeration rates in aquaculture ponds (Boyd and Teichert-Coddington 1992). These estimates were found to be different from those obtained using expressions developed by Banks and Herrera (1977). The new method was developed using measurements of dissolved oxygen in ponds at the El Carao station over a period of a few days. The measurements were carried out in ponds to which formalin and copper sulfate had been applied in an attempt to reduce the rates of oxygen production and consumption. In separate experiments, the Honduras group previously made estimates of oxygen consumption by pond sediments, obtaining values that were in the same range as reaeration rates resulting from the action of moderate winds (Teichert-Coddington et al., unpublished).

The intent of the project was to carry out measurements in ponds in which the magnitude of processes (other than reaeration) that affect dissolved oxygen concentrations were reduced or measured accurately. For example, sediment oxygen demand was to be eliminated by the use of a plastic liner. Water column respiration and primary production were to be reduced by filling the lined ponds with clean, unfertilized water just prior to the initiation of the reaeration tests. In addition, it was hoped that steady, sustained winds would prevail during the time when the tests were being conducted.

Materials and Methods

This research was carried out at the El Carao station in Honduras between 16 and 23 February 1992. The dates were selected based on the availability of the ponds in relation to other experiments conducted at El Carao and on a previous history of relatively high winds and low rainfall rates at this time of year. Data analysis was carried out at El Carao, Honduras, and at Davis, California.

The original intent was to measure reaeration rates in two ponds lined with polyethylene sheeting to eliminate oxygen consumption by the sediments. However, difficulties were encountered during pond filling, and the lining

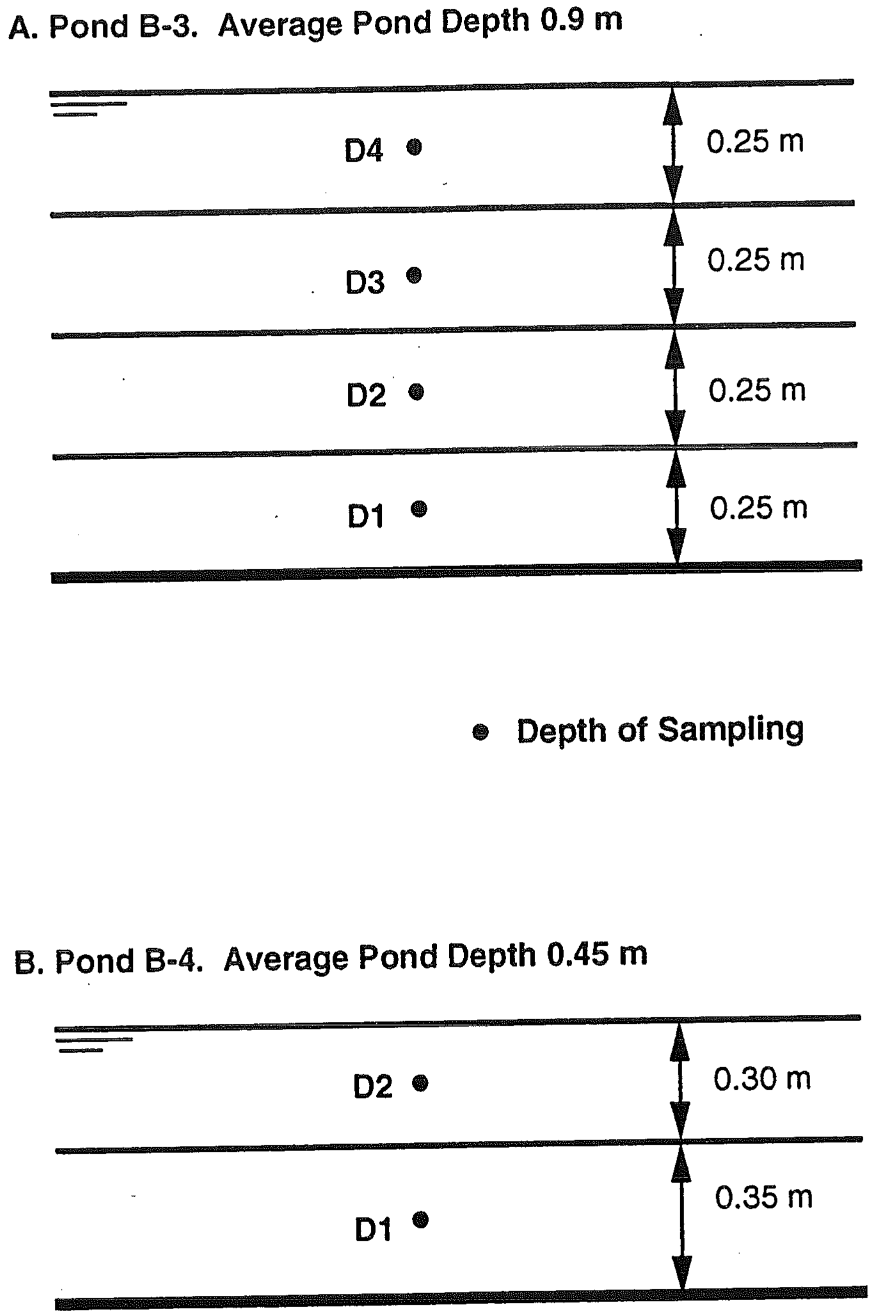

Figure 1. Depths at which temperature and dissolved oxygen concentrations were monitored in ponds B-3 and B-4. The average depths of ponds B-3 and B-4 were 0.90 and 0.45 m, respectively. The depths indicated in the Figure correspond to the depths at the sampling station, which was deeper than the average depth for the whole pond.

could not be used. Two adjacent ponds were used, ponds B-3 and B-4. The unlined ponds were filled just prior to the beginning of the reaeration tests, after a two-week drying period. Pond B-3 was filled to an average depth of 0.90 m and pond B-4 was filled to 0.45 m. The ponds were deoxygenated with sodium sulfite, using cobalt chloride as a catalyst. Dissolved oxygen concentrations and wind velocities were monitored as functions of time (Boyd and Teichert-Coddington 1992, ASCE 1977). The ponds were treated right after filling to control phytoplankton growth, using copper sulfate at a concentration of approximately 3 mg/L. They were then deoxygenated using cobalt chloride and sodium sulfite. Dissolved oxygen concentrations and temperatures were monitored in the ponds using automatic monitoring equipment available at El Carao (Boyd and Teichert-Coddington 1992). These parameters were monitored at four depths in pond B-3 and at two depths in pond B-4 (Figure 1) at 30-minute intervals.

Simultaneous measurements of wind speed (at three locations), air temperature, photosynthetically active radiation (μEinst m^2/s), and total radiation (kw/m) were collected. Wind speed was measured 3.0 m above the water level in the deep pond and 0.5 m above the water surface in both ponds. The anemometers were calibrated and tested prior to the start of the experiment and calibration equations between them were obtained (Figure 2). All wind speed measurements were then corrected based on the

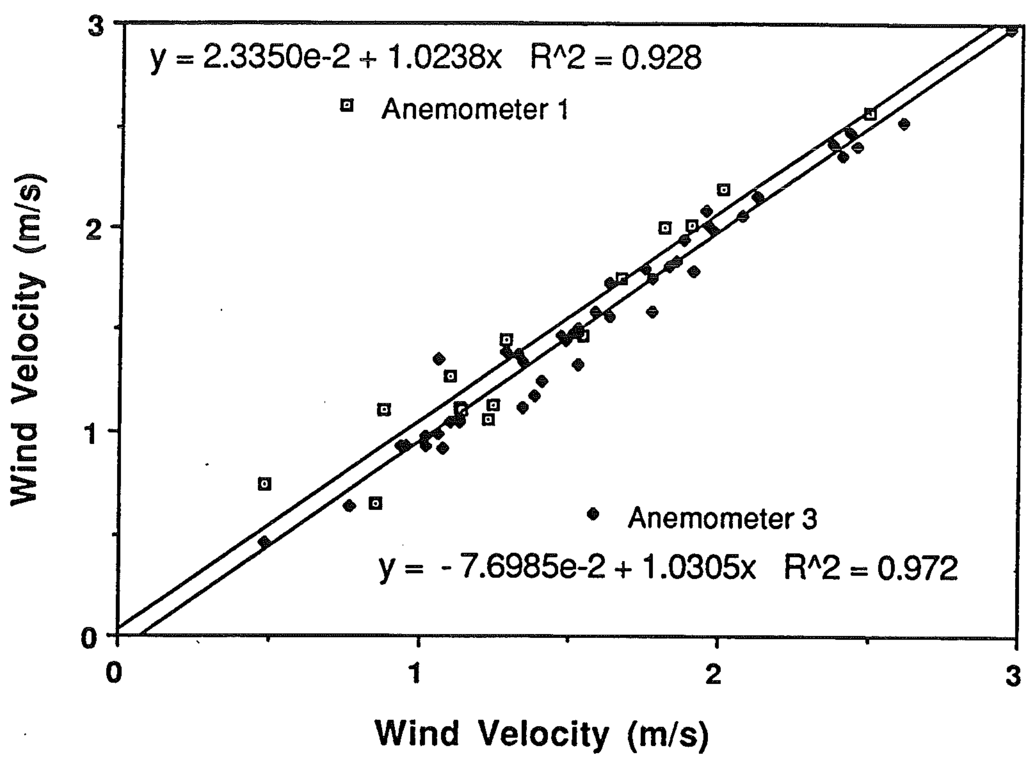

Figure 2. Comparison among wind measurements obtained with the three anemometers used. Anemometers 1 and 3 are plotted on the x-axis and regression equations are derived for these anemometers against Anemometer 2.

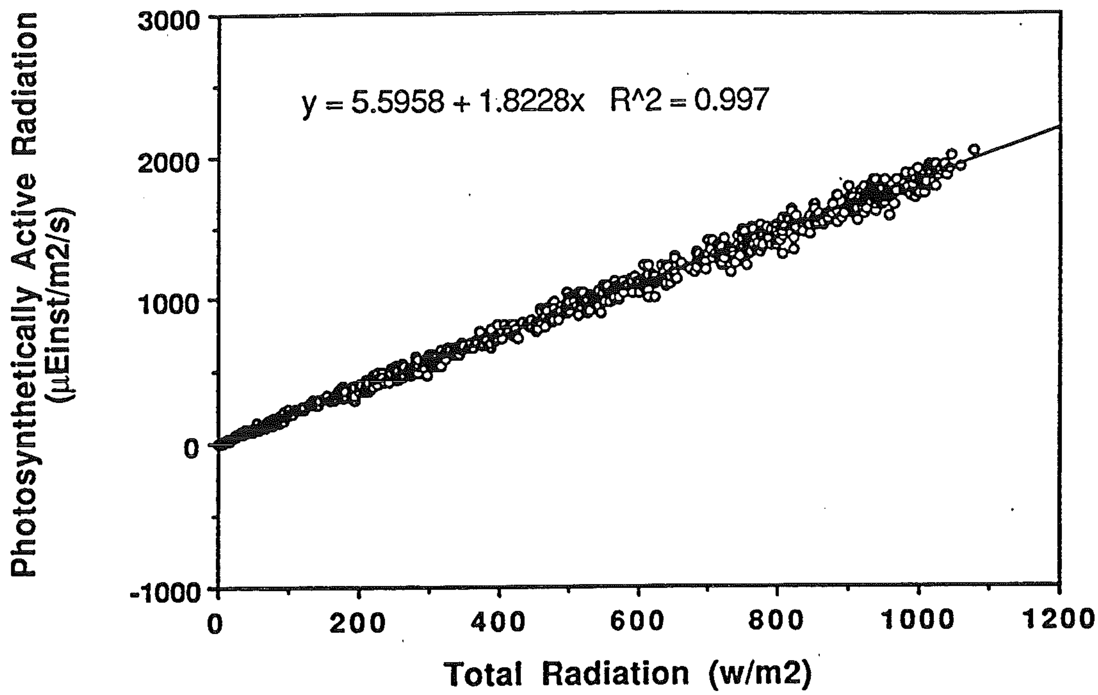

Figure 3. Relationship between photosynthetically active radiation, as measured with the quantum sensor, and total radiation, as measured with a photometer. Data correspond to a 74-day period starting on Julian Day 24.

calibration equations. Solar radiation measurements were collected over a period of approximately two and a half months (Figure 3). The purpose of these measurements was to establish a relationship between two values that could be used in models of temperature stratification when only quantum sensor measurements are available.

Deoxygenation and pond treatment were repeated three days after initiation of the experiment. Pond treatment consisted of the addition of formalin at a concentration of approximately 20 mg/L and copper sulfate at a concentration of approximately 3 mg/L.

Water-column oxygen consumption and production rates were monitored with daily light and dark bottle tests at approximately 0800 and 1300 hours. Rates of sediment oxygen demand were measured on the fourth day using sealed, 10-cm diameter PVC tubes incubated over a 24-hour period (Teichert-Coddington et al., unpublished).

Analysis of the data consisted of the estimation of rates of change in dissolved oxygen concentration at each of the depths monitored. The rates were then compared to the available information on rates of oxygen consumption and production by other processes in the ponds, and to estimates of reaeration rates made using existing expressions (Boyd and Teichert-Coddington 1992, and Banks and Herrera 1977):

$$REAER.B/TC = (0.017\ WS - 0.014)\ (DOS - DOP)\ (1.024^{T-20})\ \Delta\ /\ (D*9.07) \quad (1)$$

$$REAER.B/H = (0.03\ WS^{0.5} - 0.0132\ WS + 0.00157\ WS^2)\ (DOS - DOP)\ /\ D \quad (2)$$

Where:

REAER.B/TC	=	Rate of reaeration estimated with the expression proposed by Boyd and Teichert-Coddington (1992), $g/m^3/h$
REAER.B/H	=	Rate of reaeration estimated with the expression proposed by Banks and Herrera (1977), $g/m^3/h$
WS	=	Wind speed, m/h
DOS	=	Saturation dissolved oxygen concentration, g/m^3
DOP	=	Dissolved oxygen concentration in the pond, g/m^3
T	=	Pond temperature, °C
D	=	Pond depth, m
∂	=	ratio of oxygen transfer coefficient in pond water to that in clean water

Overall mass balances on dissolved oxygen in the ponds were considered rather than mass balances for each of the water column layers represented by the depths monitored:

$$\Delta DO\ /\ \Delta t = REAER + PROD - WCRESP + SEDRESP \quad (3)$$

Where:

$\Delta DO/\ \Delta t$	=	Rate of change in dissolved oxygen concentration over a time interval (g O2/m^2/h)
REAER	=	reaeration rate (g $O_2/m^2/h$)
PROD	=	Primary production rate of oxygen (g $O_2/m^2/h$)
WCRESP	=	Rate of oxygen consumption in the water column (g $O_2/m^2/h$)
SEDRESP	=	Rate of oxygen consumption in the sediments (g $O_2/m^2/h$)

The original proposal called for the use of Equation (3) for the estimation of REAER, and the establishment of relationships between REAER and measured wind velocities.

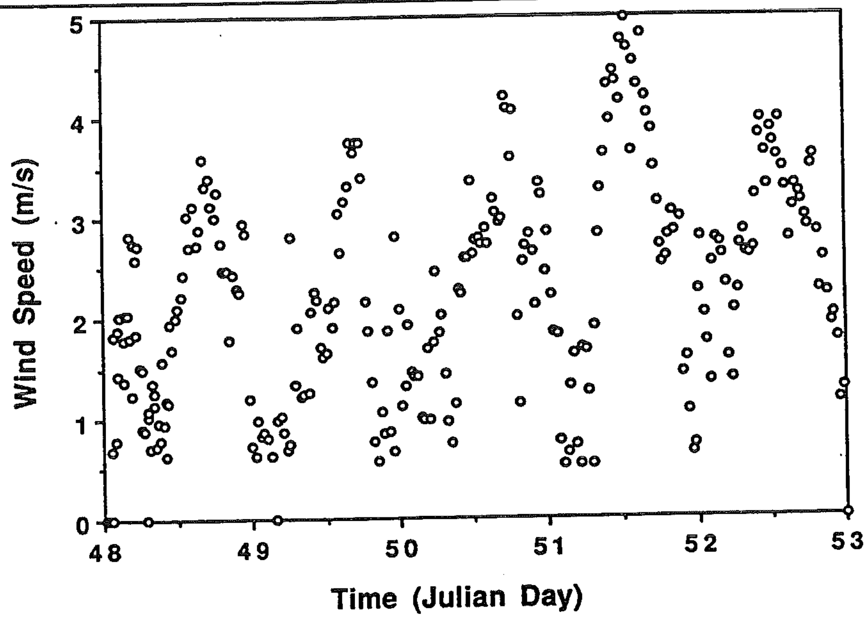

Figure 4. Wind velocities at three meters above the water level in the deep pond during the experiments. Minimum wind speeds detectable with the anemometers used was approximately 0.5 m/s. Wind speeds have been corrected using the equations shown in Figure 2.

Results and Discussion

Wind speeds were highly variable during the five days monitored, and were often under 1 m/s during the first three days of the test (Figure 4). There was a definite diurnal pattern, with higher wind speeds in the early afternoon and lower wind speeds around midnight. The pattern of wind speeds and the maximum values obtained were similar to those reported by Boyd and Teichert-Coddington (1992). However, wind speeds were generally lower than those reported by Boyd and Teichert-Coddington (1992), in which wind speeds below 1 m/s were infrequent.

The low wind speeds resulted in low rates of reaeration calculated using the expressions of Boyd and Teichert-Coddington (1992) and Banks and Herrera (1977) (Figure 5). In Figure 5, the instantaneous rates of reaeration are calculated using saturation concentrations and pond dissolved oxygen concentrations corresponding to the measurements collected closest to the surface in both ponds. Boyd and Teichert-Coddington (1992) indicated that reaeration rates for wind speeds less than 1 m/s were "small and not highly correlated with wind speed.". In addition, they recommended that for these low wind speeds, a reaeration rate of 0.008 g/m2/h be used (equivalent to approximately 0.009 and 0.018 mg/L/h for pond depths of 0.9 and 0.45 m, respectively and a pond dissolved oxygen concentration of 0 mg/L). In fact, the value of 0.008 g/m2/h corresponds to a wind speed of 1.29 m/s in the reaeration equation proposed by Boyd and Teichert-Coddington (1992). Although Boyd and Teichert-Coddington recommended that the Banks and Herrera (1977) expression be used for wind speeds higher than 4.5 m/s, the values shown in Figure 5 are based on either Equations 1 or 2 for the full range of wind speeds encountered.

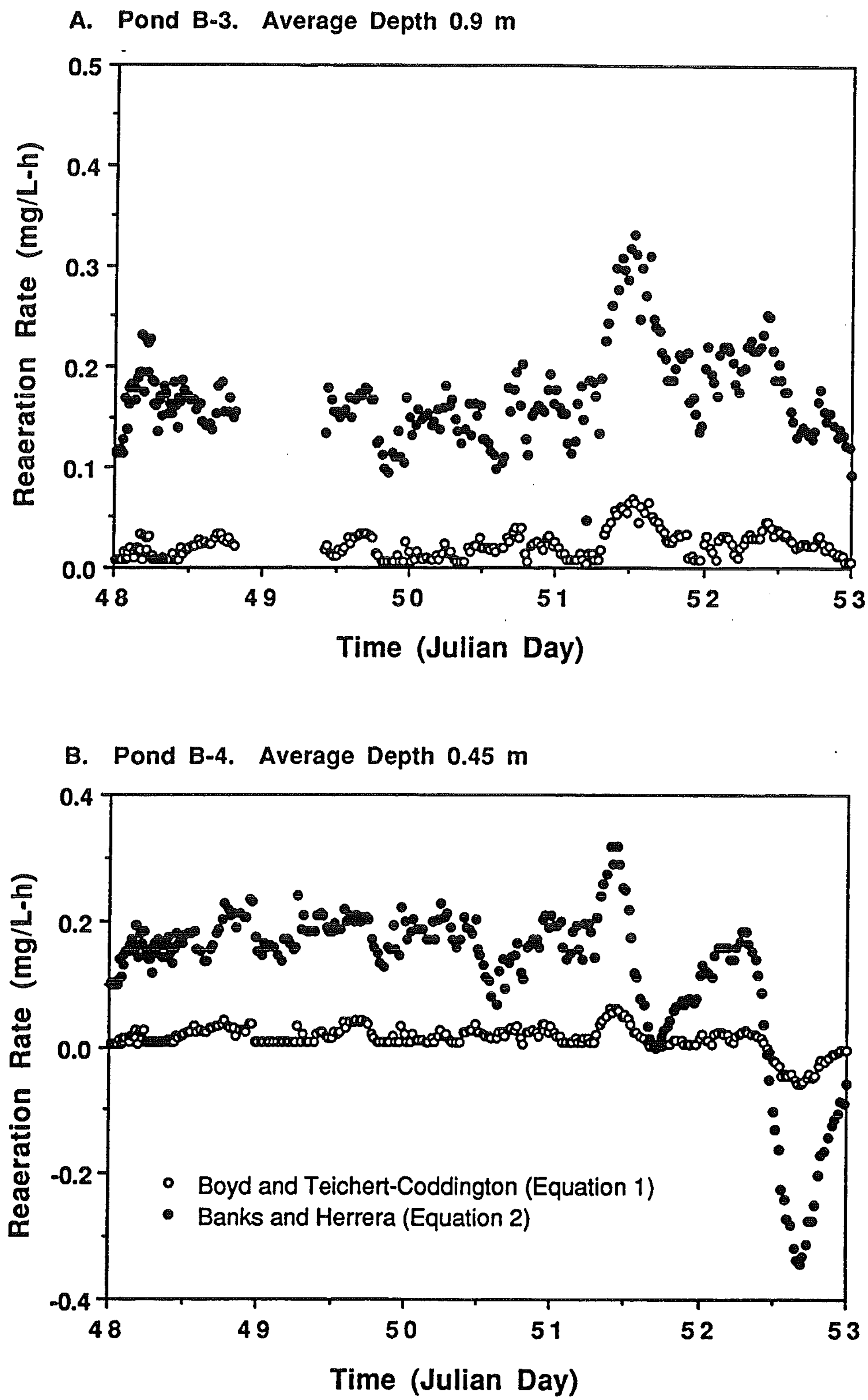

Figure 5. Instantaneous reaeration rates in Pond B-3 (A) and Pond B-4 (B), estimated using Equations 1 and 2.

Table 1. Rates of primary production and water column respiration obtained from Ponds B-3 and B-4 using light and dark bottles incubated 0.15 m below the water surface.

Date (Julian Day)	Pond	Net Production $mg\ L^{-1}\ h^{-1}$	Water Column Respiration $mg\ L^{-1}\ h^{-1}$	Gross Production $mg\ L^{-1}\ h^{-1}$	Sediment Respiration $mg\ L^{-1}\ h^{-1}$	Secchi Disk Depth m
48	B-3	-0.01	-0.07	0.06		0.27
49	B-3	-0.21	-0.27	0.06		0.30
50	B-3	-0.05	-0.08	0.03		0.34
51	B-3	-0.64	-0.70	0.06	0.03	0.29
52	B-3	-0.01	-0.13	0.12		0.35
48	B-4	-0.03	-0.07	0.04		0.27
49	B-4	-0.54	-0.60	0.06		0.30
50	B-4	0.09	-0.21	0.30		0.34
51	B-4	0.05	-0.72	0.77	0.08	0.32
52	B-4	1.35	-0.30	1.65		0.45

Rates of primary production and water column respiration were estimated from light-dark bottles and are shown in Table 1. The rate of sediment oxygen demand was measured for one 24-hour period (Julian Days 51 to 52) at five stations in each of the ponds. The average respiration rates obtained were 0.69 and 0.84 g $O_2/m^2/d$ for ponds B-3 and B-4, respectively. The corresponding ranges were 0.33 to 1.08 and 0.43 to 1.20 g $O_2/m^2/d$.

Even though light and dark bottle oxygen consumption/production rates and sediment oxygen demand were measured, the uncertainty in extrapolating these measurements for calculating instantaneous rates throughout a 24-hour period are great enough to be the subject of further research projects (e.g., Teichert-Coddington and Green 1992, Szyper et al., 1992).

Estimates of sediment oxygen demand obtained from the analysis of oxygen concentration changes in discrete volumes in ponds have been attempted by Teichert-Coddington et al. , unpublished and by Losordo (1988) and others. In all cases, these investigators found large fluctuations in sediment oxygen demand between different locations in the same pond. The variation was large enough to make use of a method based on discrete sampling impractical for pond monitoring and oxygen modeling (Losordo 1988). The alternative method of estimating sediment oxygen demand by use of whole pond measurements, however, can result in high overestimations due to the sensitivity of the calculations of estimates of water column respiration, and some researchers consider the method based on discrete samples to be more reliable.

Several factors contributed to making the data unsuitable for the estimation of reaeration rates as planned. The principal factor arose from our inability to control primary production and sediment and water column respiration rates. This resulted in rates of oxygen consumption and production that were difficult to estimate accurately and that had high enough magnitudes to have significant effects on the calculation of dissolved oxygen transferred through reaeration using Equation 3 (Table 1).

Comparison of the magnitude of the reaeration rates as estimated using Equations 1 and 2 (Figure 5) and the oxygen consumption and production rates from Table 1 confirm this point. Furthermore, in many cases the magnitude of the rates of gross production and of water column respiration exceeded the rates of reaeration estimated using Equations 1 and 2. All these factors contributed to the maintenance of low dissolved oxygen concentrations in the ponds (Figures 6 and 7), except toward the end of the tests, when concentrations increased as the water took on a green tint. In addition, the ponds exhibited distinct diurnal oxygen concentration cycles, with concentrations increasing during the day and decreasing at night, again confirming the relative importance of the oxygen consumption and production processes with respect to reaeration.

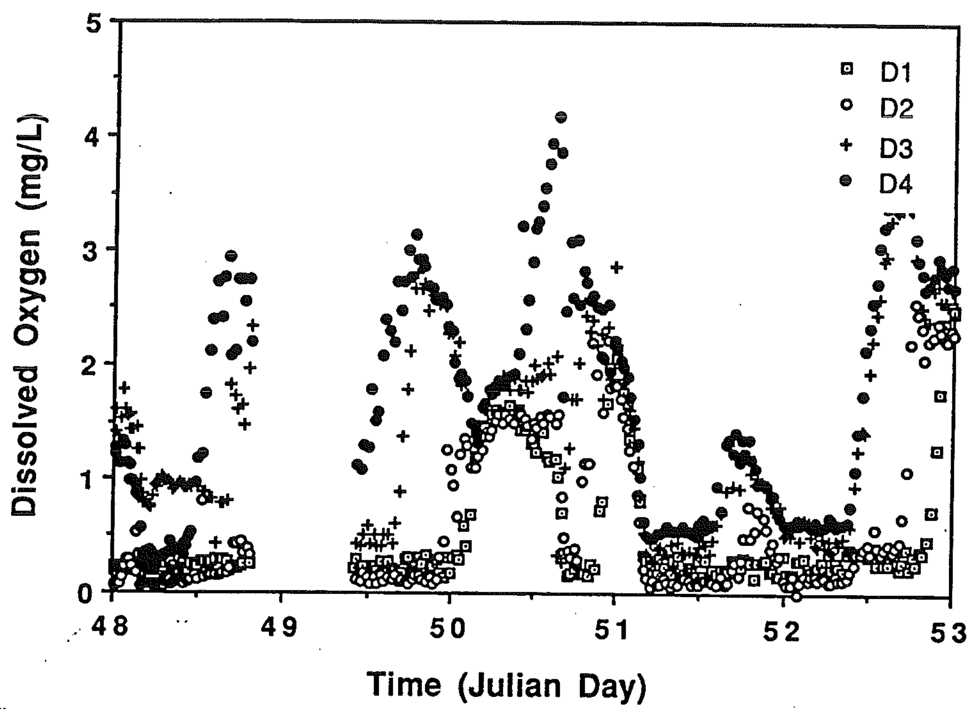

Figure 6. Dissolved oxygen concentrations at four depths in Pond B-3 (average pond depth 0.90 m) (D1 through D4 correspond to the depths as indicated in Figure 1 for Pond B-3).

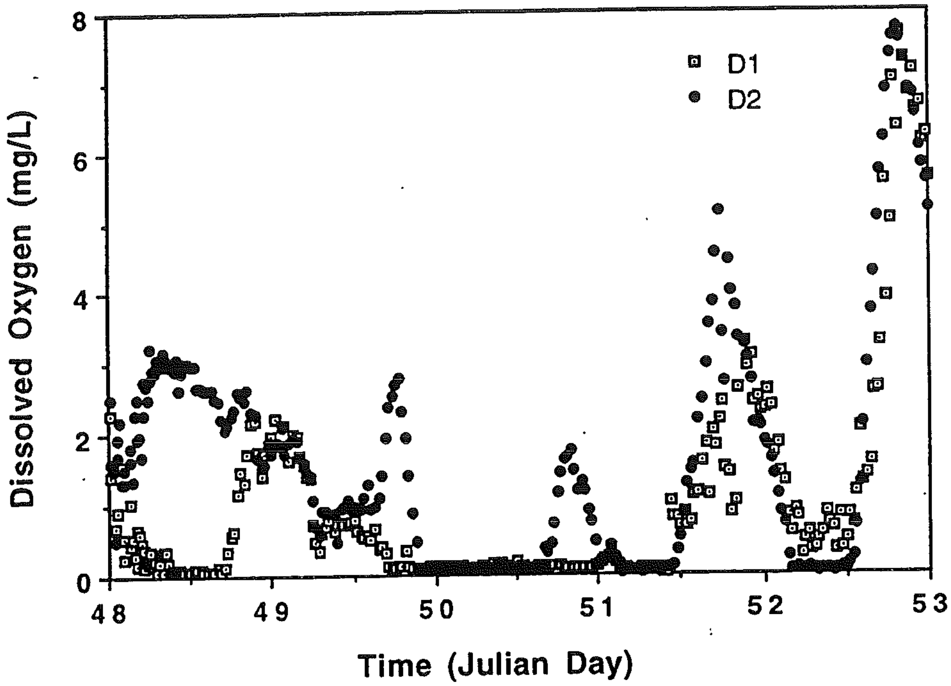

Figure 7. Dissolved oxygen concentrations at two depths in Pond B-4 (average pond depth 0.45 m) (D1 and D2 correspond to the depths as indicated in Figure 1 for Pond B-4).

Overall, the difficulty in making reliable, accurate estimates of oxygen production and consumption rates in the ponds rendered the data of little use for the original purpose of developing improved methods for estimating rates of reaeration as a function of wind speed.

Conclusions

The project was proposed to build on the work that had been carried out at the El Carao station by Boyd and Teichert-Coddington (1992) by providing important information for the continued development of models and analysis methods for temperature and diel oxygen measurements. The methodology proposed and followed is still considered to be valid as long as site conditions are suitable. Unfortunately the limitations encountered at the site during these experiments resulted in data that were not suitable for the detailed calculation of reaeration rates. The data, however, are being used in other DAST projects dealing with stratified ponds (e.g., Culberson and Piedrahita 1992).

The measurement of reaeration rates in aquaculture ponds and the establishment of simple methodologies for accurately estimating these rates based on wind speed measurements is still considered high priority. The estimates of reaeration rates obtained with Equations 1 and 2 (Figure 5) differ substantially, confirming the need for continued research in this area. It is hoped that there will be future opportunities for conducting experiments similar to those performed in this project under different circumstances. Lined ponds, a water supply with low concentrations of organic and inorganic particulates and correspondingly low oxygen production and demand rates, the presence of steady winds, and less-restrictive time constraints for installing and testing equipment and for repeating the experiments several times will be prerequisites for conducting the experiments successfully.

The project provided an opportunity for the UC Davis PI to visit a CRSP field site, allowing direct collaboration for the first time between field and DAST groups in a short-term project. The visit gave the UC Davis PI new insight into the conditions under which data are collected at the field sites, which will be helpful in the planning of future CRSP experiments.

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Factors Influencing Infestations of *Oreochromis niloticus* by Diplostomatid Cysts (Black Spot Disease)

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Introduction

Both wild and cultured tilapias and *Clarias* in Africa are subject to infestations of trematode metacercaria. These infestations result in the occurrence of very hard dark-colored cysts on fins, on the skin, and under the skin that are characteristic of black spot disease. The disease vector is the metacercaria of either *Neascus* or *Diplostomum*, of the family Diplostmatidae. Unlike other metacercarial cysts, these have a layer of melanin and sometimes of iridescent pigments (Paperna 1982).

The final host of diplostomatids responsible for black spot disease in Africa is thought to be birds, specifically piscivorous birds such as herons and sea gulls, as is the case on other continents. The primary hosts have been identified as snails of the genera *Bulinus* and *Melanoides*, although other snail species are possible carriers.

The health risk to people consuming infected fish is small, but fish with more than a few cysts on fins represent risk sufficient for producers to withhold them from the market. A filet with subcutaneous cysts is also of reduced quality because of the sandy texture.

Objectives

This study examined factors influencing the relative number of infested tilapia and cyst density per fish. Factors evaluated include snail population density, time since pond draining, and the developmental stage and sex of fish.

Materials and Methods

Twenty-two ponds at Rwasave Station were used. Thirteen of the ponds contained only *Oreochromis niloticus* at densities ranging from 100 to 700 fish per are, whereas nine polyculture ponds contained from 20 to 160 *Clarias gariepinus* per are, plus *O. niloticus* at densities ranging from 150 to 1400 fish per are. Random sub-samples of a monthly fish sample and of harvested fish were taken to examine for the presence of black spot disease. An index of infestation (IOI) was determined for each sample, based on the number of cysts found per 4 cm^2 of fish surface. The index equaled 0 for no cysts, 1 for 1-20 cysts, 2 for 21-40 cysts, and 3 for more than 40 cysts. Snail populations were estimated by dipnet scrapings along an 8-m length of shore on two sides of each pond.

Results

No differences in the infestation rates of male and female tilapia were found. Significant correlations were found between the number of snails present in the pond and indices of infestation greater than one ($p = 0.024$). Time since last draining also correlated positively with IOI ($p = 0.003$). Disease incidence increased with age for fish classed as fingerling, juvenile, or adult. This increase is contradictory to the observations of other workers reported by Paperna (1982), who noted that infestations of older fish were rarely observed. The early deaths of infected fish may have reduced the opportunity to observe older, infected fish in those studies.

Three snail genera are common at Rwasave Station: *Limnaca*, *Biomphilaria*, and *Bulinus*. All ponds containing *Clarias* were devoid of snails. However, some infested tilapia were observed in these ponds, probably because they were infected as fingerlings before stocking. As noted above, reduced snail density was correlated with reduced infestation. Unfortunately, infestation rates could not be correlated to the presence or absence of *Clarias* because there were too few *Clarias* polyculture ponds with the same production duration as the all-tilapia ponds.

The ponds showing the highest infestation rate were those "in production" for more than nine months. Ponds in this category are often used for holding small female tilapia at high densities, or are ponds that have been neglected.

Anticipated Benefits

The incidence of black spot disease in Rwanda can be reduced by limiting snail density and avoiding continuous pond use for nine months or longer without draining. Fingerling production centers and research centers are most likely to benefit from this research, as they would have ponds corresponding to the high-risk category. Recommendations for reducing access of some piscivorous birds to ponds are being developed at Rwasave Station.

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Effect of Temperature on Growth of *Oreochromis niloticus*

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Introduction

Tilapia (*Oreochromis*) species are among the most widely cultured fish in the world. Ideal for tropical areas, tilapia are hardy, omnivorous, fast-growing, and easily spawned. However, many tropical areas include highland regions where average water temperatures are thought to remain too low for adequate growth of tilapia. Rwanda is a high altitude equatorial African country in which tilapia culture is practiced in ponds at elevations of 1300 to 2500 m. Despite the predicted limitations on growth, some Rwandan fish farmers have achieved tilapia yields of over 2500 kg/ha/yr. This production, together with the relative culture advantages of tilapia when compared to other species, has created interest in the role of water temperature on tilapia growth.

Temperature is a critical aspect of the pond environment, affecting survival as well as growth, rate of development, activity, and reproduction in tilapia (Balarin and Hatton 1979). The growth rates of most tilapia decrease below a temperature range of 17.2-19.6°C (Bishai 1965). The upper temperature range is 38-40°C. For *O. niloticus*, the upper lethal limit appears to be 41°C (Denzer 1967).

The effects of temperature on digestion and evacuation rate have been examined in other fishes, including brown trout, *Salmo trutta* (Elliott 1972), channel catfish, *Ictalurus punctatus* (Shrable et al. 1969), and rainbow trout, *Oncorhynchus mykiss* (Brocksen and Bugge 1974). Studies using tilapia have not been extensive. Soderberg (1990) determined the effect of temperature on the growth of blue tilapia (*Tilapia aureus*). Some work has been done on the ability of the fish to acclimate to and withstand low water temperatures (Chervinshi and Lahau 1976). Caulton (1975) observed the diurnal movement and temperature preferences of *T. rendali* in lakes. *T. rendalli* appeared to prefer warm waters during the day and then to migrate to cooler waters at night. The present study will evaluate the effect of temperature on the appetite and growth of tilapia (*O. niloticus*) in laboratory conditions.

Materials and Methods

Four temperature/feeding studies were conducted in 110-liter aquaria. The aquaria had constant aeration and were flushed twice daily to remove wastes. Water for the experiment was city water that was passed through a chlorine filter. Temperatures were regulated with heaters or a water chiller (Frigid Unit Model D1-33). The photo period was 14:10 light/dark. Oxygen, ammonia, pH, and chlorine were monitored in each study.

Data were analyzed by analysis of variance and Duncan's multiple range test to determine differences among means.

Experiment 1
Oreochromis niloticus averaging 5.1 g in weight were stocked into the aquaria at a density of 20 fish per tank. The treatments consisted of four constant temperatures– 16°C, 20°C, 24°C, and 28°C. Each treatment was replicated five times.

The fish were fed to satiation twice each day. The feed used was a commercial catfish diet (32% protein), ground and repelleted to an appropriate size for the fish. Daily feed consumption for the fish in each aquarium was measured and the fish were weighed every two weeks.

Experiment 2
Juvenile tilapia (*O. niloticus*) with an average weight of 10.6 g were stocked into the aquaria at a density of 20 fish per tank. Treatments consisted of two cyclic temperature regimes (16-24°C, with a daily average of 20°C, and 20-28°C, with a daily average of 24°C) with five replicates per treatment. Fish were acclimated to experimental conditions over a two-week period.

The fish were fed to satiation once daily when the temperature reached its maximum. The feed used was a commercial catfish diet (32% protein) ground and repelleted to an appropriate size for the fish. Daily feed consumption for the fish in each aquarium was measured and the fish were weighed every two weeks.

Experiment 3
A third temperature/feeding trial was initiated on 27 January 1992 and completed on 23 March 1992 to simultaneously compare two of the static temperature regimes with the cyclic regimes. Juvenile tilapia (*O. niloticus*) weighing an average of 15.7 g were stocked into the aquaria at densities of 20 fish per tank. There were four treatments—two cyclic temperature regimes (16-24°C, with an average temperature of 20°C, and 20-28°C with a daily average of 24°C) and two static temperature treatments (20°C and 24°C)—with five replicates per treatment. The fish were fed to satiation when the temperature reached its maximum. The duration of this trial was 54 days.

Experiment 4
A fourth temperature/feeding trial was initiated on 2 April 1992 and completed 27 May 1992 to analyze the effect of feeding at different temperature points during the diurnal temperature fluctuation cycles. Juvenile tilapia (*O. niloticus*) averaging 19.3 g were stocked into the aquaria at densities of 15 fish per tank. The reduction in numbers of fish per tank compared to the previous studies was due to ammonia levels in the previous studies that were higher than desired.

This study consisted of four treatments. There were five replicates per treatment in this study, which lasted 56 days.

(1) Cyclic temperature (20-28°C, with fish fed when water temperature was 24°C).
(2) Cyclic temperature (20-28°C, with fish fed when water temperature was 28°C).
(3) Static temperature 24°C, with fish fed at the same time of day as those in Treatment #1.
(4) Static temperature 24°C, with fish fed at the same time of day as those in Treatment #2.

Results and Discussion

Experiment 1
The weight gains of fish grown at the different temperatures were significantly different. Fish grown at the highest temperature had the best growth ($P \leq 0.05$). The average weight gains of fish at the various temperatures per sample period are illustrated in Figure 1.

Of the water quality parameters measured, ammonia was the most difficult to control, and ranged as high as 0.5 mg/L. Because of this problem, the decision was made to flush the tanks twice a day and thereby maintain an ammonia level within the 0.0 - 0.3 mg/L range. The dissolved oxygen concentration ranged from 6 to 10 ppm, pH ranged from 6.5 to 8.0, and chlorine concentrations ranged from 0.0 to 0.1 ppm.

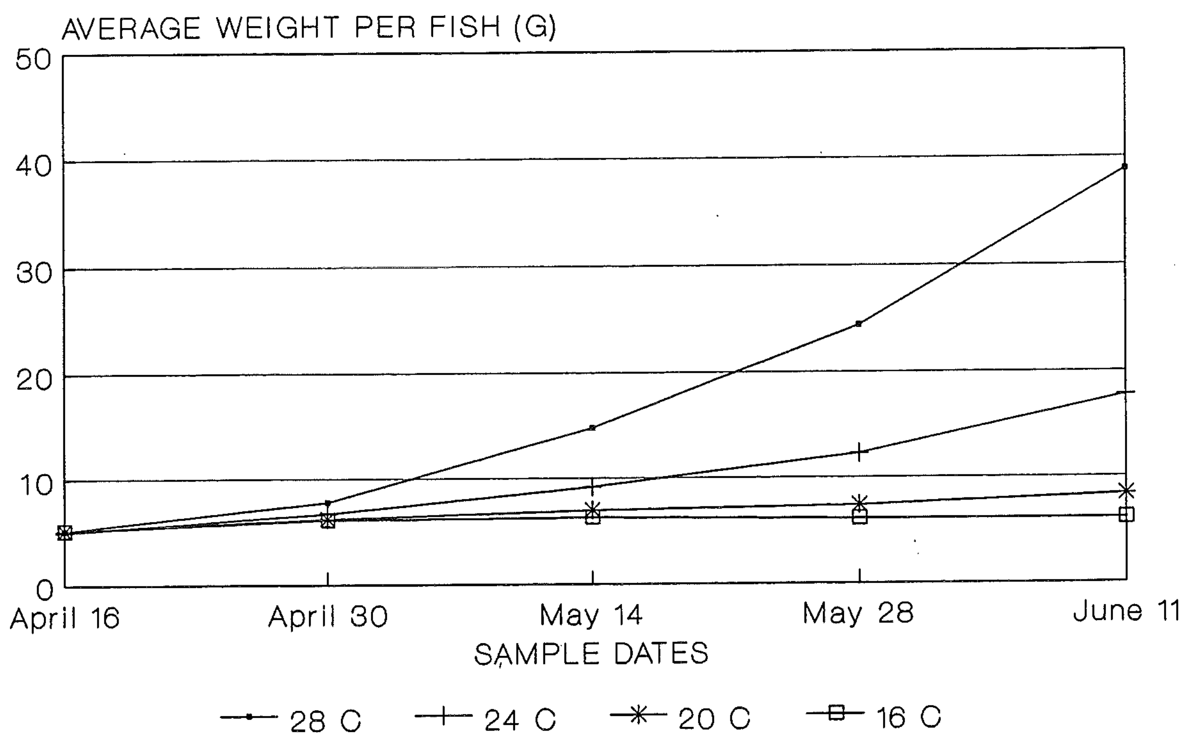

Figure 1. Growth of tilapia at four static temperatures: 16°C, 20°C, 24°C and 28°C

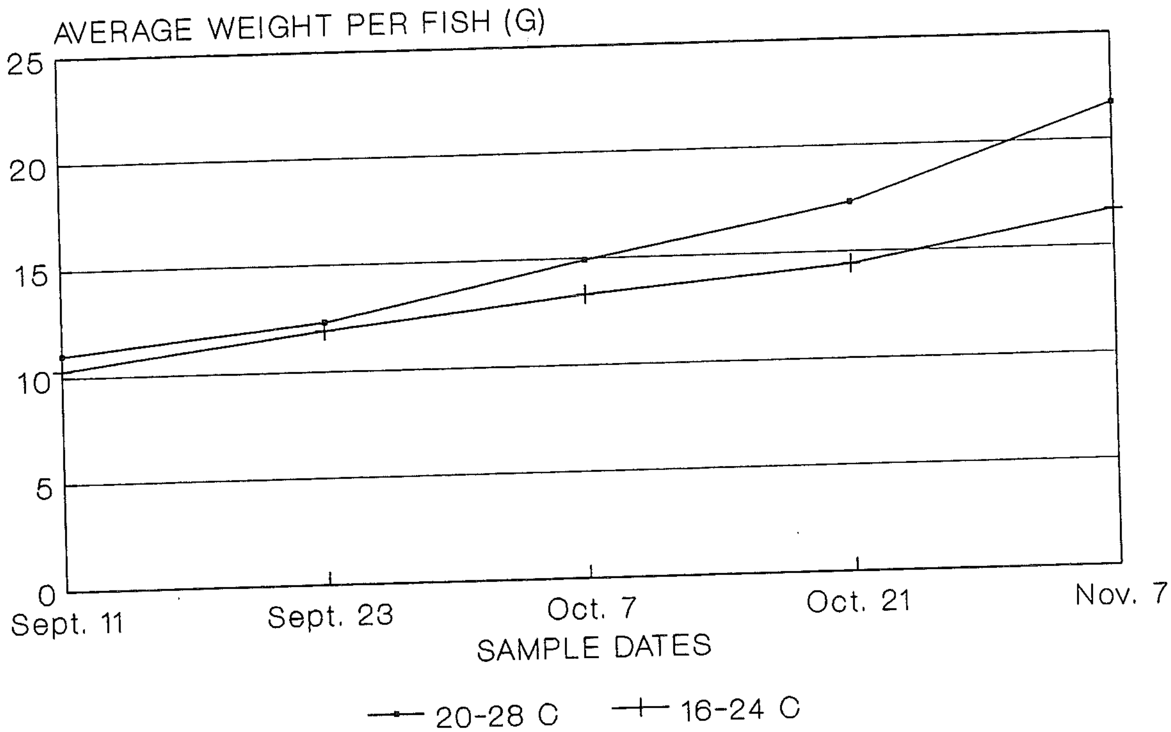

Figure 2. Growth of tilapia maintained in two cyclic temperature regimes: 20-28°C and 16-24°C

The results of this experiment were as anticipated; growth increased with increasing temperature. Data from this study were used as baseline data for Experiment 2.

Experiment 2
The growth of fish in the 20-28°C temperature regime was significantly greater ($P \leq .05$) than the growth of fish in the 16-24°C regime (Figure 2). As expected, the generally higher temperature levels resulted in greater weight gain. The low temperature regime appeared to improve growth compared to the static 16°C and 20°C temperature treatments. However, fish in the high temperature regime had poorer growth than those in the static 24°C and 28°C treatments.

Experiment 3
This study compared two of the static temperatures to the cyclic regimes simultaneously. The final average fish weight for each treatment was 34.5 g for the static 24°C, 28.1 g for the cyclic 20-28°C, 23.8 g for the static 20°C, and 20.8 g for the cyclic 16-24°C. These results along with the results from the first two studies indicate that the fish grew better in a static temperature environment than in a cyclic temperature environment (Figure 3). This

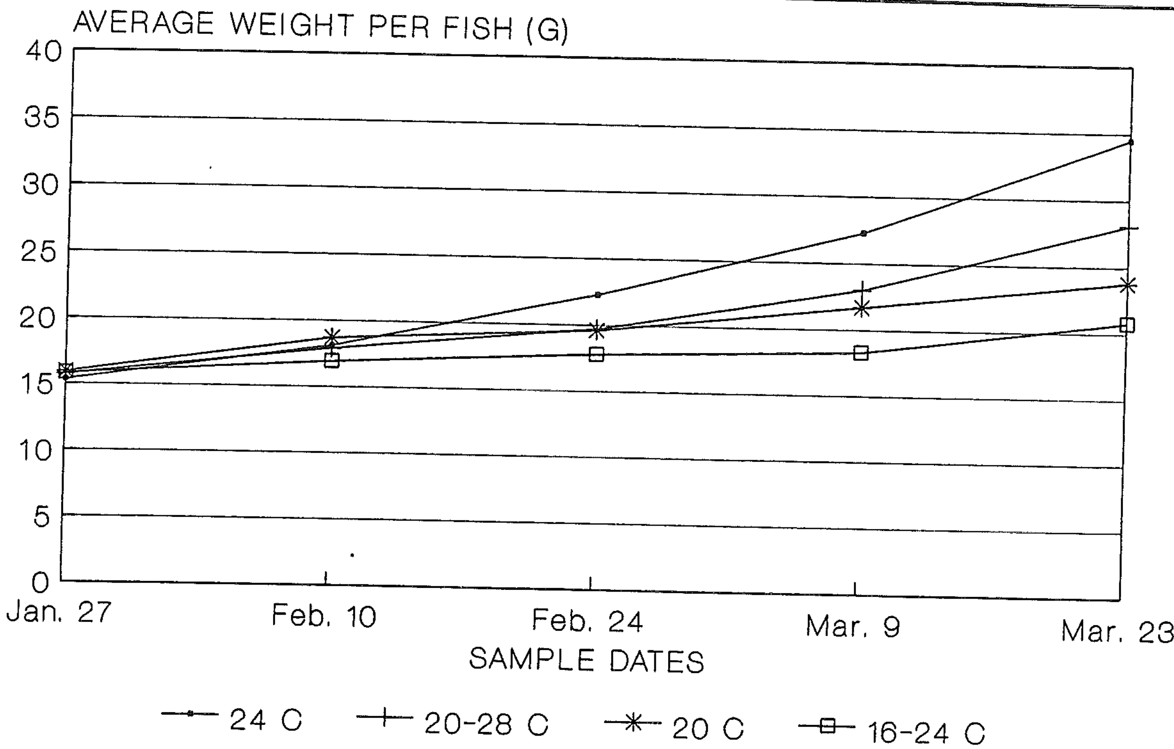

Figure 3. Comparison of tilapia grown at two static temperatures (24°C, 20°C) and two cyclic temperature regimes (20-28°C, 16-24°C)

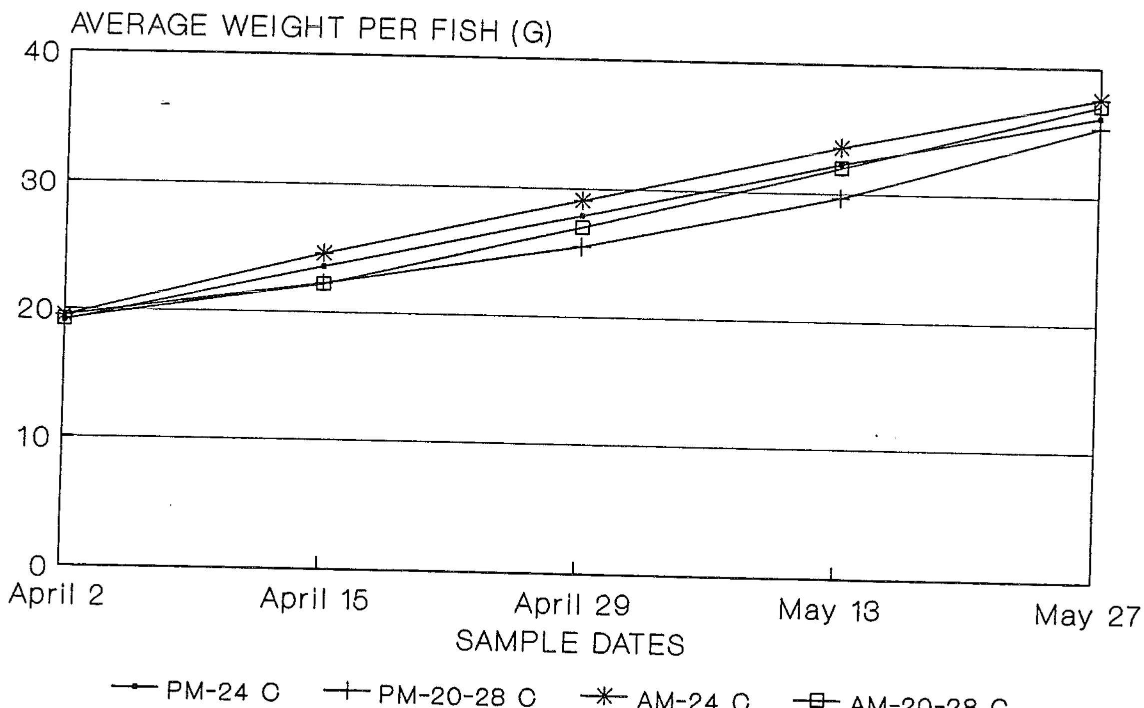

Figure 4. Comparison of tilapia fed at the high temperature of the cycle or at the mean temperature of the cycle (20-28°C fed at the 28°C, 20-28°C fed at 24°C) with a time of day feeding control (24°C)

finding contradicts the findings of Yuanming et al. (1989), in which *O. niloticus* grew better under conditions of fluctuating temperatures. The two static temperatures they used were 28°C and 30°C, and the two fluctuating temperatures were 28 ± 4°C and 30 ± 4°C.

Experiment 4
The two treatments fed in the morning (cyclic treatment fed when water temperature was 24°C, static treatment fed at the same time) had a slightly higher weight gain than the two treatments fed in the evening (cyclic treatment fed when water temperature was 28°C, second static treatment fed at the same time) (Figure 4). There is apparently no difference in weight gain when feeding at 24°C or 28°C in a cyclic temperature regime (20°-28°C).

The temperature regimes used in these experiments mirror the temperature variations that occur in Rwanda (Hanson et al. 1988).

Table 1. Average initial weight, final weight, and final weight gain per fish for the tilapia in experiment two.

Treatment	Initial Weight (g)	Final Weight (g)	Weight Gain (g)
20 - 28°C	10.96	21.68	10.72
16 - 24°C	10.32	16.62	6.30

Table 2. Average initial weights per fish, final weights, and final weight gains per fish for the tilapia in experiment three.

Treatments	Initial Weights (g)	Final Weights (g)	Weight Gain (g)
24°C	15.3	34.5	19.2
20-28°C	15.7	25.9	12.4
20°C	15.9	23.8	8.0
16-24°C	15.8	20.8	5.1

Table 3. Average initial weights per fish, final weights, and final weight gains per fish for the tilapia in experiment four.

Treatments	Initial Weights (g)	Final Weights (g)	Weight Gain (g)
24*	19.1	36.2	17.1
20-28 (*28)	19.5	35.4	15.9
24**	19.5	37.6	18.1
20-28 (**24)	19.2	37.1	17.9

* Fed in Evening.
** Fed in Morning.

Anticipated Benefits

The data from these studies will provide information about how tilapia respond to various temperatures and perhaps give insight into management practices.

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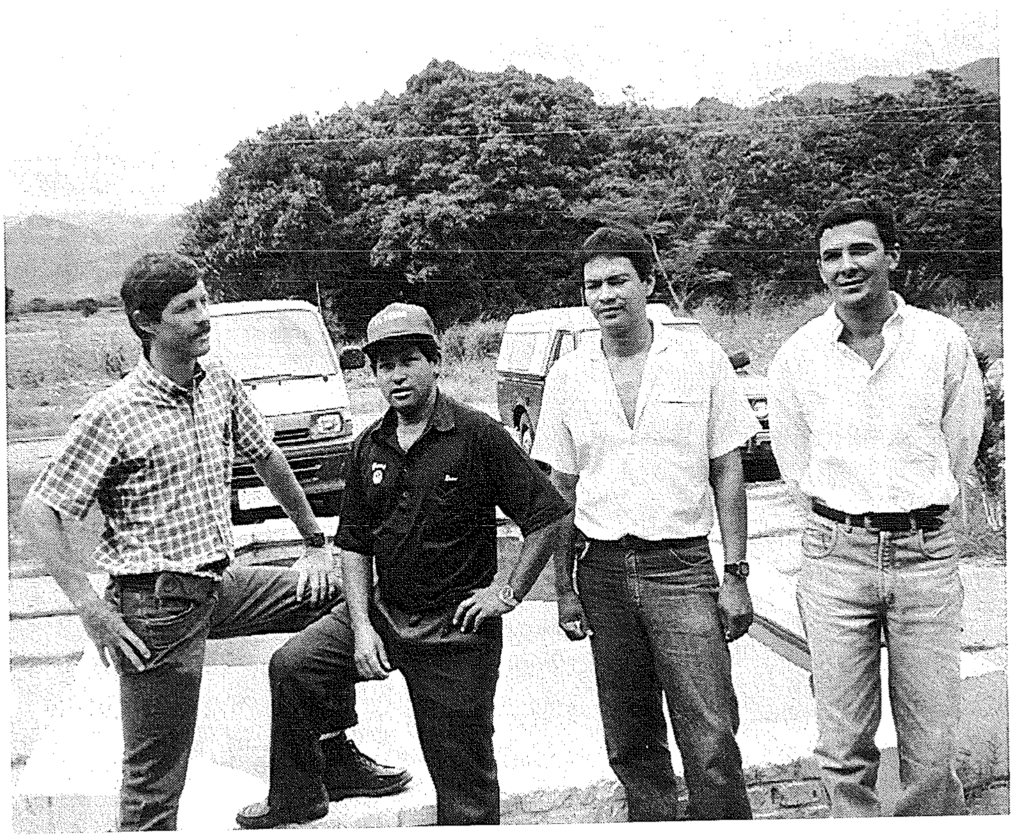

Influence of Temperature and Treatment Duration on Production of All-Male *Oreochromis niloticus* Fry

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Introduction

Sex reversal of tilapia (*Oreochromis niloticus*) fry is usually done at temperatures ranging from 26 to 30°C. However, achieving these temperatures in cooler climates may be costly. Other researchers have attempted, with somewhat discouraging results, to sex-reverse *O. niloticus* fry at temperatures similar to those found in Rwanda (about 20°C), and have reported high rates of mortality (Guerrero 1975). This study investigates how temperature and treatment duration affect sex reversal.

Objectives

This experiment had three objectives:

1. To compare sex-reversal success at ambient (20°C) and elevated temperatures (heated to 27°C),
2. To determine the best duration of hormone treatment, and
3. To compare the sex ratio of non-treated fry raised at ambient temperatures with that of non-treated fry raised at elevated temperatures.

Materials and Methods

Eggs and fry were taken from mouths of *O. niloticus* females and incubated until the yolk sacs were absorbed. For each of four treatments, three 50-liter aquaria were each stocked with 600 fry and exposed to the following treatments:

1. "MTA" signifies fry that received hormone-treated feed (60 mg methyltestosterone per kg feed) at ambient temperature (20±2°C);
2. "MTC" signifies fry that received hormone-treated feed (60 mg methyltestosterone per kg feed) at elevated temperature (27±2°C);
3. "TOA" signifies fry that received feed without hormone at ambient temperature;
4. "TOC" signifies fry that received feed without hormone at elevated temperature.

Feed consisted of 50% ground chicken feed and 50% fish meal, with vitamin C and tetracycline supplements. The hormone α-methyl-testosterone was added to the feed for the "MTA" and "MTC" treatments at 60 mg/kg feed.

Aquarium heaters (300 watts) were used to maintain temperature in the MTC and TOC treatments.

At days 20, 30, and 40 of the experiment, one-third of the fry were removed from each aquarium and grown out in cages or other containers for about 70 additional days until they attained a size of 2 grams each. These groups of fry became treatments MTA20, MTA30, MTA40, MTC20, and so forth. All fish in grow-out cages received the same feed as the TO treatments, but without medication, until an outbreak of *Flexibacter columnaris* forced a continuation of the medication for the remainder of the grow-out period. Sex determination was by aceto-carbamine squash technique (Guerrero and Shelton 1974) of about 20 fish from each of the three replicates per treatment (due to escapement, some cages contained fewer than 20 fish).

Results

Sex Reversal

The percentage of males was generally greater with greater treatment duration. However, elevated temperature (MTC) was shown to result in a greater percentage of males than ambient temperature (MTA) only at the 30-day duration. The percentage of males resulting from treatment MTC40 was unexpectedly low (Table 1). The small size of the fish made sexing difficult but visual examination after fish grew larger indicated that the result was reliable.

Chi-square comparisons indicate that all hormone treatments except the 20-day hormone treatment at 27°C (MTC20) gave a higher percentage of males than the controls (Table 2). Temperature effect results are conflicting but it can be concluded that at the higher temperature the 30-day hormone treatment is adequate for successful sex reversal. This result is consistent with the existing literature. However at 20°C, results indicate that it is probably better to treat for 40 days (Tables 1 and 2).

Fry Growth Rates

At ambient temperature, fish increased in total length by 0.27 mm per day, whereas at the elevated temperature fish grew an average of 0.68 mm per day. The regression of total length vs cumulative degree-days (°C), with 15°C used as the zero growth point, resulted in the following equation:

$$Y = 8.12 + 0.053X \quad (r^2 = 83.5\%)$$

where : X = degree-days, and
Y = total length in mm.

Mortality in the elevated temperature treatment was 1.5% over 30 days, whereas it was 8.7% in the ambient temperature treatment.

This experiment demonstrated that sex-reversal of *O. niloticus* at temperatures lower than ideal is possible. The longer duration of treatment required at lower temperatures may be preferable to the higher costs of heating water in cooler climates.

Table 1. Results of sexing by the aceto-carbamine technique. Identical letters following "Percent males" indicate those groups not significantly different by chi-square test. "MTA20" indicates the MTA (ambient temperature) treatment group sampled after 20 days of treatment.

Treatment	Number of Males	Number of Females	Percent Males
MTA20	40	18	69 b[1]
MTA30	47	11	81 bc
MTA40	52	3	95 cd
TOA20	23	26	47 a
TOA30	29	29	50 a
TOA40	28	25	53 a
MTC20	33	21	61 ab
MTC30	55	2	96 d
MTC40	47	12	80 b
TOC20	25	32	44 a
TOC30	29	21	58 a
TOC40	26	25	51 a

[1] Numbers followed by the same letter are not significantly different.

Table 2. Chi-square comparison summary regarding percentage of males. The 'a' refers to the possibility of falsely assuming a difference in treatment effects.

Hormone Effects

MTA20>TOA20 a = 3.2 %	MTC20=TOC20
MTA30>TOA30 a = 0.1 %	MTC30>TOC30 a = 0.00%
MTA40>TOA40 a = 0.00%	MTC40>TOC40 a = 0.31%

Temperature Effects

MTA20=MTC20 a > 5.0 %
MTA30<MTC30 a = 1.92%
MTA40>MTC40 a = 3.61%

Treatment Duration Effects

MTA20=MTA30 a = 19.51%	MTC20<MTC30 a = 0.00%
MTA30=MTA40 a = 5.52%	MTC30>MTC40 a = 1.21%
MTA40>MTA20 a = 0.13%	MTC20<MTC40 a = 4.73%

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Production of Nile Tilapia (*Oreochromis niloticus*) in Aquatic Microcosms Fertilized With Rabbit Excreta

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Introduction

Conducting statistically valid experiments in full-scale, environmentally variable ponds requires numerous, relatively large ponds and comparatively large inputs of capital and of personnel effort. The use of model ponds or microcosms (Warren and Davis 1971) may be a useful alternative that could accelerate aquacultural research. Simplicity within spatial limits and ease of control, manipulation, and measurement are advantages of these systems (Franco 1991). Reduced ecological complexity, problems of scale, and behavioral constraints of model systems may lead to misinterpretation, however.

Objectives

The objectives of this study were to explore the use of microcosms as a tool for studying the dynamics of tropical aquaculture ponds and to examine the potential use of rabbit excreta as a pond fertilizer suitable for integrated farming systems.

Materials and Methods

Twelve insulated fiberglass tanks, each 1.12 m long, 1.25 m wide, and 0.48 m deep, were used to simulate earthen ponds. Water volume used was 0.65 m^3. Light intensity was 100 watts/s/m^2 at the water surface for a 12-hour light period per day. Tanks were enclosed in a well-insulated building at the Oak Creek Laboratory of Biology at Oregon State University, Corvallis, Oregon. Water temperature was maintained with a 250-watt submersible heater in each tank. Wind was simulated with a scroll-case fan which created turbulence and enhanced gas exchange at the surface. A layer of soil about 5 cm thick mixed with rabbit manure was supplied to each tank initially to establish microbial activity.

Seven hand-sexed Nile tilapia (*Oreochromis niloticus*) juveniles were stocked per tank, and microcosm performance was observed over a 90-day period. Three rabbit excreta treatments were tested. The first two corresponded to loading rates of 50 and 75 kg/ha/d, and the third was a continuously adjusted rate determined by PONDCLASS guidelines (Lannan, unpublished). The fertilizer treatments were compared to a control treatment where fish were fed a prepared ration. Water quality variables and fish growth and reproduction were monitored. The nitrogen and phosphorous contents of rabbit excreta were measured.

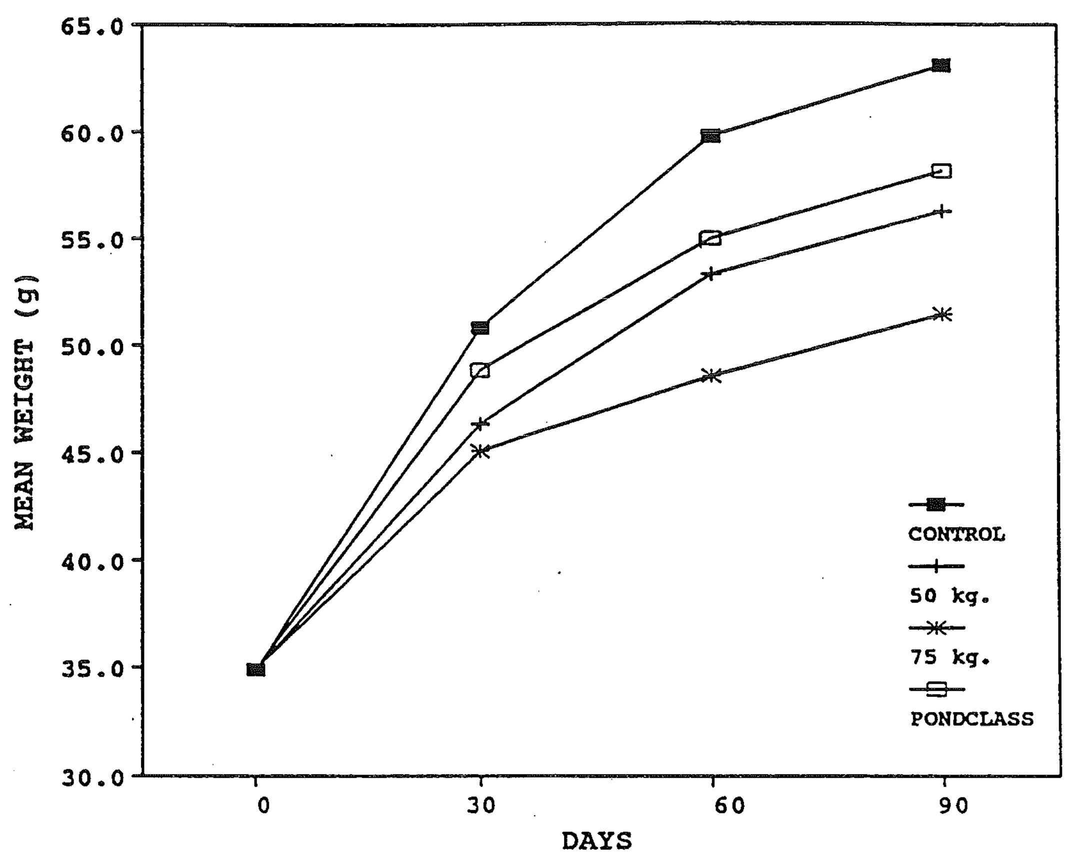

Figure 1. Mean monthly body weight of Nile tilapia (Oreochromis niloticus), both sexes included.

Results

Statistical differences were detected between control and fertilized treatment effects on dissolved oxygen concentration, net primary productivity, total alkalinity, total ammonia, and orthophosphate concentration. Primary productivity was influenced more by light penetration than by nutrient limitation. Rabbit excreta over-loading was observed in the 75 kg/ha/d treatment. Fish growth was greatest in the control (fed directly) treatment, and in the PONDCLASS (adjusted input rate) treatment (Figure 1). Low growth in the 50 and 75 kg/ha/d treatments was apparently due to low dissolved oxygen and high total ammonia concentrations present. Extrapolated fish production corresponded to 6205, 4563, 3686 and 4869 kg/ha/yr for control, 50 kg/ha/d, 75 kg/ha/d, and PONDCLASS treatments, respectively.

The nitrogen content of rabbit excreta varied according to rabbit size and the presence or absence of urine, water wastes, and food droppings. Urine plus water wastes provided 28% of the total nitrogen content in excreta; food droppings provided 12%.

Anticipated Benefits

Extrapolated fish production levels indicated that fish performance in microcosms was reasonably similar to that in earthen ponds. Treatment effects on water quality and system performance were significantly discernable, suggesting that such model systems may be useful in examining pond dynamics. Use of these microcosms may allow some research in tropical aquaculture of tilapia to be conducted in the laboratory and in non-tropical environments of the US.

Rabbit fertilizer was determined to be a potentially rich source of nutrients for use in fish ponds. Rabbit urine should be included in such inputs as it contributes a large fraction of the nitrogen present in rabbit wastes. The use of small mammals such as rabbits may be particularly appropriate for small subsistence farms where integrated production and nutrient recycling are utilized.

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Socioeconomic Factors Affecting The Transfer and Sustainability of Aquaculture Technology in Rwanda

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Objectives

The objective of this study was to evaluate the socioeconomic factors that affect transfer and sustainability of aquaculture technology in Rwanda. Specific objectives include:

1. Establish baseline data about farmers operating Rwandan fish ponds.
2. Profile circumstances and motivations underlying decisions of individuals who have discontinued fish culture in Rwanda.
3. Describe practices and technical proficiency of fish farmers having no regular contact with extension.
4. Obtain basic production and farming system information from Rwandans.

Methods and Materials

Interviews were conducted with 121 active farmers including pond group members and individual operators in early 1992. Interviews were conducted with 23 dropouts about their reasons for quitting fish culture. Interviews were conducted in the native Kinyarwandan language using a standardized set of questions and response frameworks. Separate interview schedules were developed for each of the three categories of respondents. The analysis uses a four-category typology to summarize the data; men in groups; women in groups; individual owners of both sexes; and dropouts who quit fish farming.

Results

Group pond operators were nearly equally divided between males and females but most private pond operators were men. Because men are favored by local authorities, local pond groups provide a means for increasing farm activity for women. Because men are favored by local authorities, local pond groups provide a means for increasing farm activity for women. This pattern reflects the traditional land tenure system that inhibits women's access to land. Only 15 percent of the women group farmers were household heads while more than 90 percent of the other farmers headed households. This is a major compositional difference in the sample.

More than half the active farmers visited their ponds on a daily basis. Another third visited several times a week. When fish farmers visited their ponds, they tended to spend an hour or less each time. More women in groups reported stays of an hour or more, but more men in groups had the longest stays.

Women reported having sufficient feed for their fish most of the time. Direct access to garden waste may facilitate feeding practices. Men in groups and private pond operators tend to experience more problems obtaining sufficient feed. Almost half the active farmers fed their fish every day or nearly every day. Ninety percent of the women in groups fed their fish several times a week or more often. The three categories of active farmers each fed a similar pattern of substances to their fish. Leaves and manure were the most commonly applied pond inputs. Women in groups tended to supply sorghum beer waste and slaughter waste more often than other farmers. Private farmers tended to use less compost, but instead employed a more diverse set of substances as pond inputs.

About a fourth of the sample had trouble finding fingerlings. Group women were somewhat less likely to encounter this problem. Water supply problems were not frequently encountered by respondents. Private farmers experienced more difficulties keeping their pond full (31 percent).

About 71 percent of active women group farmers tended to use one large harvest. In contrast, male groups and private farmers more frequently employed multiple partial harvests. Men seem to have used the pond more often for meals or limited cash sales than women. Male group farmers had the largest harvested pond area, but women harvested more fish by weight.

Private ponds tended to be smaller than group ponds. With respect to marketing practices, fewer private farmers sold fish (77 percent), than did group men (91 percent). About half the group farmers of both sexes sold most of their last harvest for cash. Again private farmers were least likely to sell any fish. Those that did sold lesser proportions than the others. Group women farmers tended to get the best price for their fish. None reported receiving less than 100 RWF per kilogram. Almost a third of the men said they obtained more than 140 RWF per kilogram. About a quarter of the private farmers received less than 100 RWF per kilogram.

Few sold any of their crops to middlemen. Only a few more said they sold some to restaurants or bars. No women reported any sales to either outlet. Almost a third of the men in groups sold fish in the market. Fewer women and private farmers sold fish in the market as home consumption, and informal sales seemed to exhaust their supply. Nearly everyone (85 percent) sold fish to other people, primarily neighbors. From extension reports it is known that most fish sales take place on the pond bank to friends and neighbors. Word-of-mouth precedes an impending harvest. Willing buyers then purchase the fish at known prices soon after they are seined.

Almost half (48 percent) of the male group farmers reported problems selling their fish. This category tended to expect and receive the highest price for their fish, explaining some part of their slow sales. A third of the women and private farmers reported problems. About 55 percent of the group men reported difficulty selling at the desired price.

Women were more satisfied with the price they received for their fish. Only a third of the male group members were satisfied. Men reported more problems selling fish at a desired price, women reported the least. About 81 percent of the group women said they could sell their fish for less if they needed to do so. More men said that there are many people who don't like to eat fish. Three-quarters thought that a larger fish would be easier to sell. The major set of problems farmers associated with fish culture related to the marketing of the product. About half the respondents said they had problems getting the right price for their fish. Most said they could move the fish for a lower price. Only 63 percent of private farmers felt this way, compared to 89 percent of the group women growing fish. More men in pond groups thought that there were many people who did not like to eat fish (44 percent). A third of the women felt this way, but only about a quarter of the private farmers agreed. Overall, around 70 percent thought that a larger type of fish would be easier to sell. Most respondents saw their extension monitor twice a month.

Private farms saw the extensionist slightly more often. Respondents gave yes or no answers to a series of questions about "How is the monitor most helpful?" Most thought the monitor was helpful in feeding fish, harvesting fish, and stirring up compost. Monitors supplied nets when needed for harvest. Almost a third of the women said the monitor was helpful in marketing. Only six percent of the other respondents mentioned this assistance.

About half the male group farmers thought that the monitor gave good advice about garden crops. Only a quarter of the women felt this way compared to three-quarters of the private farmers. This is a notable difference in perception between men and women. Nearly all said that the monitor provided needed technical information, was able to help solve problems, was available when needed, came when expected, gave good answers to farmer questions, and brought the net when it was needed. Women were less satisfied with monitor performance in almost every dimension. Women also were more likely to say that the monitor did not come when expected. But women were not necessarily dissatisfied with extension assistance; they simply were less uniformly positive about the nature of the help they were getting than were men.

Most male and private farmers had heard of other fish species beside tilapia. Only about a third of the women had heard of other species. Overall, about half the sample was satisfied with tilapia as a species. Women who wanted other ponds did not want to be private pond owners, but would much rather join another pond cooperative. Apparently, the sociability and mutual support associated with group membership, the possibility of independent cash income, and the shared burden of fish farming tasks were advantages particularly valued by women.

Membership in a pond group was not perceived as a particularly advantageous avenue for receiving credit or marais land. About 18 percent of the male group members saw some advantage in obtaining credit, but few active farmers saw fish culture as conferring any particular advantages in these regards.

Private pond operators were more interested in additional private ponds than membership in a cooperative. About seven percent of the group farmers thought group membership made it easier to get land. No group members thought it was easier to get land to grow fish than for other crops, however.

The main thing that keeps Rwandan farmers from growing bigger fish and obtaining larger harvests is a shortage of inputs. About two-thirds saw insufficient manure and other nutrients as limiting the size of the fish they grow. Almost half blamed the species. Around ten percent identified cool water as a limit to fish growth and reproduction.

Groups had most of their contact with extension through the fish culture monitor. Five-eighths of the men and three-quarters of the women reported no other extension contacts. More than half the private and dropout farmers reported that the fish culture monitor was their only contact.

Most farmers did not think that fish farming make it harder to care for other crops, although active group women were more likely to feel this way (15 percent). Active group farmers reported some conflict with neighbors over marais property boundaries (12 percent). Theft of the fish themselves was a problem for 30 percent of the private farmers, a higher level than in the other categories. Active male group farmers were also somewhat more likely to report this problem (21 percent). Only a few thought fish were easier to steal than other crops. Three-quarters of the private pond owners reported problems with animals, primarily birds. Losses from these predators are particularly hard to prevent.

The major difference between dropout farmers and the active respondents pertained to the amount of work required by the pond. Almost 17 percent of the dropouts said there were times when the fish pond was too much work, versus 4 percent or less for the others. More than 60 percent of the respondents felt that the fishpond was worth the work. The private farmers were most likely to think so (77 percent). Even 61 percent of the dropouts agreed, suggesting that other extenuating factors precipitated their withdrawal from fish culture, and not the activity itself.

More than 80 percent of the active farmers thought that fish culture fit well with other activities, as did the dropouts (77 percent). More than 85 percent of the active farmers felt the fishpond made the best use of land. Many dropouts also agreed (61 percent). This pattern of findings further suggests that other circumstances were causing dropout farmers to abandon the practice of fish culture, and that no one single factor was causing farmers to quit.

Only a few of the pond groups broke up because of inability to collaborate. They gave 22 different problems, a third relating to group processes. The ponds they abandoned had not reverted to other parties. Most would join a pond group again if given the opportunity.

Anticipated Benefits

Understanding the circumstances and motivation that shape individual decision processes will be a significant step toward designing and maintaining a technology transfer effort that will be sustainable and effective.

An Approach to Integrate Gender Variables into the Rwanda Project of the Pond Dynamics/Aquaculture Collaborative Research Support Program

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The objective of this document is to describe the existing linkages between the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) in Rwanda and Rwanda field-based scientists, and to aid their efforts to strengthen work with women farmers in technology assessment and adaptation. The document explains a strategy for improving the communication among participants in aquaculture technology development, transfer, and adoption, to integrate women as active partners in aquaculture development in Rwanda. Information obtained from a preliminary study of "Women's Participation in Fish Culture Activities in Rwanda" is also used in exploring the strategy to integrate women. This study is partially supported by the PD/A CRSP and thus can be viewed as an initial effort towards the integration of gender issues in the collaborative program. Prior to these efforts, Auburn University assisted in developing an aquaculture program in Rwanda through a USAID-funded project which encouraged the participation of women farmers.

1. Gender Variable in Research For Technology Development: An Overview

The international agricultural research community has been criticized for neglecting the gender variable in technology development. Jiggins (1986), in her study of gender-related impacts and the work of the International Agricultural Research Centers, concludes that "Neglect of gender issues in agricultural research and technology development holds output and welfare below potential." Swaminathan (1989) argues that the "development of technologies specifically tailored to women's specific occupations and the involvement of women in technology development and transfer have received inadequate attention from both scientific and administrative departments of governments." Currently, the general consensus of the development community is that the scientists in the National Research Programs (NRP's) and International Research Program (INRP) should deliberate on social aspects of research such as technology development for women's productive activities and demystifying technology for women. At the same time women in development scholars need to expand their efforts to integrate gender issues into technology development research. These communities of scholars should endeavor to create modes of communication to define guidelines for working together to assist women producers in developing regions. The communication gap between technology producers and technology consumers should be closed. In order to attend to the technology needs of African women farmers, Saito and Weideman (1990) recommend that the scope of the research should be expanded to incorporate review of current research programs for research gaps, development of a research agenda which responds to needs of women farmers, focus on the crops and livestock produced by women, technologies and farming systems suitable to the circumstances of women farmers, post-harvest operations, and appropriate labor-saving tools and machinery.

The PD/A CRSP has supported a study of social aspects of technology use in Rwanda that is in progress (Molnar 1992). Oregon State University's current "gender integration initiative" is a modest but timely effort to counter criticism of a gender gap in technology development in Rwanda. The preliminary Study of Women's Participation in Fish Culture Activities in Rwanda is illustrative of the growing partnership and commitment among various groups to integrate Rwanda women farmers into aquaculture development.

2. Aquaculture in Rwanda

Aquaculture is often combined with agriculture, horticulture, livestock production, and rural development with great success, as farmers realize that they can supplement their food supplies and income with small-scale fish farms (Vincke, 1988, Brown 1985, Schwartz et al. 1988, Kutty 1986, Coche and Demoulin 1986). In Rwanda, aquaculture is classified as extensive aquaculture characterized by low capital input and high labor input. Aquaculture in the Rwandan context is based on soil principles of recycling and refurnishing land with organic manure, and it bears important implications for sustainable low-input agriculture development. In Rwanda, aquaculture is promoted as an integrated production activity and it is associated with other agricultural practices; typically, it is linked with gardens, animal husbandry, or forestry (Hishmunda and Moehl 1989). Marginal land may be used for fish farming when it cannot be used for crop production (Brown 1985, Mitchison 1986, Veverica 1990). In the present development era, Rwanda faces the dual dilemma of declining land productivity and an escalating population. Dramatic increases in population place greater pressure on arable land, and agriculture is being abandoned (Randolph and Sanders 1988). In this context, aquaculture is a viable alternative production process for sustaining land resources and improving households' income potential and nutrition.

3. Rwanda Women in Aquaculture

Aquaculture sector development at the global level has been viewed as a measure to improve food security and as a means of supplementing income for the farm families. In many countries, particularly in Africa, the aquaculture sector is based almost entirely on extensive farming practices, primarily for subsistence and barter, with any surplus being sold in rural markets (Nash et al. 1987). Aquaculture, particularly on a small scale, is labor-intensive, energy-efficient, and conserving of natural resources (Egna 1990). In Africa, women are active participants in labor-intensive subsistence production. Nearly 80 percent of economically active women in Sub-Saharan Africa are in agriculture (U.N. 1991). In Africa, women farmers could be the single most cost-effective, available resource for alleviating the African food crisis (Blumberg 1989). In Rwanda, women represent 50.6% of the population, and 97.9% of the women are agriculturists contributing to nation's food supply. The women also are burdened with constraints of high illiteracy, relatively limited access to land, lack of property ownership rights, frequent pregnancy, and excessive demands on their time.

In Rwanda participation by women has led to the rapid and successful growth of aquaculture (Veverica 1990). Rwanda women have successfully demonstrated their interest and ability to utilize the modern aquaculture technology developed and disseminated through the USAID-funded Rwanda Fish Culture project 1983-1988 and later by the fish culture component of the Natural Resources Management Project (Koran 1989). The PD/A CRSP activities in aquaculture research is built on these prior research collaborations. The persons involved in the research and extension in the projects continued their informal work with women farmers. "Women fish farmers are most productive and easiest to work with. Extension workers are asked to seek out women trainees on the rationale that women's economic rewards from fish enterprise will be invested in family well-being" (Nyirahabimana 1989).

In 1988, 23.1% of the fish farmers were women. It is estimated that more than half of the fish ponds are "managed" by women (i.e., the pond belongs to the family but women are in charge of fertilizing the pond and feeding the fish). Their numbers increased year by year and were 25.4% in 1990. A major challenge for the PD/A CRSP in Rwanda is to strengthen linkages with fish farmers, one-fourth of whom are women burdened by gender-specific production constraints to assist them in adoption or adaptation of the aquaculture technology.

4. Institutional Linkages for Gender Variable Integration

This effort for including a social science research component with the gender issues focus in the Rwanda PD/A CRSP is a combined effort of the Executive Director of PD/A CRSP, the Director of the Women in International Development (WID) Program at Oregon State University, the PD/A CRSP scientist in Rwasave Station, and the Extension officer based at Kigembe Research Station in Rwanda. These four female professionals initiated the process of the project to focus on women in aquaculture in Rwanda. Oregon State University's Women in International Development program director took a leading role in developing the project and identifying the resources with a strong commitment of support from the PD/A CRSP Executive Director. In Rwanda, similar collaboration was forged between scientists in Rwasave Station and Kigembe Station. The commitment and informal collaboration among these professionals culminated in a project emphasizing gender integration in technology development. The project with components are:

- A colloquium to facilitate trialogue between production scientists, extension personnel, and women farmers who have adopted fish cultivation technology;
- Development of an in-depth project case on "Rwanda Women in Fish Production," using focus groups and personnel interviews of fish farmers; and
- Development of background information and a survey instrument for a long-term study of a sample of women adopters and non-adopters of fish farming technology. The survey will identify intra-household resource allocation impact, production, marketing, and consumption possibilities and constraints at the household level.

4.i. Project Resource Linkages

This three-phase project on "Rwanda Women In Aquaculture Production," was formulated in a co-financing mode. The contributing agencies are: Oregon State University (OSU), USAID-Women in Development Office, Program Support Grant, PD/A CRSP, USAID/Kigali, and Ministry of Agriculture, Livestock and Environment - Director of Livestock and Animal production. This funding structure is complex. But it also illustrates the commitment of various agencies in supporting the project (Figure 1). The institutional linkages chart also identifies current institutional linkages utilized for assisting women's participation in aquaculture activities and the institutional units where WID programs and interests exist. In those units where WID interest exists, future programs and projects can be developed to improve the access of resources and training for women fish farmers. Such efforts should be collaborative efforts among the units to avoid duplication of efforts and waste of human and financial resources.

4.ii. USA - Rwanda Institutional Linkages

At OSU the project was developed by the Women in Development Program supported by the PD/A CRSP management entity. In Rwanda the collaborators were CRSP scientists associated with Rwasave Fish Culture Research Station of the National University of Rwanda and the Ministry of Agriculture, Livestock, and Natural Resources officers placed at Kigembe National Fish Culture Research Station (Figure 1). The Rwasave Station is the site for PD/A research. The research focuses on production ecology, fingerling production, and stocking, fish nutrition, and pond productivity. The PD/A CRSP science supporting the technology is complex for the farmer population, which has limited formal education, and aquaculture at farm level is labor intensive. The research at the Rwasave Station also includes experiments on agriculture/garden crops, livestock, and fish pond systems independent of PD/A CRSP research activities. Efforts are made to develop the Research Station as an economically viable, self-supporting enterprise. With such an objective in view, the products from the experiment farms, such as fingerlings, farms produce, and fish, are sold to the general public.

4.iii. Rwasave Station PD/A CRSP Farmer Linkages
The farmer linkages for CRSP in the Rwasave Fish Culture Station are informal. The CRSP research activities include field trials in the aquaculture ponds operated by individual farmers and farmer groups. These field trials serve the purpose of technology assessment at the farm level. Some of these farmer groups either include women or women-only groups. Women farmer contacts are created through field trial opportunities. At the supply end the Rwasave Station sells fingerlings for pond stocking for a nominal price and provides technical advice to the extension agents and farmers. Currently, Rwasave Station staff and Kigembe Station personnel collaborate in training the extension agents, although Kigembe Station And MINAGRI are in charge of all extension and training activities. The training contents are fish ball preparation, net-making and repair, fingerling selection, and pond fertilization. The training activities focusing on fish ball preparation and net-making were held with the hope of developing small enterprises. It has to be emphasized that many of the dissemination activities are informal and are carried out as additional work beyond the mandated research responsibilities and work hours related to technology generation and assessment research. In this scenario, efforts to integrate a gender perspective is ad hoc and entirely based on project personnel's individual commitment and concern for Rwanda women farmers.

But PD/A CRSP promises potential to build on these informal efforts to develop gender-integrated field research programs. The PD/A CRSP can adopt explicit guidelines to integrate gender issues into the research agenda, and to specifically seek the women fish farmers' perspective of aquaculture technology adoption constraints during field trials. It may also be advantageous to identify a few women farmer operated fish ponds and monitor them continually for their specific performance and constraints in utilizing CRSP technology.

4.iv. CRSP Link With SPN Station in Kigembe
PD/A CRSP formal farmer linkages began in 1989 in Rwanda. But prior to this time, Auburn University was working in Rwanda through the USAID-supported National Fish Culture Project, with Kigembe station as headquarters until 1988. Auburn still works with them on a consultancy basis through the NRMP project. The link between current PD/A CRSP personnel at Rwasave and SPN personnel at Kigembe was developed over the time, since Auburn University was involved in both projects.

Rwasave Research Station has informal linkages with the Kigembe National Fish Culture Service Station (SPN). The scientists in the two stations foster and maintain informal communications on technology needs and production constraints of the farmers. Moehl (1991) recommends a formal research relationship between these two centers. The women in aquaculture colloquium project demonstrated a visible but informal linkage between CRSP scientists at the Rwasave Station and SPN scientists at the Kigembe Station.

4.v. Kigembe SPN Research Station Farmer Linkages

The National Fish Culture Service located at Kigembe has extensive facilities for integrated aquaculture research and demonstration units. The service is given an official mandate to train extension agents and coordinate all the fish culture extension efforts in Rwanda. The station is funded by USAID to train farmers. Thus the SPN station at Kigembe is a logical choice to play an important role in expanding women's access to aquaculture technology by increasing the number women in the farmers in the formal training programs and reaching women in the villages to expand their participation in fish culture activities. The center is equipped with training facilities including class rooms and shared housing for trainees. The station activities emphasize integrated livestock and fish pond systems. Hence the station plays a key role in training trainers to transfer aquaculture technology to the farmers. The linkages with the farmers are in the format of technology advice and intensive training for fish farmers at the station as well as field demonstrations.

Women farmer's participation in training is not directed by predetermined objectives and followed through by planned intervention efforts. Women are integrated, however, because of the interest and commitment of the station personnel. The station can make a far-reaching impact towards targeting women by establishing mandatory guidelines for identifying and including women farmers in training programs and field visits in proportion to their participation in agriculture activities. In order to make the station an economically viable enterprise, it has various commercial activities, such as a pond-side canteen for visitors, and the sale of fish and livestock products to the public. By nature of its structure as a production, training, and sales center with a focus on integrated production systems, the station is an excellent venue for training women in integrated farming systems methods. Such integrated training program can assist women in gaining technological know-how for developing cereal crop and animal production (including aquaculture aspects). Rwandan women farmers can be trained to produce diverse products to deal with households' consumption imbalances and at same the time to counter natural resource degradation with appropriate land and soil management techniques. The commercial end of the station can create an understanding among farm women about agricultural product marketing and pricing. The PD/A CRSP cannot have an impact on expanding women's participation in aquaculture without infringing on SPN activities. Thus the informal collaboration between PD/A CRSP based at Rwasave station and SPN at Kigembe can be made formal and a process should be developed for coordinating gender integration into technology assessment, training, and adoption.

5. "Women in Aquaculture Production" Project as Facilitator for Integration of Gender Variable in Rwanda Aquaculture Research and Extension

The project on "Women in Aquaculture Production" acted as a catalyst to generate interest and strengthen formal and expanded collaboration to integrate gender variables in the National and International PD/A research efforts in Rwanda. Two components of the project are a) Colloquium on Rwanda Women in Aquaculture planned as a forum for a trialogue among technology adopters, disseminators and developers, and b) Qualitative study to learn about the perceptions of women farmers, extension agents, and fishery scientists on women's role, participation level, and reasons and constraints for women's participation in aquaculture activities in Rwanda. Such scope for WID integration is traced to the linkage with the current USAID emphasis on integration of WID issues into the projects in progress and strengthening social science component in Collaborative Research Support Programs including the Pond Dynamics/Aquaculture program in Rwanda.

Colloquium Objectives
The objectives of the colloquium were as follows:

- To create a forum for Rwanda aquaculture extension personnel, women fish-farmers, production scientists, non-government organization professionals and policy makers, and program managers to share the experiences of achievements and constraints in transferring fish production technology to Rwandan women farmers.
- To develop guidelines for integrating household-level fish consumption and processing and local fishery market linkages into the extension information package.
- To develop recommendations for improving working relationships between the various groups working to improve aquaculture production, natural resource utilization methods, and women's productivity.

5.i. Program Collaborators, Participants, and Activities
The colloquium was held at the National Fish Culture Research Station, Kigembe, from 17 to 21 February 1992. The program was organized by the joint efforts of Dr. Revathi Balakrishnan, Director, Women in International Development, Oregon State University, USA; Ms. Karen Veverica, PD/A CRSP project Rwasave, Rwanda; Ms. Pélagie Nyirhabimana, Director, Fisheries, Aquaculture and Apiculture, Ministry of Agriculture, Livestock and Environment, Government of Rwanda (MINAGRI-GOR); and Mr. Paul Mpawenimana, Acting Director of the National Fish Culture Service based in Kigembe. The colloquium was attended by 65 participants including the organizers. The participants were represented by 28 women fish framers, 10 fishery extension agents, 12 planners and program managers; 7 scientists, 2 non-government organization representatives, and 4 international volunteers representing the U.S. Peace Corps and Dutch volunteers (SNV).

The participants were selected by a process of formal letter of invitation by the Director of Livestock and Animal Production to the commune leaders (the local administrator in local government), and relevant department heads. The local scientists and SPN personnel were entirely responsible for identifying the participants. The Oregon State investigator developed the program and material support in close consultation with counterparts in Rwanda.

The three-day program included working sessions in the following categories: mixed groups that included representatives from the diverse group of participants who were assigned to create a balanced mix of participants representing various backgrounds. To capitalize on the venue, the participants were given a tour of aquaculture production and research facilities.

A general evaluation by observation and comments of the participants indicated that the women farmers valued the opportunity to share their experiences and frustrations in their role as women fish farmers. The colloquium achieved the objective of opening up communication among the various groups involved in assisting women farmers to improve productivity in the fishery sector. The colloquium created awareness of women's needs for production inputs and aquaculture technical information among the participants themselves, the extension agents, scientists, and representatives of Ministries and Non-Government Organizations. An important result of the colloquium is that women were pleased to find a forum centered on their needs as women fish farmers, and the recognition by the colloquium organizers and ministerial representatives of their key role in increasing Rwandan food production. Many women expressed their view by stating that this is the first program which has given them an opportunity to be in one place with scientists, planners, and extension agents to share their experiences and problems.

5.ii. Shared Experiences of Women Farmers' Participation in Aquaculture
In the general forum each woman was given a few minutes to state their reason for adopting aquaculture and their problems in aquaculture production. A few women had long years of experience in aquaculture, but most women adopted the activity at the time USAID-Auburn project was implemented. The most frequently stated constraints were lack of land, fertilizers, and animals to generate compost for pond fertilization, and problems with local government authorities. Women participated in aquaculture because they perceived fish as a substitute for meat at family meals, as a way to improve the nutrition of their children, and as a possible source of additional income.

5.ii.a. Reasons for Participating in Fish Farming
A main reason for women's participation in fish farming was access to fish for the family meal. Several women fish farmers mentioned that it was difficult for them to buy meat so they opted for fish farming to produce their own fish.

Nutrition center education also played an important role in adoption. The women of Cyangugu and Kayove (Gisenyi) communes were taught to eat the fish called Isambaza (*Limnothrissa* spp.) at the Nutrition Center. They preferred to produce fish themselves rather than buying it so often.

Aquaculture activities were done in groups. Some are organized as all-women farmers groups and others are mixed groups of male and female farmers. In the mixed groups some women have their husbands in the groups. These men are called upon during their wives' absence to replace them in the pond work.

The women organized themselves to have their own fish production groups. Others entered aquaculture activities as a group, by the encouragement of their local administrative bodies or churches, and some to get access to valley bottom land (marais land) for production.

Some groups decided on fish farming instead of other agricultural activities. The women of Rwamiko (Gikongoro) had difficulty producing enough agricultural produce in the hills (colline) around the homestead, so they adopted the practice of cultivating in the lowlands. In the lowlands, however, where the soil conditions are poor for agriculture, they opted for fish farming.

5.ii.b. Women Farmers' Experience in Fish Farming
The woman with the most experience in fish farming was Mrs. Candide Uwibambe of the urban community of Ngoma. She started fish farming in 1957 through an association. The most recent fish farmers began their activities in 1990-1991. Some women started in the 1970s, but the majority of the women who are fish farmers started in 1986-1987. The time line coincides with USAID support for expanded National Fish Culture Service (SPN). A spill-over benefit of USAID-sponsored integrated aquaculture research and extension has been the increased participation of women.

5.ii.c. Quality of Women's First Efforts in Fish Farming
Based on their personal experience women in general observed that the quality of their first efforts at fish farming were very variable. Some women fish farmers who started on their own without the help of an extension agent, dug the ponds poorly and often on inappropriate sites. By contrast, others did fairly well. Those who were assisted by extension agents with proper techniques did not have those problems. The management of water, fertilization, feeding, and breeding of fishes posed some difficulties for the women who had not had training or advice from extension agents.

5.ii.d. Women's Perception Problems to Participate in Fish Farming
Certain women fish farmers know of problems caused by their neighbors and the administrative authorities who opposed fish farming. Some authorities were not well-informed and opposed aquaculture with the reasoning that the ponds bred mosquito larvae. The neighbors opposed fish farming with the reasoning that the land used for aquaculture ponds took it away from crop production. (The scientists did not weigh the mosquito problem to be a real

one. Their perception is that ponds with fish are actually beneficial since the fish consume mosquito larvae). This may well be a problem of abandoned ponds and poor management of ponds. Further, it may well illustrate a knowledge gap and divergence in the perception of problems between farmers and scientists.

Yet another problem experienced by some groups was the disintegration of the production groups precipitated by a lack of cooperation or relocation of women.

The problems directly related to production are poor pond construction, poor choice of species to raise, lack of manure and nutrient food for the ponds, poor harvesting techniques, lack of harvesting equipment, and predators (thieves, birds, and frogs).

Women also expressed the feeling that the support for aquaculture is not as extensive and intensive as it was for agricultural production . This may be due to the perception among the local administrators and planners that food production is related only to crop production (and does not include fish production). The demand for marais (lowland) for fish ponds might be perceived as competition for limited land area in a land-starved, overpopulated country.

Though women expressed their interest in integrated aquaculture production, at the present time integration is limited to fish ponds and garden crops on pond dikes. Predominant reasons for not including livestock are lack of resources to own livestock and theft of livestock. These concerns may suggest that there are situation-specific constraints to utilizing the aquaculture production techniques on farm.

The majority of women fish farmers mentioned the difficulty that they had in preparing fish for consumption.

Women sold part of the pond harvest. The fish harvests were not large enough to leave a surplus for the market, and a large-scale marketing structure is not yet needed. Informal market networks may exist.

5.iv. Small Working Group Discussions: A Gambit for Cross Communication

5.iv.a. Small Group Formation and Purpose

The groups were formed to encourage participation of women farmers, extension agents, scientists, planners, and non-government organizations in each group. Guidelines were provided in order to focus on major ideas related to participation of women in aquaculture activities in Rwanda. Participants other than women fish farmers were requested to play a listening role, different from their usual role being the "experts" and "authorities". This role reversal was difficult for the experts who are accustomed to the status conferred by formal education and association with formal organizations. The participants made a diligent effort to encourage the women to express themselves freely, but often lapsed into their traditional "advisor" role.

The work was done in three distinct groups having almost the same composition of participants, which represented various training and experience backgrounds for discussing the precise themes proposed. Each group included representatives of women farmers, scientists, ministries and non-government organizations.

5.iv.b. Problems Identified in Small Communication Groups
In these group sessions, the participants jointly searched and exposed problems in detail. In the small group session women reiterated that fish farming was important because of its potential for increasing family food, for improving child nutrition, and for increasing cash.

In most of the cases, as revealed in the first session of experience exchange, women stated that it was necessary to increase the visits of the technicians on site, and to watch over the formation of women fish farming groups.

Another important general problem was lack of manure for the ponds. Scientists and extension agents recommended integration of livestock production (e.g., swine production) with fish farming.

Livestock raising in certain areas of Rwanda presented some unique problems, such as a lack of feed for the livestock, women's poor management of livestock, and women's inability to obtain credit to purchase livestock. But for women in certain areas, where it was customary to carry out diverse agricultural activities in the swamp and get the assistance of men in the mixed groups for livestock management, the problem of raising livestock for manure was not considered to be a big problem. Also the pond sites are far from home and it is unthinkable to keep livestock away from home, especially at night, due to theft.

The issue of credit for fish farming was raised. Women did not want credit, but the "experts" advised women to consider it at this colloquium. Most women saw fish farming as an activity that requires little or no cash, and is able to generate cash. Among the women who were interested in credit as a potential source of finance, most who had tentatively approached the bank had been refused because of their illiteracy and lack of collateral.

The point concerning the price of fish was raised. The results were that the price of fish was fixed in several areas relative to that of meat and was always lower than the price of meat. In some areas the price of fish was fixed by the extension agents who organized the sale themselves.

In certain areas like Bwakira and Kigembe, the availability of land for construction of new ponds was obstructed by neighbors and authorities. Certain groups, on the other hand, enjoyed access to a large area of land for many years. Others submitted to the effects of population pressure for land.

Concerning the information for women fish farmers, it was brought out that information dissemination of aquaculture technology has been very neglected and that the present forum was the first forum for information-sharing among women fish farmers, extension agents, and scientists. Meanwhile, given the responses of women to their colleagues on a given problem, one finds that they are very aware of the problems of fish farming. Due to inadequate time, the forum did not include extensive sessions on technology information dissemination. Women and other participants visited the integrated aquaculture facilities as part of the program and benefitted by observing first hand the integrated small animal, garden crop, and fish production system.

All the land is held by the government with the farmer given usrufact rights. At the discretion of Commune administrator (Burgomaster), the women's group gets access to land for ponds. Thus women's participation is dependent on authorities willingness to provide access to the land. In addition the implements used to dig ponds are owned by men of the household. Even if the women form their own groups to operate fish ponds they do not have direct access or control over other inputs. Many administrators see little reason to distribute land to women when there are so many men requesting land.

5.v. Demonstration of Integrated Aquaculture Activities: Guided Tour of Kigembe National Fish Culture Station

A site visit of the Kigembe station was organized for the participants in three groups under the guidance of SPN staff. The participants were presented with the following yield information from the station's integrated fish production activities. This is net fish production resulting from animal waste falling directly into ponds:

Integrated System	**Net Fish Production***
pig-fish:	5.1 tons/hectare/year
chicken-fish:	6.5 tons/hectare/year
rabbit-fish:	6.1 tons/hectare/year
duck-fish:	4.5 tons/hectare/year

* Resulting from animal waste falling directly into the pond.

The same groups which had been formed for the group discussion were maintained to tour the facility. The tour time gave them an opportunity to continue their dialogue. The scientists who are involved in integrated aquaculture technology assessment research guided the tour explaining the various practices. For many women participants and others who are novices to the concept of integrated aquaculture, the tour was instructive. The women fish farmers were very impressed by the production cycle of integrating rabbit hutches, poultry sheds, and piggery units over the pond, and their impact on fish production. The women also observed the large size of station-grown tilapia. This gave the scientists an opportunity explain the importance of fish nutrition and pond management.

At the end of the tour, the participants assisted in harvesting *Clarias* and tilapia from two separate ponds that were to be served for the concluding-session lunch hosted by Station personnel.

5.vi. Demonstration of Use of Small Fish in Meal Preparation
During formal discussion and the informal chat the women continually raised the issue of using the small fish in meal preparation. In order to educate them, a small demonstration was organized by the Rwasave CRSP scientist on the methods of preparing of ground fish balls or sauce from small fish.

Women's interest in fish-based meal preparation alternatives for family consumption is illustrative of the dual role women play in production systems as producers and consumers. Rural women in Rwanda, as providers, adopt fish farming to increase income and food resources for the family. As farmers they seek production technology to improve aquaculture production, and as mothers and wives wishing to nourish the family, they seek knowledge of fish processing. Due to the culturally conditioned gender-segregated roles, at this time it is good to have female extension agents, as men would be shy to comment on cooking techniques and would not enter a kitchen.

6. Recommendations of the Colloquium
Each group named a representative to present its recommendations after two days of deliberation. Women fish farmers were given equal time and priority in the order of presentation. The recommendations as presented by the groups are recorded in this section.

6.i. Women Fish Farmers—Technology Adopters
Women fish farmers generated the following requests:

i. The communal-level authorities and the directors of agricultural services should help them with the same consideration as that shown to other agricultural activities.
ii. The training officers of the National Fish Culture Service should come to villages to offer an extensive on-site training course for farmer groups.
iii. The fishery technicians and scientists should visit them often to advise them on how to increase fish production.
iv. Field visits should be organized to observe integrated aquaculture activities, particularly livestock integration.

6.ii. Extension Agents—Technology Disseminators
Extension agents recommended that:

i. There should be a greater degree of collaboration with the administrative authorities. The term administrative authorities is broadly interpreted by the participants. It can be local government administrators, or supervisors or officials from various ministries.

ii. Those who have found themselves unable to resolve an aquaculture production problem in their local area should be able to contact a technician from the National Fish Culture Service.

iii. Abandoned ponds should be given to capable people with the support of the commune authorities.

iv. Their training responsibilities should not include agricultural aspects.

6.iii. Government Ministry Representatives—Technology Planner

Ministry representatives recommended that:

i. There should be competitions for rewarding farmers who have achieved good fish harvests. Such fish competitions should offer special prizes for the encouragement of women fish farmers.

ii. There should be an increase in the number of extension agents as trainers to assist women in aquaculture methods.

6.iv. Researchers—Technology Developers

The researchers, after hearing the women for two days, appreciated women farmer's enthusiasm and admired women's ability to assimilate the technical details of aquaculture production. They agreed that the women should be trained directly by the aquaculture scientists to avoid loss of information through extension agents. In many instances they felt the fish farming technology is not absorbed adequately by the extension agents. This inadequate preparation of extension agents leads to the dissemination of misinformation or inadequate information to farmers. In particular, women farmers may have to deal with further-degraded information, passed through the male heads of the farmer group or spouses.

The scientist group recommended that:

i. The researchers should develop information necessary for fish production by technical notes, radio, or other mass communication means, to be placed at the disposal of fish farmers in general and women fish farmers in particular, as well as any interested third parties such as non-government organizations promoting fish culture.

ii. The priority information content areas are the choice of site, the staking and construction of ponds, the management of the water, the choice and breeding of appropriate fish species, the fertilization of the ponds and feeding of the fish, pest and predator control, harvesting techniques, preserving and preparing fish for eating, and public health and its relationship to fish farming.

iii. The researchers and other technicians should work closely with fish farmers.

iv. The political-administrative authorities should be made aware of the role of fish farming in rural development in order to eliminate the farmer's poor production methods.

6.v. Non-Government Organization Representatives—Technology and Input Transfer Facilitator
The Non-government organization group recommended that the National Fish Culture Service should investigate the different possibilities of financing fish farming activities and inform those concerned. In Rwanda this group actively promotes women's participation in income generating activities, including fish production. They are effective in organizing groups and moving material inputs and credit. But their ability to provide technical know-how is limited. There is no formal link between CRSP scientists and NGO's who are favored to assist women's participation in the aquaculture sector. The feasibility of providing aquaculture training by CRSP scientists for the NGO promoters of aquaculture should be explored.

7. Qualitative Study on Women's Participation in Aquaculture
Two groups of women, namely those who participated in the colloquium and a few who represented women's fish farming groups who did not attend the event were interviewed in a group situation. Questionnaires were also administered to the extension agents and scientists. The outcome of the study is presented in the case study document.

8. Proposed Institutional Linkages and Action Guidelines for PD/A CRSP Rwanda to integrate Gender Variable
PD/A CRSP independently can do the following to integrate gender role sensitivity into research:

1. Test the nutrient content of the household materials and local plants used by the women to support fish growth and advise them on their relative values or propose other alternatives to improve feed quality.
2. Develop opportunities to share women farmer's technology needs, either by visiting with them directly or developing similar colloquia in other parts of the country.

Since the PD/A CRSP does not have extension agent, the following can be done in collaboration with other institutions such as SPN and MINAGRI, who have extension responsibilities.

1. Formalize farmer linkages to specifically include ponds operated by women farmers and to get their feed-back on the effectiveness of PD/A technologies.
2. Target women directly for training in the PD/A Rwasave Station or in collaboration with Kigembe National station.
3. Continually update the information available to fishery extension agents.
4. Identify the NGO's that work with aquaculture activities targeted for women. Improve the technical skill of the NGO field workers organizing aquaculture activities.

9. Conclusion
At a time when there is an escalating concern about farmer linkages within the PD/A CRSP, this project has provided an opportunity to close the communication gap between technology producers and technology consumers. Especially in Rwanda, where 98% of the women are

agriculturists, understanding women farmers' needs for technology is synonymous with understanding production technology needs of the labor force in agriculture.

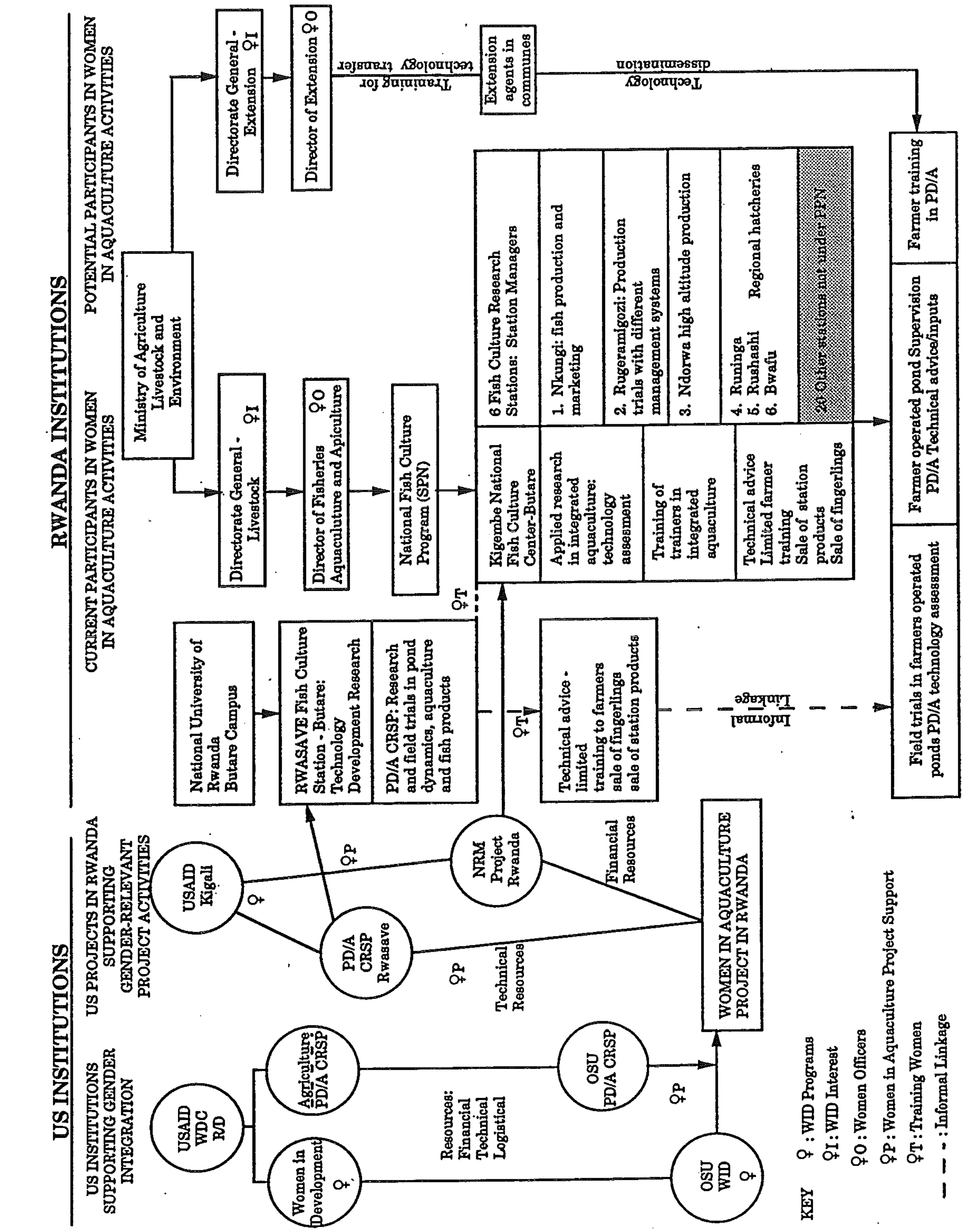

Figure 1: Institutional Linkages for Gender Integrated Aquaculture Development

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On the Role of Urea in Pond Fertilization

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Abstract

Two experiments were conducted to better understand the role of urea in pond fertilization. In Experiment 1, urea dissolved in pond water disappeared at rates of 303 mg urea-N/L/d under ambient sunlight conditions and 102 mg urea-N/L/d under dark conditions. Total alkalinity decreased in dark aquaria and increased in sun-exposed aquaria, which is consistent with stoichiometric expectations. Urea hydrolysis in distilled water exposed to light was negligible.

Experiment 2 was a toxicity test. Median lethal concentrations (LC50's) of urea at 24 and 96 hours exposure were 19,700 mg/L and 16,800 mg/L for sex-reversed male Nile tilapia (*Oreochromis niloticus*) fingerlings, and 17,000 mg/L and 16,000 mg/L for silver barb (*Puntius gonionotus*) fingerlings. All test fish survived a 96-hour exposure to 14,000 mg urea/L, whereas no fish survived a 48-hour exposure to 22,000 mg urea/L.

A recent experiment on fertilization with urea and NPK (14-14-14) gave higher yields of Nile tilapia than fertilization with ammonium sulfate and potassium nitrate after a 90-day growout period. Urea applied at a fertilization rate of 21 kg N/L/week (approximately 2.1 mg urea-N/L) disappeared at a rate of at least 350 mg urea-N/L/d.

Introduction

Urea, a major nitrogen (N) fertilizer for land-crop production, is also a popular N source for stimulating algal productivity in pond aquaculture. Urea purchased in crystalline form dissolves quickly in water, but hydrolyzes very slowly to yield carbon dioxide and ammonia according to the following reaction (Chin and Kroontje 1963):

$$CO(NH_2)_2 + H_2O \text{ ---> } CO_2 + 2NH_3 \qquad (1)$$

The presence of the enzyme urease, which is common among bacteria, fungi, yeasts, algae and higher plants, greatly accelerates urea decomposition (Leftley and Syrett 1973, Morris 1974). Although algae play the dominate role in urea decomposition in some marine environments (Mitamura and

Saijo 1975, 1986), metabolic pathways for algal uptake of urea are still unclear. Release of ammonia in urea-grown algal cultures suggested that urea may be broken down by algae and urea-N utilized as ammonia (Little and Mah 1970, Uchida 1976). On the other hand, Healey (1977) reported that freshwater algae may take up urea intact, breaking it down enzymatically once inside the cell. It has been shown that algae of the families Prasinophyceae, Xanthophyceae, Bacillariophyceae, Chrysophyceae, Myxophyceae, and Euglenophyceae contain urease, whereas algae of the family Chlorophyceae, including several *Chlorella* spp., contain ATP:urea amidolyase (Leftley and Syrett 1973).

Urea occurs naturally in aquatic environments as a degradation product of dissolved and particulate organic matter (Mitamura and Matsumoto 1981), zooplankton excretion, and bacterial degradation of purines and pyrimidines (Mitamura and Saijo 1986). Studies using urea labelled with radioactive 14C and 15N have clearly demonstrated that urea is rapidly recycled and may represent a significant source of both C and N to marine phytoplankton (Mitamura and Saijo 1975, Mitamura 1981, Mitamura and Matsumoto 1981, Kristiansen 1983, Ignatiades 1986). At Kaneohe Bay in Hawaii, Harvey and Caperon (1976) reported that daytime urea uptake accounted for approximately 53% of the algal N requirement.

Urea input rates used in aquaculture systems are orders of magnitude greater than what occurs in natural aquatic systems. Research presented here describes two experiments designed to improve understanding of urea dynamics and utilization in pond fertilization.

Materials and Methods

Two experiments were conducted at the Asian Institute of Technology, located approximately 42 km northwest of Bangkok, Thailand (14.2°N 100.5°E). Experiment 1 examined the decomposition of urea, while Experiment 2 evaluated urea toxicity to Nile tilapia (*Oreochromis niloticus*) and silver barb (*Puntius gonionotus*) fingerlings.

Experiment 1

Urea hydrolysis and decomposition was examined in 50 liters of water contained in 75 liter glass aquaria. Three treatments consisted of pond water exposed to light, pond water without exposure to light, and distilled water. Aquaria were suspended in outdoor cement tanks (6 m^3). Water in aquaria and cement tanks was kept at the same level to prevent overheating of aquaria exposed to sunlight. In the dark treatment, aquaria were completely covered with black plastic cellophane to prevent algal photosynthetic activity. There were three replicate aquaria per treatment. The initial urea concentration in pond-water treatments was 4 mg urea-N/L, compared with 5 mg urea-N/L in the distilled-water treatment. Urea was first dissolved in water before being added to aquaria. Pond water had the following initial characteristics: pH = 9.0; alkalinity = 510 mg/L as $CaCO_3$; and chlorophyll a = 21 mg/m^3. The following water quality measurements were made daily: urea-N (urease method, Parson et al. 1984), ammonia-N (phenolhypochlorite method, Solórzano 1969), pH, alkalinity (potentiometric method using 0.02N HCl to titrate the sample to pH 5.1; APHA 1985), and minimum-maximum temperatures. Measurements continued until Day 20, when severe rains disrupted the experiment.

Experiment 2
A static bioassay to evaluate urea toxicity to two species of fish was conducted in 75-liter glass aquaria filled with 60 liters tap water. Sex-reversed male Nile tilapia fingerlings (mean weight of 7.1 g) were exposed to urea concentrations of 1000, 10000, 14000, 16000, 18000, 20000, 22000 and 25000 mg/L. Silver barb fingerlings (mean weight of 11.1 g) were exposed to urea concentrations of 1000, 10000, 14000, 18000, 22000 and 25000 mg/L. Fish were acclimatized in aquaria for one week and were fed floating pelleted feeds at 5% of body weight. Feces, uneaten feed, and other solids were siphoned from the aquaria daily. One third of the water in each aquarium was replaced daily with water having the same concentration of urea. An air pump provided constant aeration to aquaria. Accumulative mortality of 20 test fish/treatment was determined after 12, 24, 48, 72, and 96 hours. A fish was counted dead if it did not respond to touch by glass rod. Water temperature, dissolved oxygen (DO; Yellow Springs meter Model 54A),and pH were measured daily. Total ammonia was analyzed from aquaria where mortality was observed. Probit analysis (Finney 1971) determined the urea lethal concentration at which 50% of test fish died (LC50) for 24, 48, and 98 hours.

Regression analyses were done according to Steel and Torrie (1980). Means are given with ± 1 standard error (S.E.) in parentheses; statistical significance is assumed at p <≤0.05.

Results

Urea decomposition and uptake
Figure 1 shows that urea in pond water exposed to sunlight disappeared in 15 days, whereas urea-N concentrations were still at approximately 50% of initial values after 19 days in pond water kept in the dark. Linear regression analyses indicate loss rates of 303 ± 14 µg urea-N/L/d (r^2=0.94) and 102 ± 7 µg urea-N/L/d (r^2 = 0.79) in pond water under light and dark conditions, respectively. Urea measurements from Days 1 to 3 after application were contaminated and excluded from analysis. Urea concentrations in distilled water remained almost constant throughout the experiment.

Total ammonia-N concentrations steadily increased under dark conditions, peaking at about 1.8 mg N/L on Day 16 (Figure 2). Pond water exposed to light exhibited peak ammonia-N concentrations of about 0.8 mg NH_3-N/L on Days 4 and 5, after which concentrations gradually decreased until no trace was detected by Day 15 (Figure 3). Ammonia-N concentrations in distilled water remained low throughout the experiment, ranging from 0.03 to 0.37 mg NH_3-N/L. The combined total of urea-N and NH_4 -N essentially remained at initial concentrations for both pond water in the dark and distilled water. Under lighted conditions, both forms of N had disappeared by Day 15.

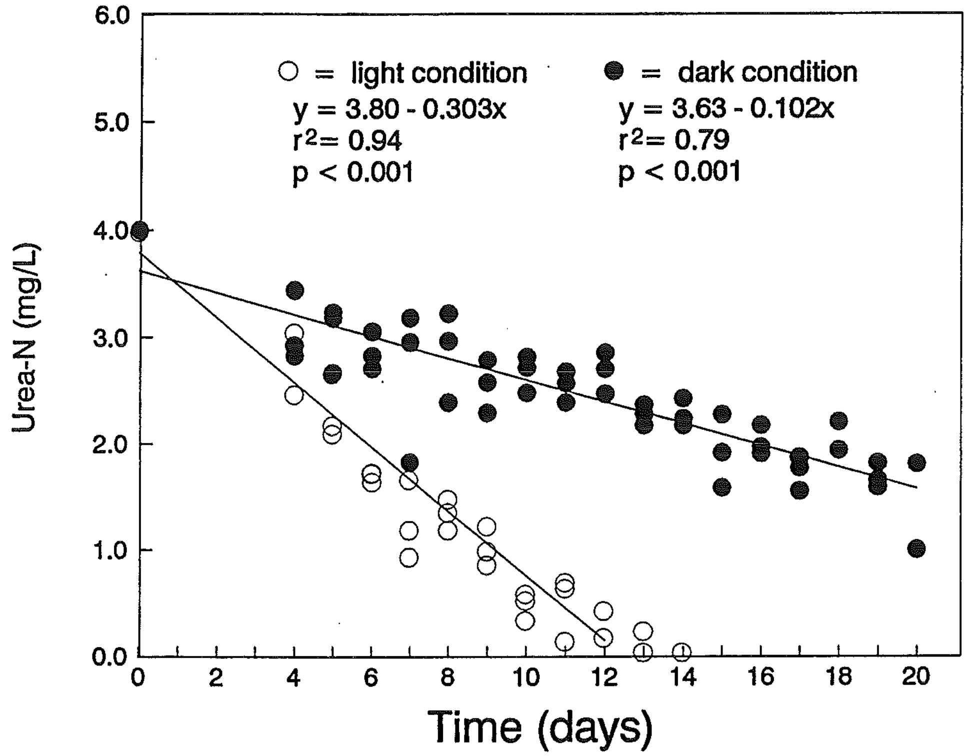

Figure 1. Disappearance of urea-N in pond water in aquaria exposed to sunlight and kept in the dark (Experiment 1).

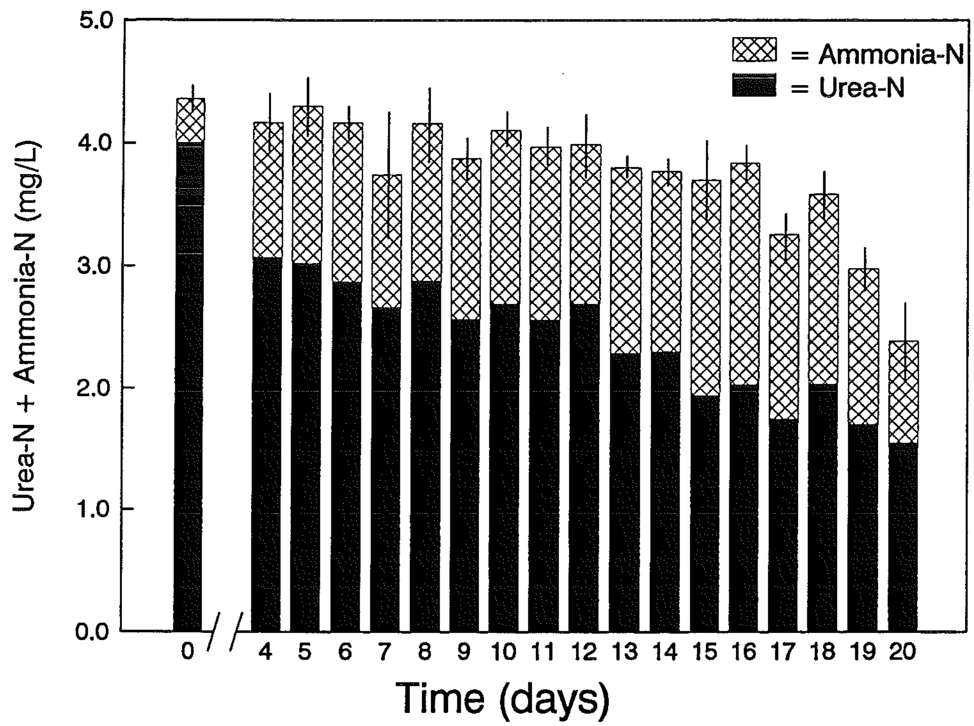

Figure 2. Accumulative urea-N and ammonia-N concentrations (±1 s.e.) in aquaria kept under dark conditions (Experiment 1).

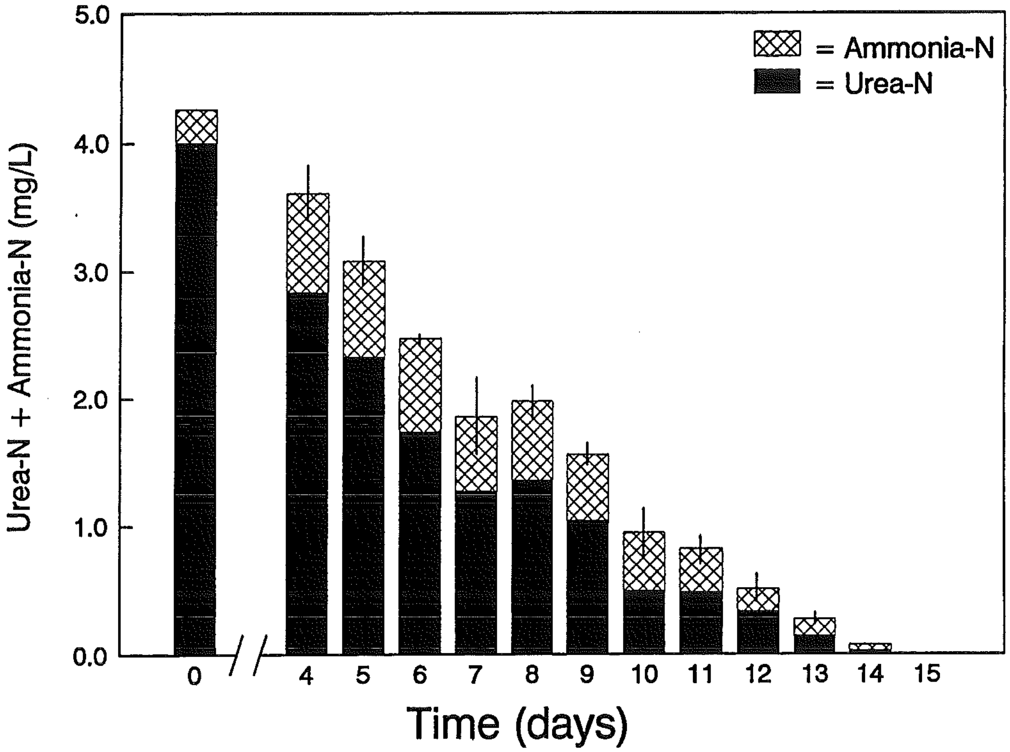

Figure 3. Accumulative urea-N and ammonia-N concentrations (±1 s.e.) in aquaria exposed to ambient sunlight (Experiment 1).

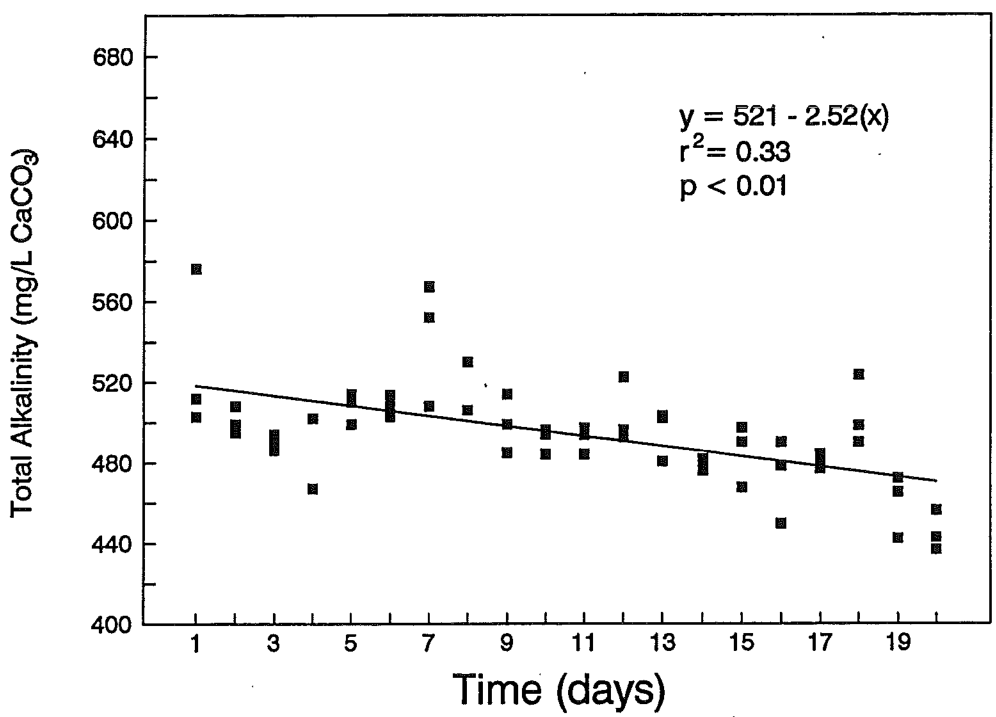

Figure 4. Decrease of total alkalinity (mg/L $CaCO_3$) over time in pond water incubated under dark conditions (Experiment 1). Initial urea-N concentration was 4 mg/L.

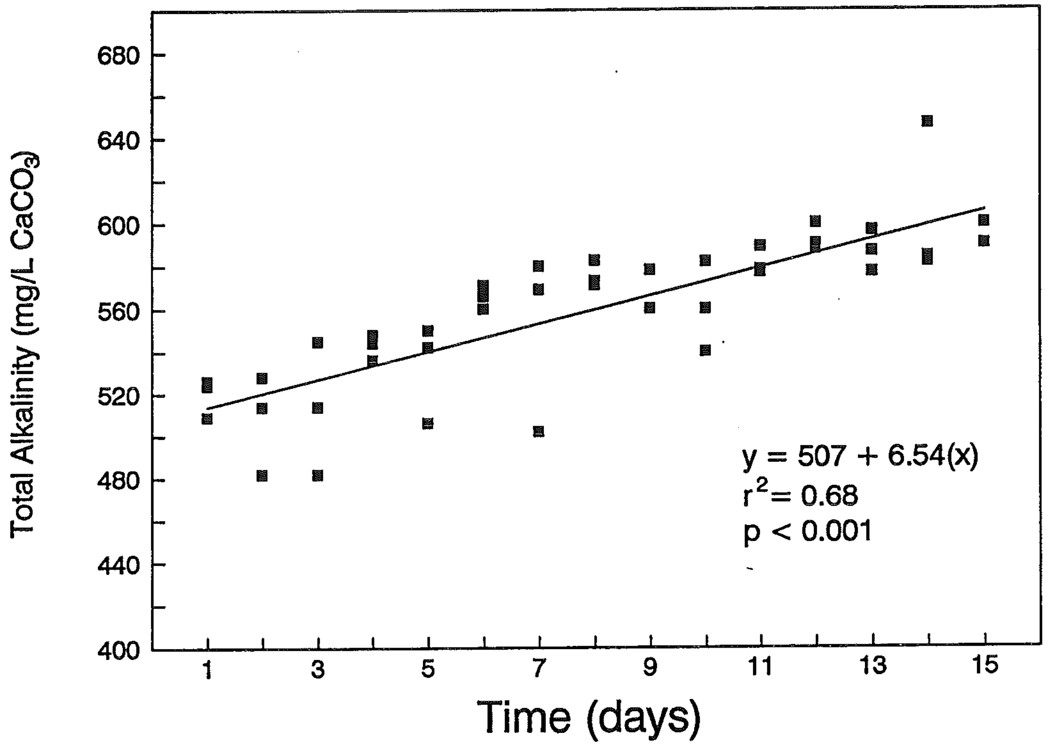

Figure 5. Increase of total alkalinity (mg/L $CaCO_3$) over time in pond water incubated under ambient sunlight conditions (Experiment 1). Initial urea-N concentration was 4 mg/L.

Although alkalinity often showed considerable within-treatment variability, a significant linear decrease was observed in the dark treatment (Figure 4), whereas a significant linear increase was noted in pond water under lighted conditions (Figure 5). No significant variations in pH were observed over time for any treatment. Temperatures ranged from 28.0°C to 33.6°C during the experiment.

Urea toxicity

Mortalities of tilapia and silver barb exposed to different urea concentrations are presented in Table 1. All test fish survived the 96-hour exposure to 14000 mg urea/L, whereas no fish survived the 48-hour exposure to 22000 mg urea/L. Median lethal concentrations (LC50's) of urea at 24 and 96 hours exposure were 19700 mg/L and 16800 mg/L for tilapia, and 17000 mg/L and 16000 mg/L for silver barb.

Water quality measurements during the 96-hour experiment gave the following ranges: temperatures from 25.4°C to 30.5°C, DO concentrations from 3.1 to 8.2 mg O_2 /L, and pH from 8.2 to 8.9. Total ammonia-N concentrations, measured in aquaria where fish mortality was observed, varied between fish species. In aquaria with tilapia, the mean total ammonia concentration was 5.9 $\pm$ 0.3 mg NH4-N/L, of which approximately 1.2 mg N/L was present as unionized ammonia (NH3-N). For silver barb, the mean total ammonia concentration was 2.0 $\pm$ 0.1 mg NH4-N/L, or approximately 0.4 mg NH3-N/L.

Table 1. Toxicity of urea to *Oreochromis niloticus* and *Puntius gonionotus* fingerlings (Experiment 2). Numbers represent accumulative total of dead fish.

Number of Fish	Exposure Time (hours)	Concentration of Urea (mg/L)							
		1000	10000	14000	16000	18000	20000	22000	25000
				Oreochromis niloticus					
20	12	0	0	0	0	0	1	4	10
20	24	0	0	0	1	2	3	17	20
20	48	0	0	0	2	5	11	20	20
20	72	0	0	0	4	8	16	20	20
20	96	0	0	0	5	15	19	20	20
				Puntius gonionotus					
20	12	0	0	0		0		11	20
20	24	0	0	0		2		17	20
20	48	0	0	0		5		20	20
20	72	0	0	0		10		20	20
20	96	0	0	0		20		20	20

Discussion

Negligible urea decomposition rates in distilled water supported observations of Chin and Kroontje (1963) that chemical disassociation of urea is slow and requires enzymatic activity. In pond water, linear regressions from Experiment 1 gave urea decomposition rates of 102 µg urea-N/L/d under dark conditions, and 303 µg urea-N/L/d when exposed to daylight (Figure 1). Assuming 12 hours of daylight per 24-hour day and similar rates between treatments under nighttime/dark conditions, urea decomposition in pond water exposed to daylight was about 17 µg urea-N/L/hour as compared to about 4 µg urea-N/L/hour in water kept completely dark. These results support investigations demonstrating a strong relationship between urea decomposition and algal photosynthetic activity (Ignatiades 1986; Mitamura 1986a,b). In eutrophic Kaneohe Bay (Hawaii), Harvey and Caperon (1976) obtained dark decomposition rates of about 30% of daytime measurements, a proportion similar to that found in this study. It is not clear whether dark uptake rates represent effects of residual algal urease, bacterial activity, or heterotrophic uptake by algae (Ignatiades 1986). It has been reported, however, that urea assimilation by algae is suppressed by ammonium concentrations of 1-2 µg-at N/L (Kristiansen 1983, Mitamura

1986b). Results here do not support those conclusions:Figure 3 indicates high urea uptake rates in the presence of up to 1 mg ammonia-N/L (71 µg-at N/L).

Mitamura and Saijo (1975) and Mitamura and Matsumoto (1981) showed that urea can be a source of both N and C for phytoplankton in coastal waters. In the former study 38-84% of decomposed urea-C was assimilated, yet urea-C represented only about 0.5% of the total inorganic C incorporated. This supports the possibility that algae cleave urea into ammonia and CO_2 internally (Healey 1977). A pond fertilized with urea at a rate of 0.4 g urea-N/m²/d would receive approximately 0.34 g urea-C/m²/d. Although this would represent less than 10% of the algal-C requirement in a productive pond, urea could still make a small but significant C contribution in a C-limited system.

Urea decomposition and uptake rates in natural waters often follow first-order kinetics, or a hyperbolic function of ambient concentrations (Harvey and Caperon 1976, Horrigan and McCarthy 1981, Kristiansen 1983, Mitamura 1986a). Those studies are in contrast to the linear decomposition rates illustrated in Figure 1. Mitamura and Saijo (1975), also reported linear urea decomposition rates, in coastal waters of Mikawa Bay, of 0.24 µg urea-N/L/h and 0.02 µg urea-N/L/h under light and dark conditions, respectively however. These rates are about two orders of magnitude less than our results in pond water, differences which probably reflect both lower ambient urea concentrations and lower algal productivity in Mikawa Bay. Warmer temperatures in our study also may have facilitated urea metabolism; maximum decomposition rates occur at about 30°C with a Q10 value of 1.8 (Mitamura 1986b).

Urea loss rates reported for fertilized systems compare more closely to our results. Pautong (1991) measured a decomposition rate of 350 µg urea-N/L/d in culture tanks receiving 21 kg urea-N/ha/week. In fertilized flooded rice fields, Cao et al. (1983) reported a disappearance of 15 kg urea-N/ha/5 d (≈300 mg urea-N/m²/d), Mosier et al. (1989) reported a disappearance of 80 kg urea-N/ha/4 d (≈2000 mg urea-N/m²/d). Assuming a pond of 1-m depth, an equivalent decomposition rate from Experiment 1 would be approximately 300 mg urea-N/m²/d.

Because of apparent linearity (Figure 1), urea decomposition rates can be used to estimate efficient fertilization frequency schedules based on desired rates of urea-N input and maintenance of a N-limited system. Actual urea loss rates in earthen ponds may be greater than reported here, however, as contact with bacteria-rich sediments may accelerate urea decomposition (C.E. Boyd, personal communication, 1992).

Alkalinity changes due to urea decomposition depend on ammonia production and oxidation processes. Urea hydrolyzed in water yields NH_3 and CO_2 [equation 1]. Ammonia is basic and combines with water to produce NH_4^+ and OH^- as follows:

$$NH_3 + H_2O ---> NH_4^+ + OH^-$$

If NH_4^+ is oxidized to NO_3^-, the net result is two equivalents of H^+ per oxidized mole of urea, and a reduction of total alkalinity (Hunt and Boyd 1981). Experiments by Hunt and Boyd (1981) demonstrating alkalinity losses through urea oxidation were conducted in the dark, preventing any algal uptake of ammonia. Similar reductions in alkalinity were noted in dark aquaria from Experiment 1 (Figure 4). But if phytoplankton utilize NH_4^+ before it can be oxidized to nitrate, according to Equation 2 alkalinities should increase with the hydrolysis of urea. Increased alkalinities observed in aquaria exposed to sunlight in Experiment 1 (Figure 5) support this conclusion. Vlek and Craswell (1979) also reported an increase in pH and alkalinity in flooded rice fields after urea application. Magnitudes of alkalinity losses and gains in Experiment 1 were greater than can be accounted for by urea decomposition alone, and probably reflect additional ammonia production and recycling from metabolized particulate N and dissolved organic N in pond water.

Urea toxicity to fish appears to be of little concern. Tests showed that urea concentrations of up to 14000 mg/L resulted in no silver barb or tilapia mortalities after 96 hours (Table 1). This concentration approximates weekly applications of >900 kg urea-N/ha/d in a 1-m deep pond, easily 200 times reasonable loading rates. Results for tilapia and silver barb compare with 96-hour mortality thresholds of 1000 mg/L for *Labeo rohita* fry (Triphati et al. 1974) and 20000 mg/L for *Oreochromis mossambicus* (Planichamy et al. 1985). Sarkar and Konar (1985) reported, however, that feeding activity in *O. mossambicus* can be affected by urea concentrations of about 400 mg/L or less.

Urea appears to be an excellent fertilizer for stimulating natural food production in pond aquaculture. Urea is readily utilized by phytoplankton as a source of N and possibly C, it increases alkalinity under N limiting conditions, and it has no apparent toxicity to fish at reasonable loading rates. Urea is also relatively inexpensive. On a gross weight basis, urea is often ten times more expensive than commercially available manures, but per kilogram of available (i.e., soluble) N, urea may be up to seven times less expensive than chicken manure (Knud-Hansen et al. In press).

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Strategies for Stocking Nile Tilapia *(Oreochromis niloticus)* in Fertilized Ponds

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A 149-day growout experiment tested the effects of stocking density, partial harvesting, and additional stocking on net fish yield (NFY) and on harvest size of Nile tilapia. Tilapia were raised in 220-m^2 earthen ponds, which received 10 kg dry weight chicken manure/ha/d with urea and triple superphosphate to give a total fertilization rate of 5.0 kg N/ha/d and 1.2 kg P/ha/d. The five treatments were stocking densities of 1, 2, and 3 fish/m^2, fish stocked at 1 fish/m^2 with an additional 1 fish/m^2 added after 2.5 months, and fish stocked at 2 fish/m^2 with 50% of fish removed after 2.5 months.

Stocking density significantly affected fish production. Extrapolated mean NFY's (n=3) in ponds stocked at 1, 2, and 3 fish/m^2 were 6562, 8863, and 12,349 kg/ha/yr, respectively, and mean weights were 335, 230, and 214 g/fish, respectively. Mean NFY for the first 2.5 months exceeded 18,000 kg/ha/yr in ponds stocked at 3 fish/m^2. Although the differences were not significant, partial stocking gave higher total NFY's than partial harvesting, i.e., 10,047 kg/ha/yr compared to 8307 kg/ha/yr. The additional stocking did not significantly affect the growth of the originally stocked fish. Mean harvest weights of fish stocked at 1 fish/m^2 were similar to those of the originally stocked fish in the treatment receiving an additional 1 fish/m^2 after 2.5 months.

Presented at the Third International Symposium on Tilapia in Aquaculture.

Effects of Calcium Carbonate Treatments on Soil and Water Chemistry in Laboratory Experiments

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Introduction

Aquatic primary productivity has often been shown to be related to total alkalinity levels in both natural environments and aquaculture ponds. Fish production in managed aquaculture ponds has also been shown to be related to alkalinity. When factors such as light or other nutrients are not limiting, dissolved inorganic carbon (DIC) has often been identified as the limiting nutrient. When alkalinity is low, DIC is low ($CO_{2(aq)}$, $HCO_3^-{}_{(aq)}$, and $CO_3^{2-}{}_{(aq)}$ as sources of inorganic carbon); the practice of supplementing the natural supply of nutrients in a pond system (fertilization) under these circumstances is of little value (Boyd 1979). Additionally, waters with low alkalinities are poorly buffered against changes in pH (Allen 1972, Boyd 1979).

Optimum values for good productivity or pond production range from 20 mg/L (Boyd 1974) to 100 or more mg/L as $CaCO_3$ (Schaeperclaus 1933, 1961). Recent CRSP research indicated that DIC was limiting in some ponds when alkalinity was below approximately 33 mg/L (McNabb et al. 1990).

The application of lime to neutralize the acidity stored in the pond bottom soils is a common aquacultural practice. Pond water alkalinity can also be raised to acceptable levels by liming. Boyd (1974) adapted an agricultural lime requirement method for a specific group of soils for use in aquaculture ponds in the Southeastern United States. In this method, estimates of pond lime requirements were based on observed chemical relationships in the soils and waters of Alabama ponds. Few subsequent efforts to determine soil-water relationships relevant to lime requirement estimation have been made. Categorizing such relationships according to soil type would be an important first step in this direction.

Objectives

The objectives of this study were twofold:

1. To conduct laboratory experiments to determine relationships between pH or base saturation (soil) and alkalinity or hardness (water) for specifically defined soil types, and
2. To obtain and analyze soil chemical data from tropical soils for pH-percent base saturation relationships.

This report focuses on Objective 1.

Materials and Methods

Soil samples were obtained from aquaculture sites in Rwanda, the Philippines, and Honduras. Where possible, samples were obtained both from within ponds and from undisturbed areas of similar soil outside the ponds for comparison. Additional samples were collected from non-aquaculture sites in Oregon to ensure that a wide range of organic matter contents, texture, and mineralogy types were available for comparative evaluation. All samples were air-dried, crushed, passed through a 2-mm mesh sieve, and homogenized prior to testing.

Baseline physical and chemical data were obtained for each soil. These data included percentages of sand, silt, and clay, pH, cation exchange capacity (CEC), and exchangeable cations (potassium, calcium, magnesium, and sodium). Sand, silt, and clay percentages were determined by the hydrometer method (Soil Physical Analysis Lab, OSU). extractable bases and CEC's were determined using a modification of the ammonium acetate method (Horneck et al. 1989). Base saturation values were calculated by the sum of cations method. Soil pH was measured in 1:2 (soil:water) solutions using two buffers selected to bracket the expected range of pH values.

One-gram samples of soil were weighed into 50-mL centrifuge tubes and treated with 35 ml of deionized water or aqueous calcium carbonate ($CaCO_3$) suspensions (0.25 to 12 mmol/kg). Five treatments with three replicates each were used with each soil. The most concentrated $CaCO_3$ suspension was a molality calculated to completely neutralize soil acidity (100% or greater base saturation). Aliquots of the $CaCO_3$ suspensions were added to the soil samples from a repipet dispenser. The aqueous soil/solution mixtures were reacted for 24 hours on a reciprocating shaker.

The soil suspension equilibrium pH values were determined immediately after the 24-hour reaction period. Each tube was shaken by hand for approximately five seconds immediately before measuring the pH value. The tip of the combination electrode was positioned in the supernatant approximately 1 cm above the surface of the settled soil.

The aqueous and solid portions of each mixture were separated immediately after the completion of pH measurements by centrifugation at 20,000 g for 20 minutes. A subsample of approximately 10 ml of the supernatant was taken for alkalinity determination. Another subsample was diluted for dissolved calcium analysis by atomic absorption spectrophotometry (AAS). Total alkalinity was determined by titration with 0.0176N HCl using a Radiometer ABU 80 Autoburette and Radiometer PHM 64 Research pH Meter. Dissolved calcium was determined on a Perkin-Elmer 5000 atomic absorption spectrophotometer. Base saturation (soil) and total hardness (water) values were calculated from the supernatant calcium concentrations obtained by AAS.

Results

Calcium carbonate neutralization experiments were carried out on 32 of 39 available soils. Physical and chemical data for the soils will be included in our final report. The soils are being grouped according to organic matter content, texture, and the activity of the clay fraction (in soils with > 35 % clay). When grouping is complete, curves will be fit to the data (e.g., $CaCO_3$ applied vs. alkalinity), providing a means for calculating the amount of $CaCO_3$ required to achieve desired results (e.g., specific levels of water alkalinity or soil pH) in ponds on particular soil types.

The total amount of $CaCO_{3(s)}$ necessary to elevate the soil solution or pond water alkalinity to desired levels is a function of the total stored acidity in the soil. The soil acidity is a function of a suite of physical and chemical variables including texture (clay percent), mineralogy (kaolinite, smectite, etc.), organic C content, native soil pH values, CEC, and base saturation.

Graphs of the solution alkalinity as a function of $CaCO_3$ added are shown in Figures 1 and 2 to demonstrate the relationship between stored acidity and soil alkalinity for several of the soils tested. Our final report on these experiments will include data for all the soils, as well as information regarding other chemical relationships observed in the soil-water systems (e.g., the relationship between $CaCO_3$ added and soil pH).

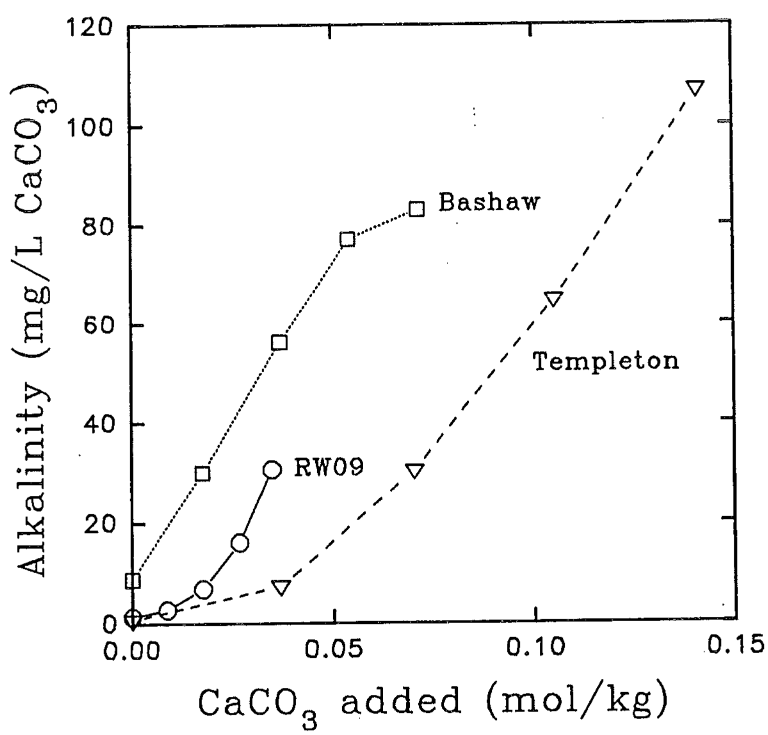

Figure 1. Solution alkalinity as a function of calcium carbonate added for several mineral soils treated in the laboratory. Bashaw and Templeton are clayey soils from Oregon and RW09 is a clayey soil from the Rwasave Station in Rwanda.

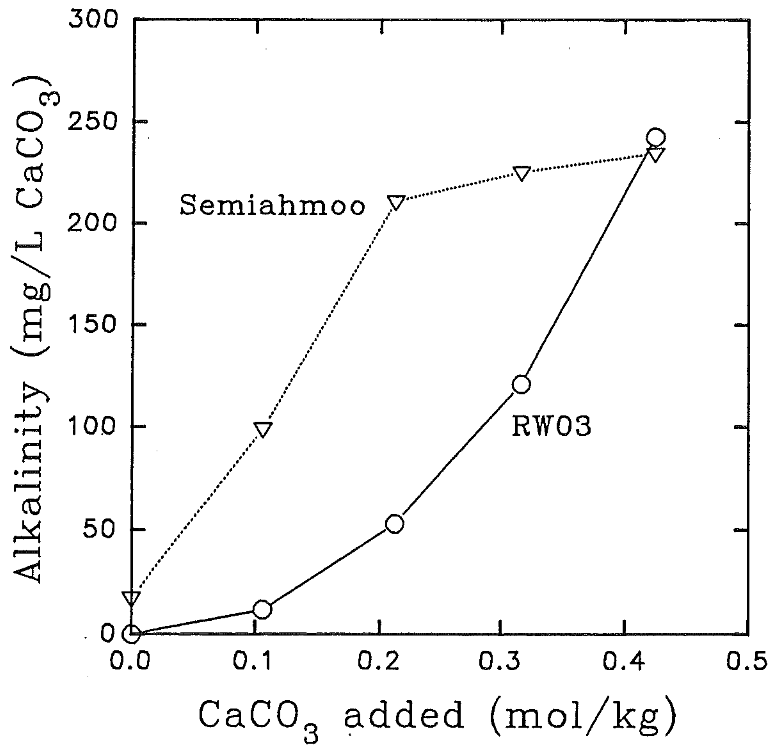

Figure 2. Solution alkalinity as a function of calcium carbonate added for two organic (peat) soils treated in the laboratory. Semiahmoo is an Oregon soil and RW03 is a soil from Rwanda.

Anticipated Benefits

The results of these experiments should prove useful to aquaculturists working to maintain minimum alkalinity levels in ponds on different types of acid soils.

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Diel Cycles of Planktonic Respiration Rates in Briefly Incubated Water Samples from a Fertile Earthen Pond

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Introduction

Daytime respiration in planktonic communities is an important component of metabolic and ecosystem materials budgets because it is critical to the distinction between gross and net primary production (Bender et al. 1987, Weger et al. 1989). Its estimation is essential to the study of dissolved oxygen mass balances through diel cycles, for purposes such as predicting the overnight depletion of dissolved O_2 (Giovannini and Piedrahita 1990, Madenjian 1990). Respiration may also be used to index microbial biomass (Costa-Pierce et al. 1984) or general water quality (e.g., biochemical oxygen demand).

Estimating daytime respiration (dR), and thus distinguishing gross primary production (GPP) and daytime net primary production (dNPP), has been difficult without the stable-isotope techniques that have been used to resolve materials pathways and define respiration in lighted populations and communities (Bender et al. 1987, Weger et al. 1989). These authors have reviewed the specific difficulties inherent in carbon-14 and other light- and dark-bottle methods. Free-water methods, which obtain net rates of change by assaying sequential water samples for oxygen or carbon dioxide, are inherently unable to resolve daytime respiration from photosynthesis (Odum 1956, Hall and Moll 1975). GPP is estimated with these methods only through extrapolations or assumptions about respiration.

Real-time assessment of daytime respiration in planktonic communities, in a form readily integrated with free-water observation of net rates, would improve the accuracy and applicability of the free-water approach to primary production estimates (Giovannini and Piedrahita 1990). We present here the results of automated frequent-interval assessment of water column community respiration in briefly incubated samples of pond water, with simultaneous measurement of free-water net changes in dissolved O_2.

Materials and Methods

Respiration was assessed as the rate of O_2 depletion in water samples of approximately 100 ml volume, automatically drawn from a pond and confined in an opaque plastic pipe apparatus for 21 minutes of each 30 minute interval through four diel cycles. Nighttime rates were compared with net changes in free water as a check on the method. Water was quickly confined, its light field (in this case darkness) rapidly set, and net changes in O_2 concentration recorded with a polarographic probe.

Observations were made in a freshwater earthen pond of 1600-m^2 surface area and 0.8-m depth at the University of Hawaii's Mariculture Research and Training Center on the windward coast of the island Oahu. The pond had been fertilized weekly with chicken manure and urea for about one year as part of an investigation of fish growth in fertilized, unfed ponds. A cohort of approximately 2000 hormonally sex-determined yearling males (Guerrero 1979) of a local strain of red tilapia (*Oreochromis mossambicus*) inhabited the pond.

A submersible pump (Rule 2000) was placed at a depth of 10 cm about 5 m from one corner of the pond. Once every 30 minutes the pump flushed and filled a plastic pipe receiver on the bank. The receiver consisted of a series of fittings and solenoid valves, providing a chamber for incubating and stirring the water sample, and ports for sensors which recorded water properties in a data logger (Campbell CR21X). The incubation chamber consisted of a 3.8-cm (i.d.) PVC plastic "tee" with its bottom arm blocked by a stopper; a magnetic stirring bar in the chamber was driven by a motor below the stopper. Dissolved O_2 concentration (by YSI 5739 polarographic probe) and temperature (by thermocouple) were recorded at the end of a 2-minute period of water flow; O_2 concentration was recorded every 3 minutes during the subsequent 21-minute incubation of trapped water. Oxygen consumption by the probe matched manufacturer's specifications; it was negligible compared with observed depletion and was not subtracted.

A weather station located about 150 m from the pond recorded air temperature, solar irradiance at λ = 400-700 nm (with a LiCor LI190SB quantum sensor), and wind speed at 0.5 m above water level (Met One). These parameters were recorded as means for 30-minute intervals. Samples for analysis of chlorophyll *a* were collected each day on duplicate 0.45 mm pore membrane filters and analyzed by fluorometry (Parsons et al. 1984).

Diel patterns of dissolved O_2 concentration were used to calculate net primary production and nighttime respiration by the method of Hall and Moll (1975), adapted for frequent-interval sampling. Net rates of change for each time interval were multiplied by the lengths of intervals to provide net production or respiration estimates, which were summed for day and night periods. Diffusion corrections based on wind speed and dissolved O_2 saturation were made to interval rates of change according to Banks and Herrera (1977).

Two 48-hour periods in August 1991 were evaluated.The second period began about three weeks after the first, when phytoplankton standing stocks (as chlorophyll *a*) had doubled from those of the first period, to approximately 80 mg /L. Vertical temperature profiles showed strong daytime density stratification (3 to 4°C between top and bottom). Detailed profiles presented by Szyper and Lin (1990) indicate that under such conditions water samples from a depth of 10 cm are little affected by mixing with other depths except during late night to early morning.

Results

All four diel cycles of dissolved O_2 concentration in pond water, and the depletion rates of the incubated samples, reflected the pattern of the example shown in Figure 1 (Day 2 of Period 1). During daylight, O_2 was depleted in incubated water samples at variable rates ranging from near 0 to 47 mmol/L (0-1.5 mg/L) per 21-minute period, in a linear pattern (small dots). Respiration rates are the slopes of these plots of concentration on time. After 1800 hours, with no photosynthetic O_2 production, depletion patterns in the incubation chamber generally tended toward the next free-water sample concentration (open circles), indicating that depletion rates in the chamber represented those in the pond. Exceptions may be attributed to convective mixing of surface water with water of other depths or locations (Szyper and Lin 1990). Nighttime values of incubation-derived respiration rates had a mean for all dates of 23.1 mmol O_2 /L/h (SD = 7.5), differing by less than 10% from mean nighttime free-water depletion rates (25.0 mmol/L/h; SD = 6.9); the difference is of marginal significance at a = 0.05 (t = 1.968, N = 186). Nighttime respiration rates were consistently smaller in absolute value than daytime rates.

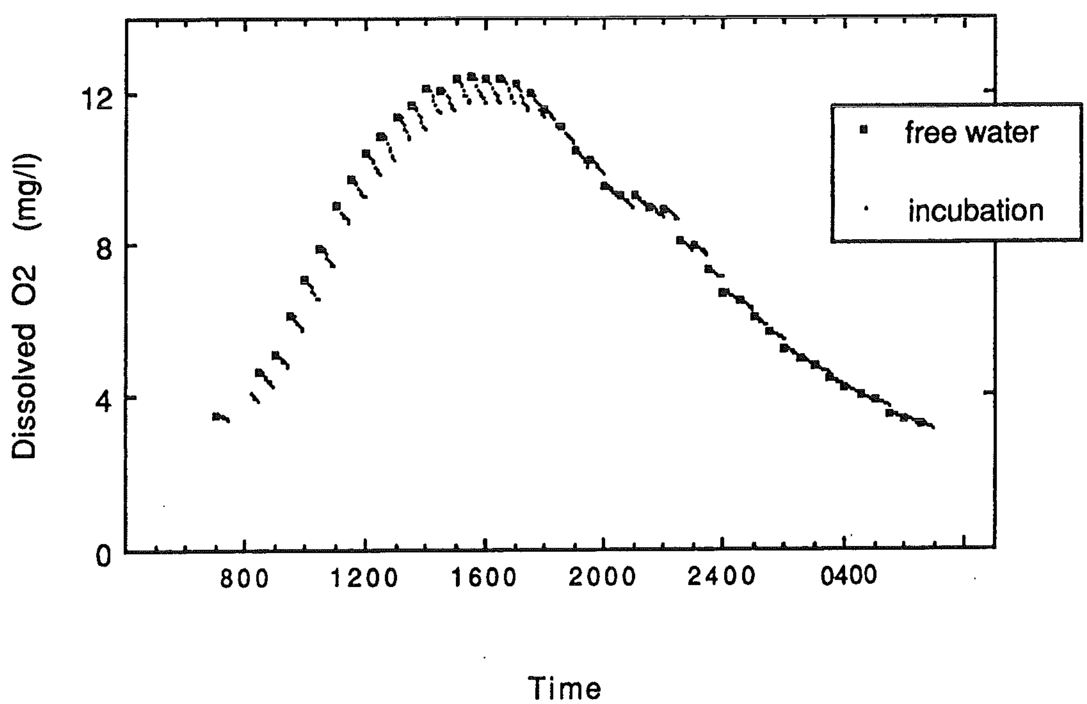

Figure 1. Concentration of dissolved oxygen in pond water and in the incubation chamber during a diel cycle.

Components of diel cycles of production and respiration are presented in Figure 2. Net rates of change, represented by open circles, are negative during night and some daylight hours. Daytime net primary production (dNPP) is the daytime sum of areas between the open circles and the horizontal axis (zero net change). The sloping lines underlying the daytime net rates represent the interpolated daytime respiration estimate recommended by Hall and Moll (1975) for situations when respiration is not measured. These lines connect dawn and dusk turning points in the trends of net rates. The ends of these lines are taken here to define the daytime period. This definition allows negative interval values of dNPP ($dNPP_i$) at low light levels (respiration exceeding DO production), and makes interval GPP (GPP_i) in this method (net change plus interpolated respiration) always equal to or greater than zero.

Respiration rates in the chamber (dark circles in Figure 2) generally followed net rates of change in free water during the nighttime period, as noted above. During the daytime, incubation produced generally greater rates (in absolute value) than the interpolation estimates. Daytime community respiration rates had an overall mean of 44.1 mmol O_2 /L/h (SD = 24.4), which exceeded the mean of the interpolated day rates (27.8 mmol/L/h, SD = 8.8) by 58%.

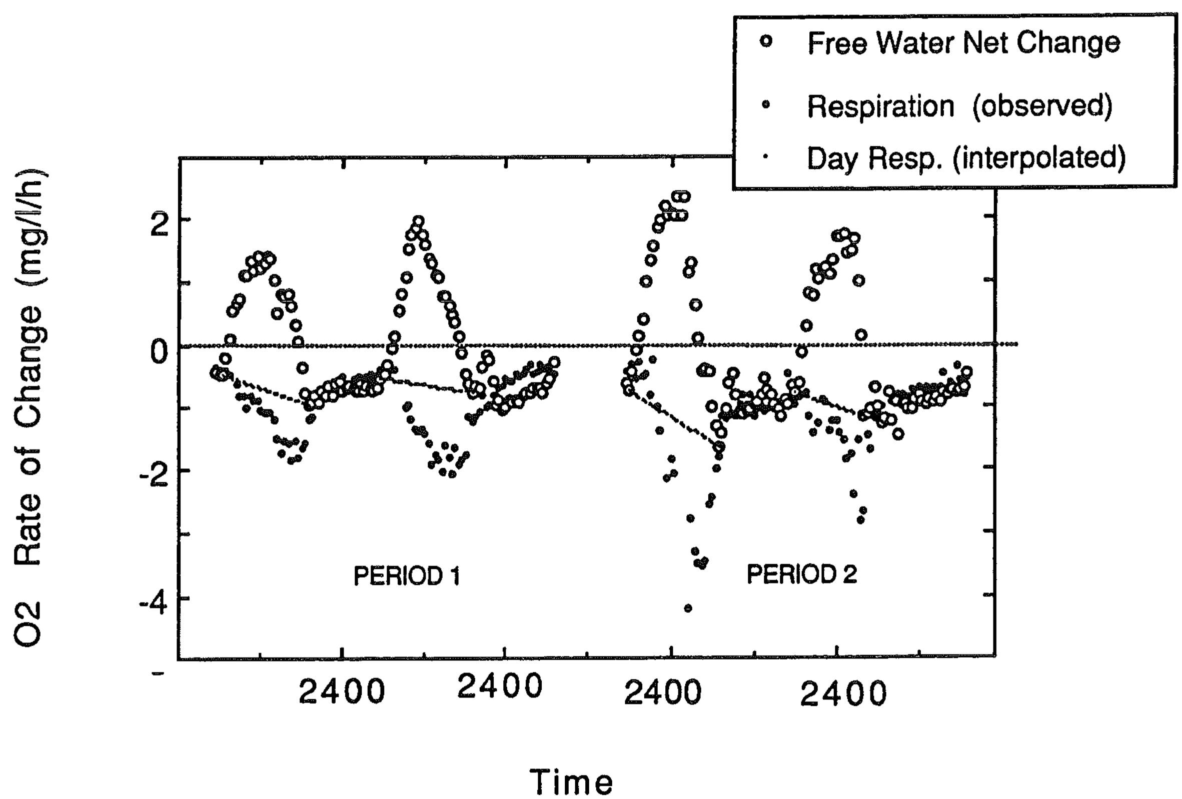

Figure 2. Components of production and respiration.

The areas between the open and dark circles during daytime represent GPP; comparison of the interpolated respiration lines and the dark circles shows the extent to which GPP would be underestimated without incubation experiments. GPP_i estimates made by adding observed respiration rates to net rates of change showed a few negative values during the defined daytime period, which were retained.

Respiration rates ranged from 3 to 134 mmol/L/h and varied in a diel pattern similar to patterns exhibited by light, temperature, and dissolved O_2 concentration. Maximum irradiance values occurred near noon; maxima for temperature and O_2 concentration lagged several hours behind that of light, as is typical, being greatest between 1500 and 1700 hours.

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VIII. PUBLIC SERVICE AND PROJECT DEVELOPMENT

Public Service

As Pond Dynamics/Aquaculture CRSP projects in developing countries become integrated into USAID's "country strategy," opportunities have arisen for providing support to scientific research institutions for training and for extending CRSP research results to the people of these countries. In each country project of the CRSP, researchers have recognized these opportunities and have assisted their counterparts in initiating appropriate activities. Although ancillary to the Global Experiment and site-specific studies, these activities contribute to institution building and increased food production, thereby furthering the main strategic approach. These activities also help to promote international scientific linkages through the exchange of technical information. As a result of these contributions, research capabilities have been substantially strengthened and private fish farming operations have been assisted in every developing country in which the CRSP has been active. Some of these important contributions are described below.

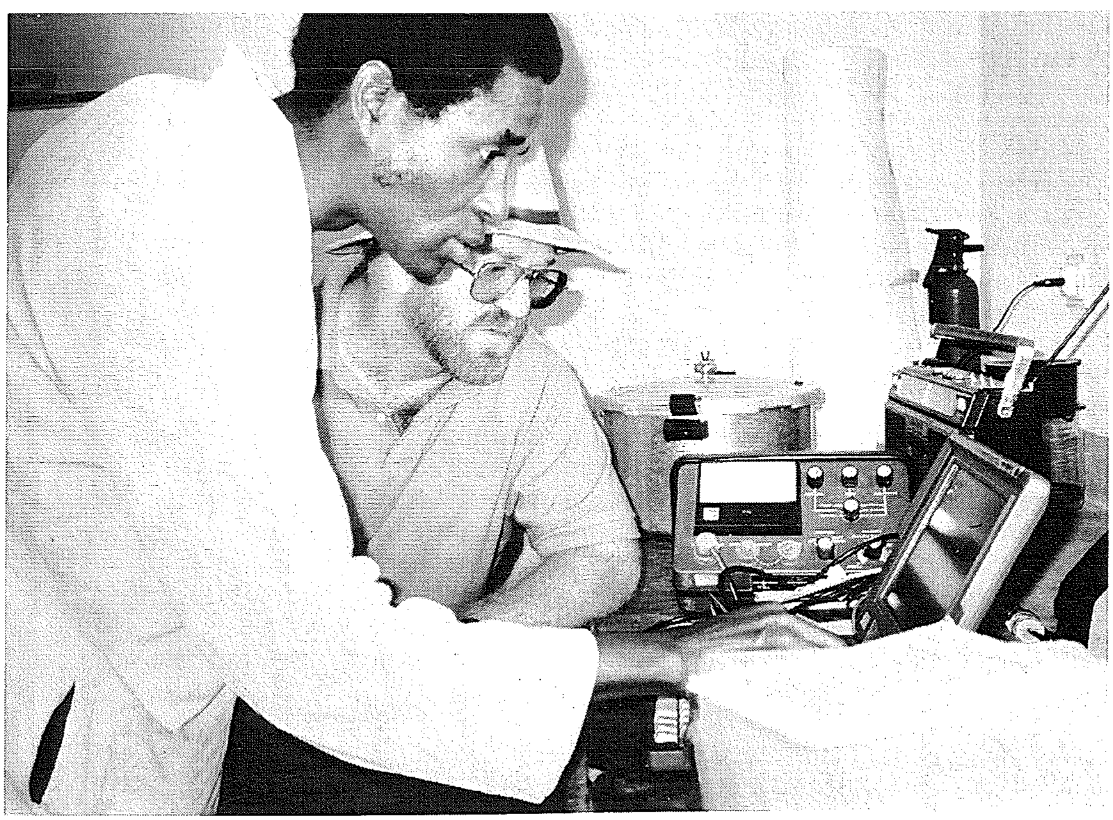
Institution Building

The research activity of the CRSP has resulted in major improvements to the research infrastructure of the collaborating host country institutions. In addition, CRSP scientists working in each country serve as advisors in the research programs of students at host-country universities and make contributions to curriculum development. In Rwanda, the Rwasave station has been officially designated a department in the School of Agronomy of the National University of Rwanda, the only research station so honored. CRSP Research Associate Karen Veverica serves as an advisor to the Ministry of Agriculture's Aquacultural Strategy Commission. The commission has recommended that the Rwasave Station be designated the coordinating center for all aquaculture research in Rwanda. The formats of CRSP work plans and technical reports have been adopted as models for Rwandan research proposals and research reports. In addition, CRSP researchers conduct short courses and teach at the University of Rwanda.

The Rwasave Station is now the premier water quality analysis laboratory in Rwanda. The station attracts funding from outside sources, including the European Economic Community, which has funded the construction of ponds and aquaria at the station. Fifty-one ponds are available for research, with surface areas ranging from 3.3 to 7 ares. The importance of the research station to Rwanda has been demonstrated by the level of support given CRSP researchers to carry out lab and field studies at a time when many other activities within the country have been severely constrained by internal political problems.

In Thailand, Chris Knud-Hansen again offered "Experimental Design and Analysis in Aquaculture," a statistics course that attracts many non-aquaculturists at AIT, as it is the only course offered in statistical analysis for research methods. Kevin Hopkins presented a seminar at AIT on "Methods for Screening Culture Systems," and lectured on methods for reporting fish growth. Hans Guttman, CRSP Research Assistant for the project in northeast Thailand, conducted a workshop for extension staff at the Department of Fisheries at Udorn Thani. Topics included water quality analysis, data interpretation and presentation, and experimental design and statistics. While in the Philippines, Kevin Hopkins also presented a seminar on reporting fish growth. Participants included members of the Freshwater Aquaculture Center and the Project on Genetic Improvement of Tilapia, (a genetics project concentrating on the production of YY "super males" through selective breeding of sex-reversed fish.)

El Carao, the CRSP research station in Honduras, is recognized by the Ministry of Natural Resources as the appropriate site for the national aquaculture program center. The "El Carao Method," a production regime for growing monosexed tilapia fingerlings in ponds enriched with chicken litter and urea, is currently disseminated to farmers and extensionists from the El Carao station. Farmers who buy fingerlings from the station receive a work plan outlining the El Carao method, along with enough guapote tigre fingerlings to eliminate unwanted tilapia reproduction. A model tilapia farm under construction in Villanueva will also assist in dissemination of the CRSP methodology. The farm is being funded by FEPROEXAAH, a Honduran trade association formed to promote non-traditional exports.



Training

Although training is not formally a component of this CRSP, the involvement of students from host countries and the United States constitutes an important part of the CRSP's international outreach. Informal training activities such as short courses and workshops are frequently conducted at the CRSP research sites or at other overseas locations (both in host countries and regionally) by CRSP researchers. Over 400 individuals have benefited from informal training activities since the beginning of the program; at least 75 individuals received training during this reporting period. Many additional individuals are known to have benefited through similar contacts with CRSP activities and scientists, even though their numbers were not recorded.

In Rwanda, Karen Veverica conducted a pond construction workshop for fish farmers from Matyazo. Although pond construction has traditionally been done by men, 60% of the workshop attenders were women, reflecting the CRSP's continued emphasis on facilitating women's participation in aquaculture. Veverica also conducted a seine management workshop, and a seine-making workshop that was attended by representatives of numerous non-government organizations. The CRSP funded two conferences at Rwasave during this reporting period. The first focused on managing tilapia production at high elevations, and was attended by ministry personnel, university professors and students, FAO personnel, Peace Corps volunteers, aquaculture station managers, model farmers, extension and training specialists, and CRSP trainees. The Colloquium on Rwanda Women in Aquaculture, offered by Revathi Balakrishnan of OSU in association with Veverica and Pelagie Nyirahabimana, was attended by women fish farmers, extension agents, scientists, and government officials. Peace Corps trainees from Burundi and the Congo also visited the Rwasave station to learn about composting rates, stocking rates, fish growth at different elevations, and pond sampling as a farmer training tool. Karen Veverica initiated a weekly seminar series at the Rwasave Station to discuss topics related to conducting and analyzing research. CRSP Research Associate Venantie Mukasikubwabo taught plant biology at the University of Rwanda, and Veverica supervised trainees at the Rwasave station. Anaclet Gatera, Rwasave station manager, completed the Aquaculture Training Program at Auburn University.

In Honduras, CRSP researchers conducted a short aquaculture training course and follow-up seminar for the twenty-two farmers and extensionists who participated in the on-farm trials of CRSP production systems. Claude Boyd presented a seminar on Management of Shrimp Pond Bottom Soils for 32 shrimp pond owners and managers in Choluteca.

Farmers have actively participated in the CRSP on-farm studies in Thailand. These studies will speed the extension of research results to the field. In Northeast Thailand, the CRSP supports the outreach efforts of AIT in providing the research component for an adaptive management system. As problems are identified through outreach activities they will be integrated into the CRSP research agenda.

Enthusiasm generated by such informal training and by exposure to activities at the CRSP research sites has led some students to pursue university degree programs, either at institutions in their own countries or at participating U.S. universities. Students have pursued degrees in at least seven overseas institutions and at all of the collaborating universities in the U.S.

Prior to this reporting period at least 105 degrees (B.S., M.S., and Ph.D.) were awarded, and during this period another three were completed. Over 70 theses have been completed under the direction of CRSP researchers. Theses completed during this period are:

- Franco, L.F. 1991. Nile tilapia (*Oreochromis niloticus*) production in tropical microcosms fertilized with rabbit excreta. M.S. Thesis, Oregon State University, Corvallis, Oregon.
- Nath, Shree. 1992. Total and available nutrients in manures for pond aquaculture. M.S. Thesis, Oregon State University, Corvallis, Oregon.
- Bowman, J.R. 1992. Classification and management of earthen aquaculture ponds, with emphasis on the role of the soil. Ph.D. Dissertation, Oregon State University, Corvallis, Oregon.

The number of individuals involved in all forms of training, from non-degree activities through work on advanced degrees, has climbed to well over 400 since the beginning of the program. Most of the trainees have come from PD/A CRSP host countries (Panama, Philippines, Indonesia, Honduras, Thailand, and Rwanda); however, the benefits of CRSP-related training have extended well beyond the borders of the six collaborating countries, as evidenced by the fact that participants have been drawn from at least 25 countries over the course of the program. The interdisciplinary nature of aquacultural research attracts students from a wide range of academic disciplines. Many participants take positions in schools, banks, agricultural research institutes, national parks services, development projects, and agricultural extension services, where they are able to increase public awareness of aquaculture's importance in food systems.

Linkages

The CRSP ties with the International Center for Living Aquatic Resources Management (ICLARM) have been strengthened this year with the appointment of Roger Pullin to the External Evaluation Panel. The renewal of the CRSP presence in the Philippines has afforded the opportunity for CRSP and ICLARM scientists to collaborate more closely. Plans are underway to develop a handbook of aquacultural research techniques. This handbook is an outgrowth of the CRSP work plans, and will address a need identified by CRSP scientists in the early stages of the program—to establish standardized techniques for use in aquacultural research worldwide. In the future, data from the CRSP Central Data Base will be added to ICLARM's data base.

The CRSP has established and maintained important linkages with other organizations involved in aquacultural and agricultural research and development. Michigan State University (MSU) serves as the North Central Regional Aquaculture Center (NCRAC) under a grant from the U.S. Department of Agriculture Cooperative State Research Service. MSU was identified as the lead university for the NCRAC largely because of its long-standing involvement in the PD/A CRSP. The CRSP also maintains close ties with the International Center for Aquaculture (ICA), in Auburn, Alabama through Auburn University's involvement in the CRSP.

Members of the Data Synthesis and Analysis Team (DAST) at the University of California, Davis (UCD), Hawaii's Mariculture Research and Training Center and the Hawaii Institute of Marine Biology to evaluate data collected from Hawaiian research ponds using CRSP models. Such collaborative work not only provides additional data for validating CRSP models, but also extends the usefulness and applicability of CRSP models and research efforts.

In Rwanda, the CRSP advises the USAID/Kigali Mission and the Natural Resources Management Project on natural resource issues. CRSP researchers also advise the Ministry of Agriculture's Aquaculture Strategy Commission in establishing research priorities and in proposing suitable research/extension linkages. This commission has recommended that the Rwasave Station coordinate all aquaculture for Rwanda, and that the CRSP work plan and technical report format be adopted for presenting research proposals and reporting research results. The CRSP's success in supporting women in fish farming has attracted additional funding to study women's participation. The Program and Project Coordination/Women in Development (WID/PPC) and the Kigali Mission are supporting the study of women's participation in fish farming; the results will help improve and extend support services to women fish farmers. The European Economic Development fund has also made major contributions to the Rwasave station for the construction of facilities, support of extension personnel, and support of technical publications.

In Honduras, researchers have collaborated with the newly formed Sustainable Agriculture and Natural Resources Management (SANREM) CRSP in developing a research agenda to address Honduran farmers and fishermen's concerns about the land and water degradation resulting from inadequate soil conservation and excessive pesticide use. CRSP researchers served as consultants for Peace Corps volunteers on the formation of a computerized data base for recording and analyzing the Peace Corps aquacultural activities in Honduras. The CRSP maintains ties with numerous other organizations. These include:

African Aquaculture Society
Africa Development Bank
Board for International Food and Agricultural Development and
  Economic Concerns (BIFADEC), Washington, D.C.
Boy Scouts, Rwanda

CARE, Honduras
Catholic University of Leuven (CUL), Belgium, Rwanda
Central Luzon State University, Freshwater Aquaculture Center, Philippines
Consultative Group on International Agricultural Research (CGIAR), Washington , D.C.
Department of Aquaculture (DINAAC), Panama
Department of Fisheries, Udorn Thani, Thailand
Department of Renewable Natural Resources (DIGEPESCA), Honduras
Escuela Agricola Panamericana, Honduras
Fish Culture Research Institute, Szarvas, Hungary
Food and Agriculture Organization of the United Nations (FAO), Rome, Italy
Freshwater Aquaculture Center (FAC), Philippines
Gondol Research Station, Ensenada, Mexico
Honduran Federation of Agricultural and Agroindustrial Producers and Exporters (FEPROEXAAH)
INSORMIL CRSP, Honduras
Institut Pertanian Bogor (IPB), Indonesia
International Development Research Centre (IDRC) of Canada, Malaysia
International Rice Research Institute (IRRI), Philippines
International Center for Aquaculture (ICA), Auburn University, Alabama
International Center for Living Aquatic Resources Management, Philippines
J.F.K. Agricultural School, Honduras
National Agricultural Library, Washington, D.C.
National Association of Honduran Aquaculturists (ANDAH)
National Inland Fisheries Institute (NIFI), Thailand
National Marine Fisheries Service (NMFS), La Jolla, California
National Technical Information Services, Springfield, Virginia
North Central Regional Aquaculture Center (NCRAC). E. Lansing, Michigan
Peace Corps, Honduras, Thailand, Burundi, Rwanda
Red Cross, Rwanda
Sustainable Agriculture and Natural Resources Management (SANREM) CRSP
Special Program for African Agricultural Research (SPAAR), Washington, D.C.
The University of the Philippines in the Visayas
Western Regional Aquaculture Consortium (WRAC), Seattle, Washington

Project Development

New Areas of Emphasis for the CRSP

Sensitivity toward the environment and appreciation of the need for sustainable agriculture have always been characteristic of the PD/A CRSP. Worldwide attention is now focusing on sustainable development to meet the needs of the present without compromising the ability of future generations to meet their own needs. This year, the CRSP helped in natural resource policy development and implementation at several sites. Women play a pivotal role in agricultural production and family nutrition, and the CRSP has taken an active role in encouraging women in aquaculture. Transfer of successful and appropriate technology continues to take place, as the private sector capitalizes on CRSP research. Models and guidelines developed by CRSP researchers are being used in directing on-farm trials, the "acid-test" of new techniques and technologies. Finally, the CRSP approach recognizes that new technology does not operate in a vacuum; socioeconomic studies to analyze optimal resource use are part of the research plan.

Natural Resource Management

As environmental concerns motivate the creation of more sustainable agricultural systems worldwide, aquacultural production will continue to fill an important niche. Pond production of animals and plants is an important component of integrated agricultural systems in several ways. Aquaculture ponds provide an efficient means of conserving water in areas where water supplies are limited. Further, effluent from ponds need not be dumped directly into natural waterways, but can be used for crop irrigation. Pond mud—often high in organic matter and rich in nutrients—can be partially removed and used as a fertile soil additive for land crops. Aquaculture is easily integrated with other forms of agricultural production, such as chicken-fish and duck-fish operations. Farm by-products such as manures, grasses, inedible plant parts, and composts can be used as nutrient sources in aquaculture ponds. CRSP research at all sites continues to emphasize efficient utilization of these agricultural by-products to enhance production in ponds, and to contribute to sustainability by recycling farm materials.

Karen Veverica provided substantial input for a study required for implementation of the USAID-funded Natural Resources Management Project, which was jointly funded by the USAID Mission in Kigali and Auburn University's Program Support Grant. Collaborative research in integrated agriculture-fish culture systems has been undertaken with Belgian researchers and with the International Development Research Centre (IDRC). The on-farm polyculture studies in Rwanda help farmers to identify environmentally appropriate pond management techniques, determined in this case by the altitude of the pond site. CRSP researchers assisted USAID/Honduras and ECOLAGO, a private Honduran foundation, in assessing lake fisheries in Lake Yojoa, and in Thailand, CRSP researchers contributed to the curriculum of the AIT Natural Resources Program.

CRSP experiments in Honduras addressed water quality issues, which are of concern not only in ponds during the production cycle, but also as effluents leave ponds and are returned to the larger ecosystem. Experiments continue in Honduras and Thailand to determine the most efficient level of nutrient input so farmers can manage fertilizer use to ensure optimal fish production without pollution. CRSP scientists at all sites share a concern for the wider environment and the effects of aquacultural production on it. Environmental concerns must be given highest priority in all countries, whether temperate or tropical, lesser-developed or highly developed, as researchers attempt to find improved techniques for meeting the nutritional needs of a rapidly growing world population.

CRSP scientists are also involved in research geared toward increasing food production using indigenous fish species. For example, in Honduras researchers have included *Cichlasoma maculicauda*, a native cichlid, in studies of feeding rations and aeration. In Thailand researchers have studied environmentally-induced ovarian development and hatchery techniques for fry production of the walking catfish, *Clarius batrachus*. Species such as *C. batrachus* are suitable for aquaculture and can contribute greatly to overall food production because they are already well-known, desired food fish and are hardy. This hardiness makes it possible for farmers to stock and grow them at relatively high densities or in oxygen-poor water; it also means that the fish can be marketed *live*, an important factor to consumers in many regions. Using indigenous species wherever possible reduces potential risks to ecosystems which may result from the indiscriminate use of exotic species.

Women in Development

Over one quarter of the fish farmers in Rwanda are women. Many of them benefit from CRSP management strategies using low-cost agricultural waste to enhance pond productivity, which increases family income and improves household nutrition. Sixty percent of those attending at a CRSP-sponsored pond construction workshop were women, although pond construction traditionally has been done by men. The Director General of the Ministry of Agriculture of the Government of Rwanda acknowledged the importance of women fish farmers in his closing remarks to the Colloquium on Rwanda Women in Aquaculture. The Colloquium was jointly sponsored by USAID's Women in Development Office, the Kigali Mission, and the CRSP, for the purpose of documenting and extending the success of the CRSP to other sites. The Colloquium and the subsequent case studies identified ways of increasing extension support to include women, and to address the issues deemed most important by women fish farmers. The socioeconomic study described below also noted that women fish farmers face additional constraints, including lack of access to land and to extension services. The impact of fish farming on household nutritional status and economic welfare was also addressed. Women from eleven countries have been involved in CRSP-related training or other educational activities since the inception of the program, and account for more than 25% of all training that has occurred because of the CRSP's existence.

Private Sector Involvement

The Rwasave Fish Culture Research Station in Rwanda has become self-supporting, using funds generated from the sale of fish, pork, produce, and water quality laboratory services. The laboratory now regularly contracts for soil and water analyses, and is becoming a major analytical center for newly implemented sewage treatment plants. CRSP researchers also advise private and communal farms on integrated fish farming, and collaborate with private farmers in conducting on-farm trials of techniques developed at the CRSP research site.

The El Carao Research Station in Honduras has also become almost completely self-supporting through the sale of fingerlings to local fish farmers. The shortage of fingerlings in the area, though problematic in the short run, indicates the enthusiasm with which aquaculture is being embraced by local farmers. The potential for aquaculture is recognized both by USAID/ Honduras and the private sector. Although bananas and coffee are now the top two export crops of Honduras, it is expected that aquaculture crops will eclipse them in the near future. CRSP research will likely be expanded as the industry grows, to support efforts to resolve environmental and production problems. The CRSP has helped create the groundwork for much of the institutional capability of the tilapia industry. As an example, the tilapia production technical advisor for FEPROEXAAH and the managers of numerous farms in the north have all received their training through the CRSP. The industry is benefiting from baseline data that have been established and groundwork that has been laid through ten years of CRSP research and training. The FEPROEXAAH demonstration farm now under construction will serve as a model production farm, disseminating the "El Carao" method of tilapia production developed by CRSP researchers at the El Carao station. In the south, ANDAH has requested CRSP research assistance on issues of water quality that affect production and environment, and in analyses of data on native larvae. ANDAH has made sizeable contributions toward initiating a research site in Choluteca through a self-assessed charge on each pound of exported shrimp, and has committed funds and in-kind contributions for the future as well. In addition to the private sector support, the Government of Honduras is donating the facility at the Lujosa Agricultural Experiment Station, as well as the salaries for a biologist and a technician.

CRSP research findings do not benefit only host country producers. The four-fold growth of aquaculture during the eighties makes it the fastest growing segment of U.S. agriculture, and its full potential has not yet been reached (USDA Aquaculture Situation and Outlook, March 1991). With per capita seafood consumption rising, and capture fisheries in decline, world aquaculture production will have to triple by the year 2000 to keep pace with demand. Aquaculture expansion will probably become pronounced in the South and Southeast, where farmers searching for new cash crops are expected to convert more agricultural land to aquacultural production. Water quality and water conservation, key issues addressed by CRSP research, will be critical in the further development of the aquaculture industry in these regions.

Socioeconomic Studies

Socioeconomic studies have taken on increasing importance. In Rwanda, a study is underway to compare the economics of resource utilization in aquaculture to that of other agricultural crops. As a result, farmers will have another tool to use in determining how to use their scarce resources most productively. In Honduras, varying nutrient input regimes were analyzed for economic optimization, and the methodology was shared with farmers participating in on-farm trials. Such information is important to fish farmers, as the most economically efficient production method (i.e., highest net profit) does not always result from the greatest biological production (i.e., highest gross yield). In Honduras, for example, the prevailing interest rate had a significant impact on the economic viability of production systems.

Participation in International Scientific Meetings and Conferences

CRSP scientists continue to maintain contact with the wider aquaculture community and share the results of their research through participation in scientific meetings and conferences.

- Chris Knud-Hansen, Kevin Hopkins, and Jim Szyper attended the Third International Symposium on Tilapia in Aquaculture in Abidjan, Côte d'Ivoire, 11-16 November 1991. Knud-Hansen presented a paper co-authored by C. Kwei Lin, "Strategies for stocking Nile tilapia (*Oreochromis niloticus*) in fertilized ponds." Szyper presented "Effects of pond depth and mechanical mixing on production of *Oreochromis niloticus* in manured earthen ponds," co-authored by Hopkins.

- Jim Szyper attended the meeting of the American Society of Limnology and Oceanography in Santa Fe, New Mexico, in February. He presented a poster on "Diel Cycles of Respiration Rates in Briefly-Incubated Water Samples from a Fertile Pond," co-authored by Raul Piedrahita and Phil Giovannini.

- Hillary Egna and Marion McNamara participated in International Centers Day in Washington DC in October 1991.

- Revathi Balakrishnan presented the Report of the Colloquium on Rwandan Women in Fish Farming at the Farming Systems Research Conference held September 1992 in East Lansing, Michigan.

- Balakrishnan, Egna, McNamara, Joyce Neumann and Mike Skladany attended the CRSP Council Social Sciences Workshop in Lexington, Kentucky in June 1992. David Acker of OSU also attended as an invited speaker, and gave a presentation entitled "Issues of Developing Effective Researcher-Extension-Farmer Linkages for Technology Transfer."

- The following papers were presented by CRSP researchers at the World Aquaculture Society meeting in Orlando, Florida in May 1992.

  Knud-Hansen, C.F., and A.K. Pautong. The role of urea in fishpond fertilization.
  Knud-Hansen, C.F., and H. Guttman. Fish pond management by algal assay. Poster presentation.
  Szyper, J.P., L.Z. Rosenfeld, R. Piedrahita, and P. Giovannini. Diel cycles of respiration rates in briefly-incubated water samples from a fertile earthen pond.
  Culberson, S.D., and R.H. Piedrahita. Modification of stratified temperature model to accommodate reduced data inputs: Identifying critical requirements.
  Brune, D.E., C.M. Drapcho, and R.H. Piedrahita. Pond oxygen dynamics: Design and management strategies.

- In addition to those presenting papers, the following researchers attended the WAS meeting: Bart Green, David Teichert-Coddington, Karen Veverica, Jean Damascene Bucyanandi, Ted Batterson, Kevin Hopkins, Kitjar Jaiyen, and C. Kwei Lin.

VIII. PROGRAM MANAGEMENT AND TECHNICAL GUIDANCE

The basic organizational structure of the Pond Dynamics/Aquaculture CRSP remained the same as in previous years, although new appointments were made to the Management Entity, the Technical Committee, and various advisory bodies.

Management Entity

Oregon State University is the Management Entity (ME) for the Pond Dynamics/Aquaculture CRSP and is the primary grantee of USAID. The Program Management Office (PMO) is the operational component of the ME. The PMO is the link between USAID and the CRSP projects, which are organized through subcontracts to two U.S. universities and the Consortium for International Fisheries and Aquaculture Development (CIFAD). The PMO is located in the Office of International Research and Development (OIRD) on the main campus of Oregon State University, in Corvallis, Oregon. This location within OIRD affords the Management Office support in accounting, purchasing, and other services. The Management Entity is fully integrated into the larger framework of international agricultural programs at Oregon State University and derives benefits from interacting with these programs. The CRSP, formerly part of the Department of Fisheries and Wildlife in the College of Agriculture, now reports directly to the Vice President for Research, Graduate Studies, and International Programs through the Assistant Vice President for International Research and Development. Ties to the Department of Fisheries and Wildlife are maintained through faculty appointments, academic interests, and research subcontracts.

The Program Management Office provides executive linkage between the Management Entity and operations under the CRSP. During this reporting period, members of the Program Management Office included:

- Hillary S. Egna, Director (1.0 FTE)
- Marion McNamara, Assistant Director (1.0 FTE)
- Hilary Berkman, Data Base Manager (0.4 FTE to 3/92; 0.5 FTE from 4/92)
- Naomi Weidner, Secretary (0.5 FTE, on leave 6/92-6/93)
- Nancy Astin, Secretary (0.5 FTE, temporary replacement for Naomi Weidner through 5/93).

The Management Entity (ME) is responsible for:

- Receiving funds committed by USAID to the CRSP and assuming accountability for their use;
- Providing funds to the participating institutions, and ensuring compliance with the terms of the Grant;

- Providing a focal point for the interaction of the Technical Committee, Board of Directors, External Evaluation Panel, USAID staff, and BIFADEC/JCARD;
- Executing the decisions of the governing and advisory bodies;
- Implementing the program; and
- Maintaining liaisons with overseas and domestic participants.

The PMO is also responsible for communications, publications, and management of the CRSP Central Data Base.

Specific accomplishments include:

- Preparation of CRSP budgets and subcontractual modifications for extending funding and performance periods;
- Coordination of new administrative and contractual details for collaborative research projects in Thailand, the Philippines, Rwanda, and Honduras;
- Site visit to Egypt with a cross-CRSP team to follow up on proposal for a collaborative aquaculture research project with Egypt under the National Agricultural Research Project (NARP);
- Coordination of planning and logistics for the External Evaluation Panel review, including appointment of new EEP members and development of EEP Scope of Work;
- Organization of the tenth annual CRSP meeting in Orlando, Florida from18-20 May 1992, and participation in attendant Board Meetings and Technical Committee meetings;
- Development of questionnaires for evaluating the Annual and Technical Committee meetings, and for coordinating meeting logistics to better enable host country participants to attend;
- Assistance in processing travel clearances for CRSP personnel and approvals for purchases of restricted goods for country projects;
- Addition of all data from the Fourth Work Plan to the CRSP Central Data Base;
- Coordination of CRSP Data Base review;
- Publication of research results in technical report series;
- Preparation, publication, and distribution of detailed quarterly reports summarizing technical and administrative progress;
- Preparation, publication, and distribution of a Manual of Policy and Operating Procedures for the PD/A CRSP;
- Coordination of production for the *Handbook of Analytical Methods*
- Initiation and implementation of a peer review for PONDCLASS, the DAST-developed pond management expert system software and users' manual for personal computers;
- Submission of CRSP publications to National Agricultural Library for inclusion in the CD-ROM data base;
- Submission of data from the Central Data Base for inclusion in the National Agricultural Library computer network;

- Maintenance of the CRSP mailing list, which reaches over 300 people in 35 countries;
- Maintenance of the CRSP directory, which lists participants' addresses, telephone numbers, and electronic mail codes (e.g., FAX, BITNET, TELEX, MCI);
- Organization of and participation in Board Meetings and Technical Committee meetings;
- Attendance at the Consultative Group on International Agricultural Research (CGIAR)-sponsored International Centers Day, 23 October 1991.

In addition, the PMO contributed to the following CRSP Council activities:

- CRSP Council Conference Calls on:
  2 July 1992
  11 August 1992
  3 October 1991
- Presentations to Congress, the United States Department of Agriculture, the National Science Foundation, the Environmental Protection Agency, and USAID, March 1991;
- Development of By-laws and MOU for CRSP Council;
- Full meeting of the CRSP Council in Washington DC, 11 through 13 Dec; and
- CRSP Council Social Sciences Workshop, Lexington, Kentucky.

Three advisory groups support the management of the CRSP— a Board of Directors (BOD), a Technical Committee (TC), and an External Evaluation Panel (EEP). These groups work closely with the PMO to guide the CRSP through policy decisions, budget allocations, research strategy, review, and evaluation.

Technical Committee

Technical guidance is provided by a Technical Committee composed of the Principal Investigators of CRSP Research Projects and at-large members appointed by the Board of Directors. The Technical Committee has four standing subcommittees: Work Plans, Materials and Methods, Budgets, and Technical Progress. Special committees are convened as needed. The Technical Committee convened a Data Base Evaluation Committee which recommended future directions of the CRSP Central Data Base to the Board of Directors and the full Technical Committee at the tenth Annual Program Meeting. The membership of the Technical Committee and subcommittees is presented in Table 1.

Table 1. Membership of the Technical Committee and subcommittee assignments.

Name	Institution	Subcommittees[1]
Principal Investigators (Voting Members)		
Ted Batterson	Michigan State University	
Claude Boyd	Auburn University	M
Jean-Damascéne Bucyanayandi	National University of Rwanda	W
Jim Diana	University of Michigan	T, EP
Peter Edwards	Asian Institute of Technology, Thailand	
Carole Engle	University of Arkansas at Pine Bluff	
Ricardo Gomez	DIGEPESCA	T
Kevin Hopkins, Chair	University of Hawaii	M
Jim Lannan	Oregon State University	T
Raul Piedrahita	University of California, Davis	M*, EP
Tom Popma, Secretary	Auburn University	W
Wayne Seim	Oregon State University	B*
Non-Voting Members		
John BahamΔ	Oregon State University	
Revathi BalakrishnanΔ	Oregon State University	
Jim BowmanΔ	Oregon State University	
Steve Culberson	University of California, Davis	
Bryan Duncan	Auburn University	
Bart Green	Auburn University	W, EP
Sompong Hiranyawat	National Inland Fisheries Institute, Thailand	
Chris Knud-Hansen	Michigan State University	
Kitjar Jaiyen	Thailand Department of Fisheries	
Kwei Lin	University of Michigan and AIT	B
Eduardo LopezΔ	Central Luzon State University	
Lucas Lopez	DIGEPESCA	
Joseph MolnarΔ	Auburn University	
Shree Nath	Oregon State University	
Pélagie NyirahabimanaΔ	National Fishculture Service, Rwanda	
Eugene Rurangwa	National University of Rwanda	
Bill Shelton	University of Oklahoma	
Jim Szyper	University of Hawaii	W*, M
David Teichert-Coddington	Auburn University	B
Sompote Ukkatawewat	National Inland Fisheries Institute, Thailand	
Karen Veverica	Auburn University	M
	Oregon State University	
<u>At-large Members</u>		
Donald Garling	Michigan State University	
George Tchobanoglous	University of California, Davis	
<u>Ex-officio Members</u>		
Hilary Berkman	Oregon State University, Management Entity	
Hillary Egna	Oregon State University, Management Entity	
Harry Rea	R&D/AGR, USAID	
Lamarr Trott	R&D/AGR, USAID	

[1] W=Work Plans; B=Budgets; T=Technical Progress; M=Materials and Methods; EP=Executive Panel

* Subcommittee Chairpersons

Δ Temporary Member of Technical Committee

Board of Directors

As the primary policy-making body for the CRSP, the Board of Directors takes an active role in program guidance. The Board is composed of three members, one of whom is elected chairman. Each of the participating institutions is represented on the Board. The USAID Program Manager for the PD/A CRSP and the CRSP Director serve as ex-officio members. All Board members function in the objective interest of the CRSP regardless of their institutional affiliation. During this reporting period, the Board members were:

- Dr. Robert Fridley, University of California at Davis, Chair:
- Dr. Philip Helfrich, University of Hawaii (CIFAD institution);
- Dr. R. Oneal Smitherman, Auburn University;
- Dr. Lamarr Trott, NMFS, RSSA to R&D/AGR, Ex-Officio Member;
- Ms. Hillary Egna, Oregon State University, CRSP Director, Ex-Officio Member.

The Board of Directors convened six times during this reporting period.

• 4 December1991	Telephone Conference Call
• 29 April 1992	Telephone Conference Call
• 18, 19, 20 May 1992	Orlando, Florida
• 18 August 1992	Telephone Conference Call

The Board of Directors is responsible for:

- Review of program budgets and allocation of funds to research projects and the Management Office;
- Recommendations to the Management Entity on budget allocations;
- Evaluation of the administrative and technical accomplishments of overseas research projects and U.S.-based research activities;
- Advice to the Management Entity on policy guidelines; and
- Review of the performance of the Program Director and Management Entity.

Specific accomplishments and recommendations made during this reporting period include:

- Approval of management and research budgets;
- Annual meeting agenda input and approval;
- Advice on international travel procedures;
- Guidance on efforts to strengthen the program;
- Participation by Chair in December meeting of full CRSP Council;
- Participation in the tenth annual program meeting in May 1992;
- EEP selection and input on EEP scope of work.

External Evaluation Panel

The External Evaluation Panel (EEP) is responsible directly to AID and BIFADEC for the review and evaluation of the technical progress of the CRSP. The panel is composed of impartial senior scientists who represent the major disciplines of the CRSP. During this reporting period, Drs. Richard Neal, National Marine Fisheries Service (NMFS), and Roger Pullin, International Center for Living Aquatic Resources Management (ICLARM), were appointed by the Board of Directors and approved by AID to serve on the EEP. Dr. Homer Buck, Illinois Natural History Survey, continued his service, attending the tenth annual meeting in Orlando, Florida in May 1992, and preparing the annual EEP review of the program.

CRSP Publications

The CRSP facilitates technology dissemination through its various publications. These publications reach a broad domestic and international audience. During this reporting period, the number of publications resulting from CRSP research continued to grow. Over 330 reports and theses have resulted from CRSP research worldwide.

The two publication series that were launched in 1987 have attracted many new readers. Over 300 people in more than 35 countries now receive our publications. These two publications highlight CRSP research on a variety of subjects related to aquaculture. *CRSP Research Reports* contains scientific papers written by CRSP researchers. The goal of *CRSP Research Reports* is to publish all research produced by CRSP activities, with the exception of research related directly to the Global Experiment. For this purpose, *Collaborative Research Data Reports* was created.

Collaborative Research Data Reports contains the results and data from the Global Experiment, along with interpretations of site-specific results. The first volume of *Collaborative Research Data Reports* is a reference for the series; it contains descriptions of sites and experimental protocols for the Global Experiment. Subsequent volumes focus on each research site separately by experimental cycle.

These two publications add to the information base that the CRSP has established over ten years. Other reports published by the CRSP Program Management Office include Annual Administrative Reports, Quarterly Reports, Program Grant Proposals, Work Plans, CRSP Directories, and Instructions for Data Entry. The *Handbook of Analytical Methods* compiled by the Materials and Methods Committee of the Technical Committee was also published through the Management Office.

A number of documents were prepared and disseminated during this reporting period. These are briefly described below. Reports of CRSP research that were *not* processed by the Program Management Office are listed in Appendix B.

Administrative Reports

Annual Administrative Report

Pond Dynamics/Aquaculture CRSP, Program Management Office. January 1992. Ninth Annual Administrative Report. Office of International Research and Development, Oregon State University, Corvallis, Oregon. 172 pp.

Quarterly Reports

Pond Dynamics/Aquaculture CRSP, Program Management Office. October 1991. Quarterly Report, July-September 1991, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 7 pp.

Pond Dynamics/Aquaculture CRSP, Program Management Office. January 1992. Quarterly Report, October-December 1991, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 8 pp.

Pond Dynamics/Aquaculture CRSP, Program Management Office. April 1992. Quarterly Report, January-March 1992, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 8 pp.

Pond Dynamics/Aquaculture CRSP, Program Management Office. July 1992. Quarterly Report, April-June 1992, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 11 pp.

Policy and Operating Procedures

Pond Dynamics/Aquaculture CRSP, Program Management Office. August 1992. Policy and Operating Procedures. Office of International Research and Development, Oregon State University, Corvallis, Oregon. 26 pp.

Manuals

Technical Committee of the Pond Dynamics/Aquaculture CRSP. Handbook of Analytical Methods. July 1992. Pond Dynamics/Aquaculture CRSP, Program Management Office. Office of International Research and Development, Oregon State University, Corvallis, Oregon. 142 pp.

Lannan, J.E. Users Guide to PONDCLASS©: Guidelines for Fertilizing Aquaculture Ponds. In press. Pond Dynamics/Aquaculture CRSP, Program Management Office. Office of International Research and Development, Oregon State University, Corvallis, Oregon.

Directory

Pond Dynamics/Aquaculture CRSP, Program Management Office. October 91 and June 92. CRSP Directory. Office of International Research and Development, Oregon State University, Corvallis, Oregon.

The CRSP Directory was updated twice during this reporting period, in October 1991 and June 1992. The directory contains an organizational chart and the addresses of current CRSP members from USAID, BIFADEC, USAID Missions, the CRSP Council, the External Evaluation Committee, Technical Committee, Management Entity, Board of Directors, and the

Collaborative Research Projects. The directory also contains electronic mail and FAX access codes.

Newsletters
With the emergence of the CRSP technical publications and quarterly reports, the relative need for a program newsletter has declined. *Aquanews* is an occasional publication. It serves to inform CRSP participants and others of program activities that are not of a technical nature. *Aquanews* contains information on meetings, travel of CRSP participants, and site visits. The Data Analysis and Synthesis Team publishes a quarterly newsletter with the goal of improving communication between the DAST and the Principal Investigators in the field. Additionally, the CRSP continues to take advantage of other vehicles for communication such as the USAID *Star* newsletter (of the Office of Agriculture's Bureau of Research and Development) and *BIFADEC Briefs*, both of which carried articles and photos provided by the PMO. In addition, the PMO contributes to the international newsletter at OSU. Improved communications among Collaborative Research Support Programs has resulted in exchanges between newsletters.

Technical Reports

CRSP Research Reports
Alvarenga, H.R. and B.W. Green. 1989. Produccion y aspectos economicos del cultivo de tilapia en estanques fertilzados con gallinaza. (Production and economic aspects of tilapia cultivation in ponds fertilized with chicken litter.) CRSP Research Reports 91-39, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon StateUniversity, Corvallis, Oregon. 1 p.

Engle, C.R. and M. Skladany. 1992. The economic benefit of chicken manure utilization in fish production in Thailand. CRSP Research Reports 92-45, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 8 pp.

Green, B.W. 1992. Substitution of organic manure for pelleted feed in tilapia production. CRSP Research Reports 92-46, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

Green, B.W. and H.R. Alvarenga. 1989. Effecto de diferentes tazas de aplicacion de gallinaza en la produccion de tilapia. (The effect of different application rates of chicken litter on tilapia production.) CRSP Research Reports 91-38, Program Management Office, Pond Dynamics/ Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

Green, B.W. and D.R. Teichert-Coddington. 1991. Comparison of two samplers used with an automated data acquisition system in whole-pond, community metabolism studies. CRSP Research Reports 92-47, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

Hopkins, K. and A. Yakupitiyage. 1991. Bias in seine sampling of tilapia. CRSP Research Reports 92-44, Program Management Office, Pond Dynamics/ Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

Knud-Hansen, C.F., C.D. McNabb, and T.R. Batterson. 1991. Application of limnology for efficient nutrient utilization in tropical pond aquaculture. CRSP Research Reports 92-43, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

Liu, K.M. and W.Y.B. Chang. 1992. Bioenergetic modelling of effects of fertilization, stocking density, and spawning on growth of the Nile tilapia, *Oreochromis niloticus* (L.). CRSP Research Reports 92-48, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

McNabb, C.D., T.R. Batterson, B.J. Premo, C.F. Knud-Hansen, H.M. Eidman, C.K. Lin, K. Jaiyen, J.E. Hanson, R. Chuenpagdee. 1991. Managing fertilizers for fish yield in tropical ponds in Asia. CRSP Research Reports 91-37, Program Management Office, Pond Dynamics/ Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 6 pp.

Piedrahita, R.H. 1991. Calibration and validation of TAP, an aquaculture pond water quality model. CRSP Research Reports 91-33, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

Piedrahita, R.H. 1991. Modeling water quality in aquaculture ecosystems. CRSP Research Reports 91-34, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

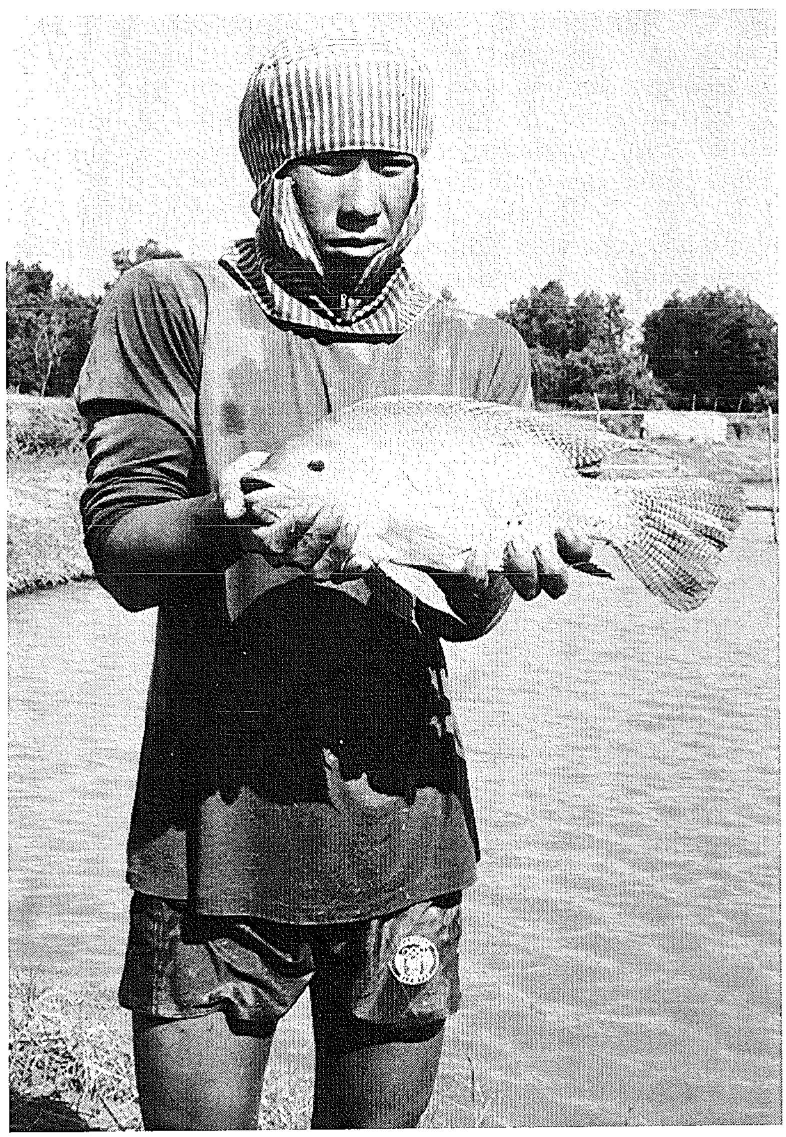
Piedrahita, R.H. 1991. Engineering aspects of warmwater hatchery design. CRSP Research Reports 91-35, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

Piedrahita, R.H. and P. Giovannini. 1991. Fertilized non-fed pond systems. CRSP Research Reports 91-36, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

Piedrahita, R.H. 1991. Simulation of short-term management actions to prevent oxygen depletion in ponds. CRSP Research Reports 92-41, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

Szyper, J.P., K.D. Hopkins, C.K. Lin. 1991. Production of *Oreochromis niloticus* (L.) and ecosystem dynamics in manured ponds of three depths. CRSP Research Reports 92-40, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.

Szyper, J.P., C.K. Lin. 1991. Techniques for assessment of stratification and effects of mechanical mixing in tropical fish ponds. CRSP Research Reports 91-31, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1 p.
Teichert-Coddington, D.R., B.W. Green, R.W. Parkman. 1991. Substitution of chicken litter for feed in production of Penaeid shrimp in Honduras. CRSP Research Reports 92-42, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research & Development, Oregon State University, Corvallis, Oregon. 1 p.



IX. STAFF SUMMARY

The Pond Dynamics/Aquaculture CRSP represents the joint efforts of more than 40 professional and support personnel from U.S. universities. It also represents the collaborative efforts of over 45 scientists, technicians, and graduate students from project sites in four host countries. The expertise of host country and U.S. personnel is broad-based and encompasses the major fields of specialization included in this CRSP: Limnology and Water Quality; Fisheries and Aquaculture; Soil Science; Sociology; Data Management, Analysis, and Modeling; Research Administration; and Agricultural Economics.

The major United States-based research activity, Data Analysis and Synthesis, involves eight researchers from the University of California at Davis and Oregon State University. Scientists from Auburn University, the University of Arkansas at Pine Bluff, Oregon State University, and the University of Hawaii also participate in additional U.S.-based research activities.

The CRSP regularly collaborates with other groups and institutions in the development of host country projects. For example, in northeast Thailand, the CRSP supports the outreach efforts of the Asian Institute of Technology by providing the research component for an adaptive management system. In Rwanda the CRSP researcher regularly meets with the Ministry of Agriculture's Aquaculture Strategy Commission to advise on establishing research priorities and in proposing suitable research-extension linkages. Researchers also meet with the USAID/Kigali Mission and the Natural Resources Management Project to advise on natural resource issues. Numerous private voluntary organizations take advantage of the training offered by the CRSP. Peace Corps Volunteers in Rwanda and Honduras consult regularly with CRSP researchers on project design and implementation. Private sector farmers in Honduras take advantage of CRSP expertise by attending seminars conducted by resident and visiting researchers. While these trainees are not formally part of the CRSP staff, they enhance the outreach ability of the CRSP by transmitting CRSP technologies and information.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Research Admin.	Field(s) of Specialization: Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	Location of Work (1)
BOARD OF DIRECTORS						
Robert Fridley	Chairman	X	X	X		Davis, California
Philip Helfrich	Member	X		X		Kaneohe, Hawaii
R. Oneal Smitherman	Member	X		X		Auburn, Alabama
AT-LARGE TECHNICAL COMMITTEE						
Donald Garling	Member			X		East Lansing, Michigan
George Tchobanoglous	Member			X		Davis, California
MANAGEMENT ENTITY						
Hillary Egna	Director	X	X	X		Corvallis, Oregon
Marion McNamara	Assistant Director	X				Corvallis, Oregon
Hilary Berkman	Data Base Manager		X	X	X	Corvallis, Oregon
Naomi Weidner ((to 6-92)	Secretary	X				Corvallis, Oregon
Nancy Astin (from 6-92)	Office Assistant					Corvallis, Oregon
DATA ANALYSIS AND SYNTHESIS TEAM						
DATA ANALYSIS AND SYNTHESIS TEAM - OREGON STATE UNIVERSITY						
James Lannan (2)	Principal Investigator	X		X	X	Newport, Oregon
Shree Nath	Graduate Student		X	X		Corvallis, Oregon

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.
(2) Personnel involved in two projects.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Research Admin.	Field(s) of Specialization: Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	Location of Work (1)
DATA ANALYSIS AND SYNTHESIS TEAM - UNIVERSITY OF CALIFORNIA AT DAVIS						
Raul Piedrahita	Principal Investigator		X	X	X	Davis, California
Steven Culberson	Research Assistant		X	X	X	Davis, California
Philip Giovannini	Post-Graduate Researcher		X	X	X	Davis, California
Zhimin Lu	Post-Graduate Researcher				X	Davis, California
George Max	Fiscal Officer	X				Davis, California
HONDURAS						
HONDURAS - AUBURN UNIVERSITY						
Bryan Duncan	U.S. Principal Investigator	X		X		Auburn, Alabama
Claude Boyd (2)	U.S. Researcher	X	X	X		Auburn, Alabama
David Teichert-Coddington	U.S. Research Associate	X	X	X		Comayagua, Honduras
Bartholomew Green	U.S. Research Associate	X	X	X		Auburn, Alabama
Donald Large (2)	Fiscal Officer	X				Auburn, Alabama
HONDURAS - HOST COUNTRY PERSONNEL						
Ricardo Gomez	H.C. Principal Investigator	X		X		Comayagua, Honduras
Luis A. Lopez	H.C. Research Associate			X		Comayagua, Honduras
Nelson Claros	H.C. Chemist		X			Comayagua, Honduras
Sagrario Calix	H.C. Secretary	X				Comayagua, Honduras
Miguel Zelaya	H.C. Lab Technician			X		Comayagua, Honduras
Myra Lara	H.C. Biologist/ Chemist			X		Comayagua, Honduras

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.
(2) Personnel involved in two projects.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Research Admin.	Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	Location of Work (1)
			Field(s) of Specialization			
RWANDA						
RWANDA - OREGON STATE UNIVERSITY						
Wayne Seim	U.S. Co-Principal Investigator	X	X			Corvallis, Oregon
Richard Tubb	U.S. Co-Principal Investigator	X	X	X		Corvallis, Oregon
Felicien Rwangano	Graduate Student			X		Corvallis, Oregon
Revathi Balakrishnan	U.S. Principal Investigator					Corvallis, Oregon
Robert Halvorsen	Fiscal Officer	X				Corvallis, Oregon
RWANDA - AUBURN UNIVERSITY						
Tom Popma	U.S. Principal Investigator	X		X		Auburn, Alabama
Karen Veverica	U.S. Research Associate		X	X		Butare, Rwanda
Claude Boyd (2)	U.S. Researcher	X				Auburn, Alabama
Mohammed Ayub	Cooperative Researcher	X				Auburn, Alabama
Joseph Molnar	U.S. Principal Investigator (Sociology)					Auburn, Alabama
Donald Large (2)	Fiscal Officer	X				Auburn, Alabama
RWANDA - UNIVERSITY OF ARKANSAS AT PINE BLUFF						
Carole Engle	U.S. Principal Investigator	X		X		Pine Bluff, Arkansas
Ann Gannam (to July 92)	U.S.Researcher			X		Pine Bluff, Arkansas
Harold Phillips	U.S. Research Assiatant			X		Pine Bluff, Arkansas

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.
(2) Personnel involved in two projects.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Research Admin.	Field(s) of Specialization: Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	Location of Work (1)
RWANDA - HOST COUNTRY PERSONNEL						
Dr. J. Bucyanayandi	H.C. Principal Investigator	X		X		Butare, Rwanda
Maurice Ntahobari	Rector of UNR	X				Butare, Rwanda
J. Nshimyumuremyi	Vice Rector	X				Butare, Rwanda
A. Muhawenimana	Dean, Faculty	X				Butare, Rwanda
A. Gasiga	Professor	X				Butare, Rwanda
Eugene Rurangwa	Station Manager	X		X		Butare, Rwanda
Anaclet Gatera	Asst. Manager			X		Butare, Rwanda
Lieven Verheust	UNR Researcher	X		X		Butare, Rwanda
Dirk Lamberts	Production Manager		X			Butare, Rwanda
Ngoy Kasongo	Lab Technician		X			Butare, Rwanda
G. Ndahimana	Asst. Lab Technician	X				Butare, Rwanda
L. Umugiraneza	Sec./Computer operator				X	Butare, Rwanda
F. Sindikubwabo	Lab Assistant		X			Butare, Rwanda
Evariste Ndabazi	Lab Asstistant		X			Butare, Rwanda
Immacultee Nyabenda	Station Agronome			X		Butare, Rwanda
J. B. Munyandege	Extentions Agent/Ngoma			X		Rwanda
S. Nyirakamana	Ext.entions Agent/Shyanda			X		Rwanda
T. Ruhumuliza	Station Foreman			X		Butare, Rwanda
D. Nyirabali	Storekeeper/Cashier	X				Butare, Rwanda
P. Nsabimana	Seine Crew Leader			X		Butare, Rwanda

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.
(2) Personnel involved in two projects.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Research Admin.	Field(s) of Specialization: Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	Location of Work (1)
E. Kajyibwami	Hatchery Technician		X			Butare, Rwanda
A. Dushimabategetsi	Pond Manager			X		Butare, Rwanda
J. Uwumuremyi	Pond Manager			X		Butare, Rwanda
THAILAND						
THAILAND - UNIVERSITY OF MICHIGAN						
James Diana	U.S. Principal Investigator		X	X	X	Ann Arbor, Michigan
C. Kwei Lin	U.S. Co-Principal Investigator	X	X	X		Bangkok, Thailand
Tracy Willoughby	Fiscal Officer	X				Ann Arbor, Michigan
THAILAND - MICHIGAN STATE UNIVERSITY						
Ted Batterson	U.S. Principal Investigator	X	X		X	East Lansing, Michigan
Chris Knud-Hansen	U.S. Research Associate		X	X	X	Bangkok, Thailand
Colleen J. Sober	Fiscal Officer	X				East Lansing, Michigan
THAILAND - HOST COUNTRY PERSONNEL						
Kitjar Jaiyen	H.C. Co-Principal Investigator		X	X		Bangkok, Thailand
Peter Edwards	H.C. Co-Principal Investigator			X		AIT, Thailand
Sompote Ukatawewat	H.C. Research Associate	X		X		Ayutthaya, Thailand
Tanaporn	H.C. Research Assistant			X		Bangkok, Thailand
Wongbathom Konmonrat	H.C. Research Assistant				X	Bangkok, Thailand
Kiengkai	H.C. Research Assistant		X	X		AIT, Thailand
Chintana	H.C. Research Assistant			X		Bangkok, Thailand
Manoj Yomjinda	H.C. Research Assistant		X			AIT, Thailand

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.
(2) Personnel involved in two projects.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Research Admin.	Limnology/ Water Quality	Fisheries/ Aquaculture	Data Management	Location of Work (1)
		Field(s) of Specialization				
Kriengkrai Satapornvanit	H.C. Research Assistant		X			AIT, Thailand
Archin Chamnankuruwet	H.C. Research Assistant			X		AIT, Thailand
Somchai Vaipoka	H.C. Research Assistant			X		Ayutthaya, Thailand
Vorathep Muthuwam	H.C. Research Assistant		X			AIT, Thailand
Ye Qifeng	H.C. Research Assistant				X	AIT, Thailand
THAILAND/PHILIPPINES - UNIVERSITY OF HAWAII						
Kevin Hopkins	U.S. Co-Principal Investigator	X		X	X	Hilo, Hawaii
James Szyper	U.S. Co-Principal Investigator	X	X	X		Kaneohe, Hawaii
PHILIPPINES - HOST COUNTRY PERSONNEL						
Eduardo Lopez	H.C. Principal Investigator			X		Munoz, Nueva Ecija, Philippines
SOILS - GLOBAL						
John Baham	U.S. Co-Principal Investigator					Corvallis, Oregon
James Lannan (2)	U.S. Co-Principal Investigator	X		X	X	Corvallis, Oregon
James Bowman	U.S. Research Associate		X	X		Corvallis, Oregon

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.
(2) Personnel involved in two projects.

X. FINANCIAL SUMMARY

This section summarizes the expenditures of USAID, non-federal, and Host Country funds for CRSP research activities and program management. This unaudited summary is intended to provide an overview of CRSP program budgets and matching support.

The expenditure of USAID funds by Collaborative Research Projects, Special Topics Research, and Program Management is presented in Table 1 for the PD/A CRSP contract year of 1 September 1991 to 31 August 1992. This is the second year of the third grant, which runs through 31 August 1995, and which provides core funding of $920,000 per year. Table 1 shows the allocation of core funding through the budget year 1 September 1991 to 31 August 1992. Enhancement funds of 20% were allocated for the period of 1 May 1991 to 30 April 1992, and enhancement funds of 9% were allotted for the period of 1 May 1992 to 30 April 1993. Because the budget period for the enhancement funding is not congruent with the core funding budget year, enhancement funding is shown prorated as noted.

The information of Program Management Office expenditures includes three main categories: Operations and Administration, Communications, and Data Base Management. This CRSP is unique in including the research-oriented functions of Data Base Management and technical communications in the Program Management Office. Additional detail on the Program Management Office is provided in Section VIII of this report. The financial figures for the U.S. Research Component include expenditures to support the Data Analysis and Synthesis Team's activities at the University of California at Davis and at Oregon State University.

Cost-sharing contributions from the U.S. institutions are presented in Table 1. The average percentage of funding borne by U.S. universities is 24%, which fulfills the USAID requirement. Host Country contributions (in U.S. dollars) are also presented in Table 1. These data were provided by the Principal Investigators of the projects. Although Host Country cost sharing is not required, these contributions reflect a continuing commitment to participation in the CRSP by our collaborators.

Table 1. Expenditure of funds from USAID and participating institutions

	USAID Funds		Program Enhancement Funds*		US Cost Sharing		Total, all US funds		Host Country Contribution	
	1991-92	Cumulative	1991-92	Cumulative	1991-92	Cumulative	1991-92	Cumulative	1991-92	Cumulative
Research Program										
Honduras: Auburn	$109,164	$268,144	$20,262	$30,393	$21,232	$51,229	$150,658	$349,766	$45,000	$90,000
Rwanda: Auburn	$102,552	$195,383	$8,250	$12,375	$31,322	$49,620	$142,124	$257,378	$28,451	$61,544
OSU	$50,178	$140,596	$10,970	$16,455	$13,546	$28,133	$74,694	$185,184		
UAPB	$5,000	$10,000	$0	$0	$1,394	$2,227	$6,394	$12,227		
Thailand: MSU	$85,129	$163,001	$26,698	$40,047	$12,124	$53,466	$123,951	$256,514	$43,000	$86,000
UH	$53,858	$106,732	$16,746	$25,119	$20,500	$32,785	$91,104	$164,636		
UM	$121,269	$250,615	$0	$0	$91,653	$109,855	$212,922	$360,470		
Subtotal	$527,150	$1,134,471	$82,926	$124,389	$191,771	$327,315	$801,847	$1,586,175	$116,451	$237,544
U.S. Research Program										
DAST: UCD	$52,021	$100,662	$4,662	$6,993	$19,600	$34,200	$76,283	$141,855		
OSU	$35,016	$80,016	$0	$0	$8,754	$27,800	$43,770	$107,816		
Special Topics:										
Soil Studies, OSU			$10,434	$15,651	$5,914	$5,914	$16,348	$21,565		
Subtotal	$87,037	$180,678	$15,096	$22,644	$34,268	$67,914	$136,401	$271,236		
Management Entity¶ (includes some research activities)	$195,717	$414,755	$24,534	$36,801			$220,251	$451,556		
Evaluation funds§			$27,600							
TOTAL	$809,904	$1,729,904	$122,556	$183,834	$226,039	$395,229	$1,158,499	$2,308,967	$116,451	$237,544

*Prorated for eight months
¶Includes the research activities of Data Base Management and Technical Publications. Thus, over 20% of Management Entity expenditures are actually research expenditures.
§Prorated for four months

APPENDICES

Appendix A. CRSP List of Publications through December 1992

AUBURN/HONDURAS

Theses

Berrios, J. In preparation. Growth and survival of hybrid tilapia (*Tilapia nilotica* x *Tilapia hornorum*) fingerlings during the nursery phase. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Cerna, C. In preparation. Zooplankton dynamics in *Tilapia nilotica* production ponds fertilized with triple superphosphate. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Echeverria, M.A. 1992. Primary production in *Tilapia nilotica* production ponds fertilized with triple superphosphate. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Garces, C. 1986. Quantitative analysis of zooplankton in fish ponds fertilized with triple superphosphate during the rainy season. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Gomez, R. 1988. Effect of fertilizer type on the production of male *Tilapia nilotica*. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Lopez, L. In preparation. Production of *Tilapia nilotica* in ponds fertilized with layer chicken litter. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Mejia, C. In preparation. Rainy season phytoplankton dynamics in ponds stocked with *Tilapia nilotica*. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Paz, S.A. In preparation. The relationship between primary productivity and chlorophyll and their relation to tilapia production. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Sherman, C. In preparation. All female culture of *Tilapia nilotica* in ponds fertilized with chicken litter. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Publications and Reports

Alvarenga, H.R., and B.W. Green. 1985. Production of hybrid tilapia (*Tilapia nilotica* x *Tilapia hornorum*) fingerlings. CRSP Technical Report, unpublished. 12 pp. (In Spanish.)

Alvarenga, H.R., and B.W. Green. 1986. Growth and production of all male *Tilapia nilotica* and all male hybrid tilapia (*Tilapia nilotica* x *Tilapia hornorum*) in ponds. Rev. Latinoamericana de Acuicultura 29: 6-10. (In Spanish.)

Alvarenga, H.R., B.W. Green, and M.I. Rodriguez. 1984. A system for producing hybrid tilapia (*Tilapia nilotica* x *Tilapia hornorum*) fingerlings at the El Carao Aquaculture Experiment Station, Comayagua, Honduras. CRSP Technical Report, unpublished. 9 pp. (In Spanish.)

Alvarenga, H.R., B.W. Green, and M.I. Rodriguez. 1985. Pelleted fish feed vs. corn gluten as feed for tilapia and Chinese carp polyculture in ponds. CRSP Technical Report, unpublished. (In Spanish.)

Alvarenga, H.R., B.W. Green, and M.I. Rodriguez. 1987. Production of hybrid tilapia (*Tilapia nilotica* x *Tilapia hornorum*) in ponds using corn gluten as a supplemental feed. CRSP Technical Report, unpublished. 13 pp. (In Spanish.)

Berrios, J.M. 1986. Growth and survival of hybrid tilapia (*Tilapia nilotica* x *Tilapia hornorum*) fingerlings during the nursery phase in ponds. CRSP Technical Report, unpublished. 16 pp. (In Spanish.)

Boyd, C.E., and D.R. Teichert-Coddington. 1992. (In Press) Relationship between wind speed and reaeration in small aquaculture ponds. Aquacultural Engineering.

Green, B.W. and D.R. Teichert-Coddington. 1991. A comparison of two samplers used with an automated data acquisition system in whole-pond community metabolism studies. The Progressive Fish-Culturist 53(4): 236-242.

Green, B.W., 1992. Substitution of organic manure for pelleted feed in tilapia production. Aquaculture 101:213-222.

Green, B.W. 1985. Report on the induced spawning of the silver and grass carps. CRSP Technical Report, unpublished. 8 pp. (In Spanish.)

Green, B.W., and H.R. Alvarenga. 1985. Tilapia and carp polyculture in ponds receiving organic fertilization and supplemental feed. CRSP Technical Report, unpublished. 10 pp. (In Spanish.)

Green, B.W., and L.A. López. 1990. Factibilidad de la producción masira de alevines machos de *Tilapia nilotica* a través de la inversión hormonal de sexo en Honduras. Agronomía Mesoamericana 1:21-26.

Green, B.W., H.R. Alvarenga, R.P. Phelps, and J. Espinoza. 1985. Technical Report: Honduras Aquaculture CRSP Cycle I Dry Season Phase. CRSP Technical Report, unpublished. Auburn University, Alabama. 51 pp.

Green, B.W., H.R. Alvarenga, R.P. Phelps, and J. Espinoza. 1986. Technical Report: Honduras Aquaculture CRSP Cycle I Rainy Season Phase. CRSP Technical Report, unpublished. Auburn University, Alabama. 77 pp.

Green, B.W., H.R. Alvarenga, R.P. Phelps, and J. Espinoza. 1986. Technical Report: Honduras Aquaculture CRSP Cycle II Dry Season Phase. CRSP Technical Report, unpublished. Auburn University, Alabama.

Green, B.W., H.R. Alvarenga, R.P. Phelps, and J. Espinoza. 1987. Technical Report: Honduras Aquaculture CRSP Cycle II Rainy Season Phase. CRSP Technical Report, unpublished. Auburn University, Alabama.

Green, B.W., H.R. Alvarenga, R.P. Phelps, and J. Espinoza. 1988. Technical Report: Honduras Aquaculture CRSP Cycle III Rainy and Dry Season Phases. CRSP Technical Report, unpublished. Auburn University, Alabama.

Green, B.W., R.P. Phelps, and H.R. Alvarenga. 1989. The effect of manures and chemical fertilizers on the production of *Oreochromis niloticus* in earthen ponds. Aquaculture 76:37-42.

Sherman, C. 1986. Growth of all-female *Tilapia nilotica* in earthen ponds fertilized with chicken litter. CRSP Technical Report, unpublished. 14 pp. (In Spanish.)

Teichert-Coddington D.R., B.W. Green, and R.P. Phelps. 1992. Influence of water quality, season and site on tilapia production in Panama and Honduras. Aquaculture 105:297-314.

Teichert-Coddington, D.R. and B.W. Green. (In Press) Influence of daylight and incubation interval on dark-bottle respiration in tropical fish ponds. Hydrobiologia.

Teichert-Coddington, D.R.. B.W. Green, and R.P. Parkman. 1992. Substitution of chicken litter for feed in production of Panaeid shrimp in Honduras, Central America. The Progressive Fish-Culturist 53(3):150-156.

Teichert-Coddington, D.R., B.W. Green, N. Matamoros, and R. Rodriguez. 1990. Substitución de alimentos por gallinaza en la producción comercial de camarones peneidos en Honduras. Agronomía Mesoamericana 1:73-78.

Ayub, M., C.E. Boyd, and D.R. Teichert-Coddington. In preparation. Effects of urea application, aeration, and drying on total carbon concentrations in pond bottom soils.

Green, B.W., and D.R. Teichert-Coddington. 1992. Production of *Oreochromis niloticus* fry for hormonal sex reversal in relation to temperature. Submitted to the Journal of Applied Ichthyology.

Scientific Papers Presented

Alvarenga, H.R., and B.W. Green. 1988. Produccion y aspectos economicos del cultivo de tilapia en estanques fertilizados con gallinaza. (Production and economic aspects of tilapia culture in ponds fertilized with chicken litter.) Presented by H. Alvarenga at the 34th Annual Meeting of the Programa Colaborativo Centro Americano para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Jose, Costa Rica.

Green, B.W., D.R. Teichert-Coddington, and L.A. Lopez. 1992. Production of *Oreochromis niloticus* fry in earthen ponds for hormonal sex inversion. Presented at the 23rd Annual World Aquaculture Conference, May, 1992, Orlando, Florida.

Green, B.W. 1990. Substitution of organic manure for pelleted feed in tilapia production. Accepted for inclusion in the European Inland Fisheries Advisory Commission's Symposium on production enhancement in still water pond culture, Prague, Czechoslovakia, May, 1990.

Green, B.W., and H.R. Alvarenga. 1987. Efecto de diferentes tasas de aplicacion de gallinaza en la produccion de tilapia. (The effect of different rates of chicken litter application on the production of tilapia.) Presented at the 33rd Annual Meeting of the Programa Colaborativo Centro Americana para el Mejoramiento de Cultivos Alimenticios (PCCMCA), Instituto de Ciencia y Technologia Agricola, Guatemala, 30 March-4 April, 1987. Presented by H. Alvarenga. (In Spanish.)

Green, B.W., and H.R. Alvarenga. 1987. Intensive fingerling production of hybrid tilapia *Tilapia nilotica* x *Tilapia hornorum* in earthen ponds. Presented at the 18th Annual Meeting of the World Aquaculture Society, Guayaquil, Ecuador. Presented by B.Green.

Green, B., and H. Alvarenga. 1989. Sistemas de produccion de tilapia utilizando fertilizacion organica y alimentacion. Presented at the annual regional meeting of the Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Pedro Sula, Honduras. Presented by H. Alvarenga.

Green, B., and L. Lopez. 1989. Factabilidad de la produccion masiva de alevines machos de *tilapia nilotica* atraves de la inversion hormonal de sexo en Honduras. Presented at the annual regional meeting of the Programa Cooperativo Centroamericana para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Pedro Sula, Honduras. Presented by L. Lopez.

Green, B.W., H.R. Alvarenga, and R.P. Phelps. 1988. The effect of stocking rate on the production of *Tilapia nilotica* in ponds. Presented at the 34th Annual Meeting of the Programa Colaborativo Centro Americano para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Jose, Costa Rica. (In Spanish.) Presented by B.Green.

Green, B.W., R.P. Phelps, and H.R. Alvarenga. 1987. The effect of nitrogen and phosophorus sources in fertilizers used for the production of *Tilapia nilotica.* Presented by B. Green at the 18th Annual Meeting of the World Aquaculture Society, Guayaquil, Ecuador.

Teichert-Coddington, D.R., and B.W. Green. 1992. Yield improvement through maintenance of minimal oxygen concentrations in tilapia grow out ponds in Honduras. Presented at the 23rd Annual World Aquaculture Conference, May, 1992, Orlando, Florida.

Teichert-Coddington, D.R., and B. Green. 1990. Influence of primary productivity, season and site on tilapia production in organically fertilized ponds in two Central American countries. Accepted for inclusion in the European Inland Fisheries Advisory Commission's Symposium on production enhancement in still water pond culture, Prague, Czechoslovakia, May, 1990.

Teichert-Coddington, D.R., B. Green, and M.I. Rodriguez. 1989. Effectos de la tasa de alimentacion sobre la produccion de tilapia en estanques fertiliazdos con gallinaza. Presented at the annual regional meeting of the Programa Cooperativo Centroamericana para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Pedro Sula, Honduras. Presented by M.I. Rodriguez.

Teichert-Coddington, D., B. Green, N. Matamoros, and R. Rodriguez. 1989. Substitucion de alimento por gallinaza en la produccion comercial de camarones peneidos en Honduras. Presented at the annual regional meeting of the Programa Cooperativo Centroamericana para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Pedro Sula, Honduras. Presented by D. Teichert-Coddington.

AUBURN/PANAMA - AGUADULCE

Theses

Abrego, R. 1985. Uso de androgenos en alevines de *Tilapia nilotica* para la produccion de tilapias monosexuales. Licenciatura Thesis in Biology, Univ. of Panama.

Avila, M. In preparation. El efecto del policultivo del pez, *Mugil curema*, a varios densidades de siembra con la produccion de *Penaeus vannamei* y en la calidad de agua en estanques de tierra. Licenciatura Thesis in Biology, Catholic University of Chile, Santiago, Chile.

Chavez, H. 1984. Estudio trofodinamico de *Penaeus vannamei* cultivado en estanques experimentales de aguas salobres. Licenciatura Thesis in Biology, Univ. of Panama.

Hernandez de Santamaria, D. In preparation. El efecto de dietas experimentales en el crecimiento y sobrevivencia de *Penaeus vannamei* cultivado en estanques. Licenciatura Thesis in Biology, Univ. of Panama.

Lasso de la Vega, E. 1985. Variacion del zooplancton en estanques de cria de camarones blanco durante la estacion seca. Licenciatura Thesis in Biology, Univ. of Panama.

Lore, D., H.Tunon, and R. Visuetti. 1984. Efecto de la aplicacion de abonos organicos, concentrados y pescado fresco (*Dormitator latifrons*) en la produccion de *Penaeus stylirostris* y *Penaeus vannamei*. Licenciatura Thesis in Biology, Univ. of Panama.

Quesada, I. In preparation. Ocurrencia de organismos bentonicos en estanques no alimentados sembrados con *Penaeus vannamei* durante la estacion seca. Licenciatura Thesis in Biology, Univ. of Panama.

Quiroz, V. In preparation. Efectos de varios niveles de recambio de agua a la calidad de agua y en la produccion de *Penaeus vannamei* en estanques de tierra. Licenciatura Thesis in Biology, Univ. of Panama.

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Teichert-Coddington, D.R., and M. Arrue. 1988. Efectos de dietas de proteinas y densidades de siembra sobre la producción de *Penaeus vannamei* en estanques de Herra. Rev. Lst. Acui., 35:29-33.

Van Wyk, P. 1986. The relationship of pump discharge and fuel efficiency to tidal height for a brackishwater aquaculture pumping station. Masters of Aquaculture Special Project, Auburn University, Alabama.

Scientific Papers Presented

Chavez, H. December, 1984. Estudio trofodinamico de *Penaeus vannamei* cultivado en estanques experimentales de aguas salobres. Presented to the First National Scientific Congress, Univ. Panama, Panama.

De Leon, A. November, 1985. El efecto de aplicar fertilizantes inorganicos en la produccion de *Penaeus vannamei* en estanques. Presented to the Second National Scientific Congress, Univ. of Panama, Panama.

Hughes, D.G. November, 1984. The marine shrimp culture industry in Panama. Presented to the First Annual Shrimp World Marketing Conference, Acapulco, Mexico.

Hughes, D.G. November, 1985. Prediction of pond productivities: a challenge for aquaculture. Presented to the Pontifical Catholic Univ. of Ecuador, Quito, Ecuador.

Hughes, D.G., and O.M. Garcia A. June, 1984. La produccion de semilla de *Tilapia nilotica* en hapas: una comparacion de productividades de clima templada con clima tropical. Presented by David Hughes to First National Aquaculture Seminar in Univ. Nacional, Heredia, Costa Rica.

Hughes, D.G., A. Torres, and R.P. Phelps. January, 1985. Production and growth characteristics of *Penaeus stylirostris* and *P. vannamei* in monoculture and polyculture in fed and unfed earthen ponds. Presented by D. Hughes at the Annual Meeting of the World Mariculture Society, Orlando, Florida.

Hughes, D.G., G. de Gomez, E. Lasso de la Vega, R.P. Phelps, and R. Pretto Malca. January, 1987. Rainy and dry season comparisons in *Penaeus vannamei* production ponds in Panama receiving various water exchange rates: water quality variation. Poster session at World Aquaculture Society Meeting, Guayaquil, Ecuador.

Kivers, A. December, 1984. Comparacion de dos rangos y dietas alimentacias con alevines de *Tilapia nilotica* en piletas de concreto. Presented to the First National Scientific Congress, Univ. of Panama, Panama.

Kivers, A. December, 1984. Comparacion de tres densidades de seimbra de alevines de *Tilapia nilotica* en piletas de concreto. Presented to the First National Scientific Congress, Univ. of Panama, Panama.

Lasso de la Vega, E., and M. Villareal. November, 1985. Variacion del zooplancton en estanques de cria de camarones blanco durante la estacion seca. Presented to the Second National Scientific Congress, University Panama, Panama.

Lore, D., H. Tunon, and R. Visuetti. December, 1984. Efecto de la aplicacion de abonos organicos, concentrados y pescado fresco (*Dormitator latifrons*) en la produccion de *Penaeus stylirostris* y *Penaeus vannamei*. Presented by H. Tunon to the First National Scientific Congress, Univ. Panama, Panama.

Moreno, J.M. December, 1984. Alimentacion de la *Tilapia nilotica* en la etapa de alevinaje. Presented to the First National Scientific Congress, Univ. of Panama, Panama.

Moreno, J.M. December, 1984. El uso del androgeno 17-metil-testosterona en alevinaje de *Tilapia nilotica* para la produccion de Tilapia monosexuales en Panama. Presented to the First National Scientific Congress, Univ. of Panama, Panama.

Pretto, R., G. Garson, V. Batista, and M. de Leon. September, 1983. Estudio preliminar del policultivo de Peneidos con peces nativos de aguas salobres. Presented by R. Pretto to the Fifth Symposium of Latin American Aquaculture, Univ. Austral de Chile, Valdivia, Chile.

Torres, A. December, 1984. Produccion de *Penaeus stylirostris* bajo la influencia del *Penaeus vannamei*, en estanques experimentales de agua salobre con y sin alimentacion durante la epoca seca. Presented to the First National Scientific Congress, Univ. of Panama, Panama.

AUBURN/PANAMA - GUALACA

Theses

Atencio, A. 1987. Phosphorus saturation of acidic soils in tropical fish culture ponds.

Barrios, C.M. 1985. Analysis of water quality in new freshwater ponds at the Freshwater Aquaculture Station in Gualaca.

Friele, M.E.F. 1985. Stomach analyses of *Macrobrachium rosenbergii*, *Tilapia nilotica*, *Colossoma macropomum* and the hybrid *Hypophthalmichthys molitrix* x *Aristichthys nobilis* in polyculture at the Gualaca Freshwater Aquaculture Experiment Station, Panama.

Hughes, David G. Evaluation of seed production and sex-reversal methods for *Tilapia nilotica* and field verification in a tropical hatchery.

Perez, M.J. 1985. Economic and marketing study of fish and shrimp in polyculture systems in freshwater ponds at Gualaca, Chiriqui Province.

Pimentel, C.A.B. 1984. Effect of liming on new unfertilized ponds at the Gualaca Aquaculture Experiment Station.

Rios, R.A. In preparation. Identification and dynamics of zooplankton found in tropical earthen ponds receiving chicken litter at four rates.

Rodriguez, Ivonne. Feeding *Penaeus vannamei* and *Penaeus stylirostris* in nursery ponds.

Serrano, A. 1987. Economics of tilapia production in monoculture or in polyculture with prawns, and utilizing manure or a commercial pellet as the nutrient input in Gualaca, Panama.

Publications and Reports

Peralta, M., and D. R. Teichert-Coddington. Comparative production of Colossoma macropomum and *Tilapia nilotica* in Panama. Journal of the World Aquaculture Society 20(4):236-239.

Teichert-Coddington, D.R., and R.P. Phelps. 1989. Effects of seepage on water quality and productivity of inorganically fertilized tropical ponds. Journal of Aquaculture in the Tropics 4:85-92.

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Appendix B. List of Acronyms and Definitions

AID	Agency for International Development
AIT	Asian Institute of Technology, Thailand
AU	Auburn University
Baseline Data	that information and data base in some sector or aspect of a developing country which is necessary to measure change in the future
BFAR	Board for Food and Agriculture Research
BIFADEC	Board for International Food and Agricultural Development and Economic Cooperation
Bilateral Programs	assistance programs involving arrangements between a single developing country and a single donor country
BOA	Basic Ordering Agreement
Board of Directors (for a CRSP)	an advisory body selected to assist, advise, and make policy recommendations to the ME in the execution of a CRSP; members represent the interests of the CRSP
CGIAR	Consultative Group on International Agricultural Research
CIFAD	Consortium for International Fisheries and Aquaculture Development
Collaborating Institutions	institutions which form a partnership arrangement with a lead participating U.S. institution to collaborate on a specific research project
CRSP	Collaborative Research Support Program
DAI	Development Alternatives Incorporated
DAST	Data Analysis and Synthesis Team
Data Analysis and Synthesis	the process of compiling and analyzing information about pond culture systems from diverse sources into a coherent, usable format that can be applied to the development of predictive models and to the improvement of the efficiency of these systems

EEP	External Evaluation Panel - senior scientists not involved in the CRSP and selected externally for their ability to evaluate objectively the scientific progress and relevance of a CRSP program on an ongoing basis
EOP	Equal Opportunity Programs
Experimental Protocol	a detailed plan of a field experiment which specifies experimental methods, sampling schedules, data collection, etc.
Experimental Treatment	fish cultural practices (e.g., fertilizer application, supplemental feeding, etc.) which modify the physical, chemical, and biological environment
Expert System	a computerized compilation of knowledge that is used to make "intelligent" decisions about the management or status of a process or system
Field Experiments	controlled fish production experiments in which quantitative responses to different levels of treatments are measured
FTE	Full Time Equivalent
Global Experiment	the overall plan of a CRSP for research on problems and constraints, global in nature, whose results are applicable and transferable regionally and globally (worldwide)
GOR	Government of Rwanda
Grant Agreement	the formal legal document which represents a binding agreement between AID and the ME institution for a CRSP; this is the legal document for the CRSP recognized as such by AID and the recipient institutions
Grant Proposal	the formal document submitted by an ME to AID, proposing a CRSP for receiving a grant outlining the manner of implementation of the program and showing the budgetary requirements
Host Country (HC)	a developing country in which a CRSP has formal activities
INRP	International Research Project

Institutional Development	improvement in the capability of institutions in developing countries to conduct development programs for agriculture and other sectors, or for implementing educational/training, research, health, and other public programs. This may include improvements in physical facilities, equipment, furnishings, transportation, organization, but refers primarily to the development and training of a professional cadre.
IPA	Inter-governmental personnel act
JCARD	Joint Committee on Agricultural Research and Development (formerly Joint Research Committee), BIFADEC
JRC	Joint Research Council, USAID
LDC	Lesser Developed Countries
LUPE	Land Use Productivity Enhancement Project
Matching Requirement document	that sum of resources, financial or in-kind, which participating U.S. institutions must collectively contribute to a CRSP program as defined in the grant (also called "cost sharing")
ME	Management Entity
MINAGRI	Ministere de l'Agriculture, de l'Elevage, et de l'Environement (Ministry of Agriculture, Livestock and Environment)
Mission	a formally organized USAID unit in a developing country led by a Mission Director or a country representative
NGO	Non Government Organization
MOU	Memorandum of Understanding
NRP	National Research Project
MSU	Michigan State University
NIFI	National Inland Fisheries Institute, Thailand
NMFS	National Marine Fisheries Service
OIRD	Office of International Research and Development
OSU	Oregon State University

Participating Institutions	those institutions that participate in the CRSP under a formal agreement with the Management Entity which receives the AID grant
PD/A CRSP	Pond Dynamics/Aquaculture Collaborative Research Support Program
PI	Principal Investigators - scientists in charge of the research for a defined segment or a scientific discipline of a CRSP
PMO	Program Management Office
Practices	fish cultural activities related to design, management, and operation of pond culture systems
Predictive Models	mathematical models used to simulate the processes occurring in pond systems; in the context of this CRSP, predictive models are used as analytical and management tools to improve the efficiency of pond systems
Principles	the physical, chemical, and biological processes occurring in pond systems and their interactions
RENARE	Department of Renewable Natural Resources, Honduras. Now known as Dirección General de Pesca y Acuicultura, Honduras
R&D Bureau (R&D/AGR)	(Formerly S&T/AGR Bureau of Science and Technology) central bureau of AID in Washington, charged with administering worldwide technical and research programs for the benefit of USAID-assisted countries
RSSA	Resource Services Support Agreement
SNV	Scandinavian National Volunteers
SPN	Service de Pisciculture Nationale National Fish Culture Service
Subgrant Agreement	a document representing a subagreement made between the ME and a participating institution under authority of the grant agreement by the ME and AID
TC	Technical Committee - a group of scientists participating in the research of the CRSP as PI's, selected to help guide the scientific aspects of the research program of a CRSP

Title XII	the Title XII Amendment to the International Development and Food Assistance Act of 1975 as passed by the United States Congress and subsequently amended
UAPB	University of Arkansas at Pine Bluff
UCD	University of California at Davis
UH	University of Hawaii
UM	University of Michigan
UNR	Universite Nationale du Rwanda
USAID	United State Agency for International Development
USAID Project Officer	an official AID employee designated to oversee a CRSP on behalf of AID
WID	Women In International Development