TITLE XII

COLLABORATIVE RESEARCH SUPPORT PROGRAM

POND DYNAMICS/AQUACULTURE

SIXTH WORK PLAN

September 1, 1991 - August 31, 1993

Pond Dynamics/Aquaculture CRSP
Program Management Office
Office of International Research and Development
Oregon State University
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This work plan describes a standardized set of experiments to be undertaken by the Collaborative Research Support Program in Pond Dynamics/Aquaculture during the period 1 September 1991 through 31 August 1993. Program activities are funded in part by Grant No. DAN-4023-G-00-0031-00 from the United States Agency for International Development.

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INTRODUCTION

The Sixth Work Plan of the Pond Dynamics/Aquaculture CRSP was developed by the CRSP Technical Committee at a meeting in Auburn, Alabama on March 7 to 9, 1991. This work plan describes activities to be conducted by the CRSP during the period 1 September 1991 to 31 August 1993, and corresponds to the first two years of the new grant. Many of the studies described in this work plan are contingent upon the continuation of the program.

The Sixth Work Plan will be implemented in Honduras, Rwanda, Thailand, Philippines, and the USA. Field studies will concentrate on the dynamics of freshwater ponds. In addition to field activities at the research stations of the cooperating institutions, experiments with cooperating farmers are planned. Analysis and synthesis of the global data resulting from the field studies will be conducted in the United States.

The first three CRSP work plans specified identical experiments at all CRSP sites to provide a baseline for comparisons between sites. The approach for the Fourth and Fifth Work Plans, which covered the period 1 September 1987 to 31 August 1989 and 1 September 1989 to 31 August 1991, respectively, changed in that different, but related, experiments were conducted at the various sites. In this way, many more hypotheses could be tested than if the same experiments were conducted at all sites. The Sixth Work Plan follows this same approach as the Fourth and Fifth Work Plans. Different, but related, topics will be considered at each site. The particular topics to be studied at each site are based on the research needs of aquaculture in each country and the needs for more information, as identified by the CRSP Technical Committee.

The general goals of this work plan are:

1. To preserve the global nature of the CRSP experiments;
2. To conduct experiments to refine management practices for fertilized ponds;
3. To verify CRSP results with cooperating farmers;
4. To continue adding observations to the global CRSP database; and
5. To provide verified preliminary guidelines for management of fertilized ponds.

EXPERIMENTS

THE GLOBAL EXPERIMENT

The Sixth Work Plan will preserve the global nature of the CRSP and will address diverse research needs at each site. First, data will continue to be collected using standardized methods. Second, these data will be entered into the global database, which is maintained at the CRSP Program Management Office in Corvallis, Oregon, USA. The database is used by the Data Analysis and Synthesis Team in their development of generalized models and guidelines. The database also is available to the field stations and other interested researchers throughout the world. Third, related experiments are conducted at the various research stations. For example, studies on maximizing primary production and fish yield by manipulating fertilizer N:P ratios will be conducted in Rwanda, Honduras and Thailand. Supplemental feeding studies will be conducted in Rwanda, Honduras and Thailand. Fish stocking rate studies will be conducted in Thailand and Honduras.

REQUIRED MEASUREMENTS

This section of the work plan lists the minimum requirements for data collection by the CRSP projects. The accepted methods for data collection are presented in the Summary of Accepted Analytical Methods (Section 3), which starts on page 44. Detailed descriptions of accepted methods are contained in the appendices. Frequencies of data collection as specified in this section are minimum frequencies. Data may be collected more frequently at the discretion of the individual projects.

The following measurements must be taken daily:

- Solar Radiation
- Wind Speed
- Air Temperature (maximum and minimum)
- Rainfall
- Evaporation
- Mortalities
- Pond Depth
- Water Inflow and Overflow

There will be at least three intensive sampling periods for each experiment: (1) during the second week; (2) midway through the experiment; and (3) during the final week. Whole column samples collected at mid-morning should be used unless specified otherwise. The variables to be observed are:

- Total Kjeldahl Nitrogen
- Ammonia Nitrogen
- Total Phosphorous
- Secchi Disk Visibility
- Chlorophyll *a*
- Dark Bottle Respiration
- Total Suspended Solids
- Total Volatile Solids
- Total Alkalinity (3 depths: top, middle, bottom)
- Primary Productivity

Diel studies will be conducted simultaneously with the intensive sampling measurements in order to measure spatial and temporal fluctuations within a pond. Samples for diel studies will be collected at dawn, 1000, 1400, 1600, 1800, and 2300 hours, and at dawn the next day at a minimum of two depths, but preferably at three depths. The exact time of sample collection in the diel studies should be recorded. The three sampling depths will be 25 cm below the water surface, mid-depth, and 25 cm above the pond bottom. The parameters to be measured during the diel studies are:

- Dissolved Oxygen
- Temperature
- pH
- Wind (cumulative between sampling times)
- Solar Radiation (cumulative between sampling times)

Information about the fish and shrimp used in the experiments should be recorded as follows:

- Stocking
  - Total Number
  - Total Biomass
  - Individual Weights (of 10% sample)
  - Individual Lengths (of 10% sample)

- Monthly Sampling
  - Total Number in Sample
  - Total Biomass of Sample
  - Individual Weights
  - Individual Lengths
  - Reproduction Weight

- Harvest
  - Total Number of Stocked Fish Remaining
  - Total Biomass of Stocked Fish
  - Individual Weights (10% sample of stocked fish)
  - Individual Lengths (10% sample of stocked fish)
  - Total Number of Recruits
  - Total Biomass of Recruits

The following pond soil characteristics are to be determined at the beginning and end of each experiment:

- pH
- Phosphorus
- Organic Matter
- Total Nitrogen
- Cation Exchange Capacity
- Metals - Aluminum, Iron, Zinc (only when the pond is first used)
- Lime Requirement
- Exchangeable Hydrogen
- Base Saturation

Pond morphology is to be measured when the ponds are first constructed and whenever pond morphology is altered significantly. Measurements to be taken are:

- Surface Area (at 10 cm depth contours)
- Volume (at 10 cm depth contours)
- Drawing, top view, with scale

The composition of lime, inorganic, and organic fertilizers is to be determined when supplies are delivered and, for organic materials, just before they are totally used up, but not less frequently than once a month. Characteristics to be determined are:

- Percent Dry Matter
- Nitrogen
- Phosphorus
- Chemical Oxygen Demand
- Lime Neutralization Value (for lime only)

The quantities of lime and other amendments must be carefully recorded whenever they are added to the ponds.

Reference ponds are to be established and operated at each station starting the second year of this work plan.

OPTIONAL MEASUREMENTS

CRSP projects may collect any data, <u>in addition to</u> those data specified under Required Measurements, which they deem appropriate for a particular study. The methods specified in the Summary of Accepted Analytical Methods (Section 3, page 44) or in the appendices (Section 4, page 53) should be used. If a method for a particular parameter is not specified in Section 3, a method from *Standard Methods* (APHA et al., 1985) should be used whenever possible and the Materials and Methods Subcommittee of the CRSP Technical Committee should be informed. If problems are encountered while using the accepted method for a particular application, the Materials and Methods Subcommittee should be contacted. If optional measurements are made and researchers wish to have the data included in the data templates, the Data Base Manager (at the Program Management Office, Oregon State University) should be contacted.

DATA SUBMISSION

All data should be submitted to the CRSP Database Manager on either Lotus 1-2-3® or Microsoft Excel® worksheets, following the formats and procedures in the most recent CRSP *Instructions for Data Entry*. Data and accompanying text for the CRSP *Data Reports* series should be submitted to the CRSP Program Management Office within six months of harvest of each study. Please contact the Data Base Manager with questions regarding verification of data. The Data Base Manager will print the verified data for publication in *Data Reports* unless other arrangements are made in advance.

REPORT SUBMISSION

Introduction:

CRSP researchers are aware of the difficulties in compiling the results of the various experiments described in this Work Plan into a single, cohesive *Data Report* for each site. In response to these concerns, the requirements for submitting text to *Data Reports* have changed. The studies detailed in the biennial Work Plans fit the *Research Reports* format better than the *Data Reports* format; consequently, researchers will be required to submit a technical report (text and figures) in the form of a *Research Report* to the Program Management Office (see below). *Data Reports* will serve the following purposes: to protect researchers' data from unauthorized publication and use, to compile all standardized data for use in the Global Experiment and in other analyses, and to document where procedures actually used in experiments have diverged from those described in the Work Plans.

Instructions for Submission of Reports:

1. A technical report for each experiment (each study) is due six months after the experiment ends. Technical reports should be submitted in one of the following formats:

   a) As a *Research Report*, with the understanding that the manuscript will be reviewed, edited, and printed as a short (4-8 pages) report; or
   b) As a *Notice of Publication* under the *Research Reports* series. Notices of Publication are reserved for those articles that have been or will be published in a refereed journal. Authors who wish to use this format for technical reports should submit a copy of a manuscript which is "under review" by a journal, together with a cover letter. It is recommended that authors contact the CRSP Director to discuss whether this is an option.

2. Principal Investigators are also responsible for submitting a *Data Report* for each set of studies. For example, there should be one *Data Report* for Rwanda, one for Thailand, and one for Honduras for the studies described in each biennial Work Plan. The text will be confined to a "Materials and Methods" section, which should be used to describe how the materials or methods used during the studies diverged from those specified in the Work Plan. Text for *Data Reports* is due three months after the end of the latest experiment (study) described in the Work Plan. For example, text for the Rwanda *Data Report* should be submitted three months after Study 4 ends, and should include a "Materials and Methods" section for all studies completed during the course of this Work Plan.

Should difficulties in completing the Work Plan on schedule arise, please advise the Director so that an alternate reporting format can be arranged.

AFRICA—RWANDA PROJECT

Cooperating Institutions:

National University of Rwanda
Dr. Evariste Karangwa
Mr. Eugene Rurangwa

CIFAD (Oregon State University) - Lead Institution
Mr. Wayne Seim

Auburn University
Dr. Thomas J. Popma
Ms. Karen Veverica

CIFAD (University of Arkansas at Pine Bluff)
Dr. Carole Engle

Pond Systems: Cool freshwater ponds typical of higher elevations.

INTRODUCTION

The choice of objectives and experimental designs proposed for the Sixth Work Plan of the Rwandan component of the CRSP are based on the following considerations:

1. Growth of tilapia in tropical environments may be determined by environmental factors such as water quality, solar radiation, gas solubility and especially temperature, associated with specific elevations. Some workers believe the major effect of temperature on fish growth is direct and physiological, and effects derived from other members of the aquatic community are of less importance. Most authors, however, recognize the controlling influence of temperature on the structure and function of all members of the aquatic community. Laboratory studies can investigate direct effects of temperature on fish physiology. Unfortunately most laboratory studies investigate effects of constant temperatures, but time functions of changing temperature may determine outcome. To examine direct effects of changing temperatures U of Arkansas at Pine Bluff initiated laboratory growth experiments (1990-1991) which will provide additional explanation of direct effects of variable temperature regimes on fish in complex pond environments. Obviously few physical or biological factors (and their interactions) associated with pond environments at different elevations could be modeled in laboratories. In Rwanda tilapia are cultured at altitudes ranging from about 1300 to 2500 meters. What are the important aspects of water temperature regime to pond productivity? What are the climatic limits of tilapia culture as a profitable enterprise? Can supplemental feeding practices extend the range of environments where tilapia culture is a reasonable use of resources? Is supplemental feeding of greater benefit in cooler systems with lower levels of productivity? Both Rwasave Fish Culture Station and rural ponds can be utilized to examine these questions. Initial investigation is underway for Work Plan 5 on the selection of rural ponds and an examination of pond productivity for tilapia at different elevations in Rwanda. We will study tilapia production at different elevations in two experiments, one with and one without supplemental feeding (Studies 1 and 3).

2. In developing countries, such as Rwanda, the principal source of food for fish is the naturally occurring organisms in ponds enriched with waste plant and animal materials. Work is underway in Rwanda for Work Plan 5 to determine, on the basis of digestibility of protein and energy in natural food organisms, the energy and protein available to fish in these pond systems. From these data a supplemental feed can be designed to correct any protein or energy deficiency and to conserve protein for growth rather than for respiration to meet energy needs. Determining which locally available materials might satisfy these needs, and using these materials as supplemental feeds will test the concept of conserving protein for growth to enhance fish production (Study 4).

3. Success of fish farming in highland Africa will be determined by economic factors as well as by the physical and biological dynamics of pond ecosystems. Economic analysis can provide guidelines and clarify the choices involved in resource allocation. Mathematical programming techniques can be used to select combinations of enterprises that will maximize returns to the producer, given specific producers' goals.

4. Simple on-farm methods for estimating standing crops of phytoplankton may be derived from Secchi disk visibility measurements refined by including a visual comparison of color in order to estimate relative contributions of abiotic and biotic sources of turbidity. The sources of turbidity can be experimentally partitioned into phytoplankton, detritus, true color (absorbance of filtered sample at a chosen wavelength) and inorganic turbidity. If these parameters can then be related to visibility and color estimates, a simplified estimation of phytoplankton density could result. Different types of visual color comparators will be tested.

5. Maximum rates of pond primary and tilapia production have not been determined for Rwanda, partially because of the low physical and economic availability of inorganic and organic fertilizers. Maximum pond productivity achieved at each CRSP site provides necessary data for our modeling and expert system data bases and additionally provides a benchmark for comparisons within Rwanda on potential productivity. An experiment designed to reach such maximum rates also provides the opportunity to determine the point at which nitrogen is no longer a limiting factor, and factors such as those associated with climate, base water quality and other pond system variables become limiting (Study 2).

There are five studies planned for Rwanda in the Sixth Work Plan (Figure 1). The goal of these studies is to more fully understand the factors affecting pond dynamics and fish growth under climatic conditions considered marginal for tilapia production, using the limited nutrient inputs available to most potential producers in economically depressed regions.

Figure 1. Schedule for Data Collection in Rwanda during the Sixth Work Plan.

Study Title	Site	1991 Sep	Oct	Nov	Dec	1992 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1993 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Study 1. Productivity of Tilapia Ponds at Different Elevations	Various	******************																							
Study 2. Nitrogen Required for Maximum Primary and Fish Production in Rwandan Ponds	Rwasave			***********************																					
Study 3. On-Farm Studies - Supplemental Feeding in Private Ponds at Five Elevations	Various										******************************														
Study 4. Locally Available Feedstuffs to Improve Utilization of Natural Pond Food Organisms by Tilapia	Rwasave																					***************			
Study 5. Economic Analysis of Aquaculture Production Technologies	Various									**															

RWANDA STUDY 1: PRODUCTIVITY OF TILAPIA PONDS AT DIFFERENT ELEVATIONS

Objective: To quantify the influence of elevation on tilapia production in relation to temperature regime and water quality parameters.

Significance: This study, along with laboratory experiments on growth conducted under Work Plan 5, will help determine, by comparison with Study 3, Work Plan 6, whether growth by tilapia is depressed because the temperature approaches the physiological limits for this fish at higher elevations or because of reduced pond productivity. The appetite of warm water fish is depressed at cooler temperatures, but the available food may be efficiently utilized for growth at low or moderate food consumption rates. But if food availability exceeds the temperature-depressed appetite, productive capacity will be lost. This and the following studies will help us to better understand at what elevation tilapia culture becomes an inefficient enterprise.

Experimental Design: Twenty five ponds arrayed in five elevation zones (as described below) with one fertilizer input treatment.

Pond facilities: Five ponds at each elevation range 1350 to 1400 m, 1550 to 1600 m, 1625 m (Rwasave Station), 1750 to 1800 m, and 2150 to 2200 m. Criteria for selection of rural ponds within each elevations range are: total alkalinity,30 to 90 mg/l; hardness, 20 to 75 mg/l ; conductivity, 100 to 300 µmhos/cm; surface area, 300 to 700 m^2; minimum depth,45 to 60 cm; maximum depth, 90 to 120 cm.

Culture Period: 5 months minimum, but continuing until fish reach an average weight of 100 g.

Fish stocking rate: Male *Oreochromis niloticus* juveniles at 1 fish/m^2.

Nutrient inputs: Input rate will be 250 kg/ha/week dry weight of a locally available grass, added fresh. Inorganic nutrients will be added as urea and TSP to increase added N to 15 and P to 4 kg/ha/wk to standardize input total at all pond sites.

Water management: Addition of water at least once per week in quantities just sufficient to replace losses.

Sampling schedules: As per standard protocol except:
Physical parameters:
- Weekly: max-min water temperature, inflow, depth and Secchi disk visibility.
- 3 times during the experiment: temperature of unsaturated soil at a depth of 60 cm.
- Continuous recording of water temperature in one pond per elevation range.

Chemical parameters:
- Rwasave: standard CRSP protocol.
- Rural ponds: one soil analysis per pond and monthly measurements of total alkalinity, hardness, oxygen, total dissolved solids, and conductivity.
- No diurnal or primary productivity measurements in rural ponds.

Biological parameters:
- Weekly: quantity of nutrient input, adjusted.
- Monthly: fish weight.

- Every two weeks Secchi disk visibility will be measured and a visual color estimation made at about 10 AM.
- Corrected and uncorrected chlorophyll *a* for a composite water column sample will also be analyzed. The same sample will be used to measure total non-volatile matter. Relationships will be suggested: volatile vs non-volatile matter, chlorophyll *a* concentration and Secchi disk visibility at each color code. The sources of turbidity can then be partitioned into phytoplankton, detritus, true color (absorbance of filtered sample at a chosen wavelength) and inorganic turbidity. Different visual color comparators will be tested.

Null Hypotheses: Pond productivity for tilapia will not be correlated with elevation within the range studied. Production can not be related to physical and chemical site characteristics.

Statistical methods: One-way ANOVA, two-way ANOVA (combining data from Study 3,Work Plan 5), linear and multiple regression.

Schedule: Data collection, 6/91 to 1/92; data analysis and report writing, 3/92 to 6/92.

RWANDA STUDY 2: NITROGEN REQUIRED FOR MAXIMUM PRIMARY AND FISH PRODUCTION IN RWANDAN PONDS

Objective: For the environmental conditions of Rwasave Station, determine the inorganic nitrogen input rate required for maximizing primary and fish production with phosphorus and inorganic carbon in excess.

Significance: Nitrogen input rate necessary to achieve maximum production has not been quantified for the highland environment of Rwanda. At very high plankton densities, cool temperatures may prevent fish from taking full advantage of available food. Thus fish production may peak at nitrogen input levels less than maximum for phytoplankton. Efficient use of scarce nitrogen inputs could result from this data. Both primary and fish production rates in a nutrient optimized environment would also provide important relationships for the CRSP Global Model and Expert System.

Experimental design: Four ponds at each of four input rates of nitrogen added as urea at: 1.0, 2.3, 3.7 and 5.0 kg/ha/day. Phosphorous added as TSP at a 1:1 N:P ratio. Alkalinity maintained at least at 50 mg/l by liming.

Pond facilities: Sixteen 700 m^2 ponds at Rwasave Station.

Culture period: Five months.

Fish stocking rate: Male *Oreochromis niloticus* juveniles at $3/m^2$.

Nutrient inputs: Inorganic nutrients as under Experimental Design.

Water management: Replace water losses weekly.

Sampling schedule: Standard protocols.

Null hypothesis: Primary production is not nitrogen limited below 5 kg/ha/day N. Fish production is limited at the same N input level as primary production.

Statistical methods: Simple and multiple regression, ANOVA.

Schedule: Data collection, 12/91 to 5/92; technical report, 9/92.

RWANDA STUDY 3: ON-FARM STUDIES--SUPPLEMENTAL FEEDING IN PRIVATE PONDS AT FIVE ELEVATIONS

Objective: Previous studies (Study 3, Work Plan 5 and Study 1, Work Plan 6) evaluated pond dynamics and tilapia production in relation to elevation in 25 enriched ponds at five elevation zones. The objective of this following experiment is to determine to what extent the addition of supplemental feedstuffs to enriched ponds influences the effect of elevation on the capacity of the system to produce tilapia.

An additional objective is to investigate simple on-farm methods for estimating standing crops of phytoplankton using Secchi disk visibility and a visual color comparator to estimate relative contributions of abiotic and biotic sources of turbidity.

Significance: This study will provide an indication of the benefits of supplemental feed at higher elevations. Biological systems at cooler temperature ranges may benefit more from supplemental feeding than from pond fertilization. These results when evaluated with results of the previous study conducted without feeding, and with the controlled environment studies at Pine Bluff, will add insight into whether tilapia production at higher elevations is constrained primarily by low system productivity for natural food organisms or by physiological limitations of the fish. This insight can then be used to develop appropriate management strategies adjusted to elevation resulting in more efficient use of scarce resources in non-industrialized nations.

Results should also provide greater understanding of the relationship of turbidity and color to phytoplankton density.

Experimental design: At least five ponds at five elevations and using one feeding regime and one fertilization level. Factors associated with elevation are assumed to be the causative factors in the differences in pond system response for pond groups at each elevation range. In an earlier CRSP experiment in these rural ponds, a green grass compost was used but without supplemental feeding providing a source of comparison with the current experiment.

Pond facilities: Five ponds at each elevation range 1350 to 1400 m, 1550 to 1600 m, 1625 m (Rwasave Station), 1750 to 1800 m, and 2150 to 2200 m. As described in Study 1, criteria for selection of rural ponds within each elevations range are: total alkalinity, 30 to 90 mg/l; hardness, 20 to 75 mg/l ; conductivity, 100 to 300 µmhos/cm; surface area, 300 to 700 m^2; minimum depth,45 to 60 cm; maximum depth, 90 to 120 cm.

(In Study 3, Work Plan 5, the coefficient of variation of initial pond production estimates for the rural pond groups ranges from 10 to 15% which is less than for the Rwasave ponds, indicating random variability in rural ponds will be manageable.)

Culture Period: Five months minimum, continuing until fish reach an average weight of 100 g.

Fish stocking rate: Male *Oreochromis niloticus* juveniles at 1 fish/m^2.

Nutrient inputs: 250 kg/ha/wk fresh grass plus urea and TSP added at a rate to provide a total N of 15 and P of 4 kg/ha/day, plus a supplemental ration of rice bran at 2% of fish weight daily.

Water management: Replace evaporation and seepage losses weekly.

Sampling schedule: As per standard protocol except as noted.
Physical parameters: Physical parameters:

- Weekly: max-min water temperature, inflow, depth and Secchi disk visibility.
- 3 times during the experiment: temperature of unsaturated soil at a depth of 60 cm.
- Continuous recording of water temperature in one pond per elevation range.

Chemical parameters:

- Rwasave: standard CRSP protocol.
- Rural ponds: one soil analysis per pond and monthly measurements of total alkalinity, hardness, oxygen, total dissolved solids, and conductivity.
- No diurnal or primary productivity measurements in rural ponds.

Biological parameters:

- Weekly: quantity of nutrient input, adjusted.
- Monthly: fish weight.
- Every two weeks Secchi disk visibility will be measured and a visual color estimation made at about 10 AM.

- Corrected and uncorrected chlorophyll *a* for a composite water column sample will also be analyzed. The same sample will be used to measure total non-volatile matter. Relationships will be suggested: volatile vs non-volatile matter, chlorophyll *a* concentration and Secchi disk visibility at each color code. The sources of turbidity can then be partitioned into phytoplankton, detritus, true color (absorbance of filtered sample at a chosen wavelength) and inorganic turbidity. Different visual color comparators will be tested.

Null Hypotheses: Supplemental feeding will not influence the relative effect of elevation on tilapia growth, when compared to ponds receiving only fertilizer.

No relationship exists between visual color estimates, Secchi disk visibility and phytoplankton density that will allow the development of a simple on-farm estimation method for phytoplankton density.

Statistical methods: One-way ANOVA, two-way ANOVA (combining data from Study 3,Work Plan 5), linear and multiple regression.

Schedule: Depending on the previous study, data collection will begin 6/92 and end 1/93; reports by 9/93.

RWANDA STUDY 4: LOCALLY AVAILABLE FEEDSTUFFS TO IMPROVE UTILIZATION OF NATURAL POND FOOD ORGANISMS BY TILAPIA

Objective: Study 6, Work Plan 5 determined the digestible protein and energy content of natural food organisms consumed by tilapia in fertilized ponds. Study 7 of that same work plan investigated the benefits of a semi-purified protein-free supplemental energy source to improve the utilization of natural protein for growth. The objective of this following study is develop this information into a more practical and sustainable production practice -- to determine if local, readily available materials can be used to 'spare' more of the protein in natural food organisms for growth by tilapia.

Significance: Where commercially prepared feeds are unavailable, locally available materials could meet the energy requirements for a suitable feed alternative. Balancing protein-energy intake with a properly designed feed could increase system productivity for tilapia while lowering operating costs and increasing the efficient recycling of scarce local materials.

Experimental design: Two feed types will be tested at ration levels of 0, 2 and 4 % of body weight per day, all in triplicate. The two high energy feeds will be local materials such as molasses-enriched rice and wheat bran. Rations will be adjusted monthly in proportion to average fish weight per treatment. At the last fish sampling period twenty fish will be harvested from each pond to determine the digestibility of protein and energy of materials consumed. The lipid and crude protein content of six whole fish per treatment will be determined at the end of the experiment.

Pond facilities: Eighteen 700 m^2 ponds at Rwasave Fish Culture Station at Butare.

Culture Period: Five months.

Fish stocking rate: Mixed-sex juvenile *Oreochromis niloticus* at 2 fish/m^2.

Nutrient inputs: All ponds will be fertilized at one level with the nutrient selected on the basis of the results of Study 6 and used in Study 7 of Work Plan 5. Feed will be given as described under Experimental Design.

Water management: Replace evaporation and seepage losses weekly.

Sampling schedule: Standard Protocol.

Null Hypotheses: Locally available materials can not be used to meet the energy deficiency for tilapia of naturally occurring pond organisms, and fish production will be similar for ponds fed at the same available energy rate regardless of type of material used.

Statistical methods: ANOVA will be used to determine if the additional growth derived from the supplemental feed is greater than what could be estimated assuming a 20% protein conversion efficiency.

Schedule: 5/93 to 10/93. Data analysis and report writing 2/94.

RWANDA STUDY 5: ECONOMIC ANALYSIS OF AQUACULTURE PRODUCTION TECHNOLOGIES

Success of fish farming in highland Africa will be determined by economic factors as well as by the physical and biological dynamics of pond ecosystems. Economic analysis can provide guidelines and clarify the choices involved in resource allocation. Mathematical programming techniques can be used to select combinations of enterprises that will maximize returns (either in cash or in-kind) to the producer-given goals.

Objective: To compare the economics of resource utilization in aquaculture to that of other agricultural crops.

Significance: Fish culture is a relatively new production enterprise in Rwanda. Many fish ponds are located in elevations often considered outside the feasible range for profitable tilapia culture. Yet many farmers continue to raise fish. This study should provide indications of how fish culture compares to traditional crops from an economic perspective. It will further indicate some of the economic trade-offs between fish culture and traditional agricultural enterprises in Rwanda.

Experimental design:

1. The three major tasks of this experimental study are:
   a) To develop mathematical programming models of typical Rwandan farmers with land at two different elevations (below 1500 m and above 1500 m).
   b) To test optimal product mixes of Rwandan farmers with and without aquaculture technologies at both altitudes.
   c) To determine which production parameters have the greatest effect on a farmer's mix of crops produced.

2. Enterprise budgets will be adapted and/or developed for the principal crop enterprises of Rwandan farmers for two different elevations (below 1500 m and above 1500 m). These enterprise budgets, along with typical Rwandan farmer resource levels, will be incorporated into a linear programming framework. The model will utilize goal programming techniques to simultaneously meet farmer goals of food for home consumption, crops raised for barter or for ceremonial purposes, family food security, and income.

3. Both primary and secondary data will be utilized. Farmer surveys conducted over a two-year period will provide information on prices, resource levels, and resource requirements for different crops. Survey data will also be used to validate the models developed by comparing computer-selected product mixes without aquaculture alternatives for Rwandan farmers located at high and low elevations. Aquaculture enterprises will then be included to test the effect on optimal farm product mix with the introduction of aquaculture technologies.

4. Parametric programming will be used to test the robustness of coefficients used in the model and to determine the effect on optimal product mix of fluctuating price levels and availabilities of various production inputs. It will also be used to determine which production parameters have the greatest effect on a farmer's mix of crops produced.

Data Collection: Secondary data will be collected in Rwanda from previous surveys (including the Enquete Nacional Agricole and current World Bank and GTZ projects) on the levels of resources (land, labor, capital, fertilizer materials) commonly available on Rwandan farms. Data on fish yields and costs will be obtained from farm records collected by the Rwandan National Fish Culture Project based in Kigembe. A follow-up survey of fish farmers will document other crops being produced, land utilization, labor availability and constraints to production.

Hypothesis: Fish culture yields as much benefit to Rwandan farmers as other agricultural enterprises in terms of animal protein production for home consumption and supplemental income.

Analytical methods: Enterprise budget analysis will be used to estimate costs and returns of the aquaculture production technologies that have been and are being developed for Rwanda. Mathematical programing models will be developed utilizing MPS-PC software and will incorporate parameters that represent a farmer's need for stable yields and risk-reducing strategies.

Schedule: 5/92 to 5/93; report, 9/93

CENTRAL AMERICA—HONDURAS PROJECT

Cooperating Institutions:

Honduras Ministry of Natural Resources
Marco Ivan Rodriguez

Auburn University - Lead Institution
Dr. Claude E. Boyd
Dr. Bryan L. Duncan
Dr. David R. Teichert-Coddington
Mr. Bartholomew W. Green

Pond Systems: Tropical freshwater and brackish water ponds.

INTRODUCTION

The proposed Sixth Work Plan research in Honduras concentrates on several areas of research initiated as part of the previous Work Plan. The overall goal of the described research is to increase fish yield and production efficiency through manipulation of supplemental nitrogen fertilization, stocking rate, polyculture, and management of pond water quality and dissolved oxygen levels. Results of the Thailand PD/A CRSP demonstrated that organic fertilization plus supplemental nitrogen (as urea) resulted in increased fish yield. Preliminary results from Honduras PD/A CRSP research indicate greater primary productivity in ponds where organic fertilizer is supplemented with 17 to 35 kg N/ha per week compared to lower rates of supplemental N. The persistence of clay turbidity in ponds in Honduras requires continued application of organic matter for turbidity control. The proposed research will quantify the effect of varying the amount of organic matter applied to ponds while maintaining a constant N:P ratio.

Previous research results from Honduras showed that tilapia yield in organically fertilized ponds increased in response to increased stocking rate up to 2 fish/m^2, although mean fish weight decreased. When organic fertilization was supplemented with a formulated diet, both production and mean fish weight increased. A sale price differential related to fish size appears to be developing in Honduras, so the interaction between yield and mean fish weight under supplemental feeding is becoming more important.

Polyculture is an effective means to increase total fish yield. The tambaquí (*Colossoma macropomum*) was introduced into Honduras about seven years ago by request of the Government of Honduras. Results of research conducted as part of the Panama PD/A CRSP confirmed the tambaquí's potential for fast growth in pond culture where a supplemental feed was offered. Preliminary research results in Honduras demonstrated the potential of tambaquí as a secondary culture species in tilapia production ponds. This research showed that the tambaquí growth response was low in organically fertilized ponds, but high when offered a supplemental feed. The results also indicated that higher stocking rates of tambaquí would result in greater total fish yields. Honduran aquaculturists are very interested in incorporating this fish in their ponds, but the information necessary to make sound management recommendations is lacking.

Previous research that involved the use of mechanical (electrical) aeration to manage dissolved oxygen concentrations in fertilized and fed pond systems resulted in greater yield. However, there was some doubt as to the economics of mechanical aeration based on electrical aerators. In many parts of the humid tropics water is abundantly available, often by gravity flow. Water exchange is another mechanism for pond water quality and dissolved oxygen management available to producers with access to abundant, gravity flow water, and who are unable to obtain aerators. The proposed research will quantify the effects of low and moderate water exchange regimes on primary productivity, water quality and fish yield.

The current practice in the PD/A CRSP is to use hormonally sex-reversed male tilapia in stocking the research ponds. Population that are in excess of 97% males are routinely obtained in Honduras. However, the reproduction from only a few functional females can confound the analysis of experimental data. The PD/A CRSP in Honduras has determined that the inclusion of the native Honduran cichlid, guapote tigre (*Cichlasoma managuense*) at 500/ha will effectively eliminate tilapia reproduction through predation. Because guapote tigre is a predator and is stocked at low rates, it does not apparently decrease tilapia yields.

Four studies are planned for the Sixth Work Plan (Figure 2). The goal of these studies is to increase in fish yields through improved management practices.

Figure 2. Schedule for Data Collection in Honduras during the Sixth Work Plan.

Study Title	Site	1991				1992												1993							
		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Study 1. Supplemental Nitrogen Fertilization: Varying Manure Quantities	El Carao	******************																							
Study 2. Supplemental Feeding - Effect of Fish Stocking Rate	El Carao						**********************																		
Study 3. Stocking Rate of *Colossoma macropomum* in Polyculture with Tilapia	El Carao												**********************												
Study 4. Frequency of Water Exchange	El Carao																		***********************						

HONDURAS STUDY 1: SUPPLEMENTAL NITROGEN FERTILIZATION: VARYING MANURE QUANTITIES

Objective: To quantify the effects of supplemental nitrogen and phosphorus fertilization on tilapia yield and economics in Honduras.

Significance: Preliminary results from Study 6, Fifth Work Plan in Honduras indicate that carbon to nitrogen ratios of 6:1 and 4:1 stimulate primary production compared with ratios of 8 or 12:1. Total N in the low C:N ratios approximates N inputs found to be optimal in Thailand CRSP ponds. It now remains to be seen if fish production and/or profitability can be increased by reducing organic input and substituting it with similar inputs of inorganic N and P. It is also of interest to see if early morning pond dissolved oxygen can be increased by stimulating primary productivity with supplemental nitrogen while reducing community respiration by adding less allochthonous organic matter. Honduras Study 4 (Fifth Work Plan) indicated that oxygen stress reduced fish growth by about 23% in El Carao ponds.

Experimental design: Completely randomized design with four fertilizer treatments and three replicates per treatment:
- chicken litter (750 kg total solids (TS)/ha per week) and nitrogen supplementation based on results of Study 6, Fifth Work Plan.
- chicken litter (500 kg TS/ha per week) and nitrogen and phosphorus supplementation to approximate N:P ratio of first treatment.
- chicken litter (250 kg TS/ha per week) and nitrogen and phosphorus supplementation to approximate N:P ratio of first treatment.
- nitrogen and phosphorus fertilization to approximate total N and P applied in the first treatment.

Pond facilities: El Carao, twelve ponds, 0.90 m deep, each 0.1-ha.

Culture period: 150 to 180 days.

Fish stocking rate: Male *Oreochromis niloticus* fingerlings stocked at 20,000/ha ; guapote tigre (*Cichlasoma managuense*) fingerlings stocked at 500/ha.

Nutrient inputs: Chicken litter applied at above indicated rates; nitrogen as urea; phosphorus as triple superphosphate.

Water management: Replace evaporation and seepage after ≤ 5 cm loss.

Sampling schedules: Standard protocols except as noted below:
Biological parameters:
- Zooplankton and chlorophyll *a* : 1x/wk.
- Primary productivity, diurnal curve: 1x/wk.

Chemical parameters:
- pH, total ammonia, nitrate and organic nitrogen will be measured every other week in alternation with soluble orthophosphate and total phosphorus.

Null hypotheses: Primary production and tilapia yield will not differ with nitrogen and phosphorus source. Profitability of tilapia production will not be increased by substitution of inorganic for organic fertilizers.

Statistical methods: ANOVA, regression analysis.

Schedule: Data collection, 7/91 to 1/92; technical report, 7/92.

HONDURAS STUDY 2: SUPPLEMENTAL FEEDING - EFFECT OF FISH STOCKING RATE

Objective: To determine the effects of fish stocking rate on yield and water quality in ponds that receive a combination of organic fertilization and supplemental feed.

Significance: More efficient use of nutrient inputs and primary productivity may be possible with higher stocking rates. However, higher stocking rates often yield smaller fish. Manipulation of stocking rates may allow fish farmers to direct their production to markets with different size preferences.

Experimental design: Four stocking rates by three replicates, completely randomized design.

Pond facilities: El Carao, twelve 0.1-ha ponds, 0.80 m deep.

Culture period: 180 days or until fish growth slows.

Fish stocking rate: Male *Oreochromis niloticus* fingerlings stocked at 10,000, 20,000, 30,000 and 40,000/ha; guapote tigre (*Cichlasoma managuense*) stocked at 500/ha.

Nutrient inputs: Chicken litter (application rate to be based on results of Study 6 (revised) of Work Plan 5) for the first three months only, followed by a commercial, pelleted feed only (25% protein) six days/wk. Daily feeding rate will be 3% of the total fish biomass, and be adjusted monthly based on seine sample data. Daily ration will be fed in two equal rations.

Water management: Replace evaporation seepage after ≤ 5 cm loss.

Sampling schedule: Standard protocols except as noted.
Biological parameters:
- Zooplankton and chlorophyll a : 1x/week.

Null hypotheses: Stocking rate will have no effect on fish yield. Stocking rate will have no effect on fish size.

Statistical methods: ANOVA, regression analysis.

Schedule: Data collection, 2/92 to 7/92; technical report, 1/93.

HONDURAS STUDY 3: STOCKING RATE OF *Colossoma macropomum* IN POLYCULTURE WITH TILAPIA

Objectives: To determine the relative potential of tambaquí (*Colossoma macropomum*) in polyculture with tilapia (*Oreochromis niloticus*), to determine the optimum stocking rate for tambaquí in this polyculture and to determine the effect of polyculture on pond dynamics.

Significance: Tambaquí and tilapia are both species that are capable of fast growth. Tambaquí shows promise as a polyculture species with tilapia, especially as part of the Honduran, as well as Central American, aquacultural development package, but little is known about the optimum number of tambaquí to stock.

Experimental design: Completely randomized design. Four treatments by three replicates/treatment.

- Tilapia (100%).
- Tilapia (75%) plus tambaquí (25%).
- Tilapia (25%) plus tambaquí (75%).
- Tambaquí (100%).

Pond facilities: El Carao, twelve ponds, 0.75 m deep, each 0.1-ha.

Culture period: 150 days.

Fish stocking rate: Male *Oreochromis niloticus* and tambaquí fingerlings will be stocked in the proportions indicated above such that the total number of fish stocked is 20,000/ha; in addition, guapote tigre (*Cichlasoma managuense*) fingerlings stocked at 500/ha.

Nutrient inputs: Chicken litter (1,000 kg total solids/ha/wk) for the first two months only, followed by a commercial, pelleted feed only (25% protein) six days/wk. Daily feeding rate will begin at 3% of the total fish biomass of the fastest growing treatment; the same amount of feed will be used in all ponds.

Water management: Replace evaporation and seepage after ≤ 5 cm loss.

Sampling schedules: Standard protocols except as noted.
Biological parameters:
- Zooplankton: 1x/week.
- Chlorophyll *a*: 1x/week.
- Primary productivity, diurnal curve: every 2 weeks.

Null hypotheses: Tilapia yield will not be affected by polyculture with tambaquí. Stocking rate will have no effect on tambaquí yield. Stocking rate will have no effect on tambaquí size. Pond dynamics will not be affected by polyculture.

Statistical methods: ANOVA , regression analysis.

Schedule: Data collection,8/92 to 1/93; technical report, 7/93.

HONDURAS STUDY 4: FREQUENCY OF WATER EXCHANGE

Objective: To determine effect of water exchange frequency on tilapia yield, water quality and primary productivity.

Significance: BOD and other metabolites increase in ponds during the culture cycle and could negatively impact fish yield. Water quality could be maintained through water exchange. A large, weekly water exchange could be more effective in maintaining good water quality and more labor efficient than small, daily water exchanges. The quantity of organic materials and metabolites eliminated per unit of water exchange will be calculated.

Experimental design: Completely randomized design. Three treatments by four replicates/treatment.

- No water exchange.
- 5% (of pond volume) water exchange per day, 5 days/week.
- 25% (of pond volume) water exchange per week, 1 day/week.

Water exchange will begin once feeding with formulate diet is initiated.

Pond facilities: El Carao, twelve ponds, 0.75 m deep, each 0.1-ha.

Culture period: 150 days.

Fish stocking rate: Male *Oreochromis niloticus* fingerlings stocked at 20,000/ha ; guapote tigre (*Cichlasoma managuense*) fingerlings stocked at 500/ha.

Nutrient inputs: Chicken litter (1,000 kg total solids/ha/wk) for the first two months only, followed by a commercial, pelleted feed only (25% protein) six days/wk. Daily feeding rate will begin at 3% of the total fish biomass of the fastest growing treatment; the same amount of feed will be used in all ponds. Feeding rate will be adjusted monthly based on seine sample data. Daily ration will be fed in two equal rations.

Water management: Replace evaporation and seepage after ≤ 5 cm loss in all ponds prior to initiation of feeding. Thereafter, replace evaporation and seepage in control ponds, and follow appropriate water exchange regime in other ponds. Water exchange procedure will be to first drain water from the pond and then add the exchange water.

Sampling schedules: Standard protocols except as noted below:
Biological parameters:

- Zooplankton and chlorophyll *a* : 1x/wk.
- Primary productivity, diurnal curve: 1x/wk.

Exchange water (inlet, outlet and pond):

- Ammonia-N, total phosphorus and soluble reactive phosphorus, Kjeldahl-N, NO_3-N, dissolved oxygen, suspended solids and volatile solids: 1x/wk.

Null hypotheses: Water exchange will not affect fish yield. Water exchange will not affect primary productivity.

Statistical methods: ANOVA, regression analysis.

Schedule: Data collection, 2/93 to 7/93; technical report, 1/94.

ASIA—THAILAND PROJECT

Cooperating Institutions:

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CIFAD (Michigan State University)
Dr. Cal D. McNabb
Dr. Ted R. Batterson
Dr. Chris Knud-Hansen

CIFAD (University of Hawaii)
Dr. Kevin Hopkins
Dr. James Szyper

Pond System: Freshwater tropical ponds typical of lower elevations.

Experiments conducted under the first five CRSP work plans have addressed the relationships of fertilizer input to yield of fish --primarily tilapia-- and shrimp under standardized conditions. These relationships have been tentatively quantified. In addition, nutrient balancing, pond depth, and stocking density has been evaluated, while fertilizer types and supplemental feeding have been initiated. In the sixth plan, we will complete the fine-tuning of management alternatives and provide data to evaluate an optimal management plan for tilapia.

During the CRSP Fourth Work Plan, each country project explored several difficult topics in an effort to increase the total number of topics examined by the CRSP. The Thailand Project started research in four topics: nutrient balance, pond morphology, stocking density, and tilapia/catfish polycultures. The Thailand Project's selection of nutrient balance as a research topic was based on examining one of two fertilization strategies.. The first strategy, which has been examined by the Honduras and Rwanda CRSPs, is to increase manure loading rates to provide additional nutrients for phytoplankton production. High manure loading rates often lead to low oxygen levels and high ammonia levels which necessitate remedial action. The second strategy is to provide the minimum amount of manure required for the detritus-based food web while using inorganic fertilizers (e.g., urea and triple superphosphate) to provide additional nutrients for the base of the autotrophic food web. The Thailand Project is following this second strategy. Results from the Fourth Work Plan have shown that high yields of tilapia (over 7,000 kg/ha/yr) can be obtained by using relatively low levels of chicken manure supplemented with inorganic fertilizers. Also, by examining nutrient flux in the Thailand ponds, the project was able to show that additional phosphorus inputs were needed in newly renovated ponds in areas which have soils high in aluminum. Results of the fertilization strategies used in Thailand Work Plan Four have been presented in 14 scientific papers, technical reports and theses.

The continuing research in Thailand will emphasize: pond size and management intensity; urea cycling; fertilizer application frequency; stocking density; supplemental feeding; stocking density and supplemental feeding; staged supplemental feeding; management of dissolved oxygen; and regional verification of PD/A CRSP Management Guidelines. Nine studies are planned over the 2-year period (Figure 3).

The two goals of the Thailand Project during the Sixth Work Plan are:

1. To improve our understanding of the effects of management practices on the dynamics of fertilized tilapia ponds in tropical climates, and

2. To develop total management guidelines for tilapia ponds in Thailand.

Figure 3. Schedule for Data Collection in Thailand during the Sixth Work Plan.

Study Title	Site	1991				1992												1993							
		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Study 1. Pond Size/Management Interactions	AIT	***	***	***	***	***																			
Study 2. Nutrient Cycling - Urea Dynamics	AIT			***	***	***	***	***																	
Study 3. Fertilization Frequency	AIT									***	***	***	***	***											
Study 4. Stocking Density at High Nutrient Input	AIT															***	***	***	***	***					
Study 5. Pond Dynamics Under Semi-Intensivee and Intensive Culture Practices	Bangsai							***	***	***	***	***													
Study 6. Stocking Density and Supplemental Feeding	Bangsai													***	***	***	***	***							
Study 7. Timing of Supplemental Feeding	Bangsai																			***	***	***	***	***	
Study 8. Evaluation of Low Cost Methods for Destratification and Oxygen Conservation in Tropical Ponds	AIT																				***	***	***	***	***
Study 9. Regional Verification of Fertilizer Guidelines - Philippines	FAC										***	***	***	***	***	***	***	***	***	***	***	***	***		

THAILAND STUDY 1: POND SIZE/MANAGEMENT INTENSITY INTERACTIONS

Background: During the last six months of the Fifth Work Plan, Thailand Study 9 will be conducted at AIT to determine the relationships of pond size to fish yield using ponds ranging in size from 200 m^2 to 1,600 m^2. The effect of pond size on yields is expected to be related to the degree of intensification and management. Higher degrees of management and inputs are generally better suited to smaller ponds. This is readily apparent in the large-scale catfish and shrimp industries.

Objective: To determine the relationships of pond size to fish yield, management practices, and system efficiency.

Experimental design: Incomplete block design using four pond sizes and three levels of management as follows:

	Number of ponds		
Pond size	High fertilizer	Low fertilizer	Feed
200 m^2	a)	2	3
350 m^2	3 + a)	3	3
800 m^2	a)	2	2
1,600 m^2	a)	2	

a) Treatments in the Study 9, Work Plan 5.

Pond facilities: AIT; all ponds 1 m deep (at stadia).

Culture period: Five months.

Fish stocking rate: Sex-reversed *Oreochromis niloticus* fingerlings at 2 fish/m^2.

Nutrient inputs: To be determined based on the results of Work Plan 5

Water management: Replace evaporation and seepage losses weekly.

Sampling schedule: Standard protocols except as noted.
Physical parameters:
- Intensive measurements: every 2 wks.

Chemical parameters:
- Intensive measurements: every 2 wks.
- NO_2-N, NO_3-N, and soluble reactive phosphorus: every 2 wks.

Biological parameters:
- Intensive measurements: every 2 wks.

Hypothesis: The interaction between pond size and management intensity does not affect yield or efficiency per unit area.

Statistical methods: ANOVA and multiple regression.

Schedule: Data collection, 9/91 to 1/92; technical report, 6/92.

THAILAND STUDY 2: NUTRIENT CYCLING UREA DYNAMICS

Objective: To gain insight on the cycling of urea in pond water. To determine whether relative nitrogen availability affects how urea is cycled (i.e., whether algae uptake urea directly, or only after it has been reduced to ammonia by bacteria).

Significance: Urea is a popular source of nitrogen in aquaculture, but little is known of how it is utilized by aquatic organisms. This study will examine the fate of applied urea and should provide a basis for determining optimal fertilization frequencies of urea in aquaculture ponds. If urea accumulates in pond water even under conditions of nitrogen limitation, then less frequent urea fertilization may be more efficient. Under conditions where nitrogen is not limiting algal productivity, monitoring urea accumulation and breakdown should help clarify the role of urea fertilization (versus ammonia regeneration) in contributing to high ammonia concentrations. Comparisons of urea accumulation in treatments with and without nitrogen limitation should suggest whether urea can be taken up directly by algae.

Experimental design: Four different N:P ratios. Three replicates per treatment.

Pond facilities: AIT, twelve 400 m^2 ponds, 1 m deep (at stadia).

Culture period: Five months.

Fish stocking rate: Sex-reversed *Oreochromis niloticus* fingerlings at 2 fish/m^2.

Nutrient inputs: Input rates for all ponds will be 25 kg/ha/week of urea-N. Phosphorus will be added as triple superphosphate (TSP) to give total N:P ratios of 1:1 (promoting nitrogen limitation), 4:1, 7:1 and 10:1 (promoting phosphorus limitation).

Water management: Replace evaporation and seepage losses weekly to maintain an average water depth of 1 m.

Sampling schedule: Standard protocol except as noted.
Physical parameters:
- Intensive measurements every two weeks, rather than the standard three times during the experiment.

Chemical parameters:
- Intensive measurements every two weeks, rather than the standard three times during the experiment.
- NO_2-N, NO_3-N, soluble reactive phosphorus (SRP) and urea every two weeks.
- NO_2-N, NO_3-N, NH_4-N, SRP, urea every day for one week to be done three times during the course of the experiment.

Biological parameters:
- Intensive measurements every 2 weeks.

Null Hypotheses: Urea accumulation/breakdown does not differ under different conditions of nutrient limitation. Algae are not able to utilize urea directly as a source of nitrogen.

Statistical methods: ANOVA, regression.

Schedule: Data collection, November 1991 through March 1992; technical report, 4 months after fish harvest.

THAILAND STUDY 3: FERTILIZATION FREQUENCY

Objective: To determine the relationships between primary productivity and net fish yield with frequency of fertilization application.

Significance: Earlier CRSP/Thailand research identified optimal weekly fertilization rates for generating the greatest net fish yield with minimal negative environmental conditions (i.e., early morning dissolved oxygen and afternoon ammonia concentrations). Results of this study will demonstrate whether timing of fertilization application is important for further improving fish yields. If there is a relationship between fish production and fertilizer application then it will be an important component of pond management strategies. However, if no relationship is detected then the farmer will have more flexibility and could base frequency of fertilization around their convenience (i.e., optimizing labor costs) without any reduction of fish yield.

Experimental design: Five frequencies of fertilization. Three replicates per treatment.

Pond facilities: AIT, fifteen 400 m^2 ponds, 1 m deep (at stadia).

Culture period: Five months.

Fish stocking rate: Sex-reversed *Oreochromis niloticus* fingerlings at 2 fish/m^2.

Nutrient inputs: Input rates for all ponds will average 35 kg/ha/week of urea-N. Phosphorus will be added as triple superphosphate (TSP) to give total N:P ratios of 4:1. Results of Work Plan 5, Thailand Experiment 5 will determine whether chicken manure will also be added. The five treatment frequencies are: (1) daily, (2) two times per week, (3) weekly, (4) every 1.5 weeks, and (5) every two weeks.

Water management: Replace evaporation and seepage losses weekly to maintain an average water depth of 1 m.

Sampling schedule: Standard protocol except as noted.
Physical parameters:
- Intensive measurements every two weeks, rather than the standard three times during the experiment.

Chemical parameters:
- Intensive measurements every two weeks, rather than the standard three times during the experiment.
- NO_2-N, NO_3-N, soluble reactive phosphorus (SRP) and urea every two weeks.

Biological parameters:
- Intensive measurements every 2 weeks.

Null Hypotheses: Frequency of fertilization does not affect the rate of algal production. Frequency of fertilization does not affect the rate of fish production.

Statistical methods: ANOVA, regression.

Schedule: Data collection, May through September 1992; technical report, 4 months after fish harvest.

THAILAND STUDY 4: STOCKING DENSITY AT HIGH NUTRIENT INPUT

Objective: To determine the relationships between initial stocking density and fish growth measured both as individual growth rate and areal net fish yield.

Significance: A recent CRSP/Thailand investigation indicated that in ponds receiving high nutrient loading, net fish yield significantly increased when stocking densities were raised from 1 to 3 fish/m^2. By examining five stocking densities in ponds with optimal fertilization rates (based on net fish yield, early morning dissolved oxygen and afternoon unionized ammonia concentrations), important empirical relationships relating stocking densities to fish growth and production will be available to CRSP modelers. In addition, these results will have practical utility in Thailand, where different parts of the country have different market size preferences for tilapia.

Experimental design: Five initial stocking densities. Three replicates per treatment.

Pond facilities: AIT, fifteen 400 m^2 ponds, 1 m deep (at stadia).

Culture period: Six months (a longer experiment to better fit growth curve regressions, and to push standing stock to carrying capacity).

Fish stocking rate: Sex-reversed *Oreochromis niloticus* fingerlings at 1, 2, 3, 4, and 5 fish/m^2.

Nutrient inputs: Input rates for all ponds will be 35 kg/ha/week of urea-N. Phosphorus will be added as triple superphosphate (TSP) to give total N:P ratios of 4:1. Frequency to be determined from other Work Plan 6 experiment.

Water management: Replace evaporation and seepage losses weekly to maintain an average water depth of 1 m.

Sampling schedule: Standard protocol except as noted.

Physical parameters:

- Intensive measurements every two weeks, rather than the standard three times during the experiment.

Chemical parameters:

- Intensive measurements every two weeks, rather than the standard three times during the experiment.
- NO_2-N, NO_3-N, soluble reactive phosphorus (SRP) every two weeks.

Biological parameters:

- Intensive measurements every 2 weeks.

Null Hypotheses: Initial stocking density has no effect on net fish yield at harvest. Initial stocking density has no effect on individual fish growth rate.

Statistical methods: ANOVA, regression.

Schedule: Data collection, November 1992 through March 1993; technical report, 4 months after fish harvest.

THAILAND STUDY 5: POND DYNAMICS UNDER SEMI-INTENSIVE AND INTENSIVE CULTURE PRACTICES

Objective: To assess the contribution of natural and supplemental foods to tilapia growth and to determine the economic feasibility of supplemental feeding.

Significance: By understanding the role of supplemental feed and nutrient addition in different combinations the role of each in pond nutrition can be used to optimize management.

Experimental design: Unbalanced design with four treatments (fertilizer and feed, fertilizer alone, feed alone at rate of treatment one, feed alone ad-libitum) and four replicates per treatment.

Pond facilities: Bang Sai, sixteen 220 m^2 ponds.

Culture period: Five months.

Fish stocking rate: Sex-reversed *Oreochromis niloticus* at 3 fish/m^2.

Nutrient inputs and feeding rates: Treatments 1 and 2 with chicken manure at 250 kg/ha/wk supplemented with urea to bring nitrogen: phosphorus ratio to 4:1. Treatments 3 and 4 with no fertilization. Treatments 1 and 4 will be fed ad-libitum. Treatment 3 will be fed at a rate equivalent to treatment 1.

Water management: Replacement of evaporation and seepage losses weekly.

Sampling schedule: Standard protocols.

Null hypotheses: That fertilization alone does not provide sufficient material for maximum tilapia growth. That maximum feeding rates will not provide greater growth than combinations of fertilizer and feed.

Statistical methods: ANOVA, regression.

Schedule: Data collection 3/92 to 7/92; technical report 8/92.

THAILAND STUDY 6: STOCKING DENSITY AND SUPPLEMENTAL FEEDING

Objective: To determine the effects of stocking density on pond carrying capacity (fish size and total net yield) in fertilized ponds with supplemental feeding.

Significance: The pond carrying capacity for fish production is expected to increase with supplemental feeding, but with increasing feed input to support greater stocking density the eutrophic feedback from waste recycling may hasten unfavorable water quality for fish growth. With appropriate stocking density, extra fertility derived from supplemental feeding will be assimilated effectively to compensate for the external fertilizer input. We anticipate achieving a balanced pond culture system with abundant food supply and desirable water quality, which is the basis for maximizing pond carrying capacity in an economic way.

Experimental design: Four stocking densities (2, 3, 4, and 5 fish/m^2) with triplicate ponds for each treatment.

Pond facilities: Twelve 220 m^2 ponds of 1 m depth at Bang Sai.

Culture period: An unspecified period until the population growth rate of each treatment reaches the initial phase of asymptotic growth curve.

Fish stocking: 5-10 g size of all-male *Oreochromis niloticus* fingerlings will be stocked and reared at the densities listed above.

Nutrient input and feeding rate: Depending on the results of Study 2, but balanced total N and P at 5 and 1.5 kg/ha/day, respectively.

Water management: Evaporation and seepage losses to be made up weekly.

Sampling schedule: Intensive physical, chemical, and biological measurements will be made biweekly. Fish will be sampled biweekly to estimate feeding rate.

Null hypothesis: Stocking density does not affect pond carrying capacity.

Statistical methods: ANOVA, regression.

Schedule: Data collection 9/92 to 1/93; technical report 8/93.

THAILAND STUDY 7: TIMING OF SUPPLEMENTAL FEEDING

Objective: To determine the appropriate time for initial application of supplemental feed in fertilized ponds.

Significance: As shown in the previous fertilization experiments, the natural food derived from fertilizer enrichment alone was sufficient to support tilapia growth in a linear fashion during the early phase of grow-out cycle. Growth rate reduced at a later stage, and the duration for reduced growth increased with increasing stocking density. The inadequate natural food supply is assumed to be the limiting factor for slower growth rate, and input of supplemental feed would boost growth rate throughout the grow-out cycle. It would be of economic advantage to give supplemental diet at critical stages when the natural food becomes inadequate to support optimal fish production.

Experimental design: Application of supplemental feed will be initiated at four different time periods during a grow-out cycle; triplicate for each treatment.

Pond facilities: Twelve 220 m^2 ponds at Bang Sai.

Culture period: Fish will be reared until the pond carrying capacity is reached.

Fish stocking: 5-10 g size of all-male *Oreochromis niloticus* fingerlings will be stocked at an appropriate density as shown in the results of Stocking Density Study.

Nutrient input and feeding rate: The pond will be fertilized at a constant rate throughout the experimental period. The fertilization rate will consider the external fertilizer input and fertility derived from supplemental feeding, giving a rate of total N & P input at 5 and 1.5 kg/ha/day, respectively.

Water management: Maintain depth at 1 m with weekly input.

Sampling schedule: Intensive physical, chemical, and biological measurements will be made biweekly.

Null hypothesis: Various time period for initial supplemental feeding does not affect final fish yield.

Statistical methods: ANOVA, regression.

Schedule: Data collection 3/93 to 7/93; technical report 8/93.

THAILAND STUDY 8: EVALUATION OF LOW COST METHODS FOR DESTRATIFICATION AND OXYGEN CONSERVATION IN TROPICAL PONDS

Background: Intense daytime density stratification, characteristic of earthen ponds in warm climates, isolates bottom water from surface water, permitting severe depletion of dissolved oxygen (DO) which may persist throughout the day and night. Although fishes and shrimps can relocate from DO-depleted layers, convective overturn after nighttime cooling can create inescapable whole-pond low levels if 1) the hypolimnion is large compared to the epilimnion, or 2) respiration in sediments and bottom water has been rate-limited by low DO before exposure to the DO newly mixed in from the surface. In addition, upper-layer production of both DO and organic matter may be limited by depletion of nutrient elements when surface waters are isolated from deep-water or benthic organic remineralization.

Mechanical devices are often used to destroy density stratification and to increase or maintain DO in ponds. Night-long or continuous active aeration can improve production over emergency aeration practices; daytime aeration is usually avoided to conserve the commonly-observed surface supersaturation of DO for nighttime use. Mixing or circulation of pond waters without increasing the surface area of air-water contact is relatively inexpensive compared with active aeration, and has the potential to reduce the cost of aeration needed to optimize production.

Research performed by U. of Hawaii CRSP projects has shown that properly-timed daytime mixing (as distinct from active aeration) can relieve bottom DO depletion during daylight and early evening hours, and may conserve daytime surface supersaturation levels of DO against loss to the atmosphere. The proposed experiment will compare several low-cost strategies for pond mixing, aiming to optimize whole-pond DO regimes.

Objective: To develop and describe one or more low-cost strategies, in terms of apparatus and mode of application, which best redistribute DO in time and space for greatest benefit to cultured animals.

Experimental Design:

- Deploy at least three types of mixing apparatus (submersible water pumps, air lift or air tube mixers, fan-blade mixers) in ponds of surface areas ranging from 200 to 2,000 m^2, and determine their relative costs and capability for destratification under conditions typical of CRSP pond experiments.
- Assess stratification, mixing, and redistribution of DO with automated monitoring systems presently used in CRSP research.
- Determine optimal placement and timing for most efficient use of the best apparatus in ponds of different sizes.

Submersible water pumps will take water from within 10 to 20 cm of pond bottoms and discharge it horizontally at 5 to 10 cm below the surface; air lifts will relocate water to and from similar depths; fan-blade mixers will be deployed for greatest efficiency without undue disturbance of sediments. Operation time will be controlled and recorded automatically; power use will be monitored either automatically or manually. DO will be measured at three depths at one selected location in a pond at 15 to 30 min intervals by pumping water to the land-based monitoring system; temperature will be measured at 10 cm depth intervals by thermocouples suspended from floats at several pond locations. This will provide whole-pond assessment of stratification and show the relationship of DO distribution to temperature profiles.

Pond facilities: AIT ponds: 1 m deep; approx. 400 m^2 (and larger ponds as available). Ponds of 2,000 m^2 at UH Mariculture Research and Training Center in Hawaii.

Culture period: Five months, or as specified in collaborating experiments.

Fish stocking rate: Sex-determined fingerling *Oreochromis niloticus* at 2 fish/m^2, or as specified in collaborating experiments.

Nutrient inputs: Best rates resulting from MSU experiments, or as specified in collaborating experiments.

Sampling schedule: Standard protocol, or as specified in collaborating experiments.

Water Management: Standard protocols, or as specified in collaborating experiments.

Null hypotheses: Total energy input and other aspects of strategy required for mechanical destratification are not affected by surface area of 1 m deep ponds. Low cost mixing strategies will not increase the exposure of pond animals to DO, as indexed by the product of time and concentration ("ppm-hours"). Redistribution of DO by mixing will not conserve daytime supersaturation levels against loss to the atmosphere.

Schedule: Data collection, 4/93 to 8/93 and when other ponds are available; technical report, 10/93.

THAILAND STUDY 9: FIELD TESTING LEAST-INTENSIVE AQUACULTURE TECHNIQUES ON SMALL-SCALE INTEGRATED FARMS IN THAILAND

Objectives:

1) To test high-yielding and economical pond fertilization and fish stocking practices developed by the PD/A CRSP at two off-station locations in Thailand,
2) To describe those iterations of the PD/A CRSP Pond Management Guidelines (developed by the Data Analysis and Synthesis Team (DAST) as a computer program) that most closely approximate pond productivity and fish yield obtained at off-station locations, and
3) To obtain field validation for a simple kit to use on farms to regulate the addition of fertilizers to ponds in an efficient, cost-effective manner.

Significance: The Asian Institute of Technology (AIT) and the Thailand Project of the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) have been leaders in the development of fertilization and management practices for fish ponds in Southeast Asia. On-station work conducted by the PD/A CRSP at AIT has resulted in the development of guidelines for fertilizing and stocking fish ponds to obtain high yields of Nile tilapia (*Oreochromis niloticus*). These guidelines will be incorporated into an existing aquaculture outreach program that AIT has successfully established in Northeast Thailand, and will also be applied at an off-site fish farm north of Bangkok. On-farm testing of recommended cultural practices will validate and/or reveal shortcomings of research findings and PD/A CRSP Pond Management Guidelines.

Methodology: There will be three field components to this project: 1) on-farm activities in Northeast Thailand, 2) off-site activities on a fish farm north of Bangkok, and 3) evaluation of a biosassay field kit. The field kit will be assessed in ponds at AIT and Bang Sai, and once efficacy has been established, will be used in fish farm ponds in Northeast Thailand. The bioassay field kit will identify the degree of carbon, nitrogen, or phosphorus limitation in ponds by comparing algal growth in C-, N-, and P-enriched flasks to growth in unenriched pond water.

On-farm activities will be conducted in Northeast Thailand near Udorn Thani. Ponds will be used on up to 20 farms that participate in AIT's outreach program. Farmers in the area raise Nile tilapia in monoculture or in polyculture with common carp (*Cyprinus carpio*) and/or silver barb (*Puntius gonionotus*). For on-farm trials, sex-reversed male Nile tilapia will be stocked in June 1991 and grown through December 1991. Water quality parameters will be measured monthly throughout the grow-out period. Water quality parameters measured will include pH, alkalinity, total phosphorus, soluble reactive phosphorus, ammonia-nitrogen, and nitrate-nitrite-nitrogen. Past fertilization practices and cost and availability of urea and triple superphosphate will be studied. The same approach will be used for an off-site study conducted at the Sombat farm north of Bangkok, where acid-sulfate soils occur.

Pond facilities: Earthen ponds used by private farmers in Northeast Thailand will vary in size. Earthen ponds at the fish farm just north of Bangkok (Sombat's farm) are 160 m^2 at a depth of 1 m. For the bioassay field testing, earthen ponds at both Bang Sai and AIT will be used. At Bang Sai, ponds have a surface area of 220 m^2 at a depth of 1 m (at stadia) while AIT ponds have a surface area of 394 m^2 at 1 m of depth.

Culture period: 150 to 180 days for ponds in Northeast Thailand; 1 year for the ponds at Sombat's farm.

Fish stocking rate: All fish stocked will be sex-reversed male Nile tilapia (*Oreochromis niloticus*). Ponds in Northeast Thailand will be stocked at a variable density at the farmer's discretion. At Sombat's farm, a partial harvesting/stocking strategy will be used. Fish will be initially stocked at $1/m^2$; ten weeks later an additional 1 fish/m^2 will be stocked; ten weeks later the initially stocked fish will be harvested and an additional 1 fish/m^2 will be stocked. This pattern will be repeated until the termination of the experiment.

Nutrient inputs: Recommended input rates for ponds in Northeast Thailand will vary from pond to pond depending upon alkalinity but will have an N:P ratio of 3:1. Actual input rated will be up to the farmer since only recommendations will be made. At Sombat's farm 35 kg/ha of urea-N and 15 kg/ha of triple superphosphate will be added weekly. Phosphorus additions might vary depending upon monthly water quality data. No chicken manure will be used at Sombat's farm.

Water management: Water will be added to ponds to replace evaporation and seepage.

Sampling schedule: PD/A CRSP standard protocols will be used to sample and analyze water quality parameters which will be measured monthly throughout the grow-out period. Water quality parameters measured will include pH, alkalinity, total phosphorus, soluble reactive phosphorus, ammonia-nitrogen, and nitrate-nitrite-nitrogen. Past fertilization practices and cost and availability of urea and triple superphosphate will also be determined.

Null hypothesis: On-farm fish yields of Nile tilapia will not differ from yields predicted from N-input regressions based on studies conducted by the Thailand PD/A CRSP researchers.

Statistical methods: ANOVA, regression.

Schedule: The proposed starting date for this project is May 1991. Work will begin with the assessment of the bioassay field kit at AIT and Bang Sai Fisheries Station and identification of farmers in Northeast Thailand who will employ PD/A CRSP guidelines for fertilization and management of their fish ponds. Growout of fish in farm ponds in Northeast Thailand and at the off-site farm north of Bangkok will begin during June 1991 and continue through December 1991. Evaluation of the field testing and preparation of educational outreach materials (extension type publications) and technical papers will occur during the first four months of 1992.

THAILAND STUDY 10: REGIONAL VERIFICATION OF FERTILIZER GUIDELINES - PHILIPPINES

Background: Experiments conducted under the first three CRSP work plans used standardized experimental protocols to address the relationships of fertilizer input to yield of fish and shrimp. The biological results obtained from the Thailand Project are felt to be representative of freshwater tropical ponds typical of lower elevations although differing economic conditions in other locales could lead to different fertilizer recommendations for maximizing profit (versus maximizing fish production). This study proposes to test the DAST fertilization guidelines in the Philippines.

All previous CRSP projects were conducted with long-term on-site presence of researchers from the USA universities. This study, however, will rely on Filipino scientists at the Freshwater Aquaculture Center in Munoz, Nueva Ecija, Philippines with only twice yearly visits by scientists from the University of Hawaii. The FAC was established in the early 1970s. It is a freshwater research facility with a large number of replicated ponds with accompanying laboratories and support facilities. Over the years, researchers at the FAC have conducted pioneering work in rice-fish culture, integrated animal-fish culture systems, and fertilization yield trials. A large quantity of baseline and experimental data on the integrated animal-fish culture systems which was conducted at the FAC in the late 1970s and early 1980s and has been made available to the CRSP by ICLARM. This data will greatly facilitate the comparison of data to be collected during this study with data from other CRSP sites. Thus, the FAC is particularly well suited to be the first site for regional verification of fertilization guidelines developed by the CRSP. If this operational strategy of regional verification is successful, it can be used to greatly expand the CRSP into other countries and regions at a reasonable cost.

Objectives: The objectives of the proposed research are to conduct further experiments to develop improved chicken manure/inorganic fertilizer guidelines, and to develop generic organic/inorganic pond fertilizer guidelines for the Philippines and train extension workers in the use of these guidelines.

Experimental Design:

Study 1: This study will determine the minimum N:P ratio to maximize yield. The nitrogen loading rate will be based on the results of earlier studies. There will be four N:P ratios tested during this experiment: 1:1, 3:1, 5:1, and 7:1. Each treatment will be replicated twice.

Study 2: This study will determine the substitutability of chicken manure for urea and TSP. The best N loading rate from previous research and the best N:P ratio from Study 1 will be used. Chicken manure will then be used to substitute for 0%, 12.5%, 25%, and 50% of either N or P (depends on selected N:P ratio). The manure will be supplemented with urea and TSP to reach the desired rates.

Pond Facilities: Eight 500 m^2 ponds at the Freshwater Aquaculture Center, Munoz, Nueva Ecija, Philippines.

Culture Period: Five months for each study.

Fish Stocking Rate: Sex-reversed *Oreochromis niloticus* at 2 fish/m^2.

Nutrient inputs: As per CRSP guidelines and most current nutrient balancing experiments.

Water management: Replace evaporation and seepage losses weekly.

Sampling schedule: Standard protocols except as noted.
Chemical parameters:
- Ammonia-N, soluble reactive phosphorus, alkalinity, and dissolved oxygen: every 2 wks.

Null Hypotheses:
Study 1: N:P ratios do not affect fish yields.
Study 2: Substitution of organic fertilizer for chemical fertilizer will not affect fish yield.

Statistical methods: ANOVA.

Schedule: Data collection, 6/92 to 6/93; technical report, 8/93.

DATA ANALYSIS AND SYNTHESIS TEAM

Cooperating Institutions and Principal Investigators:

University of California at Davis
Dr. Raul Piedrahita

Oregon State University
Dr. James Lannan

INTRODUCTION

The goals and objectives of the DAST during the period covered by this work plan are based on the material presented in the Second DAST Newsletter (June 1990), and on the current status of the management guidelines and the modeling work. The objectives are directed towards the improvement of the Management Guidelines and existing models using new CRSP data and towards the development of specific applications for monitoring and optimizing the performance of whole pond systems. The DAST proposal during this work plan includes an experimental component to complement the field data being collected at the CRSP sites. This experimental component will be carried out in collaboration with the other CRSP participants.

Development of the Preliminary Pond Management Guidelines was a major achievement of the DAST during the current work plan. Field testing and refinement of the Guidelines are essential steps in the validation process. Testing of the proposed management practices and of the models developed will be carried out with data sets from the fourth and subsequent experimental work plans as these data were not used in model development. Further testing of the Management Guidelines will be carried out in the field by managing ponds in accordance with the recommendations obtained from the execution of the Guidelines computer program. Feedback from other CRSP participants will be an important component of the testing and validation processes. Refinements of some of the algorithms in the Guidelines may be possible based on CRSP data and models currently available. The OSU and UC Davis teams will collaborate in incorporating improved formulations into the Guidelines.

The examination of primary productivity in aquaculture ponds depends on an accurate understanding of the oxygen consumption and production processes occurring in the water. There are, however, deficiencies in our understanding of water column respiration processes. These deficiencies and the lack of practical field methods for measuring diel pond respiration rates have limited the development of workable analytical models to monitor the overall productivity in ponds. An example of such a model under development by the UC Davis DAST is used to estimate the efficiency of primary production in an aquaculture pond on an hourly, daily or weekly basis (Efficiency of primary production in this context is based on estimates of primary production per unit area and unit of light impinging upon the water surface). This model has been developed by examining mechanistic relationships important in primary production and is based on measurements of changes in pond dissolved oxygen concentration. Improved estimates of primary production and respiration rates will make it possible to refine the model and use it to evaluate the overall condition of primary producers in a pond on an ongoing basis, and to examine the effects of changes in pond parameters (such as depth, turbidity, or temperature) on the efficiency of primary production.

It is apparent from previous work by the CRSP DAST that water column respiration cannot be described solely by empirical temperature dependent functions. Equally problematic is the common practice of extrapolating night respiration rate measurements to daytime periods. Some laboratory and field studies have shown that respiration rates fluctuate widely over the diel cycle. Extrapolating the nighttime respiration rates over the diel period results in significant underestimation of total pond respiration, which results in low estimates of gross primary production. It is therefore critical that the processes controlling light and dark respiration rates in a pond be examined to understand primary productivity more fully. Accurate predictions of dissolved oxygen in ponds and the design of effective management practices must be based on a thorough understanding and quantification of these production and respiration rate changes.

Thermal stratification in shallow aquaculture ponds is a common occurrence. Thermal stratification is normally paralleled by the stratification of dissolved oxygen and other water quality parameters. While dissolved oxygen and temperature models have been proposed for homogeneous water columns, it has been suggested that some of the lack of realism of these models has been due to the assumption of fully mixed conditions when indeed this was not the case. A better quantification of the effects of water stratification, phytoplankton production and dissolved oxygen availability would improve the predictive quality of these models.

Models of stratified ponds have been developed at UC Davis. These models require detailed water quality and environmental data, and have resulted in predictions of water temperature and dissolved oxygen concentrations at 15 cm intervals for ponds up to 1.3 m in depth. Modifications will be made to the models as more recent CRSP data are received, and as data requirements are reduced based on model testing and sensitivity analysis. CRSP-generated data will be supplemented with more intensive or parameter-specific studies conducted previously by the UC Davis DAST, or with data from experiments being proposed for the current Work Plan. The stratified models results will be used to predict the extent of water stratification in ponds. This information will be useful for selecting pond sites or culture conditions.

Three studies are proposed by the DAST for The Sixth Work Plan (Figure 4). The goals of these studies are:

1. To improve the reliability of CRSP pond management guidelines by incorporating research findings that have become available since completion of the Provisional Guidelines.;

2. 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; and

3. To develop and test models of temperature and dissolved oxygen stratification in CRSP ponds.

Figure 4. Schedule of Activities and Reports of the Data Analysis and Synthesis Team during the Sixth Work Plan.

Study Title	1991 Sep	Oct	Nov	Dec	1992 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1993 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Study 1. Testing and Updating CRSP Management Guidelines																								
- Refine present algorithms	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***					
- Finalize second version of Guidelines																				***	***	***	***	
- CRSP participant review of Guidelines																								****
Study 2. Quantification of Light and Dark Respiration Rates																								
- Develop laboratory method for measurement	***	***	***	***																				
- Method and field measurement					***	***	***	***	***	***	***	***	***	***	***	***								
- Completion of CRSP Global Experiment																	***	***	***	***	***			
Study 3. Models for Temperature and Dissolved Oxygen in Stratified CRSP Ponds																								
- Model modification	***	***	***	***	***	***	***	***	***	***	***	***												
- Model calibration and validation													***	***	***	***	***	***	***	***	***	***	***	***

DAST STUDY 1: TESTING AND UPDATING OF CRSP MANAGEMENT GUIDELINES

The overall goal of this study is to improve the reliability of CRSP pond management guidelines, and to make the guidelines more comprehensive by incorporating research findings that have become available since completion of the Provisional Guidelines.

Objectives:

1. To use data from CRSP Work Plans four and five to verify quantitative relationships used in the Provisional Guidelines.
2. To develop new relationships to provide more comprehensive management guidelines.
3. To prepare a second, more comprehensive version of pond fertilization guidelines.

Methods: The first edition of CRSP guidelines was based mainly on data from CRSP Work Plans one through three, and on review of technical literature. Refinement of the Provisional Guidelines will be based on analysis of new CRSP data (Work Plans Four and Five) as they become available to the DAST, and the specific results of other projects being accomplished by the DAST under Work Plan Six. Wherever appropriate, the present algorithms will be replaced with expressions derived from new analyses of CRSP data. Algorithms related to primary production, respiration, and fertilization are the main areas in which revisions are likely to be made. Specifically, this study will focus on the following questions:

1. Can inorganic fertilizers satisfy the nutrient requirements of all ponds or only ponds with certain characteristics? Under what circumstances, if any, do ponds require the addition of organic material?
2. For a given climate zone and season, what is the maximum potential net primary production when primary nutrients are not limiting?
3. Are simple, on-farm methods available for partitioning water turbidity into volatile and non-volatile components?
4. Can expected fish yields be estimated for ponds in which primary nutrients are limiting?
5. Are simple, on-farm methods available for determining nutrients available in various organic fertilizers?
6. How should pond nutrient requirements be adjusted for ponds that tend to stratify?
7. How do fish stocking practices influence requirements for primary nutrients?

Components or subunits of the Guidelines will be considered independently to facilitate detailed analysis. Output obtained with the current version of the algorithms will be compared with new CRSP data as they become available to the DAST. Similar analyses will be carried out with models and algorithms developed by the DAST. Comparison between the two sets of outputs will be the primary criteria used in selecting the formulation to be used in the Guidelines. Another important criteria for selection of the formulations is data requirements, and a balance between reducing data needs and improved output realism will be sought depending on the specific application and on the uses and audience for the results.

Schedule: Review and synthesis of research findings from CRSP Field Projects is an ongoing DAST activity, and will continue as new data becomes available to the DAST. These data and the results of on-farm testing of the Provisional Guidelines will be used to refine presently used algorithms, and to develop new algorithms where appropriate. This activity will continue until March, 1993, at which time effort will shift to incorporating the algorithms into a second, more comprehensive version of the Guidelines. The revised Guidelines will be available to CRSP participants for review by August 31, 1993.

DAST STUDY 2: QUANTIFICATION OF LIGHT AND DARK RESPIRATION RATES

The overall goal for this study is 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.

Objectives:

1. To develop consistent, convenient methodologies for determination of hourly rates of community light and dark respiration in aquaculture ponds over the diel period.
2. To examine how light and dark respiration rates change over the diel period and to establish the relationships between these rates and environmental factors.
3. 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. These models will then form the basis of analysis of various experimental pond treatments and provide an ongoing objective criteria for pond system performance.

Significance: Measurement of water column respiration rates throughout the diel cycle are not available and daytime respiration is normally extrapolated from nighttime measurements. This approximation tends to result in an underestimation of daytime respiration and gross primary production rates. The results of this project will serve to improve our understanding of primary production and respiration processes and will result in better predictability of dissolved oxygen concentration in ponds, and the development of management practices to ensure optimum oxygen regimes within the physiological limitations of phytoplankton.

Methods: An apparatus will be designed to measure the change in dissolved oxygen concentration in the dark in samples that are suddenly removed from the light. The apparatus will use dissolved oxygen microprobes with fast response times so that transient changes in oxygen concentration may be measured. Initial work will be carried out with laboratory plankton cultures at various stages in their light-dark cycle. i.e. subsamples (≈ 100 mL) from a culture (≈ 10 L) in a lighted chamber. Based on the laboratory work, a methodology and equipment will be developed to measure pond respiration rates over the diel period in the field. Field research will be conducted in cooperation with the University of Hawaii CRSP, at the Mariculture Research and Training Center (MRTC) or at field sites in Thailand.

Improved pond respiration measurements based on the laboratory and field experiments will be used to estimate net primary production rates from CRSP pond data. These estimates will be incorporated into computer models and used to investigate: a) possible changes in the response of phytoplankton to light intensity between morning and afternoon; b) effects of pond treatments on production parameters; and c) effects of pond depth and turbidity on production efficiency. The results obtained from the field and modeling work will form the basis of a global CRSP experiment to be proposed by the UC Davis DAST. This experiment will use the methodology developed herein, and will serve to evaluate the pond systems at the various sites on the basis of primary production response to environmental conditions and pond treatments. The experiment will consist of a specific short-term data collection scheme to be carried out in ponds at all CRSP sites. Pond management practices will not be altered from those proposed by the individual site teams.

Schedule: Method for laboratory measurement of light/dark respiration rates by Dec 1991. Method and field measurement of respiration rates by Dec.1992. Completion of global experiment proposed by the CRSP by May, 1993. Computer model development and improvements will be ongoing and will incorporate data as they become available.

DAST STUDY 3: MODELS FOR TEMPERATURE AND DISSOLVED OXYGEN IN STRATIFIED CRSP PONDS

The overall goal of this study is to develop and test models of temperature and dissolved oxygen stratification in CRSP ponds.

Objectives:

1. To simplify the data requirements of existing temperature and dissolved oxygen stratification models and test the models with non-CRSP and CRSP data sets.
2. To incorporate into existing models the more accurate characterization of primary production and respiration rates identified in Study 3.
3. To calibrate and verify the modified/simplified models with CRSP data. Short-term data collection schemes may be proposed to CRSP field sites to generate data sets for validation of these models.

Significance: Thermal and chemical stratification are frequently observed in CRSP ponds, but all computer models and management practices currently being used and recommended ignore this stratification. The proposed work will build on models previously developed at UC Davis by incorporating findings from Study 3. The models will be used to predict dissolved oxygen and temperature in stratified ponds, and to study how these are affected by management, water quality and climate factors.

Methods: Temperature and dissolved oxygen stratification models developed previously by the UC Davis DAST will be simplified to run on data sets comparable to those being collected at the CRSP sites. The models also will be modified to incorporate the results of our work on primary production and pond respiration (DAST Study 3) as they become available. Initial testing of the models will be conducted with data obtained by reprocessing data sets originally used to test and validate the models. Reprocessing of the data sets will consist of eliminating variables not currently monitored at the CRSP sites, and reducing the temporal and spatial resolution to match those of the CRSP data. For example: measurements of solar radiation will be averaged over time periods ranging from two to four hours as is currently done for the CRSP diel cycle measurements.

After the models have been tested with these simplified data sets, they will be executed using CRSP data sets. The quality of the simulations will be determined by comparing the simulated results with actual measurements of dissolved oxygen and temperature in CRSP ponds. Depending on the quality of simulations obtained with existing CRSP data sets, specific short term data collection schemes will be proposed to the field sites. These data collection runs will be carried out in existing project ponds, will last between 24 and 48 hours, and be repeated once or twice during an experimental cycle. Data collected under this protocol will be forwarded directly to the UC Davis DAST to expedite the analysis.

Schedule: Model modification to simplify and reduce data needs, and initial model testing by August, 1992. DAST Study 3 results will be incorporated into the dissolved oxygen model as they become available. Model calibration and validation by execution with CRSP data sets by August 1993.

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Air Temperature - see Temperature, Air				
Alkalinity	Near center of each pond, take readings at 25 cm below the water surface, midwater and 25 cm above the bottom. Keep samples cool in refrigeration unit or ice chest, and analyze within 24 hours.	Hach Digital Titrator Test Kit/Alkalinity (optional).	Low or Standard Alkalinity method (as appropriate) (from "Standard Methods," APHA et al., 1985), or Hach Test Kit	mg CaCO3/L
Ammonia	Collect one sample (by pooling three 90 cm column samples) from each pond. Samples should be refrigerated and analyzed within 24 hours.	Kontes or comparable Kjeldahl nitrogen apparatus. See Nitrogen, Kjeldahl Apparatus	Nesslerization Method (Michigan State University Limnological Research Laboratory, 1984).	mg/L
Benthos Composition	Collect at least three cores of mud per pond. Process samples through a No. 30 sieve, sort organisms and fix in 10% formalin or a 70% ethanol solution. Identitfy at the order level or lower. Count number of organisms per unit volume or area.			various
Chemical Oxygen Demand - see Oxygen, Chemical Demand.				

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Chlorophyll a (corrected and uncorrected)	Collect one sample per pond by pooling three 90 cm column samples. Take samples with diel studies.		Acetone extraction and Spectrophotometric Determination, from "Standard Methods" (APHA et al., 1985)	mg/m3
Dark Bottle Respiration - see Respiration, Dark Bottle				
Depth, Pond	Install staff gauge in each pond and read to nearest 0.5 cm at same time each day, before restoring to specified depth.	No type specified.		m
Dissolved Oxygen - see Oxygen, Dissolved				
Evaporation and Inflow	Surface Inflow/Outflow and Evaporation should be determined using procedures described in Appendix F of CRSP Work Plan III, 1985, (Wood, J.W. 1974. Diseases of Pacific Salmon: Their Prevention and Treatment. pp 71-77) or comparable approaches.			mm/d (evaporation); m3/d (infiltration)
Feed Composition	See Analytical Methods Report			various

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Fish/Shrimp Length, Individual	From a representative 10% subsample of the grab sample, determine total length of each individual and express as mean length per individual.			cm
Fish/Shrimp Production	Fish and shrimp stocks will be weighed as a group and counted at stocking and harvest. Tilapia will be sexed individually. Compute gross and net production.			kg and #
Fish/Shrimp Weight, Group	At 30-day intervals throughout each experimental cycle, collect grab sample equivalents to 10% of initial stock from each pond and weigh as a group. Indicate number of individuals in sample. Note observations on reproduction and fish health.			kg/#, individual
Fish/Shrimp Weight, Individual	From a representative 10% subsample of the grab sample, determine weight of each individual and express as weight per individual.			g

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Flow, Water	See Evaporation and Inflow			
Morphometric Characteristics: Maximum Length, Maximum Width, Area, Depth, Volume	At project initiation and whenever pond facilities are altered, prepare contour maps of ponds at 10 cm intervals. Note inflow and outflow locations.			m, m2, m3, (as appropriate)
Nitrogen Total Kjeldahl	For each pond, pool three 90 cm column samples. Composite samples should be refrigerated and analyzed within 24 hours.	Kontes or comparable Kjeldahl Nitrogen apparatus	Semi-Micro-Kjeldahl Method (Michigan State University Limnological Research Laboratory, 1984)	mg/L
Oxygen, Chemical Demand	Please refer to the appendices from Work Plans III & IV, attached. (methods from: "Standard Methods for the Examination of Water and Wastewater," APHA et al., 1985).			
Oxygen, Dissolved	Near center of each pond at 25 cm below water surface, mid-water and 25 cm above the bottom. Take readings as part of diel study at seven different times beginning with pre-dawn.	Yellow Springs Instrument Model 57 Dissolved Oxygen Meter. Calibrate meter each time using the Winkler Method or HACH Digital Titrator Kit/Dissolved Oxygen.	Winkler or Iodometric method (from "Standard Methods," APHA et al., 1985)	mg/L

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
pH, Water	Near center of each pond, take readings at 25 cm below the water surface, mid-water, and 25 cm above the bottom. If a probe is used, calibrate using a precision thermometer. Calibrate meter with standard buffers at pH 7 and pH 10.	pH Meter with Combination Electrode comparable to Orion 2000 Series with Ross Model 81-55 Electrode.		pH units
Phosphorus, Total	Collect one sample (by pooling three 90 cm samples) from each pond. Samples should be refrigerated and analyzed within 24 hours.		Persulfate Digestion and Ascorbic Acid/Colorimetric Method, from "Standard Methods" (APHA et al., 1985)	mg/L
Phytoplankton Composition	Monthly and when changes in the community are observed, collect samples using a Van Dorn or Kemmerer bottle. Use a compound microscope and references to identify to appropriate taxonomic level and count or estimate bio-volume.			various
Primary Productivity	Whole pond method preferred. Light-dark bottle at three depths acceptable.			
Pond Depth - see Depth, Pond				

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Pond Soil Characteristics - see Soil Characteristics				
Pond Temperature - see Temperature, Water				
Precipitation - see Rainfall				
Rainfall	Install three rain gauges at study site; read and empty at 24-hour intervals, or more frequently to prevent gauge overflow; report average of three readings.	No type specified. Recommended gauge from Grassroot Co., Wisconsin.		cm/d
Respiration, Dark Bottle	Collect one sample (by pooling three 90 cm column samples) from each pond. Incubate for four hours or as appropriate to prevent oxygen depletion, in dark bottles suspended at mid-depth in ponds.		Oxygen method, adapted from "Standard Methods" (APHA et al., 1985).	mg C/m3/d
Salinity	Near center of each pond, collect a 500-ml sample at 25 cm below the water surface, mid-water, and 25 cm above the bottom. Mix the samples and analyze.	Use a temperature-compensated refractometer or a salinity meter.		ppt
Secchi Disk Visibility - See Visibility, Secchi Disk				

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Seepage	Determine seepage from a 24-hour water balance, preferably when there is no rainfall, inflow, or outflow: Seepage = Evap x 0.10 - (Final Depth - Initial Depth), where Evap is in mm/d and the depth measurements are in cm and and taken 24 hours apart.			cm/d
Soil, Characteristics: pH, Phosphorus, Organic Matter, Total Nitrogen, Cation Exchange Capacity, Metals (Aluminum, Iron, Zinc) , Lime Requirement, Exchangeable H, Base Saturation	At the end of an experiment and before beginning another, collect twelve 15 cm core samples from each pond, combine and dry as described in Appendix D of Work Plan III (attached). Take a subsample for each pond and analyze using a qualified local or U.S. laboratory.			As appropriate
Solar Radiation	Install Solar Monitor and Quantum Sensor and read the cummulative radiation each day and at end of each time interval during diel study.			E/m2 E/m2/d
Solids, Total Suspended	See Appendices		In: "Standard Methods" (APHA et al., 1985)	mg/L

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Solids, Volatile Suspended	See Appendices		In: "Standard Methods" (APHA et al., 1985)	mg/L
Temperature, Air	Install three maximum-minimum thermometers in the shade near ponds; read at 24-hour intervals and report average maximum and average minimum.	Maximum-minimum thermometer comparable to Taylor Model 5460.		Max°C; Min°C
Temperature, Water	Near center of each pond, take readings at 25 cm below the water surface, midwater, and 25 cm above the bottom. Take readings as part of diel study at 7 different times. If probe is used, calibrate using a precision thermometer.	YSI Model 57 Dissolved Oxygen Meter with Temperature Indicator.		°C
Total Kjeldahl Nitrogen - see Nitrogen, Total Kjeldahl				
Total Phosphorus - see Phosphorus, Total				
Total Volatile Solids - see Solids, Volatile Suspended				

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Wind Speed	Install totalizing anemometer, read at 24 hour intervals (between 0800 and 0900 hours), and calculate average hourly wind speed.	Totalizing anemometer comparable to WEATHERtronics Model 2510. The instrument should be located in the pond complex 2m above the level of the pond banks.		km/h
Visibility, Secchi Disk	At two locations in each pond, calculate Secchi Disk Visibility using procedure described by Lind (1974).			cm
Zooplankton Composition	Monthly and when changes in the community are observed, collect at least three 90 cm column samples per pond or use trap or zooplankton net, as appropriate. Use a microscope to identify at the order level and count number of organisms per unit volume.			No./m3

ADDENDUM

WORK PLANS (1 MAY 1991 THROUGH 30 APRIL 1992) FOR THE FY91 20% SUPPLEMENTAL APPROPRIATION

INTRODUCTION

In December 1990 AID granted a 20% increase in all CRSP budgets (except the Nutrition and Fisheries Stock Assessment CRSPs) for the period 1 May 1991 to 30 April 1992. This increase amounted to $196,000 for the PD/A CRSP, of which 80% was available to fund new initiatives. A formal call for proposals for activities to be funded under this new allocation was made at the Ninth Annual Meeting of the PD/A CRSP held on 7 to 9 March 1991 at Auburn University, Auburn, AL. A Technical Committee Executive Panel (EP), elected during the 1991 Annual Meeting, was charged with the responsibility of evaluating and recommending action on submitted proposals. The EP recommendations, along with those of the Program Director were forwarded to the PD/A CRSP Board of Directors (BOD) for final recommendations.

Successful proposals would fulfill several key criteria:

1) be relevant to the overall goals of the PD/A CRSP
2) be relevant to sustainable agriculture/natural resource management
3) address the constraints identified by Congress and AID for the increase.

In addition to evaluating the submitted proposals according to the above criteria, the EP established additional criteria for proposal evaluation (listed, but not prioritized):

1) technical merit
2) can the objectives be met based on research design, schedule, and budget?
3) additional recommendations set forth by the Technical Committee at the Auburn Meeting (i. e., format, page limit, deadline)
4) past performance.

A total of 16 proposals were received by the PD/A CRSP PMO by the 10 April 1991 deadline for submission. On 16 April 1991, the EP was convened, via telephone conference call, to evaluate the proposals; Hillary Egna, Program Director, also participated in the conference call. The EP's recommendations were submitted to the BOD, through the Program Director, on 18 April 1991. The BOD concurred with the EP's and Program Director's recommendations, and approved funding for eleven of the sixteen proposals. Subsequent to BOD approval, one proposal was withdrawn.

Work plans for the approved proposals follow, arranged arbitrarily. Work plans will be implemented beginning 1 May 1991, and all work completed and final reports due by 30 April 1992.

PROJECT TITLE: SOCIOECONOMIC FACTORS AFFECTING THE TRANSFER AND SUSTAINABILITY OF AQUACULTURE TECHNOLOGY IN RWANDA

Cooperating Institutions and Principal Investigators:

Auburn University, Auburn, Alabama
Dr. Joseph J. Molnar

Objectives: To establish baseline quantitative information about women and men who operate fish ponds in Rwanda; to profile the circumstances and motivations underlying decisions to discontinue the practice of fish culture; to describe the practices and technical proficiency of independently established fish farmers with no regular contact with extensionists.

Significance: Pond studies by CRSP have endeavored to develop technology relevant to on-farm circumstances. This research will incorporate socioeconomic limitations and actual farming system circumstances in developing the knowledge base for long-term growth of the activity. Systematic documentation of the way fish culture is implemented by the target population and how it fits in their lives will complement the scientific and institutional achievements of the CRSP.

Methodology:

Three categories of farmers will be interviewed: active farmers receiving extension assistance, active fish farmers not receiving regular visits from extensionists and fish farmer dropouts. Interviews will be conducted with 200 active fish farmers randomly selected from project rolls in local administrative districts purposely chosen to represent the agro-climatic diversity of the country. Contact will be made by Extension representatives. The Interviewer, a Rwandan national, will conduct interviews in the native language using a standardized set of question and response frameworks. Approximately 60 minutes will be spent with each farmer. Approximately 50 farmers who have discontinued fish culture will also be interviewed, and an additional 50 active fish farmers without significant extension assistance will also be contacted.

Separate interview schedules will be developed for each of the three categories of respondents. Each survey instrument will be developed, translated and pretested with members of each category. The survey instrument will be formulated upon consultation with the Rwandan Director of Aquaculture, currently on a degree program at Auburn University. Helpfulness and satisfaction indices will be used to determine farmer perceptions about extension assistance.

Null hypotheses: Farmer perceptions on the relative value of fish culture are unrelated to the presence or absence of extensionists. No indicators reflect sustainability of fish culture in Rwanda. No significant differences in conditions or attitudes exist between active and dropout fish farmers.

Statistical methods: Primarily non-parametric, such as Kruskal-Wallis, Mann-Whitney U, and Friedman.

Schedule:

July-September 91: develop sampling strategy and pretest instrument.
October 91 - March 92: data collection.
March - April 92: data analysis.
May 92: report issued.

PROJECT TITLE: A PRELIMINARY STUDY OF WOMEN'S PARTICIPATION IN FISH CULTURE ACTIVITIES OF RWANDA

Cooperating Institutions and Principal Investigators:

Oregon State University, Corvallis, Oregon
Dr. Revathi Balakrishnan
Ms. Karen Veverica

National Fish Culture Service, Rwanda
Ms. Pelagie Nyirahabima

Objective: To document the successes and failures of integrating Rwanda woman in aquaculture, and of extending the technology through women in other countries in the region.

Significance: Aquaculture is a viable alternative production process to sustain land resources, improve households' income potential and nutrition. In Rwanda, with its growing interest and demonstrated success in aquaculture, women farmers trained in aquaculture can contribute effectively to achieving the balanced development of productivity with sustainability. Moving beyond forestry resources, a broader perspective of sustainable development would focus on gender roles in ecological resource sustainability. In this project the focus is on women's role in natural resource management in the area of aquatic resource management through participation in aquaculture. This information will: 1) contribute to the CRSP generated knowledge base to develop gender sensitive aquaculture technology; 2) assist in structuring similar aquaculture extension programs for women in that region; and 3) generate training materials relevant to aquaculture technology transfer to women farmers.

Data Collection: Qualitative research to develop an in-depth project case study on "Rwandan Women in Fish Production," and a workshop to facilitate trialogue between production scientist, extension personnel and women farmers who have adopted fish cultivation technology. The study will utilize secondary data, and collect disaggregated data by qualitative techniques such as focus group and personal interviews. Sample: Farm women (technology adopters); production scientists (technology developers) and extension workers (technology disseminators). Workshop Format:

a. Panel shared by women farmers and extension workers
b. Panel shared by production scientists and extension workers
c. Panel shared by women farmers and production scientists.

Hypothesis: Exploratory study.

Statistical Methods: Statistical methods applicable to qualitative data.

Schedule: May 1 1991 to April 1992. Report April 1992.

Remarks: The project will be implemented by the Office of Women in International Development in the Office of International Research and Development, Oregon State University. It is a component of the OSU Rwanda PD/A CRSP. This gender integration study strengthens the socio-economic dimension of Rwanda PD/A CRSP research.

PROJECT TITLE: ON-FARM *Clarias gariepinus - Oreochromis niloticus* POLYCULTURE IN RWANDA

Cooperating Institutions and Principal Investigators:

Rwasave Fish Culture Station
Université Nationale Du Rwanda, Butare, Rwanda
Dr. Evariste Karangwa
Mr. Lieven Verheust

Oregon State University, Corvallis, Oregon
Ms. Karen Veverica

Objectives: To compare clarias-tilapia polyculture, mixed-sex monoculture of tilapia and monoculture of clarias, each at two elevations, to determine the most advantageous stocking strategy on the basis of total fish production and comparative economic benefit. Mono and mixed-sex tilapia culture will also be evaluated by comparison with results of CRSP Study 3, Work Plan 6, an on-farm, mono-sex experiment.

Significance: This experiment will result in recommendations for the application of a specific culture strategy appropriate with elevation and economic considerations. Polyculture may increase biological and economic efficiency and the sustainability of fish culture in some highland African environments.

Experimental design: Three stocking treatments will each be tested at two elevations. Stocking treatments, all at 1 fish/m^2 are: mixed-sex tilapia; 2/3 tilapia - 1/3 clarias; clarias monoculture. Five ponds used per treatment except for clarias monoculture where two ponds per elevation will be used. One fertilization level equal to that of CRSP EXP 1 and 3, Work plan 6,will be applied.

Facilities: Twenty-four rural farmer ponds, 12 at each of two elevations to include a relatively low and a relatively high elevation range. Ponds will be selected within parameters listed in the proposal.

Culture period: Culture period will be at least 5 months but will continue until fish reach an average weight of 120 g.

Fish stocking rate: One fish per m^2 (see details in design).

Nutrient inputs: Input rate will be 250 kg/ha/wk dry weight of fresh grass plus inorganic nutrients added as urea and TSP to increase added N to 15 and P to 4 kg/ha/wk.

Water management: Weekly addition to replace losses.

Sampling schedule: Standard protocol except:
Physical parameters:

- max-min temperature, inflow, depth and Secchi disk visibility: weekly.
- temperature of unsaturated soil at a depth of 60 cm: 3 times during the experiment.
- continuous temperature recording (one pond per elevation).

Chemical parameters:
- one soil analysis at termination.
- total alkalinity, hardness and conductivity: monthly.
- no diurnal or primary productivity measurements.

Biological parameters:
- fish weight: monthly.
- stomach analysis: 5 fish/pond after 3 months and 10 fish/pond at termination.

Economic parameters:
- marketing and other socio-economic data will be collected through a farmer interview.
- an enterprise budget will be developed.

Null hypothesis: Total net fish production, tilapia fingerling production, or economic benefits will not differ among treatments. Total fish production, tilapia fingerling production, or economic viability of the culture system will not differ among elevations.

Statistical methods: One and two-way ANOVA, linear, multiple regression.

Schedule: Propose starting July 1991. All ponds harvested by March 1992. Report by May 1992.

PROJECT TITLE: A CONFERENCE ON HIGH-ELEVATION TILAPIA CULTURE

Cooperating Institutions and Principal Investigators:

Rwasave Fish Culture Station
Université Nationale Du Rwanda, Butare, Rwanda
Dr. Evariste Karangwa

Oregon State University, Corvallis, Oregon
Ms. Karen Veverica

Objectives: Plan and conduct a conference on high-elevation tilapia culture which will address conditions and practices in rural, high-elevation operations. Publish proceedings. Also re-establish international collaboration and the exchange of information among those involved in aquaculture, from Peace Corp personnel to rural farmers, government agents and others.

Significance: This conference will provide a forum for sharing information on the evolving tilapia culture practices used in this region of Africa. Technology recommended encourages use of sustainable practices. Proceedings and discussion sessions will be published and a table of country statistics will be developed. The opportunity exists to improve culture and extension practices in a number of African countries.

Project design: The conference will be held at UNR, Rwasave Station in Butare in September, 1991. The elements are:

1. Country reports: a description of the history and present and future strategies in culture and extension.
2. Technical reports: Detailed presentations of applicable production or research data.
3. Site visits: Kegembe and Rwasave Stations, rural ponds.
4. Workshop sessions: Hand sexing, PONDCLASS system, demonstration of extension manuals and other materials.
5. Discussion sessions.
6. Publication preparation

Facilities: Conference room and other facilities at Rwasave Station.

Schedule: Invitations sent: 31 May 1991. Abstracts and statistics required: 30 July 1991. Conference held: 1 to 7 Sept 1991. Final revisions of papers, transcript of discussions submitted for publication: 31 Dec 1991.

PROJECT TITLE: ON-FARM TESTING OF PD/A CRSP FISH PRODUCTION SYSTEMS IN HONDURAS

Cooperating Institutions and Principal Investigators:

Auburn University, Auburn, Alabama
Dr. David R. Teichert-Coddington
Mr. Bartholomew W. Green

El Carao National Fish Culture Research Center
Ministry of Natural Resources, Comayagua, Honduras
Mr. Marco Iván Rodríguez

Objectives: To initiate on-farm testing of PD/A CRSP production technologies, and use this data to validate the PD/A CRSP Pond Management Guidelines. To provide short-term training in aquaculture to extensionists and fish farmers involved with the on-farm production trials.

Significance: Honduras 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. However, it is now time 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, serve as a teaching tool for extensionists and producers, and serve as a test of the PD/A CRSP Pond Management Guidelines.

Methodology: A 1- to 2-week short-course in aquaculture for extensionists and farmers involved with the on-farm production trials will review the basics of aquaculture including fish production, water quality, and pond construction, and to instruct the participants in the objectives and procedures of the farm testing.

On-farm production trials will be implemented on farms in the southern, central and northern regions of Honduras. Trials will be conducted with two target groups of farmers: resource-limited hillside farmers from the USAID/Honduras funded Land Use and Productivity Enhancement (LUPE) project, and small- to medium-scale commercial producers in central and northern Honduras.

A seminar will be convened to review the field-test results with all participants, and to plan for further tests contingent on appropriation of additional funds.

Pond facilities: Ponds on private farms will be utilized; pond sizes will vary. On resource-limited farms one pond will be used, while two ponds will be used on the commercial-scale farms.

Culture period: 150 to 180 days.

Fish stocking rate: On resource-limited farms: fingerling *Oreochromis niloticus* at $1/m^2$, and fingerling *Cichlasoma managuense* at $0.05/m^2$; on commercial-scale farms: male *Oreochromis niloticus* fingerlings at 2 to $3/m^2$, and *Cichlasoma managuense* fingerlings at $0.05/m^2$.

Nutrient inputs: On resource-limited farms: Compost will be the primary nutrient source for ponds. Compost management will follow the Rwanda PD/A CRSP protocol: an initial application of 1000 kg total solids (TS)/ha, followed by weekly applications of 500 kg TS/ha; supplemental nitrogen (28.5 kg/ha urea) may be added weekly. Compost pile will be mixed daily.

On commercial-scale farms: One pond will be fertilized weekly with chicken litter (750 kg TS/ha) and urea (rate dependent on results of the current Honduras CRSP experiment). After 3 months, all fertilization will be terminated and formulated feed will be added to ponds at 3% of fish biomass per day. The other pond will be fertilized weekly as per Thailand PD/A CRSP recommendation: urea (5 kg N/ha/d) and triple superphosphate (1.2 kg/ha/d) will be added weekly to give an N:P ratio to 4:1 by weight.

Water management: Water will be added to ponds to replace evaporation and seepage.

Sampling schedule: The following data will be collected at all farms:

- Soil samples will be collected for analyses; acidic soils will be limed to increase water total alkalinity to $\geq$ 20 mg $CaCO_3$/L.
- Chicken litter will be analyzed for major inorganic nutrients.
- Weights of nutrient inputs, monthly fish samples, and harvest weights.
- Regular measurement of Secchi disk visibility, and periodic samples of water for chemical analyses of major inorganic nutrients.
- Economic statistics.

Null hypotheses: On-farm fish yields will not differ from experiment station fish yields. On-farm fish yields will not differ from PD/A CRSP Management Guideline predictions.

Statistical methods: ANOVA.

Schedule: On-farm trials: 5/91 to 3/92; training course: 6/91; data review seminar: 4/92; report: 4/92.

PROJECT TITLE: ANALYSIS AND EVALUATION OF REAERATION RATES

Cooperating Institutions and Principal Investigators:

University of California, Davis, California
Dr. Raul H. Piedrahita

Auburn University, Auburn, Alabama
Dr. David Teichert-Coddington

Background: The availability of an improved method for estimating reaeration rates is an essential component of the continued development of models for predicting dissolved oxygen concentration in ponds. The work complements research being proposed by the DAST for Work Plan 6 and collaborative work being proposed with Dr. Jim Szyper of the University of Hawaii to refine methods to estimate respiration rates in the water column on ponds. Having accurate methods to estimate rates of reaeration and respiration, one can calculate the rates of oxygen consumption in the sediments from measurements of oxygen concentration in ponds. Estimates of sediment oxygen demand must be obtained from whole pond measurements rather than from the analysis of oxygen concentration changes in discrete volumes in the pond as has been attempted by various investigators. 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 the use of a method based on discrete sampling impractical for pond monitoring and oxygen modeling.

The Honduras CRSP group has made a first attempt at developing a method for the evaluation of reaeration rates in aquaculture ponds. These estimates were found to be different from those obtained with expressions developed by other researchers. The new method was developed from 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 at reducing the rates of oxygen production and consumption. In separate experiments, the Honduras group has made estimates of oxygen consumption by pond sediments, obtaining values that were in the same range as reaeration rates for moderate winds. In this project, we will estimate reaeration rates from measurements of changes in dissolved oxygen concentration in lined ponds. By using lined ponds, the sediment oxygen consumption will be eliminated and a better estimate of reaeration will be available. We will also repeat the experiments for ponds filled to different depths (0.90 and 0.45 m) to try to reduce the magnitude of pond stratification and achieve better estimates of reaeration rates.

Significance: The quantification of the various processes of the dissolved cycle in ponds has been one of the primary objectives of the DAST. Computer models have been developed to simulate the changes in dissolved oxygen concentration in ponds. Methods and techniques have been devised to analyze diel measurements of dissolved oxygen and obtain information on the rates of oxygen consumption and production through various processes. The work proposed here will provide critical information for the improved estimation of the rate of oxygen exchange between the water and the atmosphere. This improved information will complement other ongoing and proposed work by the DAST designed to obtain better estimates of water column respiration. With these improved estimates of pond respiration and reaeration rates, analysis of diel oxygen measurements will be used to obtain more reliable estimates of sediment oxygen consumption and of gross primary production. The project will also allow for the direct collaboration of field and DAST groups in a short term project that may serve as a model for future collaborations.

Objectives: The objectives of the proposed research are: 1. To develop an improved method for estimating reaeration rates from ponds. 2. To test the method by comparing it with other methods previously described.

Methods: The field work for this project will be carried out at the El Carao station in Honduras. Data analysis will be carried out at El Carao and at UC Davis. The field experiments will be conducted over a period of approximately ten days, when the UC Davis PI will be at El Carao.

Reaeration rates will be measured in two ponds similar to those used for previous reaeration rate estimates at El Carao. The ponds will be lined with polyethylene sheeting to eliminate sediment oxygen consumption . The water will be deoxygenated using sodium sulfite and cobalt chloride. Dissolved oxygen concentration and temperature will be monitored in the ponds using an automatic monitoring equipment based on a data logger and available at El Carao. Wind velocity will be monitored at 50 cm and at 3 m above the water surface.

An attempt will be made at minimizing the rates of water column respiration and primary production by filling the pond with unfertilized water and by conducting the tests right after the ponds are filled. Copper sulfate may be used in the ponds to control algae as was done in previous tests conducted at El Carao. Water column oxygen consumption and production rates will be monitored with light and dark bottle tests throughout the duration of the run. Values obtained from the light and dark bottle tests will be used to correct the oxygen measurements for determining reaeration rates. The average reaeration rate coefficients (K_{La}) will be estimated for time intervals over which wind speed remains approximately constant. Calculation of the reaeration coefficients will be according to the method recommended by ASCE.

Regression analysis of the reaeration coefficients and wind speed measurements at the two heights will be carried out to obtain relationships for estimating reaeration rates from wind speed. The statistical significance of the regressions obtained for the two heights will be examined and a recommendation will be made on the best location for wind measurements. The expressions obtained in this project for estimating reaeration rate coefficients will be compared with those obtained previously.

Schedule: The field work will be conducted during a break between the current experiments being conducted at El Carao. Two dates are possible, mid July 1991 and mid January 1992. The January 1992 dates are preferable because there is less chance of rainfall (which would affect the reaeration rates and complicate data analysis), and because wind velocities tend to be higher than in July. Data analysis will be completed by February 1992, and a report will be available by April 30, 1992.

PROJECT TITLE: PRIMARY PRODUCTION IN PD/A CRSP PONDS: REFINEMENT OF THE FREE-WATER METHODS AND GLOBAL SURVEY OF RESULTS

Cooperating Institutions and Principal Investigators:

University of Hawaii at Manoa
Dr. James P. Szyper

University of California at Davis
Dr. Raul H. Piedrahita

Background: Waste-fed or waste-enhanced pond production of fish is a key component of both traditional and developing schemes for integrated family farming worldwide. Photosynthetic oxygen production and carbon fixation are critical to waste-fed pond culture, and important for maintenance of favorable pond conditions in feed-based systems. In waste-fed ponds, autotrophic production is expected to provide a significant portion of the cultured animals' food, as are the input materials themselves and the heterotrophic production.

Work Plans 1, 2, and 3 of the PD/A CRSP specify use of a light/dark bottle method for assessment of photosynthetic production in ponds. Some projects have used this method; others adopted free-water methods. Bottle methods have presented difficulties with both execution and assumptions; calculation procedures for free-water methods have not been uniform among projects. Free-water methods have inherent advantages over bottle methods, including a high degree of resolution, the inclusion of sediment respiration, and a relative ease of automation.

They are increasingly being applied in culture ponds, both within and external to the PD/A CRSP. Several CRSP investigators have begun to address technical needs for refinement.

The proposed project will integrate information from the ongoing work on refinements, perform new experiments addressing the problem of daytime respiration, and apply the resulting method in a global analysis of primary production during Work Plans 1, 2, and 3.

Objective: To describe and disseminate a well-supported, standardized method for calculation of primary production during CRSP experiments, and to describe the trends in production during Work Plans 1 through 4.

Experimental Plan:

1. Examine the effect of corrections for atmospheric exchange on production estimates.
2. Examine the effect of different assumptions underlying the estimation of daytime respiration from nighttime data.
3. Calculate primary production by the refined method from the data of Work Plans one through four.
4. Seek and analyze trends, similarities, and differences among sites and treatments with respect to primary production during Work Plans One through Four.

Experiments addressing item 2 will involve:

- Establishment of workable apparatus (DO sensors, data logger setups, incubation vessels and environments) for small-scale examination of microbial oxygen budgets.

- Assessment of short-term dynamics (minutes to hours) of dissolved oxygen and carbon dioxide in both pond water and laboratory phytoplankton cultures.
- Examination of the response of pond water communities and cultures to manipulation of light regimes on short time scales, i.e., to turning lights on and off or screening out daylight for periods of minutes to hours.
- Comparisons of pond water confined in experimental vessels with pond water monitored in situ.

Bench scale experiments will be performed at both U. C. Davis and U. of Hawaii. Pond experiments will be performed at the U.H. pond facility, the Mariculture Research and Training Center (MRTC), where fresh and brackish water ponds are routinely monitored for DO cycles.

Expected Outcome: Results will provide 1) a consistent methodological approach to the determination of primary productivity using free water techniques; 2) a "standardized" method for comparing the response of primary production to fertilization and environmental variables; 3) an improvement in the quality of data analysis and model simulations obtained with CRSP models; and 4) a point of departure for further research on pond productivity.

Schedule: Objective 1 during 5/91 to 7/91; objectives 2, 3, and 4 during 8/91 to 1/92; data analysis and report during 2/92 to 4/92.

PROJECT TITLE: REGIONAL VERIFICATION OF FERTILIZER GUIDELINES - PHILIPPINES

Cooperating Institutions and Principal Investigators:

University of Hawaii at Hilo, Hilo, Hawaii
Dr. Kevin Hopkins

Freshwater Aquaculture Center
Central Luzon State University, Muñoz, Nueva Ecija, Philippines

Background: Experiments conducted under the first three CRSP work plans used standardized experimental protocols to address the relationships of fertilizer input to yield of fish and shrimp. The biological results obtained from the Thailand Project are felt to be representative of freshwater tropical ponds typical of lower elevations although differing economic conditions in other locales could lead to different fertilizer recommendations for maximizing profit (versus maximizing fish production). This study proposes to test the DAST fertilization guidelines in the Philippines.

All previous CRSP projects were conducted with long-term on-site presence of researchers from the USA universities. This study, however, will rely on Filipino scientists at the Freshwater Aquaculture Center in Munoz, Nueva Ecija, Philippines with only twice yearly visits by scientists from the University of Hawaii. The FAC was established in the early 1970s. It is a freshwater research facility with a large number of replicated ponds with accompanying laboratories and support facilities. Over the years, researchers at the FAC have conducted pioneering work in rice-fish culture, integrated animal-fish culture systems, and fertilization yield trials. A large quantity of baseline and experimental data on the integrated animal-fish culture systems which was conducted at the FAC in the late 1970s and early 1980s and has been made available to the CRSP by ICLARM. This data will greatly facilitate the comparison of data to be collected during this study with data from other CRSP sites. Thus, the FAC is particularly well suited to be the first site for regional verification of fertilization guidelines developed by the CRSP. If this operational strategy of regional verification is successful, it can be used to greatly expand the CRSP into other countries and regions at a reasonable cost.

Objectives: The objectives of the proposed research are to test PD/A CRSP fertilizer recommendations under Philippine conditions. To conduct experiments to develop improved chicken manure/inorganic fertilizer guidelines.

Experimental Design:

Study 1: One treatment will be to fertilize and lime at the rates suggested by the CRSP fertilization guidelines. The second treatment will be chicken manure at 70 kg/ha/wk supplemented with urea and TSP to bring the total N and total P loading to 35 kg/ha/wk and 9 kg/ha/wk, respectively. There will be four replicates of each treatment.

Study 2: The treatments tested will be 1.0, 2.3, 3.7, and 5.0 kg/ha/d of nitrogen from urea. Total phosphorus will be added at a 1:1 ratio with the nitrogen. Total alkalinity will be maintained at 50 mg/L or greater. There will be two replicates per treatment.

Pond Facilities: Eight 500 m^2 ponds at the Freshwater Aquaculture Center, Muñoz, Nueva Ecija, Philippines.

Culture Period: Five months for each study.

Fish Stocking Rate: Sex-reversed *Oreochromis niloticus* at 2 fish/m^2

Nutrient inputs: As per CRSP guidelines and most current nutrient balancing experiments.

Water management: Replace evaporation and seepage losses weekly.

Sampling schedule: Standard protocols except as noted.
Chemical parameters:
- Ammonia-N, soluble reactive phosphorus, alkalinity, and dissolved oxygen: every 2 wks.

Null Hypotheses:
Study 1: There will be no difference between the actual yields from the ponds and the yields predicted by the CRSP guidelines. There will be no difference between the yields from ponds fertilized using the CRSP guidelines and those fertilized using the nutrient balancing guidelines.
Study 2: Nitrogen loading rate does not affect fish yield.

Statistical methods: ANOVA.

Schedule: Data collection, 6/91 to 3/92; technical report, 4/92.

PROJECT TITLE: EVALUATION OF SOIL-WATER INTERACTIONS FOR THE CONTROL OF POND WATER CHEMISTRY

Cooperating Institutions and Principal Investigators:

Oregon State University, Corvallis, Oregon
Mr. Jim Bowman
Dr. James E. Lannan
Dr. John Baham

Objectives: To evaluate relationships between soil pH or percent base saturation and water hardness or alkalinity for different classes of soil. To evaluate initial (pre-flooding) pH-percent base saturation relationships for different classes of soil.

Significance: Productivity in freshwater ponds is directly related to pond water hardness and alkalinity. Information regarding the relationships between hardness or alkalinity and properties of different soil types such as pH and percent base saturation could be used to improve pond management strategies, particularly the application of lime.

Experimental design: Up to seven soil types by eight levels of water hardness. Three replicates.

Facilities: Small-scale soil-water systems will be set up in the laboratories of the Soil Science Unit, Crop and Soil Science Department, at Oregon State University.

Duration of experiments: Individual experiments may take only a few hours. Preliminary trials will be conducted to determine appropriate time to reach equilibrium in the soil-water systems.

Sampling schedule:
- Initial pH, CEC, and percent base saturation of soil samples: before setting up soil-water systems.
- Initial pH, hardness, and alkalinity of stock water solutions: before setting up soil-water systems.
- Final soil and water analyses:
  - soil pH and percent base saturation: after equilibrium has been reached.
  - water pH, hardness, and alkalinity: after equilibrium has been reached.

Null Hypotheses: Differences in soil type and initial water quality will not affect relationships among soil pH, soil percent base saturation, water pH, hardness, or alkalinity at equilibrium. Relationships between pH and percent base saturation will not be different for different classes of soil.

Statistical methods: Regression analyses.

Schedule: Collection of soil samples, 6/91-10/91; Data collection, 7/91 - 12/91; Technical report(s), 4/30/92.

DISCLAIMER

The contents of this report do not necessarily represent an official position or policy of the United States Agency for International Development, nor does the mention of trade names or commercial products constitute an endorsement or recommendation for use on the part of the United States Agency for International Development.

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INTRODUCTION

The Sixth Work Plan of the Pond Dynamics/Aquaculture CRSP was developed by the CRSP Technical Committee at a meeting in Auburn, Alabama on March 7 to 9, 1991. This work plan describes activities to be conducted by the CRSP during the period 1 September 1991 to 31 August 1993, and corresponds to the first two years of the new grant. Many of the studies described in this work plan are contingent upon the continuation of the program.

The Sixth Work Plan will be implemented in Honduras, Rwanda, Thailand, Philippines, and the USA. Field studies will concentrate on the dynamics of freshwater ponds. In addition to field activities at the research stations of the cooperating institutions, experiments with cooperating farmers are planned. Analysis and synthesis of the global data resulting from the field studies will be conducted in the United States.

The first three CRSP work plans specified identical experiments at all CRSP sites to provide a baseline for comparisons between sites. The approach for the Fourth and Fifth Work Plans, which covered the period 1 September 1987 to 31 August 1989 and 1 September 1989 to 31 August 1991, respectively, changed in that different, but related, experiments were conducted at the various sites. In this way, many more hypotheses could be tested than if the same experiments were conducted at all sites. The Sixth Work Plan follows this same approach as the Fourth and Fifth Work Plans. Different, but related, topics will be considered at each site. The particular topics to be studied at each site are based on the research needs of aquaculture in each country and the needs for more information, as identified by the CRSP Technical Committee.

The general goals of this work plan are:

1. To preserve the global nature of the CRSP experiments;
2. To conduct experiments to refine management practices for fertilized ponds;
3. To verify CRSP results with cooperating farmers;
4. To continue adding observations to the global CRSP database; and
5. To provide verified preliminary guidelines for management of fertilized ponds.

EXPERIMENTS

THE GLOBAL EXPERIMENT

The Sixth Work Plan will preserve the global nature of the CRSP and will address diverse research needs at each site. First, data will continue to be collected using standardized methods. Second, these data will be entered into the global database, which is maintained at the CRSP Program Management Office in Corvallis, Oregon, USA. The database is used by the Data Analysis and Synthesis Team in their development of generalized models and guidelines. The database also is available to the field stations and other interested researchers throughout the world. Third, related experiments are conducted at the various research stations. For example, studies on maximizing primary production and fish yield by manipulating fertilizer N:P ratios will be conducted in Rwanda, Honduras and Thailand. Supplemental feeding studies will be conducted in Rwanda, Honduras and Thailand. Fish stocking rate studies will be conducted in Thailand and Honduras.

REQUIRED MEASUREMENTS

This section of the work plan lists the minimum requirements for data collection by the CRSP projects. The accepted methods for data collection are presented in the Summary of Accepted Analytical Methods (Section 3), which starts on page 44. Detailed descriptions of accepted methods are contained in the appendices. Frequencies of data collection as specified in this section are minimum frequencies. Data may be collected more frequently at the discretion of the individual projects.

The following measurements must be taken daily:

- Solar Radiation
- Wind Speed
- Air Temperature (maximum and minimum)
- Rainfall
- Evaporation
- Mortalities
- Pond Depth
- Water Inflow and Overflow

There will be at least three intensive sampling periods for each experiment: (1) during the second week; (2) midway through the experiment; and (3) during the final week. Whole column samples collected at mid-morning should be used unless specified otherwise. The variables to be observed are:

- Total Kjeldahl Nitrogen
- Ammonia Nitrogen
- Total Phosphorous
- Secchi Disk Visibility
- Chlorophyll *a*
- Dark Bottle Respiration
- Total Suspended Solids
- Total Volatile Solids
- Total Alkalinity (3 depths: top, middle, bottom)
- Primary Productivity

Diel studies will be conducted simultaneously with the intensive sampling measurements in order to measure spatial and temporal fluctuations within a pond. Samples for diel studies will be collected at dawn, 1000, 1400, 1600, 1800, and 2300 hours, and at dawn the next day at a minimum of two depths, but preferably at three depths. The exact time of sample collection in the diel studies should be recorded. The three sampling depths will be 25 cm below the water surface, mid-depth, and 25 cm above the pond bottom. The parameters to be measured during the diel studies are:

- Dissolved Oxygen
- Temperature
- pH
- Wind (cumulative between sampling times)
- Solar Radiation (cumulative between sampling times)

Information about the fish and shrimp used in the experiments should be recorded as follows:

- Stocking
  - Total Number
  - Total Biomass
  - Individual Weights (of 10% sample)
  - Individual Lengths (of 10% sample)

- Monthly Sampling
  - Total Number in Sample
  - Total Biomass of Sample
  - Individual Weights
  - Individual Lengths
  - Reproduction Weight

- Harvest
  - Total Number of Stocked Fish Remaining
  - Total Biomass of Stocked Fish
  - Individual Weights (10% sample of stocked fish)
  - Individual Lengths (10% sample of stocked fish)
  - Total Number of Recruits
  - Total Biomass of Recruits

The following pond soil characteristics are to be determined at the beginning and end of each experiment:

- pH
- Phosphorus
- Organic Matter
- Total Nitrogen
- Cation Exchange Capacity
- Metals - Aluminum, Iron, Zinc (only when the pond is first used)
- Lime Requirement
- Exchangeable Hydrogen
- Base Saturation

Pond morphology is to be measured when the ponds are first constructed and whenever pond morphology is altered significantly. Measurements to be taken are:

- Surface Area (at 10 cm depth contours)
- Volume (at 10 cm depth contours)
- Drawing, top view, with scale

The composition of lime, inorganic, and organic fertilizers is to be determined when supplies are delivered and, for organic materials, just before they are totally used up, but not less frequently than once a month. Characteristics to be determined are:

- Percent Dry Matter
- Nitrogen
- Phosphorus
- Chemical Oxygen Demand
- Lime Neutralization Value (for lime only)

The quantities of lime and other amendments must be carefully recorded whenever they are added to the ponds.

Reference ponds are to be established and operated at each station starting the second year of this work plan.

OPTIONAL MEASUREMENTS

CRSP projects may collect any data, in addition to those data specified under Required Measurements, which they deem appropriate for a particular study. The methods specified in the Summary of Accepted Analytical Methods (Section 3, page 44) or in the appendices (Section 4, page 53) should be used. If a method for a particular parameter is not specified in Section 3, a method from *Standard Methods* (APHA et al., 1985) should be used whenever possible and the Materials and Methods Subcommittee of the CRSP Technical Committee should be informed. If problems are encountered while using the accepted method for a particular application, the Materials and Methods Subcommittee should be contacted. If optional measurements are made and researchers wish to have the data included in the data templates, the Data Base Manager (at the Program Management Office, Oregon State University) should be contacted.

DATA SUBMISSION

All data should be submitted to the CRSP Database Manager on either Lotus 1-2-3® or Microsoft Excel® worksheets, following the formats and procedures in the most recent CRSP *Instructions for Data Entry*. Data and accompanying text for the CRSP *Data Reports* series should be submitted to the CRSP Program Management Office within six months of harvest of each study. Please contact the Data Base Manager with questions regarding verification of data. The Data Base Manager will print the verified data for publication in *Data Reports* unless other arrangements are made in advance.

REPORT SUBMISSION

Introduction:

CRSP researchers are aware of the difficulties in compiling the results of the various experiments described in this Work Plan into a single, cohesive *Data Report* for each site. In response to these concerns, the requirements for submitting text to *Data Reports* have changed. The studies detailed in the biennial Work Plans fit the *Research Reports* format better than the *Data Reports* format; consequently, researchers will be required to submit a technical report (text and figures) in the form of a *Research Report* to the Program Management Office (see below). *Data Reports* will serve the following purposes: to protect researchers' data from unauthorized publication and use, to compile all standardized data for use in the Global Experiment and in other analyses, and to document where procedures actually used in experiments have diverged from those described in the Work Plans.

Instructions for Submission of Reports:

1. A technical report for each experiment (each study) is due six months after the experiment ends. Technical reports should be submitted in one of the following formats:

   a) As a *Research Report*, with the understanding that the manuscript will be reviewed, edited, and printed as a short (4-8 pages) report; or
   b) As a *Notice of Publication* under the *Research Reports* series. Notices of Publication are reserved for those articles that have been or will be published in a refereed journal. Authors who wish to use this format for technical reports should submit a copy of a manuscript which is "under review" by a journal, together with a cover letter. It is recommended that authors contact the CRSP Director to discuss whether this is an option.

2. Principal Investigators are also responsible for submitting a *Data Report* for each set of studies. For example, there should be one *Data Report* for Rwanda, one for Thailand, and one for Honduras for the studies described in each biennial Work Plan. The text will be confined to a "Materials and Methods" section, which should be used to describe how the materials or methods used during the studies diverged from those specified in the Work Plan. Text for *Data Reports* is due three months after the end of the latest experiment (study) described in the Work Plan. For example, text for the Rwanda *Data Report* should be submitted three months after Study 4 ends, and should include a "Materials and Methods" section for all studies completed during the course of this Work Plan.

Should difficulties in completing the Work Plan on schedule arise, please advise the Director so that an alternate reporting format can be arranged.

AFRICA—RWANDA PROJECT

Cooperating Institutions:

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Mr. Eugene Rurangwa

CIFAD (Oregon State University) - Lead Institution
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Dr. Thomas J. Popma
Ms. Karen Veverica

CIFAD (University of Arkansas at Pine Bluff)
Dr. Carole Engle

Pond Systems: Cool freshwater ponds typical of higher elevations.

INTRODUCTION

The choice of objectives and experimental designs proposed for the Sixth Work Plan of the Rwandan component of the CRSP are based on the following considerations:

1. Growth of tilapia in tropical environments may be determined by environmental factors such as water quality, solar radiation, gas solubility and especially temperature, associated with specific elevations. Some workers believe the major effect of temperature on fish growth is direct and physiological, and effects derived from other members of the aquatic community are of less importance. Most authors, however, recognize the controlling influence of temperature on the structure and function of all members of the aquatic community. Laboratory studies can investigate direct effects of temperature on fish physiology. Unfortunately most laboratory studies investigate effects of constant temperatures, but time functions of changing temperature may determine outcome. To examine direct effects of changing temperatures U of Arkansas at Pine Bluff initiated laboratory growth experiments (1990-1991) which will provide additional explanation of direct effects of variable temperature regimes on fish in complex pond environments. Obviously few physical or biological factors (and their interactions) associated with pond environments at different elevations could be modeled in laboratories. In Rwanda tilapia are cultured at altitudes ranging from about 1300 to 2500 meters. What are the important aspects of water temperature regime to pond productivity? What are the climatic limits of tilapia culture as a profitable enterprise? Can supplemental feeding practices extend the range of environments where tilapia culture is a reasonable use of resources? Is supplemental feeding of greater benefit in cooler systems with lower levels of productivity? Both Rwasave Fish Culture Station and rural ponds can be utilized to examine these questions. Initial investigation is underway for Work Plan 5 on the selection of rural ponds and an examination of pond productivity for tilapia at different elevations in Rwanda. We will study tilapia production at different elevations in two experiments, one with and one without supplemental feeding (Studies 1 and 3).

2. In developing countries, such as Rwanda, the principal source of food for fish is the naturally occurring organisms in ponds enriched with waste plant and animal materials. Work is underway in Rwanda for Work Plan 5 to determine, on the basis of digestibility of protein and energy in natural food organisms, the energy and protein available to fish in these pond systems. From these data a supplemental feed can be designed to correct any protein or energy deficiency and to conserve protein for growth rather than for respiration to meet energy needs. Determining which locally available materials might satisfy these needs, and using these materials as supplemental feeds will test the concept of conserving protein for growth to enhance fish production (Study 4).

3. Success of fish farming in highland Africa will be determined by economic factors as well as by the physical and biological dynamics of pond ecosystems. Economic analysis can provide guidelines and clarify the choices involved in resource allocation. Mathematical programming techniques can be used to select combinations of enterprises that will maximize returns to the producer, given specific producers' goals.

4. Simple on-farm methods for estimating standing crops of phytoplankton may be derived from Secchi disk visibility measurements refined by including a visual comparison of color in order to estimate relative contributions of abiotic and biotic sources of turbidity. The sources of turbidity can be experimentally partitioned into phytoplankton, detritus, true color (absorbance of filtered sample at a chosen wavelength) and inorganic turbidity. If these parameters can then be related to visibility and color estimates, a simplified estimation of phytoplankton density could result. Different types of visual color comparators will be tested.

5. Maximum rates of pond primary and tilapia production have not been determined for Rwanda, partially because of the low physical and economic availability of inorganic and organic fertilizers. Maximum pond productivity achieved at each CRSP site provides necessary data for our modeling and expert system data bases and additionally provides a benchmark for comparisons within Rwanda on potential productivity. An experiment designed to reach such maximum rates also provides the opportunity to determine the point at which nitrogen is no longer a limiting factor, and factors such as those associated with climate, base water quality and other pond system variables become limiting (Study 2).

There are five studies planned for Rwanda in the Sixth Work Plan (Figure 1). The goal of these studies is to more fully understand the factors affecting pond dynamics and fish growth under climatic conditions considered marginal for tilapia production, using the limited nutrient inputs available to most potential producers in economically depressed regions.

Figure 1. Schedule for Data Collection in Rwanda during the Sixth Work Plan.

Study Title	Site	1991				1992												1993							
		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Study 1. Productivity of Tilapia Ponds at Different Elevations	Various	****	****	****	****	**																			
Study 2. Nitrogen Required for Maximum Primary and Fish Production in Rwandan Ponds	Rwasave				***	****	****	****	****	****															
Study 3. On-Farm Studies - Supplemental Feeding in Private Ponds at Five Elevations	Various										****	****	****	****	****	****	****	***							
Study 4. Locally Available Feedstuffs to Improve Utilization of Natural Pond Food Organisms by Tilapia	Rwasave																					****	****	****	****
Study 5. Economic Analysis of Aquaculture Production Technologies	Various									****	****	****	****	****	****	****	****	****	****	****	****	****			

RWANDA STUDY 1: PRODUCTIVITY OF TILAPIA PONDS AT DIFFERENT ELEVATIONS

Objective: To quantify the influence of elevation on tilapia production in relation to temperature regime and water quality parameters.

Significance: This study, along with laboratory experiments on growth conducted under Work Plan 5, will help determine, by comparison with Study 3, Work Plan 6, whether growth by tilapia is depressed because the temperature approaches the physiological limits for this fish at higher elevations or because of reduced pond productivity. The appetite of warm water fish is depressed at cooler temperatures, but the available food may be efficiently utilized for growth at low or moderate food consumption rates. But if food availability exceeds the temperature-depressed appetite, productive capacity will be lost. This and the following studies will help us to better understand at what elevation tilapia culture becomes an inefficient enterprise.

Experimental Design: Twenty five ponds arrayed in five elevation zones (as described below) with one fertilizer input treatment.

Pond facilities: Five ponds at each elevation range 1350 to 1400 m, 1550 to 1600 m, 1625 m (Rwasave Station), 1750 to 1800 m, and 2150 to 2200 m. Criteria for selection of rural ponds within each elevations range are: total alkalinity,30 to 90 mg/l; hardness, 20 to 75 mg/l ; conductivity, 100 to 300 μmhos/cm; surface area, 300 to 700 m^2; minimum depth,45 to 60 cm; maximum depth, 90 to 120 cm.

Culture Period: 5 months minimum, but continuing until fish reach an average weight of 100 g.

Fish stocking rate: Male *Oreochromis niloticus* juveniles at 1 fish/m^2.

Nutrient inputs: Input rate will be 250 kg/ha/week dry weight of a locally available grass, added fresh. Inorganic nutrients will be added as urea and TSP to increase added N to 15 and P to 4 kg/ha/wk to standardize input total at all pond sites.

Water management: Addition of water at least once per week in quantities just sufficient to replace losses.

Sampling schedules: As per standard protocol except:
Physical parameters:
- Weekly: max-min water temperature, inflow, depth and Secchi disk visibility.
- 3 times during the experiment: temperature of unsaturated soil at a depth of 60 cm.
- Continuous recording of water temperature in one pond per elevation range.

Chemical parameters:
- Rwasave: standard CRSP protocol.
- Rural ponds: one soil analysis per pond and monthly measurements of total alkalinity, hardness, oxygen, total dissolved solids, and conductivity.
- No diurnal or primary productivity measurements in rural ponds.

Biological parameters:
- Weekly: quantity of nutrient input, adjusted.
- Monthly: fish weight.

- Every two weeks Secchi disk visibility will be measured and a visual color estimation made at about 10 AM.
- Corrected and uncorrected chlorophyll *a* for a composite water column sample will also be analyzed. The same sample will be used to measure total non-volatile matter. Relationships will be suggested: volatile vs non-volatile matter, chlorophyll *a* concentration and Secchi disk visibility at each color code. The sources of turbidity can then be partitioned into phytoplankton, detritus, true color (absorbance of filtered sample at a chosen wavelength) and inorganic turbidity. Different visual color comparators will be tested.

Null Hypotheses: Pond productivity for tilapia will not be correlated with elevation within the range studied. Production can not be related to physical and chemical site characteristics.

Statistical methods: One-way ANOVA, two-way ANOVA (combining data from Study 3,Work Plan 5), linear and multiple regression.

Schedule: Data collection, 6/91 to 1/92; data analysis and report writing, 3/92 to 6/92.

RWANDA STUDY 2: NITROGEN REQUIRED FOR MAXIMUM PRIMARY AND FISH PRODUCTION IN RWANDAN PONDS

Objective: For the environmental conditions of Rwasave Station, determine the inorganic nitrogen input rate required for maximizing primary and fish production with phosphorus and inorganic carbon in excess.

Significance: Nitrogen input rate necessary to achieve maximum production has not been quantified for the highland environment of Rwanda. At very high plankton densities, cool temperatures may prevent fish from taking full advantage of available food. Thus fish production may peak at nitrogen input levels less than maximum for phytoplankton. Efficient use of scarce nitrogen inputs could result from this data. Both primary and fish production rates in a nutrient optimized environment would also provide important relationships for the CRSP Global Model and Expert System.

Experimental design: Four ponds at each of four input rates of nitrogen added as urea at: 1.0, 2.3, 3.7 and 5.0 kg/ha/day. Phosphorous added as TSP at a 1:1 N:P ratio. Alkalinity maintained at least at 50 mg/l by liming.

Pond facilities: Sixteen 700 m^2 ponds at Rwasave Station.

Culture period: Five months.

Fish stocking rate: Male *Oreochromis niloticus* juveniles at $3/m^2$.

Nutrient inputs: Inorganic nutrients as under Experimental Design.

Water management: Replace water losses weekly.

Sampling schedule: Standard protocols.

Null hypothesis: Primary production is not nitrogen limited below 5 kg/ha/day N. Fish production is limited at the same N input level as primary production.

Statistical methods: Simple and multiple regression, ANOVA.

Schedule: Data collection, 12/91 to 5/92; technical report , 9/92.

RWANDA STUDY 3: ON-FARM STUDIES--SUPPLEMENTAL FEEDING IN PRIVATE PONDS AT FIVE ELEVATIONS

Objective: Previous studies (Study 3, Work Plan 5 and Study 1, Work Plan 6) evaluated pond dynamics and tilapia production in relation to elevation in 25 enriched ponds at five elevation zones. The objective of this following experiment is to determine to what extent the addition of supplemental feedstuffs to enriched ponds influences the effect of elevation on the capacity of the system to produce tilapia.

An additional objective is to investigate simple on-farm methods for estimating standing crops of phytoplankton using Secchi disk visibility and a visual color comparator to estimate relative contributions of abiotic and biotic sources of turbidity.

Significance: This study will provide an indication of the benefits of supplemental feed at higher elevations. Biological systems at cooler temperature ranges may benefit more from supplemental feeding than from pond fertilization. These results when evaluated with results of the previous study conducted without feeding, and with the controlled environment studies at Pine Bluff, will add insight into whether tilapia production at higher elevations is constrained primarily by low system productivity for natural food organisms or by physiological limitations of the fish. This insight can then be used to develop appropriate management strategies adjusted to elevation resulting in more efficient use of scarce resources in non-industrialized nations.

Results should also provide greater understanding of the relationship of turbidity and color to phytoplankton density.

Experimental design: At least five ponds at five elevations and using one feeding regime and one fertilization level. Factors associated with elevation are assumed to be the causative factors in the differences in pond system response for pond groups at each elevation range. In an earlier CRSP experiment in these rural ponds, a green grass compost was used but without supplemental feeding providing a source of comparison with the current experiment.

Pond facilities: Five ponds at each elevation range 1350 to 1400 m, 1550 to 1600 m, 1625 m (Rwasave Station), 1750 to 1800 m, and 2150 to 2200 m. As described in Study 1, criteria for selection of rural ponds within each elevations range are: total alkalinity, 30 to 90 mg/l; hardness, 20 to 75 mg/l ; conductivity, 100 to 300 µmhos/cm; surface area, 300 to 700 m^2; minimum depth,45 to 60 cm; maximum depth, 90 to 120 cm.

(In Study 3, Work Plan 5, the coefficient of variation of initial pond production estimates for the rural pond groups ranges from 10 to 15% which is less than for the Rwasave ponds, indicating random variability in rural ponds will be manageable.)

Culture Period: Five months minimum, continuing until fish reach an average weight of 100 g.

Fish stocking rate: Male *Oreochromis niloticus* juveniles at 1 fish/m^2.

Nutrient inputs: 250 kg/ha/wk fresh grass plus urea and TSP added at a rate to provide a total N of 15 and P of 4 kg/ha/day, plus a supplemental ration of rice bran at 2% of fish weight daily.

Water management: Replace evaporation and seepage losses weekly.

Sampling schedule: As per standard protocol except as noted.
Physical parameters: Physical parameters:

- Weekly: max-min water temperature, inflow, depth and Secchi disk visibility.
- 3 times during the experiment: temperature of unsaturated soil at a depth of 60 cm.
- Continuous recording of water temperature in one pond per elevation range.

Chemical parameters:

- Rwasave: standard CRSP protocol.
- Rural ponds: one soil analysis per pond and monthly measurements of total alkalinity, hardness, oxygen, total dissolved solids, and conductivity.
- No diurnal or primary productivity measurements in rural ponds.

Biological parameters:

- Weekly: quantity of nutrient input, adjusted.
- Monthly: fish weight.
- Every two weeks Secchi disk visibility will be measured and a visual color estimation made at about 10 AM.

- Corrected and uncorrected chlorophyll *a* for a composite water column sample will also be analyzed. The same sample will be used to measure total non-volatile matter. Relationships will be suggested: volatile vs non-volatile matter, chlorophyll *a* concentration and Secchi disk visibility at each color code. The sources of turbidity can then be partitioned into phytoplankton, detritus, true color (absorbance of filtered sample at a chosen wavelength) and inorganic turbidity. Different visual color comparators will be tested.

Null Hypotheses: Supplemental feeding will not influence the relative effect of elevation on tilapia growth, when compared to ponds receiving only fertilizer.

No relationship exists between visual color estimates, Secchi disk visibility and phytoplankton density that will allow the development of a simple on-farm estimation method for phytoplankton density.

Statistical methods: One-way ANOVA, two-way ANOVA (combining data from Study 3,Work Plan 5), linear and multiple regression.

Schedule: Depending on the previous study, data collection will begin 6/92 and end 1/93; reports by 9/93.

RWANDA STUDY 4: LOCALLY AVAILABLE FEEDSTUFFS TO IMPROVE UTILIZATION OF NATURAL POND FOOD ORGANISMS BY TILAPIA

Objective: Study 6, Work Plan 5 determined the digestible protein and energy content of natural food organisms consumed by tilapia in fertilized ponds. Study 7 of that same work plan investigated the benefits of a semi-purified protein-free supplemental energy source to improve the utilization of natural protein for growth. The objective of this following study is develop this information into a more practical and sustainable production practice -- to determine if local, readily available materials can be used to 'spare' more of the protein in natural food organisms for growth by tilapia.

Significance: Where commercially prepared feeds are unavailable, locally available materials could meet the energy requirements for a suitable feed alternative. Balancing protein-energy intake with a properly designed feed could increase system productivity for tilapia while lowering operating costs and increasing the efficient recycling of scarce local materials.

Experimental design: Two feed types will be tested at ration levels of 0, 2 and 4 % of body weight per day, all in triplicate. The two high energy feeds will be local materials such as molasses-enriched rice and wheat bran. Rations will be adjusted monthly in proportion to average fish weight per treatment. At the last fish sampling period twenty fish will be harvested from each pond to determine the digestibility of protein and energy of materials consumed. The lipid and crude protein content of six whole fish per treatment will be determined at the end of the experiment.

Pond facilities: Eighteen 700 m^2 ponds at Rwasave Fish Culture Station at Butare.

Culture Period: Five months.

Fish stocking rate: Mixed-sex juvenile *Oreochromis niloticus* at 2 fish/m^2.

Nutrient inputs: All ponds will be fertilized at one level with the nutrient selected on the basis of the results of Study 6 and used in Study 7 of Work Plan 5. Feed will be given as described under Experimental Design.

Water management: Replace evaporation and seepage losses weekly.

Sampling schedule: Standard Protocol.

Null Hypotheses: Locally available materials can not be used to meet the energy deficiency for tilapia of naturally occurring pond organisms, and fish production will be similar for ponds fed at the same available energy rate regardless of type of material used.

Statistical methods: ANOVA will be used to determine if the additional growth derived from the supplemental feed is greater than what could be estimated assuming a 20% protein conversion efficiency.

Schedule: 5/93 to 10/93. Data analysis and report writing 2/94.

RWANDA STUDY 5: ECONOMIC ANALYSIS OF AQUACULTURE PRODUCTION TECHNOLOGIES

Success of fish farming in highland Africa will be determined by economic factors as well as by the physical and biological dynamics of pond ecosystems. Economic analysis can provide guidelines and clarify the choices involved in resource allocation. Mathematical programming techniques can be used to select combinations of enterprises that will maximize returns (either in cash or in-kind) to the producer-given goals.

Objective: To compare the economics of resource utilization in aquaculture to that of other agricultural crops.

Significance: Fish culture is a relatively new production enterprise in Rwanda. Many fish ponds are located in elevations often considered outside the feasible range for profitable tilapia culture. Yet many farmers continue to raise fish. This study should provide indications of how fish culture compares to traditional crops from an economic perspective. It will further indicate some of the economic trade-offs between fish culture and traditional agricultural enterprises in Rwanda.

Experimental design:

1. The three major tasks of this experimental study are:
   a) To develop mathematical programming models of typical Rwandan farmers with land at two different elevations (below 1500 m and above 1500 m).
   b) To test optimal product mixes of Rwandan farmers with and without aquaculture technologies at both altitudes.
   c) To determine which production parameters have the greatest effect on a farmer's mix of crops produced.

2. Enterprise budgets will be adapted and/or developed for the principal crop enterprises of Rwandan farmers for two different elevations (below 1500 m and above 1500 m). These enterprise budgets, along with typical Rwandan farmer resource levels, will be incorporated into a linear programming framework. The model will utilize goal programming techniques to simultaneously meet farmer goals of food for home consumption, crops raised for barter or for ceremonial purposes, family food security, and income.

3. Both primary and secondary data will be utilized. Farmer surveys conducted over a two-year period will provide information on prices, resource levels, and resource requirements for different crops. Survey data will also be used to validate the models developed by comparing computer-selected product mixes without aquaculture alternatives for Rwandan farmers located at high and low elevations. Aquaculture enterprises will then be included to test the effect on optimal farm product mix with the introduction of aquaculture technologies.

4. Parametric programming will be used to test the robustness of coefficients used in the model and to determine the effect on optimal product mix of fluctuating price levels and availabilities of various production inputs. It will also be used to determine which production parameters have the greatest effect on a farmer's mix of crops produced.

Data Collection: Secondary data will be collected in Rwanda from previous surveys (including the Enquete Nacional Agricole and current World Bank and GTZ projects) on the levels of resources (land, labor, capital, fertilizer materials) commonly available on Rwandan farms. Data on fish yields and costs will be obtained from farm records collected by the Rwandan National Fish Culture Project based in Kigembe. A follow-up survey of fish farmers will document other crops being produced, land utilization, labor availability and constraints to production.

Hypothesis: Fish culture yields as much benefit to Rwandan farmers as other agricultural enterprises in terms of animal protein production for home consumption and supplemental income.

Analytical methods: Enterprise budget analysis will be used to estimate costs and returns of the aquaculture production technologies that have been and are being developed for Rwanda. Mathematical programing models will be developed utilizing MPS-PC software and will incorporate parameters that represent a farmer's need for stable yields and risk-reducing strategies.

Schedule: 5/92 to 5/93; report, 9/93

CENTRAL AMERICA—HONDURAS PROJECT

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Marco Ivan Rodriguez

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Pond Systems: Tropical freshwater and brackish water ponds.

INTRODUCTION

The proposed Sixth Work Plan research in Honduras concentrates on several areas of research initiated as part of the previous Work Plan. The overall goal of the described research is to increase fish yield and production efficiency through manipulation of supplemental nitrogen fertilization, stocking rate, polyculture, and management of pond water quality and dissolved oxygen levels. Results of the Thailand PD/A CRSP demonstrated that organic fertilization plus supplemental nitrogen (as urea) resulted in increased fish yield. Preliminary results from Honduras PD/A CRSP research indicate greater primary productivity in ponds where organic fertilizer is supplemented with 17 to 35 kg N/ha per week compared to lower rates of supplemental N. The persistence of clay turbidity in ponds in Honduras requires continued application of organic matter for turbidity control. The proposed research will quantify the effect of varying the amount of organic matter applied to ponds while maintaining a constant N:P ratio.

Previous research results from Honduras showed that tilapia yield in organically fertilized ponds increased in response to increased stocking rate up to 2 fish/m^2, although mean fish weight decreased. When organic fertilization was supplemented with a formulated diet, both production and mean fish weight increased. A sale price differential related to fish size appears to be developing in Honduras, so the interaction between yield and mean fish weight under supplemental feeding is becoming more important.

Polyculture is an effective means to increase total fish yield. The tambaquí (*Colossoma macropomum*) was introduced into Honduras about seven years ago by request of the Government of Honduras. Results of research conducted as part of the Panama PD/A CRSP confirmed the tambaquí's potential for fast growth in pond culture where a supplemental feed was offered. Preliminary research results in Honduras demonstrated the potential of tambaquí as a secondary culture species in tilapia production ponds. This research showed that the tambaquí growth response was low in organically fertilized ponds, but high when offered a supplemental feed. The results also indicated that higher stocking rates of tambaquí would result in greater total fish yields. Honduran aquaculturists are very interested in incorporating this fish in their ponds, but the information necessary to make sound management recommendations is lacking.

Previous research that involved the use of mechanical (electrical) aeration to manage dissolved oxygen concentrations in fertilized and fed pond systems resulted in greater yield. However, there was some doubt as to the economics of mechanical aeration based on electrical aerators. In many parts of the humid tropics water is abundantly available, often by gravity flow. Water exchange is another mechanism for pond water quality and dissolved oxygen management available to producers with access to abundant, gravity flow water, and who are unable to obtain aerators. The proposed research will quantify the effects of low and moderate water exchange regimes on primary productivity, water quality and fish yield.

The current practice in the PD/A CRSP is to use hormonally sex-reversed male tilapia in stocking the research ponds. Population that are in excess of 97% males are routinely obtained in Honduras. However, the reproduction from only a few functional females can confound the analysis of experimental data. The PD/A CRSP in Honduras has determined that the inclusion of the native Honduran cichlid, guapote tigre (*Cichlasoma managuense*) at 500/ha will effectively eliminate tilapia reproduction through predation. Because guapote tigre is a predator and is stocked at low rates, it does not apparently decrease tilapia yields.

Four studies are planned for the Sixth Work Plan (Figure 2). The goal of these studies is to increase in fish yields through improved management practices.

Figure 2. Schedule for Data Collection in Honduras during the Sixth Work Plan.

<table>
<tr><th rowspan="2">Study Title</th><th rowspan="2">Site</th><th colspan="4">1991</th><th colspan="12">1992</th><th colspan="8">1993</th></tr>
<tr><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th></tr>
<tr><td>Study 1. Supplemental Nitrogen Fertilization: Varying Manure Quantities</td><td>El Carao</td><td colspan="5">******************</td><td colspan="19"></td></tr>
<tr><td>Study 2. Supplemental Feeding - Effect of Fish Stocking Rate</td><td>El Carao</td><td colspan="5"></td><td colspan="6">**********************</td><td colspan="13"></td></tr>
<tr><td>Study 3. Stocking Rate of Colossoma macropomum in Polyculture with Tilapia</td><td>El Carao</td><td colspan="11"></td><td colspan="6">**********************</td><td colspan="7"></td></tr>
<tr><td>Study 4. Frequency of Water Exchange</td><td>El Carao</td><td colspan="17"></td><td colspan="6">***********************</td><td></td></tr>
</table>

HONDURAS STUDY 1: SUPPLEMENTAL NITROGEN FERTILIZATION: VARYING MANURE QUANTITIES

Objective: To quantify the effects of supplemental nitrogen and phosphorus fertilization on tilapia yield and economics in Honduras.

Significance: Preliminary results from Study 6, Fifth Work Plan in Honduras indicate that carbon to nitrogen ratios of 6:1 and 4:1 stimulate primary production compared with ratios of 8 or 12:1. Total N in the low C:N ratios approximates N inputs found to be optimal in Thailand CRSP ponds. It now remains to be seen if fish production and/or profitability can be increased by reducing organic input and substituting it with similar inputs of inorganic N and P. It is also of interest to see if early morning pond dissolved oxygen can be increased by stimulating primary productivity with supplemental nitrogen while reducing community respiration by adding less allochthonous organic matter. Honduras Study 4 (Fifth Work Plan) indicated that oxygen stress reduced fish growth by about 23% in El Carao ponds.

Experimental design: Completely randomized design with four fertilizer treatments and three replicates per treatment:

- chicken litter (750 kg total solids (TS)/ha per week) and nitrogen supplementation based on results of Study 6, Fifth Work Plan.
- chicken litter (500 kg TS/ha per week) and nitrogen and phosphorus supplementation to approximate N:P ratio of first treatment.
- chicken litter (250 kg TS/ha per week) and nitrogen and phosphorus supplementation to approximate N:P ratio of first treatment.
- nitrogen and phosphorus fertilization to approximate total N and P applied in the first treatment.

Pond facilities: El Carao, twelve ponds, 0.90 m deep, each 0.1-ha.

Culture period: 150 to 180 days.

Fish stocking rate: Male *Oreochromis niloticus* fingerlings stocked at 20,000/ha ; guapote tigre (*Cichlasoma managuense*) fingerlings stocked at 500/ha.

Nutrient inputs: Chicken litter applied at above indicated rates; nitrogen as urea; phosphorus as triple superphosphate.

Water management: Replace evaporation and seepage after ≤ 5 cm loss.

Sampling schedules: Standard protocols except as noted below:
Biological parameters:

- Zooplankton and chlorophyll *a* : 1x/wk.
- Primary productivity, diurnal curve: 1x/wk.

Chemical parameters:

- pH, total ammonia, nitrate and organic nitrogen will be measured every other week in alternation with soluble orthophosphate and total phosphorus.

Null hypotheses: Primary production and tilapia yield will not differ with nitrogen and phosphorus source. Profitability of tilapia production will not be increased by substitution of inorganic for organic fertilizers.

Statistical methods: ANOVA, regression analysis.

Schedule: Data collection, 7/91 to 1/92; technical report, 7/92.

HONDURAS STUDY 2: SUPPLEMENTAL FEEDING - EFFECT OF FISH STOCKING RATE

Objective: To determine the effects of fish stocking rate on yield and water quality in ponds that receive a combination of organic fertilization and supplemental feed.

Significance: More efficient use of nutrient inputs and primary productivity may be possible with higher stocking rates. However, higher stocking rates often yield smaller fish. Manipulation of stocking rates may allow fish farmers to direct their production to markets with different size preferences.

Experimental design: Four stocking rates by three replicates, completely randomized design.

Pond facilities: El Carao, twelve 0.1-ha ponds, 0.80 m deep.

Culture period: 180 days or until fish growth slows.

Fish stocking rate: Male *Oreochromis niloticus* fingerlings stocked at 10,000, 20,000, 30,000 and 40,000/ha; guapote tigre (*Cichlasoma managuense*) stocked at 500/ha.

Nutrient inputs: Chicken litter (application rate to be based on results of Study 6 (revised) of Work Plan 5) for the first three months only, followed by a commercial, pelleted feed only (25% protein) six days/wk. Daily feeding rate will be 3% of the total fish biomass, and be adjusted monthly based on seine sample data. Daily ration will be fed in two equal rations.

Water management: Replace evaporation seepage after ≤ 5 cm loss.

Sampling schedule: Standard protocols except as noted.
Biological parameters:
- Zooplankton and chlorophyll *a* : 1x/week.

Null hypotheses: Stocking rate will have no effect on fish yield. Stocking rate will have no effect on fish size.

Statistical methods: ANOVA, regression analysis.

Schedule: Data collection, 2/92 to 7/92; technical report, 1/93.

HONDURAS STUDY 3: STOCKING RATE OF *Colossoma macropomum* IN POLYCULTURE WITH TILAPIA

Objectives: To determine the relative potential of tambaquí (*Colossoma macropomum*) in polyculture with tilapia (*Oreochromis niloticus*), to determine the optimum stocking rate for tambaquí in this polyculture and to determine the effect of polyculture on pond dynamics.

Significance: Tambaquí and tilapia are both species that are capable of fast growth. Tambaquí shows promise as a polyculture species with tilapia, especially as part of the Honduran, as well as Central American, aquacultural development package, but little is known about the optimum number of tambaquí to stock.

Experimental design: Completely randomized design. Four treatments by three replicates/treatment.

- Tilapia (100%).
- Tilapia (75%) plus tambaquí (25%).
- Tilapia (25%) plus tambaquí (75%).
- Tambaquí (100%).

Pond facilities: El Carao, twelve ponds, 0.75 m deep, each 0.1-ha.

Culture period: 150 days.

Fish stocking rate: Male *Oreochromis niloticus* and tambaquí fingerlings will be stocked in the proportions indicated above such that the total number of fish stocked is 20,000/ha; in addition, guapote tigre (*Cichlasoma managuense*) fingerlings stocked at 500/ha.

Nutrient inputs: Chicken litter (1,000 kg total solids/ha/wk) for the first two months only, followed by a commercial, pelleted feed only (25% protein) six days/wk. Daily feeding rate will begin at 3% of the total fish biomass of the fastest growing treatment; the same amount of feed will be used in all ponds.

Water management: Replace evaporation and seepage after ≤ 5 cm loss.

Sampling schedules: Standard protocols except as noted.
Biological parameters:
- Zooplankton: 1x/week.
- Chlorophyll *a*: 1x/week.
- Primary productivity, diurnal curve: every 2 weeks.

Null hypotheses: Tilapia yield will not be affected by polyculture with tambaquí. Stocking rate will have no effect on tambaquí yield. Stocking rate will have no effect on tambaquí size. Pond dynamics will not be affected by polyculture.

Statistical methods: ANOVA , regression analysis.

Schedule: Data collection,8/92 to 1/93; technical report, 7/93.

HONDURAS STUDY 4: FREQUENCY OF WATER EXCHANGE

Objective: To determine effect of water exchange frequency on tilapia yield, water quality and primary productivity.

Significance: BOD and other metabolites increase in ponds during the culture cycle and could negatively impact fish yield. Water quality could be maintained through water exchange. A large, weekly water exchange could be more effective in maintaining good water quality and more labor efficient than small, daily water exchanges. The quantity of organic materials and metabolites eliminated per unit of water exchange will be calculated.

Experimental design: Completely randomized design. Three treatments by four replicates/treatment.

- No water exchange.
- 5% (of pond volume) water exchange per day, 5 days/week.
- 25% (of pond volume) water exchange per week, 1 day/week.

Water exchange will begin once feeding with formulate diet is initiated.

Pond facilities: El Carao, twelve ponds, 0.75 m deep, each 0.1-ha.

Culture period: 150 days.

Fish stocking rate: Male *Oreochromis niloticus* fingerlings stocked at 20,000/ha ; guapote tigre (*Cichlasoma managuense*) fingerlings stocked at 500/ha.

Nutrient inputs: Chicken litter (1,000 kg total solids/ha/wk) for the first two months only, followed by a commercial, pelleted feed only (25% protein) six days/wk. Daily feeding rate will begin at 3% of the total fish biomass of the fastest growing treatment; the same amount of feed will be used in all ponds. Feeding rate will be adjusted monthly based on seine sample data. Daily ration will be fed in two equal rations.

Water management: Replace evaporation and seepage after ≤ 5 cm loss in all ponds prior to initiation of feeding. Thereafter, replace evaporation and seepage in control ponds, and follow appropriate water exchange regime in other ponds. Water exchange procedure will be to first drain water from the pond and then add the exchange water.

Sampling schedules: Standard protocols except as noted below:

Biological parameters:

- Zooplankton and chlorophyll *a* : 1x/wk.
- Primary productivity, diurnal curve: 1x/wk.

Exchange water (inlet, outlet and pond):

- Ammonia-N, total phosphorus and soluble reactive phosphorus, Kjeldahl-N, NO_3-N, dissolved oxygen, suspended solids and volatile solids: 1x/wk.

Null hypotheses: Water exchange will not affect fish yield. Water exchange will not affect primary productivity.

Statistical methods: ANOVA, regression analysis.

Schedule: Data collection, 2/93 to 7/93; technical report, 1/94.

ASIA—THAILAND PROJECT

Cooperating Institutions:

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Dr. Chris Knud-Hansen

CIFAD (University of Hawaii)
Dr. Kevin Hopkins
Dr. James Szyper

Pond System: Freshwater tropical ponds typical of lower elevations.

Experiments conducted under the first five CRSP work plans have addressed the relationships of fertilizer input to yield of fish --primarily tilapia-- and shrimp under standardized conditions. These relationships have been tentatively quantified. In addition, nutrient balancing, pond depth, and stocking density has been evaluated, while fertilizer types and supplemental feeding have been initiated. In the sixth plan, we will complete the fine-tuning of management alternatives and provide data to evaluate an optimal management plan for tilapia.

During the CRSP Fourth Work Plan, each country project explored several difficult topics in an effort to increase the total number of topics examined by the CRSP. The Thailand Project started research in four topics: nutrient balance, pond morphology, stocking density, and tilapia/catfish polycultures. The Thailand Project's selection of nutrient balance as a research topic was based on examining one of two fertilization strategies.. The first strategy, which has been examined by the Honduras and Rwanda CRSPs, is to increase manure loading rates to provide additional nutrients for phytoplankton production. High manure loading rates often lead to low oxygen levels and high ammonia levels which necessitate remedial action. The second strategy is to provide the minimum amount of manure required for the detritus-based food web while using inorganic fertilizers (e.g., urea and triple superphosphate) to provide additional nutrients for the base of the autotrophic food web. The Thailand Project is following this second strategy. Results from the Fourth Work Plan have shown that high yields of tilapia (over 7,000 kg/ha/yr) can be obtained by using relatively low levels of chicken manure supplemented with inorganic fertilizers. Also, by examining nutrient flux in the Thailand ponds, the project was able to show that additional phosphorus inputs were needed in newly renovated ponds in areas which have soils high in aluminum. Results of the fertilization strategies used in Thailand Work Plan Four have been presented in 14 scientific papers, technical reports and theses.

The continuing research in Thailand will emphasize: pond size and management intensity; urea cycling; fertilizer application frequency; stocking density; supplemental feeding; stocking density and supplemental feeding; staged supplemental feeding; management of dissolved oxygen; and regional verification of PD/A CRSP Management Guidelines. Nine studies are planned over the 2-year period (Figure 3).

The two goals of the Thailand Project during the Sixth Work Plan are:

1. To improve our understanding of the effects of management practices on the dynamics of fertilized tilapia ponds in tropical climates, and

2. To develop total management guidelines for tilapia ponds in Thailand.

Figure 3. **Schedule for Data Collection in Thailand during the Sixth Work Plan.**

Study Title	Site	1991				1992												1993							
		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Study 1. Pond Size/Management Interactions	AIT	*	*	*	*	*																			
Study 2. Nutrient Cycling - Urea Dynamics	AIT			*	*	*	*	*																	
Study 3. Fertilization Frequency	AIT									*	*	*	*	*											
Study 4. Stocking Density at High Nutrient Input	AIT															*	*	*	*	*					
Study 5. Pond Dynamics Under Semi-Intensivee and Intensive Culture Practices	Bangsai							*	*	*	*	*													
Study 6. Stocking Density and Supplemental Feeding	Bangsai													*	*	*	*	*							
Study 7. Timing of Supplemental Feeding	Bangsai																			*	*	*	*	*	
Study 8. Evaluation of Low Cost Methods for Destratification and Oxygen Conservation in Tropical Ponds	AIT																				*	*	*	*	*
Study 9. Regional Verification of Fertilizer Guidelines - Philippines	FAC										*	*	*	*	*	*	*	*	*	*	*	*	*		

THAILAND STUDY 1: POND SIZE/MANAGEMENT INTENSITY INTERACTIONS

Background: During the last six months of the Fifth Work Plan, Thailand Study 9 will be conducted at AIT to determine the relationships of pond size to fish yield using ponds ranging in size from 200 m^2 to 1,600 m^2. The effect of pond size on yields is expected to be related to the degree of intensification and management. Higher degrees of management and inputs are generally better suited to smaller ponds. This is readily apparent in the large-scale catfish and shrimp industries.

Objective: To determine the relationships of pond size to fish yield, management practices, and system efficiency.

Experimental design: Incomplete block design using four pond sizes and three levels of management as follows:

	Number of ponds		
Pond size	High fertilizer	Low fertilizer	Feed
200 m^2	a)	2	3
350 m^2	3 + a)	3	3
800 m^2	a)	2	2
1,600 m^2	a)	2	

a) Treatments in the Study 9, Work Plan 5.

Pond facilities: AIT; all ponds 1 m deep (at stadia).

Culture period: Five months.

Fish stocking rate: Sex-reversed *Oreochromis niloticus* fingerlings at 2 fish/m^2.

Nutrient inputs: To be determined based on the results of Work Plan 5

Water management: Replace evaporation and seepage losses weekly.

Sampling schedule: Standard protocols except as noted.
Physical parameters:
- Intensive measurements: every 2 wks.

Chemical parameters:
- Intensive measurements: every 2 wks.
- NO_2-N, NO_3-N, and soluble reactive phosphorus: every 2 wks.

Biological parameters:
- Intensive measurements: every 2 wks.

Hypothesis: The interaction between pond size and management intensity does not affect yield or efficiency per unit area.

Statistical methods: ANOVA and multiple regression.

Schedule: Data collection, 9/91 to 1/92; technical report, 6/92.

THAILAND STUDY 2: NUTRIENT CYCLING UREA DYNAMICS

Objective: To gain insight on the cycling of urea in pond water. To determine whether relative nitrogen availability affects how urea is cycled (i.e., whether algae uptake urea directly, or only after it has been reduced to ammonia by bacteria).

Significance: Urea is a popular source of nitrogen in aquaculture, but little is known of how it is utilized by aquatic organisms. This study will examine the fate of applied urea and should provide a basis for determining optimal fertilization frequencies of urea in aquaculture ponds. If urea accumulates in pond water even under conditions of nitrogen limitation, then less frequent urea fertilization may be more efficient. Under conditions where nitrogen is not limiting algal productivity, monitoring urea accumulation and breakdown should help clarify the role of urea fertilization (versus ammonia regeneration) in contributing to high ammonia concentrations. Comparisons of urea accumulation in treatments with and without nitrogen limitation should suggest whether urea can be taken up directly by algae.

Experimental design: Four different N:P ratios. Three replicates per treatment.

Pond facilities: AIT, twelve 400 m^2 ponds, 1 m deep (at stadia).

Culture period: Five months.

Fish stocking rate: Sex-reversed *Oreochromis niloticus* fingerlings at 2 fish/m^2.

Nutrient inputs: Input rates for all ponds will be 25 kg/ha/week of urea-N. Phosphorus will be added as triple superphosphate (TSP) to give total N:P ratios of 1:1 (promoting nitrogen limitation), 4:1, 7:1 and 10:1 (promoting phosphorus limitation).

Water management: Replace evaporation and seepage losses weekly to maintain an average water depth of 1 m.

Sampling schedule: Standard protocol except as noted.
Physical parameters:
- Intensive measurements every two weeks, rather than the standard three times during the experiment.

Chemical parameters:
- Intensive measurements every two weeks, rather than the standard three times during the experiment.
- NO_2-N, NO_3-N, soluble reactive phosphorus (SRP) and urea every two weeks.
- NO_2-N, NO_3-N, NH_4-N, SRP, urea every day for one week to be done three times during the course of the experiment.

Biological parameters:
- Intensive measurements every 2 weeks.

Null Hypotheses: Urea accumulation/breakdown does not differ under different conditions of nutrient limitation. Algae are not able to utilize urea directly as a source of nitrogen.

Statistical methods: ANOVA, regression.

Schedule: Data collection, November 1991 through March 1992; technical report, 4 months after fish harvest.

THAILAND STUDY 3: FERTILIZATION FREQUENCY

Objective: To determine the relationships between primary productivity and net fish yield with frequency of fertilization application.

Significance: Earlier CRSP/Thailand research identified optimal weekly fertilization rates for generating the greatest net fish yield with minimal negative environmental conditions (i.e., early morning dissolved oxygen and afternoon ammonia concentrations). Results of this study will demonstrate whether timing of fertilization application is important for further improving fish yields. If there is a relationship between fish production and fertilizer application then it will be an important component of pond management strategies. However, if no relationship is detected then the farmer will have more flexibility and could base frequency of fertilization around their convenience (i.e., optimizing labor costs) without any reduction of fish yield.

Experimental design: Five frequencies of fertilization. Three replicates per treatment.

Pond facilities: AIT, fifteen 400 m^2 ponds, 1 m deep (at stadia).

Culture period: Five months.

Fish stocking rate: Sex-reversed *Oreochromis niloticus* fingerlings at 2 fish/m^2.

Nutrient inputs: Input rates for all ponds will average 35 kg/ha/week of urea-N. Phosphorus will be added as triple superphosphate (TSP) to give total N:P ratios of 4:1. Results of Work Plan 5, Thailand Experiment 5 will determine whether chicken manure will also be added. The five treatment frequencies are: (1) daily, (2) two times per week, (3) weekly, (4) every 1.5 weeks, and (5) every two weeks.

Water management: Replace evaporation and seepage losses weekly to maintain an average water depth of 1 m.

Sampling schedule: Standard protocol except as noted.
Physical parameters:
- Intensive measurements every two weeks, rather than the standard three times during the experiment.

Chemical parameters:
- Intensive measurements every two weeks, rather than the standard three times during the experiment.
- NO_2-N, NO_3-N, soluble reactive phosphorus (SRP) and urea every two weeks.

Biological parameters:
- Intensive measurements every 2 weeks.

Null Hypotheses: Frequency of fertilization does not affect the rate of algal production. Frequency of fertilization does not affect the rate of fish production.

Statistical methods: ANOVA, regression.

Schedule: Data collection, May through September 1992; technical report, 4 months after fish harvest.

THAILAND STUDY 4: STOCKING DENSITY AT HIGH NUTRIENT INPUT

Objective: To determine the relationships between initial stocking density and fish growth measured both as individual growth rate and areal net fish yield.

Significance: A recent CRSP/Thailand investigation indicated that in ponds receiving high nutrient loading, net fish yield significantly increased when stocking densities were raised from 1 to 3 fish/m^2. By examining five stocking densities in ponds with optimal fertilization rates (based on net fish yield, early morning dissolved oxygen and afternoon unionized ammonia concentrations), important empirical relationships relating stocking densities to fish growth and production will be available to CRSP modelers. In addition, these results will have practical utility in Thailand, where different parts of the country have different market size preferences for tilapia.

Experimental design: Five initial stocking densities. Three replicates per treatment.

Pond facilities: AIT, fifteen 400 m^2 ponds, 1 m deep (at stadia).

Culture period: Six months (a longer experiment to better fit growth curve regressions, and to push standing stock to carrying capacity).

Fish stocking rate: Sex-reversed *Oreochromis niloticus* fingerlings at 1, 2, 3, 4, and 5 fish/m^2.

Nutrient inputs: Input rates for all ponds will be 35 kg/ha/week of urea-N. Phosphorus will be added as triple superphosphate (TSP) to give total N:P ratios of 4:1. Frequency to be determined from other Work Plan 6 experiment.

Water management: Replace evaporation and seepage losses weekly to maintain an average water depth of 1 m.

Sampling schedule: Standard protocol except as noted.
Physical parameters:
- Intensive measurements every two weeks, rather than the standard three times during the experiment.

Chemical parameters:
- Intensive measurements every two weeks, rather than the standard three times during the experiment.
- NO_2-N, NO_3-N, soluble reactive phosphorus (SRP) every two weeks.

Biological parameters:
- Intensive measurements every 2 weeks.

Null Hypotheses: Initial stocking density has no effect on net fish yield at harvest. Initial stocking density has no effect on individual fish growth rate.

Statistical methods: ANOVA, regression.

Schedule: Data collection, November 1992 through March 1993; technical report, 4 months after fish harvest.

THAILAND STUDY 5: POND DYNAMICS UNDER SEMI-INTENSIVE AND INTENSIVE CULTURE PRACTICES

Objective: To assess the contribution of natural and supplemental foods to tilapia growth and to determine the economic feasibility of supplemental feeding.

Significance: By understanding the role of supplemental feed and nutrient addition in different combinations the role of each in pond nutrition can be used to optimize management.

Experimental design: Unbalanced design with four treatments (fertilizer and feed, fertilizer alone, feed alone at rate of treatment one, feed alone ad-libitum) and four replicates per treatment.

Pond facilities: Bang Sai, sixteen 220 m^2 ponds.

Culture period: Five months.

Fish stocking rate: Sex-reversed *Oreochromis niloticus* at 3 fish/m^2.

Nutrient inputs and feeding rates: Treatments 1 and 2 with chicken manure at 250 kg/ha/wk supplemented with urea to bring nitrogen: phosphorus ratio to 4:1. Treatments 3 and 4 with no fertilization. Treatments 1 and 4 will be fed ad-libitum. Treatment 3 will be fed at a rate equivalent to treatment 1.

Water management: Replacement of evaporation and seepage losses weekly.

Sampling schedule: Standard protocols.

Null hypotheses: That fertilization alone does not provide sufficient material for maximum tilapia growth. That maximum feeding rates will not provide greater growth than combinations of fertilizer and feed.

Statistical methods: ANOVA, regression.

Schedule: Data collection 3/92 to 7/92; technical report 8/92.

THAILAND STUDY 6: STOCKING DENSITY AND SUPPLEMENTAL FEEDING

Objective: To determine the effects of stocking density on pond carrying capacity (fish size and total net yield) in fertilized ponds with supplemental feeding.

Significance: The pond carrying capacity for fish production is expected to increase with supplemental feeding, but with increasing feed input to support greater stocking density the eutrophic feedback from waste recycling may hasten unfavorable water quality for fish growth. With appropriate stocking density, extra fertility derived from supplemental feeding will be assimilated effectively to compensate for the external fertilizer input. We anticipate achieving a balanced pond culture system with abundant food supply and desirable water quality, which is the basis for maximizing pond carrying capacity in an economic way.

Experimental design: Four stocking densities (2, 3, 4, and 5 fish/m^2) with triplicate ponds for each treatment.

Pond facilities: Twelve 220 m^2 ponds of 1 m depth at Bang Sai.

Culture period: An unspecified period until the population growth rate of each treatment reaches the initial phase of asymptotic growth curve.

Fish stocking: 5-10 g size of all-male *Oreochromis niloticus* fingerlings will be stocked and reared at the densities listed above.

Nutrient input and feeding rate: Depending on the results of Study 2, but balanced total N and P at 5 and 1.5 kg/ha/day, respectively.

Water management: Evaporation and seepage losses to be made up weekly.

Sampling schedule: Intensive physical, chemical, and biological measurements will be made biweekly. Fish will be sampled biweekly to estimate feeding rate.

Null hypothesis: Stocking density does not affect pond carrying capacity.

Statistical methods: ANOVA, regression.

Schedule: Data collection 9/92 to 1/93; technical report 8/93.

THAILAND STUDY 7: TIMING OF SUPPLEMENTAL FEEDING

Objective: To determine the appropriate time for initial application of supplemental feed in fertilized ponds.

Significance: As shown in the previous fertilization experiments, the natural food derived from fertilizer enrichment alone was sufficient to support tilapia growth in a linear fashion during the early phase of grow-out cycle. Growth rate reduced at a later stage, and the duration for reduced growth increased with increasing stocking density. The inadequate natural food supply is assumed to be the limiting factor for slower growth rate, and input of supplemental feed would boost growth rate throughout the grow-out cycle. It would be of economic advantage to give supplemental diet at critical stages when the natural food becomes inadequate to support optimal fish production.

Experimental design: Application of supplemental feed will be initiated at four different time periods during a grow-out cycle; triplicate for each treatment.

Pond facilities: Twelve 220 m^2 ponds at Bang Sai.

Culture period: Fish will be reared until the pond carrying capacity is reached.

Fish stocking: 5-10 g size of all-male *Oreochromis niloticus* fingerlings will be stocked at an appropriate density as shown in the results of Stocking Density Study.

Nutrient input and feeding rate: The pond will be fertilized at a constant rate throughout the experimental period. The fertilization rate will consider the external fertilizer input and fertility derived from supplemental feeding, giving a rate of total N & P input at 5 and 1.5 kg/ha/day, respectively.

Water management: Maintain depth at 1 m with weekly input.

Sampling schedule: Intensive physical, chemical, and biological measurements will be made biweekly.

Null hypothesis: Various time period for initial supplemental feeding does not affect final fish yield.

Statistical methods: ANOVA, regression.

Schedule: Data collection 3/93 to 7/93; technical report 8/93.

THAILAND STUDY 8: EVALUATION OF LOW COST METHODS FOR DESTRATIFICATION AND OXYGEN CONSERVATION IN TROPICAL PONDS

Background: Intense daytime density stratification, characteristic of earthen ponds in warm climates, isolates bottom water from surface water, permitting severe depletion of dissolved oxygen (DO) which may persist throughout the day and night. Although fishes and shrimps can relocate from DO-depleted layers, convective overturn after nighttime cooling can create inescapable whole-pond low levels if 1) the hypolimnion is large compared to the epilimnion, or 2) respiration in sediments and bottom water has been rate-limited by low DO before exposure to the DO newly mixed in from the surface. In addition, upper-layer production of both DO and organic matter may be limited by depletion of nutrient elements when surface waters are isolated from deep-water or benthic organic remineralization.

Mechanical devices are often used to destroy density stratification and to increase or maintain DO in ponds. Night-long or continuous active aeration can improve production over emergency aeration practices; daytime aeration is usually avoided to conserve the commonly-observed surface supersaturation of DO for nighttime use. Mixing or circulation of pond waters without increasing the surface area of air-water contact is relatively inexpensive compared with active aeration, and has the potential to reduce the cost of aeration needed to optimize production.

Research performed by U. of Hawaii CRSP projects has shown that properly-timed daytime mixing (as distinct from active aeration) can relieve bottom DO depletion during daylight and early evening hours, and may conserve daytime surface supersaturation levels of DO against loss to the atmosphere. The proposed experiment will compare several low-cost strategies for pond mixing, aiming to optimize whole-pond DO regimes.

Objective: To develop and describe one or more low-cost strategies, in terms of apparatus and mode of application, which best redistribute DO in time and space for greatest benefit to cultured animals.

Experimental Design:

- Deploy at least three types of mixing apparatus (submersible water pumps, air lift or air tube mixers, fan-blade mixers) in ponds of surface areas ranging from 200 to 2,000 m^2, and determine their relative costs and capability for destratification under conditions typical of CRSP pond experiments.
- Assess stratification, mixing, and redistribution of DO with automated monitoring systems presently used in CRSP research.
- Determine optimal placement and timing for most efficient use of the best apparatus in ponds of different sizes.

Submersible water pumps will take water from within 10 to 20 cm of pond bottoms and discharge it horizontally at 5 to 10 cm below the surface; air lifts will relocate water to and from similar depths; fan-blade mixers will be deployed for greatest efficiency without undue disturbance of sediments. Operation time will be controlled and recorded automatically; power use will be monitored either automatically or manually. DO will be measured at three depths at one selected location in a pond at 15 to 30 min intervals by pumping water to the land-based monitoring system; temperature will be measured at 10 cm depth intervals by thermocouples suspended from floats at several pond locations. This will provide whole-pond assessment of stratification and show the relationship of DO distribution to temperature profiles.

Pond facilities: AIT ponds: 1 m deep; approx. 400 m^2 (and larger ponds as available). Ponds of 2,000 m^2 at UH Mariculture Research and Training Center in Hawaii.

Culture period: Five months, or as specified in collaborating experiments.

Fish stocking rate: Sex-determined fingerling *Oreochromis niloticus* at 2 fish/m^2, or as specified in collaborating experiments.

Nutrient inputs: Best rates resulting from MSU experiments, or as specified in collaborating experiments.

Sampling schedule: Standard protocol, or as specified in collaborating experiments.

Water Management: Standard protocols, or as specified in collaborating experiments.

Null hypotheses: Total energy input and other aspects of strategy required for mechanical destratification are not affected by surface area of 1 m deep ponds. Low cost mixing strategies will not increase the exposure of pond animals to DO, as indexed by the product of time and concentration ("ppm-hours"). Redistribution of DO by mixing will not conserve daytime supersaturation levels against loss to the atmosphere.

Schedule: Data collection, 4/93 to 8/93 and when other ponds are available; technical report, 10/93.

THAILAND STUDY 9: FIELD TESTING LEAST-INTENSIVE AQUACULTURE TECHNIQUES ON SMALL-SCALE INTEGRATED FARMS IN THAILAND

Objectives:

1) To test high-yielding and economical pond fertilization and fish stocking practices developed by the PD/A CRSP at two off-station locations in Thailand,
2) To describe those iterations of the PD/A CRSP Pond Management Guidelines (developed by the Data Analysis and Synthesis Team (DAST) as a computer program) that most closely approximate pond productivity and fish yield obtained at off-station locations, and
3) To obtain field validation for a simple kit to use on farms to regulate the addition of fertilizers to ponds in an efficient, cost-effective manner.

Significance: The Asian Institute of Technology (AIT) and the Thailand Project of the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) have been leaders in the development of fertilization and management practices for fish ponds in Southeast Asia. On-station work conducted by the PD/A CRSP at AIT has resulted in the development of guidelines for fertilizing and stocking fish ponds to obtain high yields of Nile tilapia (*Oreochromis niloticus*). These guidelines will be incorporated into an existing aquaculture outreach program that AIT has successfully established in Northeast Thailand, and will also be applied at an off-site fish farm north of Bangkok. On-farm testing of recommended cultural practices will validate and/or reveal shortcomings of research findings and PD/A CRSP Pond Management Guidelines.

Methodology: There will be three field components to this project: 1) on-farm activities in Northeast Thailand, 2) off-site activities on a fish farm north of Bangkok, and 3) evaluation of a biosassay field kit. The field kit will be assessed in ponds at AIT and Bang Sai, and once efficacy has been established, will be used in fish farm ponds in Northeast Thailand. The bioassay field kit will identify the degree of carbon, nitrogen, or phosphorus limitation in ponds by comparing algal growth in C-, N-, and P-enriched flasks to growth in unenriched pond water.

On-farm activities will be conducted in Northeast Thailand near Udorn Thani. Ponds will be used on up to 20 farms that participate in AIT's outreach program. Farmers in the area raise Nile tilapia in monoculture or in polyculture with common carp (*Cyprinus carpio*) and/or silver barb (*Puntius gonionotus*). For on-farm trials, sex-reversed male Nile tilapia will be stocked in June 1991 and grown through December 1991. Water quality parameters will be measured monthly throughout the grow-out period. Water quality parameters measured will include pH, alkalinity, total phosphorus, soluble reactive phosphorus, ammonia-nitrogen, and nitrate-nitrite-nitrogen. Past fertilization practices and cost and availability of urea and triple superphosphate will be studied. The same approach will be used for an off-site study conducted at the Sombat farm north of Bangkok, where acid-sulfate soils occur.

Pond facilities: Earthen ponds used by private farmers in Northeast Thailand will vary in size. Earthen ponds at the fish farm just north of Bangkok (Sombat's farm) are 160 m^2 at a depth of 1 m. For the bioassay field testing, earthen ponds at both Bang Sai and AIT will be used. At Bang Sai, ponds have a surface area of 220 m^2 at a depth of 1 m (at stadia) while AIT ponds have a surface area of 394 m^2 at 1 m of depth.

Culture period: 150 to 180 days for ponds in Northeast Thailand; 1 year for the ponds at Sombat's farm.

Fish stocking rate: All fish stocked will be sex-reversed male Nile tilapia (*Oreochromis niloticus*). Ponds in Northeast Thailand will be stocked at a variable density at the farmer's discretion. At Sombat's farm, a partial harvesting/stocking strategy will be used. Fish will be initially stocked at $1/m^2$; ten weeks later an additional 1 fish/m^2 will be stocked; ten weeks later the initially stocked fish will be harvested and an additional 1 fish/m^2 will be stocked. This pattern will be repeated until the termination of the experiment.

Nutrient inputs: Recommended input rates for ponds in Northeast Thailand will vary from pond to pond depending upon alkalinity but will have an N:P ratio of 3:1. Actual input rated will be up to the farmer since only recommendations will be made. At Sombat's farm 35 kg/ha of urea-N and 15 kg/ha of triple superphosphate will be added weekly. Phosphorus additions might vary depending upon monthly water quality data. No chicken manure will be used at Sombat's farm.

Water management: Water will be added to ponds to replace evaporation and seepage.

Sampling schedule: PD/A CRSP standard protocols will be used to sample and analyze water quality parameters which will be measured monthly throughout the grow-out period. Water quality parameters measured will include pH, alkalinity, total phosphorus, soluble reactive phosphorus, ammonia-nitrogen, and nitrate-nitrite-nitrogen. Past fertilization practices and cost and availability of urea and triple superphosphate will also be determined.

Null hypothesis: On-farm fish yields of Nile tilapia will not differ from yields predicted from N-input regressions based on studies conducted by the Thailand PD/A CRSP researchers.

Statistical methods: ANOVA, regression.

Schedule: The proposed starting date for this project is May 1991. Work will begin with the assessment of the bioassay field kit at AIT and Bang Sai Fisheries Station and identification of farmers in Northeast Thailand who will employ PD/A CRSP guidelines for fertilization and management of their fish ponds. Growout of fish in farm ponds in Northeast Thailand and at the off-site farm north of Bangkok will begin during June 1991 and continue through December 1991. Evaluation of the field testing and preparation of educational outreach materials (extension type publications) and technical papers will occur during the first four months of 1992.

THAILAND STUDY 10: REGIONAL VERIFICATION OF FERTILIZER GUIDELINES - PHILIPPINES

Background: Experiments conducted under the first three CRSP work plans used standardized experimental protocols to address the relationships of fertilizer input to yield of fish and shrimp. The biological results obtained from the Thailand Project are felt to be representative of freshwater tropical ponds typical of lower elevations although differing economic conditions in other locales could lead to different fertilizer recommendations for maximizing profit (versus maximizing fish production). This study proposes to test the DAST fertilization guidelines in the Philippines.

All previous CRSP projects were conducted with long-term on-site presence of researchers from the USA universities. This study, however, will rely on Filipino scientists at the Freshwater Aquaculture Center in Munoz, Nueva Ecija, Philippines with only twice yearly visits by scientists from the University of Hawaii. The FAC was established in the early 1970s. It is a freshwater research facility with a large number of replicated ponds with accompanying laboratories and support facilities. Over the years, researchers at the FAC have conducted pioneering work in rice-fish culture, integrated animal-fish culture systems, and fertilization yield trials. A large quantity of baseline and experimental data on the integrated animal-fish culture systems which was conducted at the FAC in the late 1970s and early 1980s and has been made available to the CRSP by ICLARM. This data will greatly facilitate the comparison of data to be collected during this study with data from other CRSP sites. Thus, the FAC is particularly well suited to be the first site for regional verification of fertilization guidelines developed by the CRSP. If this operational strategy of regional verification is successful, it can be used to greatly expand the CRSP into other countries and regions at a reasonable cost.

Objectives: The objectives of the proposed research are to conduct further experiments to develop improved chicken manure/inorganic fertilizer guidelines, and to develop generic organic/inorganic pond fertilizer guidelines for the Philippines and train extension workers in the use of these guidelines.

Experimental Design:

Study 1: This study will determine the minimum N:P ratio to maximize yield. The nitrogen loading rate will be based on the results of earlier studies. There will be four N:P ratios tested during this experiment: 1:1, 3:1, 5:1, and 7:1. Each treatment will be replicated twice.

Study 2: This study will determine the substitutability of chicken manure for urea and TSP. The best N loading rate from previous research and the best N:P ratio from Study 1 will be used. Chicken manure will then be used to substitute for 0%, 12.5%, 25%, and 50% of either N or P (depends on selected N:P ratio). The manure will be supplemented with urea and TSP to reach the desired rates.

Pond Facilities: Eight 500 m^2 ponds at the Freshwater Aquaculture Center, Munoz, Nueva Ecija, Philippines.

Culture Period: Five months for each study.

Fish Stocking Rate: Sex-reversed *Oreochromis niloticus* at 2 fish/m^2.

Nutrient inputs: As per CRSP guidelines and most current nutrient balancing experiments.

Water management: Replace evaporation and seepage losses weekly.

Sampling schedule: Standard protocols except as noted.
Chemical parameters:
- Ammonia-N, soluble reactive phosphorus, alkalinity, and dissolved oxygen: every 2 wks.

Null Hypotheses:
Study 1: N:P ratios do not affect fish yields.
Study 2: Substitution of organic fertilizer for chemical fertilizer will not affect fish yield.

Statistical methods: ANOVA.

Schedule: Data collection, 6/92 to 6/93; technical report, 8/93.

DATA ANALYSIS AND SYNTHESIS TEAM

Cooperating Institutions and Principal Investigators:

University of California at Davis
Dr. Raul Piedrahita

Oregon State University
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INTRODUCTION

The goals and objectives of the DAST during the period covered by this work plan are based on the material presented in the Second DAST Newsletter (June 1990), and on the current status of the management guidelines and the modeling work. The objectives are directed towards the improvement of the Management Guidelines and existing models using new CRSP data and towards the development of specific applications for monitoring and optimizing the performance of whole pond systems. The DAST proposal during this work plan includes an experimental component to complement the field data being collected at the CRSP sites. This experimental component will be carried out in collaboration with the other CRSP participants.

Development of the Preliminary Pond Management Guidelines was a major achievement of the DAST during the current work plan. Field testing and refinement of the Guidelines are essential steps in the validation process. Testing of the proposed management practices and of the models developed will be carried out with data sets from the fourth and subsequent experimental work plans as these data were not used in model development. Further testing of the Management Guidelines will be carried out in the field by managing ponds in accordance with the recommendations obtained from the execution of the Guidelines computer program. Feedback from other CRSP participants will be an important component of the testing and validation processes. Refinements of some of the algorithms in the Guidelines may be possible based on CRSP data and models currently available. The OSU and UC Davis teams will collaborate in incorporating improved formulations into the Guidelines.

The examination of primary productivity in aquaculture ponds depends on an accurate understanding of the oxygen consumption and production processes occurring in the water. There are, however, deficiencies in our understanding of water column respiration processes. These deficiencies and the lack of practical field methods for measuring diel pond respiration rates have limited the development of workable analytical models to monitor the overall productivity in ponds. An example of such a model under development by the UC Davis DAST is used to estimate the efficiency of primary production in an aquaculture pond on an hourly, daily or weekly basis (Efficiency of primary production in this context is based on estimates of primary production per unit area and unit of light impinging upon the water surface). This model has been developed by examining mechanistic relationships important in primary production and is based on measurements of changes in pond dissolved oxygen concentration. Improved estimates of primary production and respiration rates will make it possible to refine the model and use it to evaluate the overall condition of primary producers in a pond on an ongoing basis, and to examine the effects of changes in pond parameters (such as depth, turbidity, or temperature) on the efficiency of primary production.

It is apparent from previous work by the CRSP DAST that water column respiration cannot be described solely by empirical temperature dependent functions. Equally problematic is the common practice of extrapolating night respiration rate measurements to daytime periods. Some laboratory and field studies have shown that respiration rates fluctuate widely over the diel cycle. Extrapolating the nighttime respiration rates over the diel period results in significant underestimation of total pond respiration, which results in low estimates of gross primary production. It is therefore critical that the processes controlling light and dark respiration rates in a pond be examined to understand primary productivity more fully. Accurate predictions of dissolved oxygen in ponds and the design of effective management practices must be based on a thorough understanding and quantification of these production and respiration rate changes.

Thermal stratification in shallow aquaculture ponds is a common occurrence. Thermal stratification is normally paralleled by the stratification of dissolved oxygen and other water quality parameters. While dissolved oxygen and temperature models have been proposed for homogeneous water columns, it has been suggested that some of the lack of realism of these models has been due to the assumption of fully mixed conditions when indeed this was not the case. A better quantification of the effects of water stratification, phytoplankton production and dissolved oxygen availability would improve the predictive quality of these models.

Models of stratified ponds have been developed at UC Davis. These models require detailed water quality and environmental data, and have resulted in predictions of water temperature and dissolved oxygen concentrations at 15 cm intervals for ponds up to 1.3 m in depth. Modifications will be made to the models as more recent CRSP data are received, and as data requirements are reduced based on model testing and sensitivity analysis. CRSP-generated data will be supplemented with more intensive or parameter-specific studies conducted previously by the UC Davis DAST, or with data from experiments being proposed for the current Work Plan. The stratified models results will be used to predict the extent of water stratification in ponds. This information will be useful for selecting pond sites or culture conditions.

Three studies are proposed by the DAST for The Sixth Work Plan (Figure 4). The goals of these studies are:

1. To improve the reliability of CRSP pond management guidelines by incorporating research findings that have become available since completion of the Provisional Guidelines.;

2. 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; and

3. To develop and test models of temperature and dissolved oxygen stratification in CRSP ponds.

Figure 4. Schedule of Activities and Reports of the Data Analysis and Synthesis Team during the Sixth Work Plan.

Study Title	1991				1992												1993							
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Study 1. Testing and Updating CRSP Management Guidelines																								
- Refine present algorithms	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
- Finalize second version of Guidelines																				*	*	*	*	
- CRSP participant review of Guidelines																								*
Study 2. Quantification of Light and Dark Respiration Rates																								
- Develop laboratory method for measurement	*	*	*	*																				
- Method and field measurement					*	*	*	*	*	*	*	*	*	*	*	*								
- Completion of CRSP Global Experiment																	*	*	*	*	*			
Study 3. Models for Temperature and Dissolved Oxygen in Stratified CRSP Ponds																								
- Model modification	*	*	*	*	*	*	*	*	*	*	*	*												
- Model calibration and validation													*	*	*	*	*	*	*	*	*	*	*	*

DAST STUDY 1: TESTING AND UPDATING OF CRSP MANAGEMENT GUIDELINES

The overall goal of this study is to improve the reliability of CRSP pond management guidelines, and to make the guidelines more comprehensive by incorporating research findings that have become available since completion of the Provisional Guidelines.

Objectives:

1. To use data from CRSP Work Plans four and five to verify quantitative relationships used in the Provisional Guidelines.
2. To develop new relationships to provide more comprehensive management guidelines.
3. To prepare a second, more comprehensive version of pond fertilization guidelines.

Methods: The first edition of CRSP guidelines was based mainly on data from CRSP Work Plans one through three, and on review of technical literature. Refinement of the Provisional Guidelines will be based on analysis of new CRSP data (Work Plans Four and Five) as they become available to the DAST, and the specific results of other projects being accomplished by the DAST under Work Plan Six. Wherever appropriate, the present algorithms will be replaced with expressions derived from new analyses of CRSP data. Algorithms related to primary production, respiration, and fertilization are the main areas in which revisions are likely to be made. Specifically, this study will focus on the following questions:

1. Can inorganic fertilizers satisfy the nutrient requirements of all ponds or only ponds with certain characteristics? Under what circumstances, if any, do ponds require the addition of organic material?
2. For a given climate zone and season, what is the maximum potential net primary production when primary nutrients are not limiting?
3. Are simple, on-farm methods available for partitioning water turbidity into volatile and non-volatile components?
4. Can expected fish yields be estimated for ponds in which primary nutrients are limiting?
5. Are simple, on-farm methods available for determining nutrients available in various organic fertilizers?
6. How should pond nutrient requirements be adjusted for ponds that tend to stratify?
7. How do fish stocking practices influence requirements for primary nutrients?

Components or subunits of the Guidelines will be considered independently to facilitate detailed analysis. Output obtained with the current version of the algorithms will be compared with new CRSP data as they become available to the DAST. Similar analyses will be carried out with models and algorithms developed by the DAST. Comparison between the two sets of outputs will be the primary criteria used in selecting the formulation to be used in the Guidelines. Another important criteria for selection of the formulations is data requirements, and a balance between reducing data needs and improved output realism will be sought depending on the specific application and on the uses and audience for the results.

Schedule: Review and synthesis of research findings from CRSP Field Projects is an ongoing DAST activity, and will continue as new data becomes available to the DAST. These data and the results of on-farm testing of the Provisional Guidelines will be used to refine presently used algorithms, and to develop new algorithms where appropriate. This activity will continue until March, 1993, at which time effort will shift to incorporating the algorithms into a second, more comprehensive version of the Guidelines. The revised Guidelines will be available to CRSP participants for review by August 31, 1993.

DAST STUDY 2: QUANTIFICATION OF LIGHT AND DARK RESPIRATION RATES

The overall goal for this study is 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.

Objectives:

1. To develop consistent, convenient methodologies for determination of hourly rates of community light and dark respiration in aquaculture ponds over the diel period.
2. To examine how light and dark respiration rates change over the diel period and to establish the relationships between these rates and environmental factors.
3. 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. These models will then form the basis of analysis of various experimental pond treatments and provide an ongoing objective criteria for pond system performance.

Significance: Measurement of water column respiration rates throughout the diel cycle are not available and daytime respiration is normally extrapolated from nighttime measurements. This approximation tends to result in an underestimation of daytime respiration and gross primary production rates. The results of this project will serve to improve our understanding of primary production and respiration processes and will result in better predictability of dissolved oxygen concentration in ponds, and the development of management practices to ensure optimum oxygen regimes within the physiological limitations of phytoplankton.

Methods: An apparatus will be designed to measure the change in dissolved oxygen concentration in the dark in samples that are suddenly removed from the light. The apparatus will use dissolved oxygen microprobes with fast response times so that transient changes in oxygen concentration may be measured. Initial work will be carried out with laboratory plankton cultures at various stages in their light-dark cycle. i.e. subsamples ($\approx$ 100 mL) from a culture ($\approx$ 10 L) in a lighted chamber. Based on the laboratory work, a methodology and equipment will be developed to measure pond respiration rates over the diel period in the field. Field research will be conducted in cooperation with the University of Hawaii CRSP, at the Mariculture Research and Training Center (MRTC) or at field sites in Thailand.

Improved pond respiration measurements based on the laboratory and field experiments will be used to estimate net primary production rates from CRSP pond data. These estimates will be incorporated into computer models and used to investigate: a) possible changes in the response of phytoplankton to light intensity between morning and afternoon; b) effects of pond treatments on production parameters; and c) effects of pond depth and turbidity on production efficiency. The results obtained from the field and modeling work will form the basis of a global CRSP experiment to be proposed by the UC Davis DAST. This experiment will use the methodology developed herein, and will serve to evaluate the pond systems at the various sites on the basis of primary production response to environmental conditions and pond treatments. The experiment will consist of a specific short-term data collection scheme to be carried out in ponds at all CRSP sites. Pond management practices will not be altered from those proposed by the individual site teams.

Schedule: Method for laboratory measurement of light/dark respiration rates by Dec 1991. Method and field measurement of respiration rates by Dec.1992. Completion of global experiment proposed by the CRSP by May, 1993. Computer model development and improvements will be ongoing and will incorporate data as they become available.

DAST STUDY 3: MODELS FOR TEMPERATURE AND DISSOLVED OXYGEN IN STRATIFIED CRSP PONDS

The overall goal of this study is to develop and test models of temperature and dissolved oxygen stratification in CRSP ponds.

Objectives:

1. To simplify the data requirements of existing temperature and dissolved oxygen stratification models and test the models with non-CRSP and CRSP data sets.
2. To incorporate into existing models the more accurate characterization of primary production and respiration rates identified in Study 3.
3. To calibrate and verify the modified/simplified models with CRSP data. Short-term data collection schemes may be proposed to CRSP field sites to generate data sets for validation of these models.

Significance: Thermal and chemical stratification are frequently observed in CRSP ponds, but all computer models and management practices currently being used and recommended ignore this stratification. The proposed work will build on models previously developed at UC Davis by incorporating findings from Study 3. The models will be used to predict dissolved oxygen and temperature in stratified ponds, and to study how these are affected by management, water quality and climate factors.

Methods: Temperature and dissolved oxygen stratification models developed previously by the UC Davis DAST will be simplified to run on data sets comparable to those being collected at the CRSP sites. The models also will be modified to incorporate the results of our work on primary production and pond respiration (DAST Study 3) as they become available. Initial testing of the models will be conducted with data obtained by reprocessing data sets originally used to test and validate the models. Reprocessing of the data sets will consist of eliminating variables not currently monitored at the CRSP sites, and reducing the temporal and spatial resolution to match those of the CRSP data. For example: measurements of solar radiation will be averaged over time periods ranging from two to four hours as is currently done for the CRSP diel cycle measurements.

After the models have been tested with these simplified data sets, they will be executed using CRSP data sets. The quality of the simulations will be determined by comparing the simulated results with actual measurements of dissolved oxygen and temperature in CRSP ponds. Depending on the quality of simulations obtained with existing CRSP data sets, specific short term data collection schemes will be proposed to the field sites. These data collection runs will be carried out in existing project ponds, will last between 24 and 48 hours, and be repeated once or twice during an experimental cycle. Data collected under this protocol will be forwarded directly to the UC Davis DAST to expedite the analysis.

Schedule: Model modification to simplify and reduce data needs, and initial model testing by August, 1992. DAST Study 3 results will be incorporated into the dissolved oxygen model as they become available. Model calibration and validation by execution with CRSP data sets by August 1993.

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Air Temperature - see Temperature, Air				
Alkalinity	Near center of each pond, take readings at 25 cm below the water surface, midwater and 25 cm above the bottom. Keep samples cool in refrigeration unit or ice chest, and analyze within 24 hours.	Hach Digital Titrator Test Kit/Alkalinity (optional).	Low or Standard Alkalinity method (as appropriate) (from "Standard Methods," APHA et al., 1985), or Hach Test Kit	mg CaCO3/L
Ammonia	Collect one sample (by pooling three 90 cm column samples) from each pond. Samples should be refrigerated and analyzed within 24 hours.	Kontes or comparable Kjeldahl nitrogen apparatus. See Nitrogen, Kjeldahl Apparatus	Nesslerization Method (Michigan State University Limnological Research Laboratory, 1984).	mg/L
Benthos Composition	Collect at least three cores of mud per pond. Process samples through a No. 30 sieve, sort organisms and fix in 10% formalin or a 70% ethanol solution. Identitfy at the order level or lower. Count number of organisms per unit volume or area.			various
Chemical Oxygen Demand - see Oxygen, Chemical Demand.				

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Chlorophyll a (corrected and uncorrected)	Collect one sample per pond by pooling three 90 cm column samples. Take samples with diel studies.		Acetone extraction and Spectrophotometric Determination, from "Standard Methods" (APHA et al., 1985)	mg/m3
Dark Bottle Respiration - see Respiration, Dark Bottle				
Depth, Pond	Install staff gauge in each pond and read to nearest 0.5 cm at same time each day, before restoring to specified depth.	No type specified.		m
Dissolved Oxygen - see Oxygen, Dissolved				
Evaporation and Inflow	Surface Inflow/Outflow and Evaporation should be determined using procedures described in Appendix F of CRSP Work Plan III, 1985, (Wood, J.W. 1974. Diseases of Pacific Salmon: Their Prevention and Treatment. pp 71-77) or comparable approaches.			mm/d (evaporation); m3/d (infiltration)
Feed Composition	See Analytical Methods Report			various

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Fish/Shrimp Length, Individual	From a representative 10% subsample of the grab sample, determine total length of each individual and express as mean length per individual.			cm
Fish/Shrimp Production	Fish and shrimp stocks will be weighed as a group and counted at stocking and harvest. Tilapia will be sexed individually. Compute gross and net production.			kg and #
Fish/Shrimp Weight, Group	At 30-day intervals throughout each experimental cycle, collect grab sample equivalents to 10% of initial stock from each pond and weigh as a group. Indicate number of individuals in sample. Note observations on reproduction and fish health.			kg/#, individual
Fish/Shrimp Weight, Individual	From a representative 10% subsample of the grab sample, determine weight of each individual and express as weight per individual.			g

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Flow, Water	See Evaporation and Inflow			
Morphometric Characteristics: Maximum Length, Maximum Width, Area, Depth, Volume	At project initiation and whenever pond facilities are altered, prepare contour maps of ponds at 10 cm intervals. Note inflow and outflow locations.			m, m2, m3, (as appropriate)
Nitrogen Total Kjeldahl	For each pond, pool three 90 cm column samples. Composite samples should be refrigerated and analyzed within 24 hours.	Kontes or comparable Kjeldahl Nitrogen apparatus	Semi-Micro-Kjeldahl Method (Michigan State University Limnological Research Laboratory, 1984)	mg/L
Oxygen, Chemical Demand	Please refer to the appendices from Work Plans III & IV, attached. (methods from: "Standard Methods for the Examination of Water and Wastewater," APHA et al., 1985).			
Oxygen, Dissolved	Near center of each pond at 25 cm below water surface, mid-water and 25 cm above the bottom. Take readings as part of diel study at seven different times beginning with pre-dawn.	Yellow Springs Instrument Model 57 Dissolved Oxygen Meter. Calibrate meter each time using the Winkler Method or HACH Digital Titrator Kit/Dissolved Oxygen.	Winkler or Iodometric method (from "Standard Methods," APHA et al., 1985)	mg/L

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
pH, Water	Near center of each pond, take readings at 25 cm below the water surface, mid-water, and 25 cm above the bottom. If a probe is used, calibrate using a precision thermometer. Calibrate meter with standard buffers at pH 7 and pH 10.	pH Meter with Combination Electrode comparable to Orion 2000 Series with Ross Model 81-55 Electrode.		pH units
Phosphorus, Total	Collect one sample (by pooling three 90 cm samples) from each pond. Samples should be refrigerated and analyzed within 24 hours.		Persulfate Digestion and Ascorbic Acid/Colorimetric Method, from "Standard Methods" (APHA et al., 1985)	mg/L
Phytoplankton Composition	Monthly and when changes in the community are observed, collect samples using a Van Dorn or Kemmerer bottle. Use a compound microscope and references to identify to appropriate taxonomic level and count or estimate bio-volume.			various
Primary Productivity	Whole pond method preferred. Light-dark bottle at three depths acceptable.			
Pond Depth - see Depth, Pond				

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Pond Soil Characteristics - see Soil Characteristics				
Pond Temperature - see Temperature, Water				
Precipitation - see Rainfall				
Rainfall	Install three rain gauges at study site; read and empty at 24-hour intervals, or more frequently to prevent gauge overflow; report average of three readings.	No type specified. Recommended gauge from Grassroot Co., Wisconsin.		cm/d
Respiration, Dark Bottle	Collect one sample (by pooling three 90 cm column samples) from each pond. Incubate for four hours or as appropriate to prevent oxygen depletion, in dark bottles suspended at mid-depth in ponds.		Oxygen method, adapted from "Standard Methods" (APHA et al., 1985).	mg C/m3/d
Salinity	Near center of each pond, collect a 500-ml sample at 25 cm below the water surface, mid-water, and 25 cm above the bottom. Mix the samples and analyze.	Use a temperature-compensated refractometer or a salinity meter.		ppt
Secchi Disk Visibility - See Visibility, Secchi Disk				

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Seepage	Determine seepage from a 24-hour water balance, preferably when there is no rainfall, inflow, or outflow: Seepage = Evap x 0.10 - (Final Depth - Initial Depth), where Evap is in mm/d and the depth measurements are in cm and and taken 24 hours apart.			cm/d
Soil, Characteristics: pH, Phosphorus, Organic Matter, Total Nitrogen, Cation Exchange Capacity, Metals (Aluminum, Iron, Zinc) , Lime Requirement, Exchangeable H, Base Saturation	At the end of an experiment and before beginning another, collect twelve 15 cm core samples from each pond, combine and dry as described in Appendix D of Work Plan III (attached). Take a subsample for each pond and analyze using a qualified local or U.S. laboratory.			As appropriate
Solar Radiation	Install Solar Monitor and Quantum Sensor and read the cummulative radiation each day and at end of each time interval during diel study.			E/m2 E/m2/d
Solids, Total Suspended	See Appendices		In: "Standard Methods" (APHA et al., 1985)	mg/L

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Solids, Volatile Suspended	See Appendices		In: "Standard Methods" (APHA et al., 1985)	mg/L
Temperature, Air	Install three maximum-minimum thermometers in the shade near ponds; read at 24-hour intervals and report average maximum and average minimum.	Maximum-minimum thermometer comparable to Taylor Model 5460.		Max°C; Min°C
Temperature, Water	Near center of each pond, take readings at 25 cm below the water surface, midwater, and 25 cm above the bottom. Take readings as part of diel study at 7 different times. If probe is used, calibrate using a precision thermometer.	YSI Model 57 Dissolved Oxygen Meter with Temperature Indicator.		°C
Total Kjeldahl Nitrogen - see Nitrogen, Total Kjeldahl				
Total Phosphorus - see Phosphorus, Total				
Total Volatile Solids - see Solids, Volatile Suspended				

SUMMARY OF ACCEPTED ANALYTICAL METHODS

Parameter	Procedure	Instrumentation	Analytical Method	Reporting Unit
Wind Speed	Install totalizing anemometer, read at 24 hour intervals (between 0800 and 0900 hours), and calculate average hourly wind speed.	Totalizing anemometer comparable to WEATHERtronics Model 2510. The instrument should be located in the pond complex 2m above the level of the pond banks.		km/h
Visibility, Secchi Disk	At two locations in each pond, calculate Secchi Disk Visibility using procedure described by Lind (1974).			cm
Zooplankton Composition	Monthly and when changes in the community are observed, collect at least three 90 cm column samples per pond or use trap or zooplankton net, as appropriate. Use a microscope to identify at the order level and count number of organisms per unit volume.			No./m3

ADDENDUM

WORK PLANS (1 MAY 1991 THROUGH 30 APRIL 1992) FOR THE FY91 20% SUPPLEMENTAL APPROPRIATION

INTRODUCTION

In December 1990 AID granted a 20% increase in all CRSP budgets (except the Nutrition and Fisheries Stock Assessment CRSPs) for the period 1 May 1991 to 30 April 1992. This increase amounted to $196,000 for the PD/A CRSP, of which 80% was available to fund new initiatives. A formal call for proposals for activities to be funded under this new allocation was made at the Ninth Annual Meeting of the PD/A CRSP held on 7 to 9 March 1991 at Auburn University, Auburn, AL. A Technical Committee Executive Panel (EP), elected during the 1991 Annual Meeting, was charged with the responsibility of evaluating and recommending action on submitted proposals. The EP recommendations, along with those of the Program Director were forwarded to the PD/A CRSP Board of Directors (BOD) for final recommendations.

Successful proposals would fulfill several key criteria:

1) be relevant to the overall goals of the PD/A CRSP
2) be relevant to sustainable agriculture/natural resource management
3) address the constraints identified by Congress and AID for the increase.

In addition to evaluating the submitted proposals according to the above criteria, the EP established additional criteria for proposal evaluation (listed, but not prioritized):

1) technical merit
2) can the objectives be met based on research design, schedule, and budget?
3) additional recommendations set forth by the Technical Committee at the Auburn Meeting (i. e., format, page limit, deadline)
4) past performance.

A total of 16 proposals were received by the PD/A CRSP PMO by the 10 April 1991 deadline for submission. On 16 April 1991, the EP was convened, via telephone conference call, to evaluate the proposals; Hillary Egna, Program Director, also participated in the conference call. The EP's recommendations were submitted to the BOD, through the Program Director, on 18 April 1991. The BOD concurred with the EP's and Program Director's recommendations, and approved funding for eleven of the sixteen proposals. Subsequent to BOD approval, one proposal was withdrawn.

Work plans for the approved proposals follow, arranged arbitrarily. Work plans will be implemented beginning 1 May 1991, and all work completed and final reports due by 30 April 1992.

PROJECT TITLE: SOCIOECONOMIC FACTORS AFFECTING THE TRANSFER AND SUSTAINABILITY OF AQUACULTURE TECHNOLOGY IN RWANDA

Cooperating Institutions and Principal Investigators:

Auburn University, Auburn, Alabama
Dr. Joseph J. Molnar

Objectives: To establish baseline quantitative information about women and men who operate fish ponds in Rwanda; to profile the circumstances and motivations underlying decisions to discontinue the practice of fish culture; to describe the practices and technical proficiency of independently established fish farmers with no regular contact with extensionists.

Significance: Pond studies by CRSP have endeavored to develop technology relevant to on-farm circumstances. This research will incorporate socioeconomic limitations and actual farming system circumstances in developing the knowledge base for long-term growth of the activity. Systematic documentation of the way fish culture is implemented by the target population and how it fits in their lives will complement the scientific and institutional achievements of the CRSP.

Methodology:

Three categories of farmers will be interviewed: active farmers receiving extension assistance, active fish farmers not receiving regular visits from extensionists and fish farmer dropouts. Interviews will be conducted with 200 active fish farmers randomly selected from project rolls in local administrative districts purposely chosen to represent the agro-climatic diversity of the country. Contact will be made by Extension representatives. The Interviewer, a Rwandan national, will conduct interviews in the native language using a standardized set of question and response frameworks. Approximately 60 minutes will be spent with each farmer. Approximately 50 farmers who have discontinued fish culture will also be interviewed, and an additional 50 active fish farmers without significant extension assistance will also be contacted.

Separate interview schedules will be developed for each of the three categories of respondents. Each survey instrument will be developed, translated and pretested with members of each category. The survey instrument will be formulated upon consultation with the Rwandan Director of Aquaculture, currently on a degree program at Auburn University. Helpfulness and satisfaction indices will be used to determine farmer perceptions about extension assistance.

Null hypotheses: Farmer perceptions on the relative value of fish culture are unrelated to the presence or absence of extensionists. No indicators reflect sustainability of fish culture in Rwanda. No significant differences in conditions or attitudes exist between active and dropout fish farmers.

Statistical methods: Primarily non-parametric, such as Kruskal-Wallis, Mann-Whitney U, and Friedman.

Schedule:

July-September 91: develop sampling strategy and pretest instrument.
October 91 - March 92: data collection.
March - April 92: data analysis.
May 92: report issued.

PROJECT TITLE: A PRELIMINARY STUDY OF WOMEN'S PARTICIPATION IN FISH CULTURE ACTIVITIES OF RWANDA

Cooperating Institutions and Principal Investigators:

Oregon State University, Corvallis, Oregon
Dr. Revathi Balakrishnan
Ms. Karen Veverica

National Fish Culture Service, Rwanda
Ms. Pelagie Nyirahabima

Objective: To document the successes and failures of integrating Rwanda woman in aquaculture, and of extending the technology through women in other countries in the region.

Significance: Aquaculture is a viable alternative production process to sustain land resources, improve households' income potential and nutrition. In Rwanda, with its growing interest and demonstrated success in aquaculture, women farmers trained in aquaculture can contribute effectively to achieving the balanced development of productivity with sustainability. Moving beyond forestry resources, a broader perspective of sustainable development would focus on gender roles in ecological resource sustainability. In this project the focus is on women's role in natural resource management in the area of aquatic resource management through participation in aquaculture. This information will: 1) contribute to the CRSP generated knowledge base to develop gender sensitive aquaculture technology; 2) assist in structuring similar aquaculture extension programs for women in that region; and 3) generate training materials relevant to aquaculture technology transfer to women farmers.

Data Collection: Qualitative research to develop an in-depth project case study on "Rwandan Women in Fish Production," and a workshop to facilitate trialogue between production scientist, extension personnel and women farmers who have adopted fish cultivation technology. The study will utilize secondary data, and collect disaggregated data by qualitative techniques such as focus group and personal interviews. Sample: Farm women (technology adopters); production scientists (technology developers) and extension workers (technology disseminators). Workshop Format:

a. Panel shared by women farmers and extension workers
b. Panel shared by production scientists and extension workers
c. Panel shared by women farmers and production scientists.

Hypothesis: Exploratory study.

Statistical Methods: Statistical methods applicable to qualitative data.

Schedule: May 1 1991 to April 1992. Report April 1992.

Remarks: The project will be implemented by the Office of Women in International Development in the Office of International Research and Development, Oregon State University. It is a component of the OSU Rwanda PD/A CRSP. This gender integration study strengthens the socio-economic dimension of Rwanda PD/A CRSP research.

PROJECT TITLE: ON-FARM *Clarias gariepinus - Oreochromis niloticus* POLYCULTURE IN RWANDA

Cooperating Institutions and Principal Investigators:

Rwasave Fish Culture Station
Université Nationale Du Rwanda, Butare, Rwanda
Dr. Evariste Karangwa
Mr. Lieven Verheust

Oregon State University, Corvallis, Oregon
Ms. Karen Veverica

Objectives: To compare clarias-tilapia polyculture, mixed-sex monoculture of tilapia and monoculture of clarias, each at two elevations, to determine the most advantageous stocking strategy on the basis of total fish production and comparative economic benefit. Mono and mixed-sex tilapia culture will also be evaluated by comparison with results of CRSP Study 3, Work Plan 6, an on-farm, mono-sex experiment.

Significance: This experiment will result in recommendations for the application of a specific culture strategy appropriate with elevation and economic considerations. Polyculture may increase biological and economic efficiency and the sustainability of fish culture in some highland African environments.

Experimental design: Three stocking treatments will each be tested at two elevations. Stocking treatments, all at 1 fish/m^2 are: mixed-sex tilapia; 2/3 tilapia - 1/3 clarias; clarias monoculture. Five ponds used per treatment except for clarias monoculture where two ponds per elevation will be used. One fertilization level equal to that of CRSP EXP 1 and 3, Work plan 6,will be applied.

Facilities: Twenty-four rural farmer ponds, 12 at each of two elevations to include a relatively low and a relatively high elevation range. Ponds will be selected within parameters listed in the proposal.

Culture period: Culture period will be at least 5 months but will continue until fish reach an average weight of 120 g.

Fish stocking rate: One fish per m^2 (see details in design).

Nutrient inputs: Input rate will be 250 kg/ha/wk dry weight of fresh grass plus inorganic nutrients added as urea and TSP to increase added N to 15 and P to 4 kg/ha/wk.

Water management: Weekly addition to replace losses.

Sampling schedule: Standard protocol except:
Physical parameters:

- max-min temperature, inflow, depth and Secchi disk visibility: weekly.
- temperature of unsaturated soil at a depth of 60 cm: 3 times during the experiment.
- continuous temperature recording (one pond per elevation).

Chemical parameters:

- one soil analysis at termination.
- total alkalinity, hardness and conductivity: monthly.
- no diurnal or primary productivity measurements.

Biological parameters:

- fish weight: monthly.
- stomach analysis: 5 fish/pond after 3 months and 10 fish/pond at termination.

Economic parameters:

- marketing and other socio-economic data will be collected through a farmer interview.
- an enterprise budget will be developed.

Null hypothesis: Total net fish production, tilapia fingerling production, or economic benefits will not differ among treatments. Total fish production, tilapia fingerling production, or economic viability of the culture system will not differ among elevations.

Statistical methods: One and two-way ANOVA, linear, multiple regression.

Schedule: Propose starting July 1991. All ponds harvested by March 1992. Report by May 1992.

PROJECT TITLE: A CONFERENCE ON HIGH-ELEVATION TILAPIA CULTURE

Cooperating Institutions and Principal Investigators:

Rwasave Fish Culture Station
Université Nationale Du Rwanda, Butare, Rwanda
Dr. Evariste Karangwa

Oregon State University, Corvallis, Oregon
Ms. Karen Veverica

Objectives: Plan and conduct a conference on high-elevation tilapia culture which will address conditions and practices in rural, high-elevation operations. Publish proceedings. Also re-establish international collaboration and the exchange of information among those involved in aquaculture, from Peace Corp personnel to rural farmers, government agents and others.

Significance: This conference will provide a forum for sharing information on the evolving tilapia culture practices used in this region of Africa. Technology recommended encourages use of sustainable practices. Proceedings and discussion sessions will be published and a table of country statistics will be developed. The opportunity exists to improve culture and extension practices in a number of African countries.

Project design: The conference will be held at UNR, Rwasave Station in Butare in September, 1991. The elements are:

1. Country reports: a description of the history and present and future strategies in culture and extension.
2. Technical reports: Detailed presentations of applicable production or research data.
3. Site visits: Kegembe and Rwasave Stations, rural ponds.
4. Workshop sessions: Hand sexing, PONDCLASS system, demonstration of extension manuals and other materials.
5. Discussion sessions.
6. Publication preparation

Facilities: Conference room and other facilities at Rwasave Station.

Schedule: Invitations sent: 31 May 1991. Abstracts and statistics required: 30 July 1991. Conference held: 1 to 7 Sept 1991. Final revisions of papers, transcript of discussions submitted for publication: 31 Dec 1991.

PROJECT TITLE: ON-FARM TESTING OF PD/A CRSP FISH PRODUCTION SYSTEMS IN HONDURAS

Cooperating Institutions and Principal Investigators:

Auburn University, Auburn, Alabama
Dr. David R. Teichert-Coddington
Mr. Bartholomew W. Green

El Carao National Fish Culture Research Center
Ministry of Natural Resources, Comayagua, Honduras
Mr. Marco Iván Rodríguez

Objectives: To initiate on-farm testing of PD/A CRSP production technologies, and use this data to validate the PD/A CRSP Pond Management Guidelines. To provide short-term training in aquaculture to extensionists and fish farmers involved with the on-farm production trials.

Significance: Honduras 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. However, it is now time 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, serve as a teaching tool for extensionists and producers, and serve as a test of the PD/A CRSP Pond Management Guidelines.

Methodology: A 1- to 2-week short-course in aquaculture for extensionists and farmers involved with the on-farm production trials will review the basics of aquaculture including fish production, water quality, and pond construction, and to instruct the participants in the objectives and procedures of the farm testing.

On-farm production trials will be implemented on farms in the southern, central and northern regions of Honduras. Trials will be conducted with two target groups of farmers: resource-limited hillside farmers from the USAID/Honduras funded Land Use and Productivity Enhancement (LUPE) project, and small- to medium-scale commercial producers in central and northern Honduras.

A seminar will be convened to review the field-test results with all participants, and to plan for further tests contingent on appropriation of additional funds.

Pond facilities: Ponds on private farms will be utilized; pond sizes will vary. On resource-limited farms one pond will be used, while two ponds will be used on the commercial-scale farms.

Culture period: 150 to 180 days.

Fish stocking rate: On resource-limited farms: fingerling *Oreochromis niloticus* at $1/m^2$, and fingerling *Cichlasoma managuense* at $0.05/m^2$; on commercial-scale farms: male *Oreochromis niloticus* fingerlings at 2 to $3/m^2$, and *Cichlasoma managuense* fingerlings at $0.05/m^2$.

Nutrient inputs: On resource-limited farms: Compost will be the primary nutrient source for ponds. Compost management will follow the Rwanda PD/A CRSP protocol: an initial application of 1000 kg total solids (TS)/ha, followed by weekly applications of 500 kg TS/ha; supplemental nitrogen (28.5 kg/ha urea) may be added weekly. Compost pile will be mixed daily.

On commercial-scale farms: One pond will be fertilized weekly with chicken litter (750 kg TS/ha) and urea (rate dependent on results of the current Honduras CRSP experiment). After 3 months, all fertilization will be terminated and formulated feed will be added to ponds at 3% of fish biomass per day. The other pond will be fertilized weekly as per Thailand PD/A CRSP recommendation: urea (5 kg N/ha/d) and triple superphosphate (1.2 kg/ha/d) will be added weekly to give an N:P ratio to 4:1 by weight.

Water management: Water will be added to ponds to replace evaporation and seepage.

Sampling schedule: The following data will be collected at all farms:

- Soil samples will be collected for analyses; acidic soils will be limed to increase water total alkalinity to ≥ 20 mg $CaCO_3$/L.
- Chicken litter will be analyzed for major inorganic nutrients.
- Weights of nutrient inputs, monthly fish samples, and harvest weights.
- Regular measurement of Secchi disk visibility, and periodic samples of water for chemical analyses of major inorganic nutrients.
- Economic statistics.

Null hypotheses: On-farm fish yields will not differ from experiment station fish yields. On-farm fish yields will not differ from PD/A CRSP Management Guideline predictions.

Statistical methods: ANOVA.

Schedule: On-farm trials: 5/91 to 3/92; training course: 6/91; data review seminar: 4/92; report: 4/92.

PROJECT TITLE: ANALYSIS AND EVALUATION OF REAERATION RATES

Cooperating Institutions and Principal Investigators:

University of California, Davis, California
Dr. Raul H. Piedrahita

Auburn University, Auburn, Alabama
Dr. David Teichert-Coddington

Background: The availability of an improved method for estimating reaeration rates is an essential component of the continued development of models for predicting dissolved oxygen concentration in ponds. The work complements research being proposed by the DAST for Work Plan 6 and collaborative work being proposed with Dr. Jim Szyper of the University of Hawaii to refine methods to estimate respiration rates in the water column on ponds. Having accurate methods to estimate rates of reaeration and respiration, one can calculate the rates of oxygen consumption in the sediments from measurements of oxygen concentration in ponds. Estimates of sediment oxygen demand must be obtained from whole pond measurements rather than from the analysis of oxygen concentration changes in discrete volumes in the pond as has been attempted by various investigators. 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 the use of a method based on discrete sampling impractical for pond monitoring and oxygen modeling.

The Honduras CRSP group has made a first attempt at developing a method for the evaluation of reaeration rates in aquaculture ponds. These estimates were found to be different from those obtained with expressions developed by other researchers. The new method was developed from 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 at reducing the rates of oxygen production and consumption. In separate experiments, the Honduras group has made estimates of oxygen consumption by pond sediments, obtaining values that were in the same range as reaeration rates for moderate winds. In this project, we will estimate reaeration rates from measurements of changes in dissolved oxygen concentration in lined ponds. By using lined ponds, the sediment oxygen consumption will be eliminated and a better estimate of reaeration will be available. We will also repeat the experiments for ponds filled to different depths (0.90 and 0.45 m) to try to reduce the magnitude of pond stratification and achieve better estimates of reaeration rates.

Significance: The quantification of the various processes of the dissolved cycle in ponds has been one of the primary objectives of the DAST. Computer models have been developed to simulate the changes in dissolved oxygen concentration in ponds. Methods and techniques have been devised to analyze diel measurements of dissolved oxygen and obtain information on the rates of oxygen consumption and production through various processes. The work proposed here will provide critical information for the improved estimation of the rate of oxygen exchange between the water and the atmosphere. This improved information will complement other ongoing and proposed work by the DAST designed to obtain better estimates of water column respiration. With these improved estimates of pond respiration and reaeration rates, analysis of diel oxygen measurements will be used to obtain more reliable estimates of sediment oxygen consumption and of gross primary production. The project will also allow for the direct collaboration of field and DAST groups in a short term project that may serve as a model for future collaborations.

Objectives: The objectives of the proposed research are: 1. To develop an improved method for estimating reaeration rates from ponds. 2. To test the method by comparing it with other methods previously described.

Methods: The field work for this project will be carried out at the El Carao station in Honduras. Data analysis will be carried out at El Carao and at UC Davis. The field experiments will be conducted over a period of approximately ten days, when the UC Davis PI will be at El Carao.

Reaeration rates will be measured in two ponds similar to those used for previous reaeration rate estimates at El Carao. The ponds will be lined with polyethylene sheeting to eliminate sediment oxygen consumption . The water will be deoxygenated using sodium sulfite and cobalt chloride. Dissolved oxygen concentration and temperature will be monitored in the ponds using an automatic monitoring equipment based on a data logger and available at El Carao. Wind velocity will be monitored at 50 cm and at 3 m above the water surface.

An attempt will be made at minimizing the rates of water column respiration and primary production by filling the pond with unfertilized water and by conducting the tests right after the ponds are filled. Copper sulfate may be used in the ponds to control algae as was done in previous tests conducted at El Carao. Water column oxygen consumption and production rates will be monitored with light and dark bottle tests throughout the duration of the run. Values obtained from the light and dark bottle tests will be used to correct the oxygen measurements for determining reaeration rates. The average reaeration rate coefficients (K_{La}) will be estimated for time intervals over which wind speed remains approximately constant. Calculation of the reaeration coefficients will be according to the method recommended by ASCE.

Regression analysis of the reaeration coefficients and wind speed measurements at the two heights will be carried out to obtain relationships for estimating reaeration rates from wind speed. The statistical significance of the regressions obtained for the two heights will be examined and a recommendation will be made on the best location for wind measurements. The expressions obtained in this project for estimating reaeration rate coefficients will be compared with those obtained previously.

Schedule: The field work will be conducted during a break between the current experiments being conducted at El Carao. Two dates are possible, mid July 1991 and mid January 1992. The January 1992 dates are preferable because there is less chance of rainfall (which would affect the reaeration rates and complicate data analysis), and because wind velocities tend to be higher than in July. Data analysis will be completed by February 1992, and a report will be available by April 30, 1992.

PROJECT TITLE: PRIMARY PRODUCTION IN PD/A CRSP PONDS: REFINEMENT OF THE FREE-WATER METHODS AND GLOBAL SURVEY OF RESULTS

Cooperating Institutions and Principal Investigators:

University of Hawaii at Manoa
Dr. James P. Szyper

University of California at Davis
Dr. Raul H. Piedrahita

Background: Waste-fed or waste-enhanced pond production of fish is a key component of both traditional and developing schemes for integrated family farming worldwide. Photosynthetic oxygen production and carbon fixation are critical to waste-fed pond culture, and important for maintenance of favorable pond conditions in feed-based systems. In waste-fed ponds, autotrophic production is expected to provide a significant portion of the cultured animals' food, as are the input materials themselves and the heterotrophic production.

Work Plans 1, 2, and 3 of the PD/A CRSP specify use of a light/dark bottle method for assessment of photosynthetic production in ponds. Some projects have used this method; others adopted free-water methods. Bottle methods have presented difficulties with both execution and assumptions; calculation procedures for free-water methods have not been uniform among projects. Free-water methods have inherent advantages over bottle methods, including a high degree of resolution, the inclusion of sediment respiration, and a relative ease of automation.

They are increasingly being applied in culture ponds, both within and external to the PD/A CRSP. Several CRSP investigators have begun to address technical needs for refinement.

The proposed project will integrate information from the ongoing work on refinements, perform new experiments addressing the problem of daytime respiration, and apply the resulting method in a global analysis of primary production during Work Plans 1, 2, and 3.

Objective: To describe and disseminate a well-supported, standardized method for calculation of primary production during CRSP experiments, and to describe the trends in production during Work Plans 1 through 4.

Experimental Plan:

1. Examine the effect of corrections for atmospheric exchange on production estimates.
2. Examine the effect of different assumptions underlying the estimation of daytime respiration from nighttime data.
3. Calculate primary production by the refined method from the data of Work Plans one through four.
4. Seek and analyze trends, similarities, and differences among sites and treatments with respect to primary production during Work Plans One through Four.

Experiments addressing item 2 will involve:

- Establishment of workable apparatus (DO sensors, data logger setups, incubation vessels and environments) for small-scale examination of microbial oxygen budgets.

- Assessment of short-term dynamics (minutes to hours) of dissolved oxygen and carbon dioxide in both pond water and laboratory phytoplankton cultures.
- Examination of the response of pond water communities and cultures to manipulation of light regimes on short time scales, i.e., to turning lights on and off or screening out daylight for periods of minutes to hours.
- Comparisons of pond water confined in experimental vessels with pond water monitored in situ.

Bench scale experiments will be performed at both U. C. Davis and U. of Hawaii. Pond experiments will be performed at the U.H. pond facility, the Mariculture Research and Training Center (MRTC), where fresh and brackish water ponds are routinely monitored for DO cycles.

Expected Outcome: Results will provide 1) a consistent methodological approach to the determination of primary productivity using free water techniques; 2) a "standardized" method for comparing the response of primary production to fertilization and environmental variables; 3) an improvement in the quality of data analysis and model simulations obtained with CRSP models; and 4) a point of departure for further research on pond productivity.

Schedule: Objective 1 during 5/91 to 7/91; objectives 2, 3, and 4 during 8/91 to 1/92; data analysis and report during 2/92 to 4/92.

PROJECT TITLE: REGIONAL VERIFICATION OF FERTILIZER GUIDELINES - PHILIPPINES

Cooperating Institutions and Principal Investigators:

University of Hawaii at Hilo, Hilo, Hawaii
Dr. Kevin Hopkins

Freshwater Aquaculture Center
Central Luzon State University, Muñoz, Nueva Ecija, Philippines

Background: Experiments conducted under the first three CRSP work plans used standardized experimental protocols to address the relationships of fertilizer input to yield of fish and shrimp. The biological results obtained from the Thailand Project are felt to be representative of freshwater tropical ponds typical of lower elevations although differing economic conditions in other locales could lead to different fertilizer recommendations for maximizing profit (versus maximizing fish production). This study proposes to test the DAST fertilization guidelines in the Philippines.

All previous CRSP projects were conducted with long-term on-site presence of researchers from the USA universities. This study, however, will rely on Filipino scientists at the Freshwater Aquaculture Center in Munoz, Nueva Ecija, Philippines with only twice yearly visits by scientists from the University of Hawaii. The FAC was established in the early 1970s. It is a freshwater research facility with a large number of replicated ponds with accompanying laboratories and support facilities. Over the years, researchers at the FAC have conducted pioneering work in rice-fish culture, integrated animal-fish culture systems, and fertilization yield trials. A large quantity of baseline and experimental data on the integrated animal-fish culture systems which was conducted at the FAC in the late 1970s and early 1980s and has been made available to the CRSP by ICLARM. This data will greatly facilitate the comparison of data to be collected during this study with data from other CRSP sites. Thus, the FAC is particularly well suited to be the first site for regional verification of fertilization guidelines developed by the CRSP. If this operational strategy of regional verification is successful, it can be used to greatly expand the CRSP into other countries and regions at a reasonable cost.

Objectives: The objectives of the proposed research are to test PD/A CRSP fertilizer recommendations under Philippine conditions. To conduct experiments to develop improved chicken manure/inorganic fertilizer guidelines.

Experimental Design:

Study 1: One treatment will be to fertilize and lime at the rates suggested by the CRSP fertilization guidelines. The second treatment will be chicken manure at 70 kg/ha/wk supplemented with urea and TSP to bring the total N and total P loading to 35 kg/ha/wk and 9 kg/ha/wk, respectively. There will be four replicates of each treatment.

Study 2: The treatments tested will be 1.0, 2.3, 3.7, and 5.0 kg/ha/d of nitrogen from urea. Total phosphorus will be added at a 1:1 ratio with the nitrogen. Total alkalinity will be maintained at 50 mg/L or greater. There will be two replicates per treatment.

Pond Facilities: Eight 500 m^2 ponds at the Freshwater Aquaculture Center, Muñoz, Nueva Ecija, Philippines.

Culture Period: Five months for each study.

Fish Stocking Rate: Sex-reversed *Oreochromis niloticus* at 2 fish/m^2

Nutrient inputs: As per CRSP guidelines and most current nutrient balancing experiments.

Water management: Replace evaporation and seepage losses weekly.

Sampling schedule: Standard protocols except as noted.
Chemical parameters:

- Ammonia-N, soluble reactive phosphorus, alkalinity, and dissolved oxygen: every 2 wks.

Null Hypotheses:
Study 1: There will be no difference between the actual yields from the ponds and the yields predicted by the CRSP guidelines. There will be no difference between the yields from ponds fertilized using the CRSP guidelines and those fertilized using the nutrient balancing guidelines.
Study 2: Nitrogen loading rate does not affect fish yield.

Statistical methods: ANOVA.

Schedule: Data collection, 6/91 to 3/92; technical report, 4/92.

PROJECT TITLE: EVALUATION OF SOIL-WATER INTERACTIONS FOR THE CONTROL OF POND WATER CHEMISTRY

Cooperating Institutions and Principal Investigators:

Oregon State University, Corvallis, Oregon
Mr. Jim Bowman
Dr. James E. Lannan
Dr. John Baham

Objectives: To evaluate relationships between soil pH or percent base saturation and water hardness or alkalinity for different classes of soil. To evaluate initial (pre-flooding) pH-percent base saturation relationships for different classes of soil.

Significance: Productivity in freshwater ponds is directly related to pond water hardness and alkalinity. Information regarding the relationships between hardness or alkalinity and properties of different soil types such as pH and percent base saturation could be used to improve pond management strategies, particularly the application of lime.

Experimental design: Up to seven soil types by eight levels of water hardness. Three replicates.

Facilities: Small-scale soil-water systems will be set up in the laboratories of the Soil Science Unit, Crop and Soil Science Department, at Oregon State University.

Duration of experiments: Individual experiments may take only a few hours. Preliminary trials will be conducted to determine appropriate time to reach equilibrium in the soil-water systems.

Sampling schedule:

- Initial pH, CEC, and percent base saturation of soil samples: before setting up soil-water systems.
- Initial pH, hardness, and alkalinity of stock water solutions: before setting up soil-water systems.
- Final soil and water analyses:
  - soil pH and percent base saturation: after equilibrium has been reached.
  - water pH, hardness, and alkalinity: after equilibrium has been reached.

Null Hypotheses: Differences in soil type and initial water quality will not affect relationships among soil pH, soil percent base saturation, water pH, hardness, or alkalinity at equilibrium. Relationships between pH and percent base saturation will not be different for different classes of soil.

Statistical methods: Regression analyses.

Schedule: Collection of soil samples, 6/91-10/91; Data collection, 7/91 - 12/91; Technical report(s), 4/30/92.