Chemistry and World Food Supplies: Research Priorities for Development
Chemistry and World Food Supplies: Research Priorities for Development

Report of a Workshop

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In the mid-1970s, the International Union of Pure and Applied Chemistry (IUPAC) launched a forward-looking initiative known as CHEMRAWN—an acronym for chemical research applied to world needs. CHEMRAWN was conceived as a series of symposia and international conferences whose discussions and published proceedings would help focus the attention of planners, policymakers, and the research community on critical world problems that could benefit from chemical research.

CHEMRAWN I, held in Toronto, Canada, in 1978, focused on future supplies of organic raw materials for the chemical industry. CHEMRAWN II—the International Conference on Chemistry and World Food Supplies: The New Frontiers—was held December 6-10, 1982, in Manila, Philippines. The published objectives of CHEMRAWN II were:

- To identify and put into perspective those areas of research and development having the potential to significantly increase food production and improve food storage and processing.

- To strengthen scientific research in developing nations, particularly in those fields that require professional competence and initiative without excessive capital and human resources.

- To accelerate implementation of research priorities and objectives by fostering cooperation among governments, industries, and universities.

The CHEMRAWN II program appears in Appendix A.*

The Board on Science and Technology for International Development (BOSTID) of the National Research Council was invited by the Agency for International Development (AID) to organize a post-CHEMRAWN II workshop for a small group of CHEMRAWN participants and speakers, with majority participation by scientists from developing countries. The broad goal of the workshop was to develop the major themes discussed

*The proceedings of CHEMRAWN II are available from Pergamon Press, Inc., Maxwell House, Fairview Park, Elmsford, NY 10523, USA.
at CHEMRAWN into recommendations for action programs that might be initiated by national governments or development assistance organizations. Specific objectives were to examine research needs and opportunities in the chemical sciences for improving food supplies in developing countries, to consider opportunities for research collaboration between scientists in developed and developing countries, and to examine the potential of networking activities in areas of chemical research related to the food supply problem.

In the spring and summer of 1982, BOSTID staff consulted experts in the fields of agriculture, chemistry, and development to define workshop topics and develop lists of possible participants. The topics were chosen to complement rather than duplicate the three agricultural subjects addressed in July 1982 by a major BOSTID workshop on biotechnology--plant cell and tissue culture, animal production, and biological nitrogen fixation. The four topics addressed at the post-CHEMRAWN II workshop were:

- Soil fertility and plant nutrition
- Plant growth regulators and plant-pest relationships
- Food science and technology
- Aquaculture and integrated farming systems

The first three topics are of general importance and match the structure of the CHEMRAWN meeting. The workshop on aquaculture and integrated farming systems was selected because of its special importance to the productivity of millions of poor and small farmers in the humid tropics, particularly in Asia.

Thirteen U.S. scientists were appointed to an NRC advisory panel to oversee planning of the workshop and the writing of the report. Members of the panel were invited to Washington, D.C., in November 1982 for a one-day planning meeting during which the workshop agenda was established. At this meeting, it was decided that a fifth working group would be formed during the workshop. A representative of each of the four primary groups would meet to discuss the cross-cutting topic of environmental monitoring and chemical analysis.

In Manila, members of the NRC panel were joined for the CHEMRAWN meeting by the 35 other workshop participants, who were primarily specialists from developing countries (see Appendix B for a complete list of participants). Pre-workshop discussions were organized for this group at the CHEMRAWN meeting site in Manila.

The BOSTID workshop was held at the conference facilities of the International Rice Research Institute (IRRI) at Los Baños, Philippines, December 11-14, 1982, where participants divided into four working groups. Each group was asked to draft reports in which they made recommendations and identified research priorities in one of the four topic areas selected earlier by the U.S. panel. Preliminary recommendations and research priorities were presented and discussed at a final plenary session.

Recommendations in this report reflect the views of participants in the four working groups. Members of the advisory panel have reviewed the final draft and endorsed the recommendations. The report is
intended as a working paper for use by AID's technical staff in its program planning activities.

Many individuals generously contributed their time and experience to the workshop and this report. Milton Archer, Eugene Kamprath, Jerrold Meinwald, Joseph Varner, and Bill Wright traveled to Washington for an early planning session. Members of the CHEMRAWN II executive committee, especially Joyce Torio of the CHEMRAWN Coordinating Office, contributed in important ways before, during, and after the conference. Meeting facilities, staffing, and local arrangements at the International Rice Research Institute were excellent thanks to Marcos Vega and his hard-working staff.
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INTRODUCTION

During the next 40 years, the world will be faced with the extraordinary challenge of increasing Third World food supplies at an unprecedented rate: it is estimated that a three- to fourfold increase in current production will be required. Planners and policymakers who must work within resource and environmental constraints might, understandably, view this as an impossible task.

Many chemists and agricultural scientists who gathered in the Philippines in December 1982 for CHEMRAWN II—the International Conference on Chemistry and World Food Supplies: The New Frontiers—believe that such an increase is possible. Their optimism is grounded in knowledge of important advances in analytical capabilities and new fundamental knowledge regarding chemical and biochemical properties of plants and animals, of soils and insects, and of the microorganisms and enzyme systems that affect productivity. They believe that with a carefully developed research agenda and adequate financial resources, the technical requirements of the food supply challenge can be met.

CHEMRAWN II recognized the complex nature of the process by which laboratory results are translated into practical field applications and, subsequently, to increases in available food. Presentations emphasized the central role of food policy and economic incentives needed to encourage technical innovation. Also noted was the importance of extension services and various components of the agricultural infrastructure—private and governmental—with trained manpower and resources required to adapt new methods and materials to local conditions. It was clear that the limitations created by inadequate agricultural policies and infrastructure deserve priority attention from planners and policymakers so that the significant research advances foreseen by conference participants can be used to full advantage.

STATEMENT OF THE PROBLEM

Largely due to the effect of famine, war, and disease, total world populations increased slowly until the present era. Scientific advances in recent times have reduced the ravages of disease, and the "green revolution" and other important advances in agricultural science following World War II have helped limit the incidence of starvation.
Nonetheless, poor nutrition is a continuing problem in many parts of the world, mainly as a result of economic problems affecting food distribution and purchase.

Healthier populations and increased food supplies combined in the 1960s to achieve an alarming population growth rate (2 percent annual increase), sufficient to double world population in 35 years. Two decades of concentrated, global efforts to reduce population growth rates have had a measurable effect in many regions, although there is general agreement that much more progress is needed within the poorest sectors. Experience, however, has shown that economic development is an essential antecedent to fertility control. Most societies are unwilling or unable to take strong control measures. Therefore, if population is to be controlled (without a return to limits imposed by war, famine, or disease) then living standards must increase and, consequently, the quantity and quality of Third World food supplies must be improved. By the year 2020, supplies must double simply to keep pace with population growth. Moreover, if current development efforts succeed, some forecasters assume a simultaneous doubling of per capita consumption brought about by expected increases in living standards.

At least two and preferably three to four times as much food will be required in less than 40 years to meet the demand brought about by a twofold increase in population and by improved living standards. There is consensus that a "second green revolution" will be necessary to achieve this goal since only limited gains can be expected from extension of current technology, easy expansion of the arable land base, or reductions in postharvest losses. 

CHEMRAWN II suggested that progress in agriculture and food science will be founded to a great extent in new scientific capabilities, many chemical in nature. The biological revolution that is receiving media attention is based on chemical science. Scientists from all disciplines are increasingly able to understand and manipulate plants and other living organisms at the chemical or molecular level. For the first time, constraints in agriculture and food science can be approached in fundamentally new ways. The new agricultural developments based on chemical science hold great potential for alleviating the world food supply problem.

ORGANIZATION OF THE REPORT

This report presents research and development opportunities identified by scientists from developed and developing countries who met for three days at the conclusion of CHEMRAWN II. Discussions in four working groups focused on the following topics:

- Soil fertility and plant nutrition
- Plant growth regulators and plant-pest relationships
- Food science and technology
- Aquaculture and integrated farming systems
Their recommendations are presented in "Summary of Recommendations and Research Priorities," and discussed in detail in the working group reports. This report also contains conclusions and recommendations of a cross-cutting group that discussed issues in environmental monitoring and chemical analysis.

COMMON THEMES

In the course of putting the report together and reflecting on the discussions, the BOSTID staff noted the following themes, which were common to each working group. They are summarized here for the benefit of the reader.

Traditional Systems

Traditional practices merit careful scientific study: they often supply critical components to the food system and, evolving over centuries, they are effective and practical, although their scientific rationale or their mechanisms of action may be poorly understood. Examples include Indonesian fermentations of cassava that provide essential vitamins and amino acids in addition to improved taste; mulching or intercropping practices that control pests; slash-and-burn procedures that clear land, sterilize soils, and concentrate nutrients; and rice-field fisheries that utilize wastes effectively and provide balanced dietary protein.

Participants observed that scientific insight can improve traditional agricultural practices and food processing procedures. Improving traditional practices can be more effective than replacing them with entirely new methods because recommendations for change based on traditional practices are more likely to be accepted by rural people who will provide most of the labor for the agricultural revolution in many developing countries.

Microorganisms and Biotechnology

Although the central role of microorganisms in the food web has been recognized for some time, scientific understanding has been too sketchy to enable agriculturalists and food scientists to use microorganisms to full advantage. Recently, however, well-publicized advances in molecular genetics have kindled active interest in the microbiological processes that many believe will, in the long run, benefit food supplies in important ways. Even in the short run, much can be gained from a better understanding of microbial processes in the soils that affect plant nutrition and fertilizer-use efficiency, of fermentations that enrich or preserve foods, and of microbial processes that transform organic wastes into animal foods in fish ponds or biodigesters. Additional opportunities exist to use microorganisms as biological control agents in combating plant pests and soilborne pathogens.
Although the long-term benefits of recombinant DNA technologies are clearly speculative, participants agreed that basic and applied research in microbiology would have important benefits independent of those that might develop as a consequence of genetic engineering.

Interdisciplinary Research

The value of interdisciplinary approaches to research in agriculture and food science was emphasized in the deliberations of every working group. Having chemists as regular or consulting members of research teams was considered to be especially important. Chemists' analytical tools and, more important, their grasp of the molecular world often provide key insights and new approaches that amplify the effectiveness of contributions from microbiologists, soil scientists, plant physiologists, and others involved in the joint research effort.

Research Collaboration

Opportunities abound for collaborative research between developed and developing country scientists in agriculture and food science. Developing country scientists have access to genetic resources and are in a position to conduct important field studies needed to translate laboratory findings into practical applications. Their counterparts in developed countries can provide analytical expertise and the reagents and sophisticated apparatus needed to complete difficult syntheses. The exchange of ideas and materials is synergistic and benefits both partners. Future developments in computer and communications technologies promise to facilitate collaborative efforts to an extent perhaps greater than that permitted by the introduction of jet air travel two decades ago.

Networking

Conscious of limited human and financial resources, working groups noted the importance of newsletters, conferences, and other mechanisms for the rapid exchange of information between scientists working on similar problems in various parts of the world. The need for central data banks, gene banks, and culture collections was stressed. The soils group, in particular, emphasized the need for tropical soils networks and the development of a mechanism for exchanging soils information between scientists using disparate classification systems.

Site Specificity

Unlike research in health or in the basic sciences and engineering, applied research in agriculture and the food sciences is highly site-specific. Profound differences in physical, cultural, and economic
environments from country to country and region to region have a substantial effect on the productivity of the food supply system. Perhaps more than for any other area of science and technology, progress in the food and agricultural sciences requires indigenous scientists to adapt and apply solutions found elsewhere to their local needs, for those technologies cannot be transferred directly.

CONCLUSION

Increasing world food supplies sufficiently to meet demand in the year 2020 is a singular challenge and an important opportunity for chemical scientists. CHEMRAWN II and the workshop that followed it demonstrated the commitment of chemists and their colleagues in related fields to work together in multidisciplinary, international efforts aimed at improving agricultural productivity and food science in the Third World. While optimistic about the capacity of their science to help overcome barriers to increasing food supplies, workshop participants were aware of the difficulties faced by those who must decide how to allocate limited resources. This report is presented in the hope that planners and policymakers will find it a useful guide to opportunities that merit immediate attention.
SUMMARY OF RECOMMENDATIONS AND RESEARCH PRIORITIES

SOIL FERTILITY AND PLANT NUTRITION

Research priorities are presented here in order of importance. A number of issues discussed by the group were considered to be very important to future progress in soil science research and to its practical application worldwide. Presented in the report under the heading "General Issues" are detailed recommendations on needs in the areas of information exchange and coordination of multidisciplinary efforts, government policy, and technology transfer.

- Improving Fertilizer-Use Efficiency
  -- Study soil and fertilizer dynamics under diverse farming systems and climates.
  -- Develop new or improved nitrogen, phosphorus, and sulfur fertilizer formulations.
  -- Develop integrated nutrient management and fertilizer scheduling for cropping systems.
  -- Develop rapid and reliable diagnostic methods for soil nitrogen, sulfur, boron, and molybdenum.
  -- Breed plants for improved nutrient utilization at different fertilizer input levels.

- Restoring Degraded Lands
  -- Develop criteria to assess degradation and estimate losses in crop productivity.
  -- Develop chemical, mechanical, and biological approaches to restore degraded lands.
  -- Evaluate soil restoration in terms of soil properties and crop performance.

- Minimizing Environmental Stress
  -- Develop soil amendments and other practices to alleviate stress due to soil acidity, salinity, drought, and waterlogging.
  -- Select and breed plants for tolerance to the above stresses.
  -- Study stress-tolerance mechanisms in plants.
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- Alleviating Soil Physical Constraints to Plant Nutrition
  - Develop techniques to assess and alleviate nutrient imbalances caused by unfavorable water, temperature, or aeration conditions.
  - Improve land-clearing and development methods.
  - Develop technologies to improve soil water availability.
  - Develop techniques for uses of organic residues.
  - Improve seedbed preparation and weed control technologies.

- Improving Soil Productivity Using Microorganisms
  - Develop more effective biological nitrogen fixation systems.
  - Evaluate vesicular-arbuscular mycorrhizal inoculation for improving nutrient uptake and plant growth.
  - Develop methods to culture vesicular-arbuscular mycorrhizae for large-scale inoculation.
  - Study basic microbial ecology to facilitate the introduction of beneficial microorganisms.

PLANT GROWTH REGULATORS AND PLANT-PEST RELATIONSHIPS

Following a period of general discussion, recommendations were prepared in eight areas by subsets of the overall working group. Individual participants contributed in more than one area, and the entire group had an opportunity to review and discuss specific recommendations. It was decided that recommendations in each area should stand independently of the others as it was not possible to judge the relative merits of one or another approach; on the contrary, all were considered important and promising. Therefore, no priority ranking is implied by the following reporting order:

- Plant Growth Regulators
  - Study developmental biology of major world crops and post-harvest development of important tropical fruits and vegetables.
  - Study use of plant growth regulators in vegetative crops.
  - Study effects of plant growth regulators on tolerance to environmental stress and disease in crops.

- Natural Plant Growth Regulators (Allelopathy)
  - Develop weed control technologies using mulches of common weeds and allelopathic crop plants.
  - Study allelopathic effects of common tropical weeds and crops.
  - Isolate and identify allelopathic compounds. Test these compounds for practical utility as plant growth regulators and as models for the development of chemical analogs.
- 8 -

- Biochemical Basis of Crop Resistance to Insect Pests
  -- Study the chemical components of the genetic basis of plant resistance to pests to help plant breeders develop reliable, pest-resistant varieties.

- Pesticides and Plant-Pest Interactions
  -- Investigate the causes of pesticide resistance and develop practices to minimize them.
  -- Study the indirect impact of pesticide and herbicide use on plant-pest interactions.
  -- Develop relatively specific pesticides.
  -- Develop application technologies that will get more of the applied pesticide to the target pest.

- Natural Product Research for Insect Pest Control
  -- Establish collaborative international research programs to develop simple, effective botanical formulations for use as pest control agents.

- Biological Control of Weeds and Insect Pests
  -- Collect and culture organisms for use as biological pest control agents.
  -- Conduct ecological studies to identify potential biological control agents.
  -- Study genetic aspects of biological control agents and their target pests.

- Plant-Microbe Interactions
  -- Investigate plant-microbe interactions for pest control.
  -- Study rhizosphere microorganisms in relation to nitrogen and phosphate dynamics.
  -- Investigate the elaboration of plant growth regulators by microorganisms and of microbial growth regulators by plants.

- Agronomic Practices
  -- Study pest population dynamics in different cropping systems.
  -- Investigate the effects of predators and parasites in different cropping systems.
  -- Study relationships among soilborne pests, agricultural chemicals, and plant growth in different cropping systems.
  -- Investigate pesticide requirements in different cropping systems.
Having agreed on the major commodities and general research areas within which specific research priorities were to be identified, the working group discussed opportunities in each category. The major research recommendations summarized below are listed in order of the relative priority assigned to them by the group; priorities within each area should be determined by local needs and resources.

- **Improving Food Quality and Availability Through Improved Fermentation Processes**
  - Identify and catalog systematically the synthetic capabilities of food fermentation organisms through a central culture collection and a network of cooperating laboratories established for this purpose; organisms used in breadmaking deserve special attention.
  - Develop fermentation technologies for producing breads from flours other than wheat or rye; special priority should be given to cassava.
  - Study traditional African cereal grain fermentations to determine their value and range of applicability.
  - Study the effect of food fermentations on mycotoxin levels in various substrates.
  - Study wet-processing fermentation of coconut as a means of producing high-grade protein and edible oil economically.
  - Determine the transferability of the Indonesian tapé ketella process to areas of Africa and Latin America where cassava is eaten.
  - Establish research projects in major geographic regions to develop technologies for producing acceptable vegetable protein substitutes for meat from locally available agricultural by-products.
  - Identify acid fermentation organisms for use in pickling tropical fruits and vegetables.

- **Packaging Materials for the Tropics**
  - Develop technologies for the local production of low-cost tropical food packaging and storage materials.

- **Improving Fish Preservation in the Tropics**
  - Develop safe, effective chemical alternatives to salt as a preservative for fish.
  - Study the effectiveness of cooling on the keeping qualities of tropical fish.
  - Develop low-salt fermentation technologies for fish preservation.
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- Reducing Lactose Intolerance and Developing Milk Extenders from Oilseeds
  -- Develop simple, safe, and inexpensive preparations that can be used to reduce the effects of lactose intolerance.
  -- Improve oilseed processing technology to provide low-cost milk extenders.

- Production and Stabilization of Rice Bran Oil
  -- Design and field-test a small, inexpensive extruder-cooker for use in processing rice bran oil by small rice mills.

- Improving Sorghum Protein Digestibility
  -- Study the causes of digestibility problems in different varieties of sorghum.
  -- Develop processing methods to improve the digestibility and nutritional value of sorghum.

AQUACULTURE AND INTEGRATED FARMING SYSTEMS

Overall Research Priorities

- Understand the interrelationships of various components and processes.

- Optimize returns through identification of the most suitable components of the system.

- Establish region-specific guidelines for operation and management of functional and economic systems.

Specific Research Priorities

- Ricefield Fisheries
  -- Study traditional rice-fish systems, including energy and materials flow, management practices, and economics.
  -- Identify fish species suitable for use in rice-fish culture.
  -- Determine fertilizer and land management practices needed to optimize yields of fish and rice.
  -- Develop chemicals for pest control and determine management practices required to minimize problems of persistence and hazard to fish and consumers.
  -- Develop waste management technologies to maintain the level and quality of water needed for rice-fish culture.
- Shrimp Culture

- Adapt existing hatchery systems for use in developing countries.
- Develop techniques for management of grow-out at low density and low-input levels.
- Develop natural feeding systems using algae and agricultural wastes as substitutes for formulated rations in grow-out ponds.
- Develop appropriate polycultures to complement bottom-feeding shrimp.

- Organic Wastes as Fish Feed

- Study mechanisms of waste-nutrient assimilation by fish, especially the role of microorganisms.
- Study waste recycling in brackish or seawater ponds.
- Study the potential of chemical or microbial pretreatment of wastes as a means of enhancing feeding value or reducing risk of disease from pathogens and parasites.
- Develop low-level technologies for the culture of live feeds, such as larvae or annelids, on organic wastes.

- Algae and Aquatic Plants as Fish Feed and Fertilizer

- Develop technologies for using aquatic plants as fertilizer or as animal or fish feed.
- Conduct site-specific research on control of aquatic plants using mixed fish cultures.
- Study the use of naturally occurring polymers as coagulants that can be used to harvest algae.

- Control of Fish Reproduction

- Develop gonad sterilization techniques in tilapia, using hormones.

- Integrated Farming Systems

- Adapt traditional integrated farming practices for swampy areas.
- Develop less expensive biogas digesters using locally available plastics or other inexpensive materials.
- Determine the value of ducks and chickens in various integrated farming systems.

- Stable Carbon Isotope Tracer Techniques in Aquaculture

- Exploit the potential of stable carbon isotope ratio techniques as a tracer of nutrient flows in aquaculture systems.
Economic and Social Issues

- Determine the infrastructural requirements of aquaculture and integrated farming systems.
- Develop systems for aquaculture and integrated farming that permit stepwise introduction of the system.
- Study sociocultural impacts of aquaculture projects, including effects on employment patterns and income distribution.
WORKING GROUP REPORTS
Agricultural research made substantial contributions to the increased production of food in developing countries during the 1970s. The worldwide average increase of 3.5 percent per year is largely attributable to the application of breakthroughs in agricultural research.

There is less optimism about progress in the remaining decades of this century, however. "Agriculture Towards the Year 2000," a 1979 study by the Food and Agriculture Organization (FAO), indicates that a 4 percent annual increase in food production over the next two decades is needed in order to meet food demands in developing countries. About one-third of the additional food is expected to be produced on 200 million hectares (ha) of new lands, and two-thirds by increasing yields on land already under cultivation.

Bringing new, often marginal land into production will require new technology. The research and development focus is therefore shifting from fertile soils and irrigation to agro-ecological regions with serious soil and climatic constraints, such as the humid tropics, the semiarid tropics, the acid savannas, the tropical wetlands, and the steeplands. In these regions, it is especially important that science and technology be applied to increase food production while preserving the natural resource base and using scarce chemical resources most efficiently.

This working group has recommended a research framework for consideration by AID and other donor agencies and has identified five priority areas needing research. In order of importance they are:

- Improving fertilizer-use efficiency
- Restoring degraded lands
- Minimizing environmental stress
- Alleviating soil physical constraints to plant nutrition
- Improving soil productivity using microorganisms.

A strategy for information gathering, exchange, and coordination relative to agricultural research in less developed countries was discussed (see "Information Exchange and Coordination of Multidisciplinary Efforts"). The group agreed that the highest priority should
be given to the proposed strategy in order to make current and future research effective in raising agricultural productivity in developing countries.

A description of how the conclusions and recommendations were reached is discussed in the following section.

The Decision-Making Process

As a starting point, the group focused on research priorities proposed by Sanchez and Nicholaides (1982) in a report to the Technical Advisory Committee of the Consultative Group on International Agricultural Research. Table 7 of that report, titled "Priority rankings of research components by agro-ecological zones," presents a summary of research opportunities in soil science and plant nutrition in developing countries identified by scientists participating in seven major studies undertaken since 1976. After discussion and modification, information in the table served as the blueprint for the research areas outlined in this report.

All committee members participated openly in the deliberations. The final priority areas and subheadings represent a consensus. Responsibility for writing various sections of the report was assigned to one or more scientists in the specific area. Initial drafts were reviewed by the entire group. The chairman reviewed the final draft.

IMPROVING FERTILIZER-USE EFFICIENCY

Floods, droughts, disease, and pest epidemics destroy crops over vast areas and are frequently considered the major factors limiting world food production. Yet, over time, plant nutrient constraints have limited production more than any other factor. Even with the development of improved rices and wheats, most developing countries are not able to produce enough food to meet their needs. Although significant advances have been made in understanding soil chemistry, soil fertility, and fertilizer use in developed countries, very little of this knowledge can be extended to developing countries, not only because their soils are different but because they have entirely different climates, diverse crops, and different cropping systems.

As a proportion of farm profits, fertilizer costs have risen with the absolute price of energy and are often beyond the means of resource-poor farmers. It is therefore essential that nutrient-use efficiency be maximized through a better understanding of nutrient constraints and the development of efficient fertilizers.

Soil and Fertilizer Dynamics Under Diverse Farming Systems and Climates

Too little information is available on the dynamics of plant nutrients in flooded rice soils, tropical Ultisols and Oxisols, and many crops or
cropping systems common to the tropics. Research on nutrient dynamics of nitrogen and sulfur is particularly important.

Research needed on nitrogen dynamics was summarized in a review by Bouldin and colleagues (1980). They suggested that (1) nitrogen management research follow an integrated approach since nitrogen uptake at a desired yield level is a function of many factors including the quantities of nitrogen that are (a) mineralized from existing soil organic matter, (b) applied as organic wastes or manures, (c) fixed biologically, and (d) applied as chemical fertilizer; (2) research be conducted on ways to maximize nitrogen recycling from crop residues, rotations, legume interplantings, and sources of organic nitrogen; and (3) nitrogen loss mechanisms be quantified, particularly leaching in well-drained soils and denitrification and ammonia volatilization in wetlands and rice soils.

Sulfur is another important element that is becoming increasingly deficient in tropical soils. In many ways, the reactions of sulfur are similar to those of nitrogen. Fuller understanding of soil sulfur transformations and losses is important if the fertilizer sulfur-use efficiency is to be increased.

New and Improved Fertilizer Formulations

The fertilizers available to farmers in the tropics and subtropics were designed for use on temperate zone soils and crops with mechanized agriculture. Given the soils, crops, climate, and socioeconomic conditions of tropical agriculture, these fertilizers may not meet plant nutrient needs. Different fertilizer formulations and cultural practices are generally needed for efficient crop production in the tropics.

Effective fertilizers for tropical soils might differ significantly from those currently available. For example, they might be less water soluble and therefore cheaper to process (even highly reactive rock phosphates may be adequate, at least for acid tropical soils). They might also contain lower amounts of the major nutrients (nitrogen, phosphorus, and potassium) to allow incorporation of other essential elements such as sulfur, calcium, magnesium, or even micronutrients, which are sometimes absent or are present in insufficient amounts.

- The International Fertilizer Development Center, in Muscle Shoals, Alabama, is currently conducting research on fertilizer formulations specifically for tropical agriculture. The center is also developing technologies to allow fertilizers to withstand tropical conditions. More support is needed for work of this kind.

Nitrogen is the plant nutrient most often found to be deficient in terms of land area in the tropics (Sanchez 1976). Thus, it is generally considered to be the most important single input for increasing crop yields in developing countries. Unfortunately, the amounts of nitrogen typically required to achieve desired yields make
it the most expensive fertilizer input. An important component of the high cost of fertilizer nitrogen is the fact that nitrogen-use efficiency is notoriously low, generally 50 percent or less (Prasad and De Datta 1979), and is even lower in poorly managed, flooded rice systems. Research is needed:

- To improve nitrogen-use efficiency by developing fertilizer formulations with inhibitors of microbial reactions such as urea hydrolysis and nitrification.
- On the effectiveness of slow-release nitrogen fertilizers under different tropical soil-climatic conditions.

Some slow-release materials and inhibitor formulations have proved effective with rice in India (Prasad 1982). Encouraging results with sulfur-coated urea and urea supergranules have been obtained under the International Network on Soil Fertility and Fertilizer Evaluation for Rice trials (INSFFER 1980).

Nutrient Management and Fertilizer Scheduling for Cropping Systems

In tropical and subtropical countries it is possible to grow more than one crop a year. Therefore, recommendations on fertilizer use must consider the residual effects of fertilizer applied to the previous crop. For example, work in India (Tandon et al. 1981) showed that in a maize-wheat rotation (grown in one year), application of phosphate fertilizer to wheat and farmyard manure to maize was more cost effective than fertilization of each crop. Such information can come only from long-term fertilizer experiments conducted in developing countries (see "Long-term Field Research for Sustained Productivity").

Rapid and Reliable Diagnostic Methods to Assess Soil Fertility

Soil fertility is evaluated through soil and/or plant analysis in conjunction with measurements of crop responses obtained in pot and field studies. Obtaining the required chemical analyses is a major problem in many developing countries because of lack of equipment or chemical reagents, and insufficient trained personnel. Large numbers of small farms and poor infrastructure, which create problems in transporting samples to laboratories and returning fertilizer recommendations to farmers, complicate the process. Research needed to improve assessment of soil fertility includes:

- Development and/or adaptation of simple nutrient tests or analysis procedures that are practical in developing countries. Particularly important are rapid and reliable methods for sulfur, boron, molybdenum, and nitrogen.
Development and testing of methods to estimate fertilizer nutrient requirements for farmers based on relatively few soil and plant analyses but combined with field experiments that test fertilizers, land characterization information, cropping history, yield targets, and so forth.

Breeding Plants for Improved Nutrient Use at Different Input Levels

Sanchez and Salinas (1981) note the need for selecting and breeding crop cultivars that can make better use of low levels of available plant nutrients in many Ultisols and Oxisols of the tropics. There is also a need to select or breed crop cultivars that can make efficient use of nutrient-rich soils in countries where it is possible to add large amounts of fertilizer.

RESTORING DEGRADED LANDS

It is estimated that 1.5 billion ha of cultivated land exists in the world today, and that an additional 2 billion ha were once biologically productive. The rate at which land is becoming unsuitable for agriculture due to soil degradation is estimated to be 5-7 million ha/yr, about 30 percent of which is due to accelerated soil erosion (Kovda 1977, Barney 1980). Annually, 1 million ha of cropped land, originally derived from forest, is totally abandoned due to complete degradation (Salati and Vose 1982). Moreover, desertification is leading to abandonment of vast areas of grazing land.

The need for new land development can be drastically reduced by (1) increasing production per unit area of existing land, (2) improving soil and crop management to decrease the rate of soil degradation, and (3) restoring eroded and degraded land. As a matter of principle, land restoration should be given higher priority than the development of new land by deforestation.

The method chosen for soil restoration will depend on the nature of the degradation process. Soils deficient in plant nutrients can be reclaimed by addition of appropriate quantities of chemical fertilizers. Productivity of acidic soils with high exchangeable aluminum can be at least partially restored by liming, although additional research is needed to find management solutions where subsoils are also highly acid. Saline soils respond to leaching provided that adequate drainage exists to wash out excess salts. Planting appropriate crop species and suitable cultivars for acid or saline soils can also contribute to improvement of degraded lands.

Restoration of eroded and compacted soils is a more complex problem. The loss of 20 mm/yr of surface soil by water erosion is not uncommon for Alfisols on gentle slopes, whereas the rate of new soil development from bedrock in tropical regions is estimated at 1-13 mm per 1,000 years (Lal 1982). Many severely degraded soils in tropical areas will eventually develop some grass cover; and in more humid
areas, scrub and secondary forest will develop if protected from animals and firewood collection. Natural regeneration can form the basis of agroforestry restoration programs such as those attempted in Costa Rica (Budowski 1981).

Assessment of Soil Degradation and Crop Productivity Loss

When assessing soil degradation and the consequent loss of productivity, factors considered should include nutrient content, total organic matter, total porosity and pore-size distribution, available water-holding capacity, and rooting volume. It is also important to evaluate "soil-loss tolerance" for typical benchmark soils and major tropical crops. The range of soil-loss tolerance should be evaluated for different fertilizer input levels.

Chemical, Mechanical, and Biological Approaches to Restoration of Degraded Land

Effects of chemical amendments on erosion rates should be quantified in terms of yields of important tropical crops. This work should be coordinated by an international network using standardized methodology. Because "miracle" products without beneficial or scientifically validated efficacy are actively marketed, all new products must be thoroughly investigated.

Economic field studies are needed for different soils and environments to compare reclamation through tillage versus use of selected plant species and/or fertilizers or improved water management. Studies of the restorative effects of grass and legume covers are also required for different soils. Managed fallows should be evaluated in terms of the buildup of organic matter, changes in porosity and available water-holding capacity, effective cation exchange capacity, infiltration rate, and so forth. Perennial or seasonal crop species that can be grown on eroded soils with minimal chemical input should be identified.

Agroforestry is a long-term but promising method of soil restoration. Basic food crops such as cassava, dryland rice, millet, grain legumes, and maize might be considered for such systems. Long-term, basic agronomic research is required in addition to evaluation of the effects of trees and deep-rooted shrubs and woody species on nutrient recycling, alterations in micro- and mesoclimates, loosening of compacted soil horizons, and improvements in soil quality.

Evaluation of Soil Restoration in Terms of Soil Properties and Crop Performance

The restorative mechanism of different techniques of tillage or chemical amendment should be studied. Some techniques may alleviate
soil physical constraints while others improve nutritional aspects. Basic information about these mechanisms is needed to determine the best combination of techniques to apply under a given set of circumstances.

MINIMIZING ENVIRONMENTAL STRESS

Widespread soil constraints such as acidity, low amounts of available phosphorus, salinity, and drought severely reduce crop productivity in developing countries. The conventional solution is to remove these constraints by sufficient liming, superphosphate applications, drainage, and irrigation, respectively. This approach modifies the soil to improve the likelihood that the plant will meet its nutritional and environmental needs. In response to the economic impact of the energy crisis, a different approach has been developed based on the use of plants that tolerate existing soil constraints. More cost-benefit research is needed to evaluate these approaches. Also needed is fundamental research to uncover the physiological and enzymatic mechanisms that allow some plant species to tolerate soil stresses more effectively.

Alleviating Stress Due to Soil Acidity, Salinity, Drought, and Waterlogging

Soil acidity is a major barrier to the development of large areas of the humid tropics and acid savannas. Although topsoil acidity can be eliminated by liming to pH 5.5 in order to neutralize the exchangeable aluminum, economic factors render this straightforward solution appropriate to only a small proportion of the acid soils.

- Research is needed to develop a package of practices that will minimize the effects of soil acidity on important tropical crops. Programs are needed to select or breed plant species and varieties tolerant to aluminum and manganese toxicities; to develop sufficient soils information to design procedures that require only enough lime to satisfy plant needs for calcium and magnesium while decreasing aluminum below toxic levels and to promote downward movement of calcium and magnesium into the subsoil; to develop liming methodologies that prolong its residual effects; and to promote fertilizer practices that do not develop secondary acidity.

Three major types of salinity can be distinguished: salinity in irrigated areas, secondary salinity caused by mismanagement of irrigation water, and coastal salinity caused by infiltration by seawater. Technology for improving saline soils through irrigation, drainage, and gypsum application is one of the most advanced and quantified aspects of soil science. Nevertheless, the application of such knowledge in many irrigation projects in the developing world is often inadequate.
Beyond the extension of existing knowledge, research is needed to discover the relative tolerance of new species and cultivars to salinity and to evaluate the use of green manures to ameliorate saline or high-sodium (sodic) soils.

Drought and waterlogging are physical constraints that can be partially removed by tillage practices, land forming and shaping, mulching, surface and/or subsurface drainage. Most research in this area has been conducted on temperate soils.

Research is needed to adapt, for tropical soils, techniques developed in temperate regions for reducing soil drought and waterlogging constraints.

Selecting and Breeding Plants for Stress Tolerance

In the past, plant breeders attempted to breed for maximum adaptability to varied soil conditions. This approach has been largely successful, but more specifically adapted cultivars will be needed to overcome adverse factors in problem soils where the use of chemical amendments is impractical. Thus, genotypes of many crop plants must be found that are more tolerant of such factors as soil acidity, iron deficiency, or salinity than cultivars developed for a wide range of conditions.

Problem soils are sufficiently common to warrant specialized plant breeding programs. Acid soils, for example, constitute 18 percent of world soils (or over 2.4 billion ha), while salinity affects about 1 billion ha worldwide (Massoud 1974). One-third of irrigated soils, about 77 million ha, are sufficiently affected by salinity to reduce average crop yields (Eckholm 1976). In the humid tropics, salinity affects as many as 40 million ha of potential rice soils (Ponnampuruma 1977). About 25 percent of world soils are calcareous and likely to be iron-deficient either on a regular basis or as a result of mismanagement or restricted water supply. The economic importance of research to identify and exploit plant genotypes able to withstand such stresses has been emphasized (Vose 1982).

Current development efforts include trials to identify rice genotypes tolerant to high levels of aluminum and salinity and of low soil-phosphorus (International Rice Research Institute--IRRI); the selection of pasture grasses tolerant to soil acidity (Centro Internacional de Agricultura Tropical--CIAT); and plant breeding programs in the United States to develop soybean and sorghum cultivars tolerant to iron deficiency. In Brazil, wheat-breeding programs have for many years taken into account selection for aluminum tolerance, while existing Phaseolus cultivars are aluminum-tolerant as the result of natural selection. The salt-tolerant kollar grass (Diplachne fusca) in the Indus valley of Pakistan has enabled water buffalo to be supported on previously barren soil.

Short-term research needs include:

- Testing late progeny (e.g., F4 or F5) of widely based crosses to uncover potential stress-tolerance characteristics in otherwise well-adapted material.
Surveying existing cultivars to identify and classify potentially useful tolerance characteristics.

Determining whether existing plants (crops, grasses, shrubs, trees) are the most appropriate for the soil conditions.

Experimenting with mutation techniques (Vose 1981) as a means of increasing genetic variation. Stress-tolerance factors could be surveyed with ease in very large populations by planting on appropriate stress-inducing soils and harvesting the survivors.

Developing promising tissue culture techniques to select efficiently for tolerance to salinity and high aluminum and manganese.

Transferring tolerance factors to existing, high-yielding types, since such characteristics are frequently found in relatively low-yielding cultivars.

There is a further need to breed for drought, cold, or heat tolerance in certain crops beyond the "normal" or "average" range of climatic adaptation. Examples include heat and cold tolerance in rice, heat tolerance in maize, and tolerance of the potato to tropical conditions. Drought tolerance is a widespread requirement.

Research needs include:

Surveying existing collections more extensively to identify drought- and temperature-tolerant varieties for use in breeding programs. The possibility should be examined that success with drought-tolerant wheat in Canada could be applied to other crops.

Development of mutation techniques to enhance existing variation. The widely grown California rice cultivar, Calrose, for example, is a modern, short-straw crop obtained by mutation from an existing cold-tolerant, long-strawed variety.

Success with any of the suggested approaches will require close collaboration between plant breeders, plant physiologists, and soil chemists.

Stress Tolerance Mechanisms in Plants

By applying relatively simple selection and crossing procedures, considerable progress can be made in the development of stress-tolerant cultivars. In the long term, however, much more basic scientific knowledge will be required concerning the genetics of tolerance to stress factors. A recent symposium (Saric 1982) highlighted the potential nutritional variability in crop plants.
Support is needed for basic physiological studies of stress tolerance mechanisms (for example, aluminum, manganese, and salt tolerance) and of other genetic variables such as tolerance to low levels of phosphorus, zinc, copper, and boron.

In the long term, better understanding of such mechanisms will permit a more specific approach to the genetics of stress-tolerance factors that will enable breeding programs to proceed on a more rational and efficient basis.

ALLEVIATING SOIL PHYSICAL CONSTRAINTS TO PLANT NUTRITION

It is important to recognize that linkages exist among soil chemistry and chemical soil fertility (as expressed in terms of nutrient availability and uptake, and fertilizer-use efficiency) and the management of soil physical properties. If soil physical properties are not maintained at an optimum level, the value of expensive chemical applications may be seriously decreased. For example, all physical transport phenomena in soils (water, solutes, and heat) are influenced by transmission pore-size distribution and by the continuity and stability of the pores. Both inherent and applied plant nutrient availability depend on drainage conditions and soil aeration (Lal 1979). Studies of plant nutrient leaching are meaningful only when conducted in conjunction with studies of soil-water movement and distribution. Both capacity and intensity factors are easily influenced by alteration in bulk soil density. The magnitude of diurnal and seasonal fluctuations in soil temperature influences a number of factors, including root growth, volatilization rates for some nutrients and fixation rates of others, and the rates of uptake and translocation of nutrients at the soil-root interphase (Lal and Greenland 1979).

Soil physical properties can be manipulated by addition of chemicals to regulate hydrological characteristics, to increase or decrease hydrophilic properties, and to influence mechanical strength and regulate splash and soil detachment. The latter is a major factor in soil erosion involving the selective removal of colloid fractions, enriched in essential plant nutrients, that results in severe yield reductions and pollution of natural waters (Lal 1976).

It is therefore important that fertilizer and nutrient management research be closely integrated with the management of soil physical properties. Research objectives include greater use of inherent and applied nutrients, improved soil-water utilization, and decreased risks of soil erosion. Specific research needs for different soils and environments follow.

Techniques to Assess and Alleviate Nutrient Imbalances Caused by Unfavorable Water, Temperature, or Aeration Conditions

Nutrient-water and nutrient-temperature interactions should be studied for major food crops and for different soil groups in
the tropics. Fertilizer-use efficiencies should be investigated under different soil moisture and temperature regimes.

- Research should be conducted to determine whether adverse effects of transient flooding and poor aeration of upland soils can be alleviated by adding oxygenating chemicals such as calcium peroxide. If so, calcium peroxide can be added as fertilizer.

- Soil temperature-induced nutrient imbalances for tropical food crops should be studied. Soil temperature regime as a physical constraint should be considered for breeding cultivars that will tolerate high root-zone temperatures.

- Crop yield/soil erosion models for a range of chemical fertilizers and amendments are urgently needed. The information obtained will indicate fertilizer requirements for eroded soils.

Improved Land Clearing and Development Methods

The potential use of chemicals in land clearing in the tropics has not been fully explored. In addition to mechanical methods, chemicals may be particularly appropriate when clearing soils with shallow surface horizons where the surface soil should not be disturbed because subsoil characteristics (acidity, aluminum toxicity, etc.) are not favorable for root growth. Some rhizomatous weeds (such as Imperata cylindrica) are more effectively eliminated and controlled by chemical than mechanical means.

Technologies to Improve Soil Water Availability

Synthetic organic chemicals are available that can be used to modify certain physical properties such as hydrophobicity and water retention. Examples of these chemicals include long-chain (C₁₂ to C₁₈) hydrocarbons with hydrophobic end-groups, gel-forming polysaccharides, and related high molecular weight polymers and polyvinyl and polyacrylamide materials (De Boodt 1979, Hamblin and Greenland 1977). Information is needed to determine where changes in soil physical properties can be induced to have a significant, favorable influence on crop growth and sustained production. Field trials are needed to enable adequate economic evaluations of such materials and to establish criteria for laboratory studies.

Organic Residue Utilization

Use of synthetic chemicals to modify soil properties involves high risks and may not always be cost effective. It is important,
therefore, to continue research to further develop the use of organic residues and manures. The effectiveness of adding nutrients by returning crop or animal residues to the soil depends on the relative nutrient element concentration, nutrient status of the soil's root zone, the rate of mineralization, the prevalent micro- and mesoclimate and its alteration by the amount and mode of residue application, and phase differences between the time of nutrient release by mineralization and crop nutrient requirements at critical growth stages. These factors strongly interact with other factors that affect the activity of soil fauna and flora (e.g., earthworms, centipedes, termites, microorganisms).

Subsistence farmers in the tropics meet fertilizer needs by adding crop residues or other organic manures, which can be added as mulch, incorporated into the soil, burnt to provide cation-rich ash, or added as compost. In the humid and subhumid tropics, the use of crop residues as "mulch" reduces soil erosion, creates a favorable hydrothermal regime, maintains soil organic matter content, and stimulates the activity of the soil fauna and microflora. In addition, organic materials improve soil physical properties, particularly in relation to the extent and proliferation of roots and to the storage and transmission of water and nutrients. These materials have important though indirect effects on the mineralization, translocation, and absorption of plant nutrients. The interactions between organic manures, physical conditions, root development, and nutrient uptake is an important subject for future research.

The effectiveness of both inherent and fertilizer-applied plant nutrients can be increased by obtaining research information on:

- Nutrient availability in relation to chemical analysis of crop residues, nutrient balance of the soil, time of residue application, and crop nutrient requirements
- The use of chemicals to regulate biodegradation and mineralization of crop residues
- Fertilizer-mulch interactions as a function of crop yield at different levels of fertilizer and mulch for a range of soils, mulch materials, and crops
- Herbicide-mulch interactions (for weed control) for different mulch rates, for different herbicides and methods of application (ultra-low volume, electrodyne, etc.), and for a range of residues commonly available in the tropics
- The effects on soil and crop growth of anaerobic decomposition of crop residues in hot, humid environments.

Seedbed Preparation and Improved Weed Control

Tillage has long been practiced to provide suitable conditions for optimum stand establishment and plant growth. However, accelerated
soil erosion and more costly energy resources have generated interest in the concept of reduced tillage. Use of some form of reduced tillage has proved to be economically feasible under a wide range of conditions. Advantages include lower labor and fuel requirements, reduced soil temperature, increased flexibility in timing of farm operations, moisture conservation for the critical growth period, and control of soil erosion by wind and water (Lal 1982).

Under monsoon conditions, for example, a substantial delay in planting may occur during the wet season as a result of extra seedbed operations that ultimately lead to loss of prime growing time. Reduced tillage can especially contribute to the success of double or triple cropping systems (two or three crops per year) because of the shorter "turn-around time." It is important to develop a set of cultural practices involving the use of reduced tillage that are practical and economically attractive.

One of the primary objectives of tillage is weed control. Numerous reports have indicated that for certain crops, the only benefit of tillage is control of weeds. The use of chemicals for weed control thus raises the possibility of reducing or totally eliminating tillage. The first successful substitution of herbicides for tillage was demonstrated by Davidson and Barons (1954) with corn and peas. Since then, numerous reports of success with reduced tillage in various crops have been published. However, consistent and satisfactory herbicide performance is imperative if this concept is to be widely accepted.

A successful no-tillage herbicide system should have both contact and residual components. There will a be continuing need to develop new herbicides and to use existing ones more efficiently. Cooperative efforts between industry and field researchers will be required to develop herbicides that are effective against weeds but safe to farmers, crops, and the environment. In addition to practical, problem-solving efforts, basic research is needed to understand reactions of various herbicides in soils varying in clay minerals, moisture regime, and surface chemistry. Finally, strict quality control of products entering markets is needed, and facilities should be developed for rapid analysis of herbicides by specialist-operated laboratories run by a national agency.

Research needs include:

- Developing herbicides for reduced tillage systems that kill existing vegetation before crop emergence and suppress growth of weeds germinating from seeds but that are safe to primary and succeeding crops. The herbicide system must compare favorably in cost with other methods of cultivation.

- Developing herbicide formulations (including soil-applied herbicides) that selectively control weeds (both annuals and perennials) on a persistent basis, and that are effective at both pre- and post-emergence stages in the control of weeds for crops under continuous monoculture or under sequentialcroppings.
In addition to research on herbicide-soil-crop interactions for dryland soils, much more effort is needed on wetland soils where most of the world's rice is grown.

**IMPROVING SOIL PRODUCTIVITY USING MICROORGANISMS**

**Improving the Effectiveness of Biological Nitrogen Fixation Systems**

Biological nitrogen fixation (BNF) should be incorporated into farming systems to the maximum extent that is economically feasible. Currently known plant systems that are capable of fixing all of the nitrogen needed for their growth include the aquatic fern *Azolla* with *Anabaena* bacteria, legumes with bacterial *Rhizobium*, and some woody perennials (alders and casuarinas) with actinomycetes of the genus *Frankia*. Other plant systems (including grasses, cotton, and tomatoes) with associated nitrogen-fixing bacteria contribute such small amounts of nitrogen that they are significant only in severely nitrogen-limited cropping systems and in a long-term ecological sense. No practical way to improve or manage these systems for crop production is yet available.

When improved legume seeds are used, or a new legume is introduced to an area, inoculation with high-quality inoculant carrying selected strains of rhizobia should be used to assure performance of the nitrogen-fixing system. Woody perennials capable of forming root nodules with *Frankia* should also be inoculated when they are introduced. Inocula are grown in chemically defined media for both *Rhizobium* and *Frankia*, but current practice requires that infected plant root material serve as inoculant carrying *Frankia*. Research is needed to:

- Develop a commercially useful medium for growth of *Frankia*.
- Develop a commercial formulation of the *Rhizobium* inoculant that uses low-cost carriers convenient for farmers.

Increased biological nitrogen fixation results from improved growth and proper functioning of the plant-bacteria system when limiting factors are removed, such as ineffective nodulation due to the lack of the proper *Rhizobium* strain, phosphorus deficiency, pest damage, or an inadequate host plant. However, increased use of biological nitrogen fixation will require the integration of plant and cropping systems so as to benefit the farmer. Compared to cereal grains, legume yields are poor and need to be increased dramatically, which in turn would significantly reduce the cost of protein. The development of alternate uses for legume products is needed to provide market stability and increase their economic value. The leaves, stems, and tubers of the winged bean, for example, can serve as a major source of feed for the livestock industry. Oil from soybeans or peanuts can be used for industrial plastics and fuel.
Research needs include:

- Comparative studies of the ability of commonly cultivated legumes to fix nitrogen when grown as a monocrop, as a mixed crop, or in rotation with cereal crops.

- Field studies under different agro-ecological conditions to measure the total nitrogen added to the soil, both from root nodules and increased root growth.

Several legume species are capable of growing and nodulating in tropical soils without using Rhizobium inoculant. In developing countries, this practice, together with the use of farm-grown seeds, is prevalent. However, it is not known whether the indigenous Rhizobium strains are as efficient as high-quality inoculant with selected strains. Serologically marked inoculant strains can be used to indicate whether inoculated or soil rhizobia form nodules. Where nutrients in addition to nitrogen are deficient, application of these nutrients may stimulate growth enough to reveal the inadequacy of the soil rhizobia as compared to selected strains. It may also be that several indigenous strains are competing and that the less efficient types prevail.

A significant constraint to nitrogen fixation in most soils is the deficiency or imbalance of certain nutrients. Low levels of phosphorus, for example, reduce nodulation and nitrogen-fixing capacity. Chemical analysis of the soils on which legumes are grown, and fertilizer trials using different levels of nutrients, would provide sufficient data to help maximize the amount of nitrogen fixed. Furthermore, most legumes require an initial supply of nitrogen for maximal growth and nodulation. There is little data on the amount and form of nitrogen to apply and the timing of application except with regard to cultivation of soybean. Research on nutritional requirements of the important tropical legumes will greatly benefit farmers.

Information on the benefit of legumes when grown in association with other crops is available to a large extent in temperate countries, especially on legume-pasture associations. The allelopathic or synergistic effect of various legume-crop mixtures needs further investigation in developing countries. Reliable information about the benefits of legumes with different crop combinations would help farmers select crops that provide the maximum yields.

Leaves and flowers of legumes are a major source of protein for people and livestock in developing countries. Both annual and perennial legumes are used, but the effect of removing foliage on nitrogen fixation is not known. Systematic removal of foliage may, in fact, increase the total nitrogen fixed and therefore the total protein produced. Studies in this area will benefit small farmers, particularly those using an integrated farming system.

Research is under way on biological nitrogen fixation in many national and international agricultural research institutions. A network of international legume inoculation trials is being conducted by national scientists with the coordination of the NifTAL (Nitrogen
Fixation in Tropical Agricultural Legumes) project at the University of Hawaii. This project also provides training for agricultural scientists through short courses and intern training, maintains a collection of selected Rhizobium strains, supplies inoculant, conducts farming systems research, and publishes a newsletter. Five centers of the Consultative Group on International Agricultural Research (CGIAR) -- IRRI, CIAT, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Institute of Tropical Agriculture (IITA), and International Centre for Agricultural Research in the Dry Areas (ICARDA)--have biological nitrogen fixation research components on their mandated legume crops and also provide training. The FAO has inaugurated a program of field demonstration of legume inoculation and plans to help coordinate national activities. UNESCO supports a network of recognized Microbiological Resources Centers (MIRCENs) with Rhizobium emphasis in Kenya, Brazil, and the United States, but financial support for the training and research programs has waned. A recent National Research Council workshop (1982) established research priorities in the field of biological nitrogen fixation.

Although much research is already being conducted on biological nitrogen fixation, the working group agreed that:

- The highest priority for developing countries is continued and expanded research on the legume-rhizobia and the Azolla-Anabaena systems, in order to develop practical technologies to optimize the contribution of biological nitrogen fixation to tropical farming systems.

Evaluating Vesicular-Arbuscular Mycorrhizae and Large-Scale Culture for Inoculant Production

Plant nutrients in soils undergo many transformations, depending on soil conditions. Thus, availability of nutrients to plants is not simply correlated with the total amounts of nutrients present in the soil. Soil microorganisms are known to be involved in most nutrient transformations. Many soils, for example, fix a large portion of added phosphorus, which limits plant growth and plant productivity in general since the bound phosphorus is unavailable to the plant.

Early work in soil microbiology demonstrated the ability of certain microorganisms to solubilize fixed forms of phosphate and other micronutrients, thereby making them available to plants. Among these microorganisms are the vesicular-arbuscular mycorrhizal fungi (VA mycorrhizae), which were first found associated with the roots of some trees. Recent research has shown that VA mycorrhizae are also present on most field crops, and their role in increasing phosphorus uptake from the soil has been demonstrated. VA mycorrhizae have potential for improving phosphorus and micronutrient uptake in soils where these are present in fixed form.
Use of VA mycorrhizae to improve phosphorus and micronutrient uptake by various crops will require research on the basic ecology of associations between the fungi and the host plants. Little is known about this interaction.

Research should be undertaken on:

- The response of various crops, under different soil conditions, to inoculation with VA mycorrhizae
- Formulation of growth media to allow VA mycorrhizae to be cultured in the absence of host plants
- Improving techniques for inoculating with VA mycorrhizae
- The specificity of associations between VA mycorrhizal species and different plant species
- The persistence of VA mycorrhizae in soils to determine the need for further inoculation
- The interrelationships between VA mycorrhizae and rhizobia and their combined effect on biological nitrogen fixation by different legumes.

Basic Studies of Microbial Ecology

The root-soil interface and zone of influence has been termed the plant rhizosphere. Nutrients and other chemicals in the soil do not simply migrate to the root and into the plant but must pass through a complex biological zone around the root, which is often enshrouded in a mucilaginous layer thickly populated with bacteria and fungi. The rhizosphere population is exceedingly complex but important since it both positively and negatively affects the movement of nutrients and other chemicals and water into the roots. The rhizosphere is also important because it is the site of infection by many pathogenic organisms, including fungi and nematodes.

Even though biological activity in the root zone has been known for more than 60 years, so little is understood about the precise role of rhizosphere microorganisms that they are often ignored. The microbial enshrouding of the root has been known for less than 30 years, and its biological complexity has frustrated many workers. However, recent reports (Schroth and Hancock 1982) of disease suppression by inoculating seed with large numbers of bacteria of the genus _Pseudomonas_ indicate that a greater understanding of microorganisms in the rhizosphere can lead to improved plant growth. Rhizosphere microorganisms are susceptible to manipulation by biological and/or chemical agents; however, the role of soil properties remains to be clarified.
Research should be conducted on:

- Disease suppression by inoculation of plants with nonpathogenic microorganisms
- The causes of disease suppression by studying factors such as competition, toxicity, and growth stimulation
- The economic feasibility of inoculation practices to suppress disease
- Basic microbial-niche theory studies in soils.

In the near term, research in this area will be of importance only for certain crops known to be responsive and where most other limiting factors have been removed. Plant-microbe interactions are discussed in the report of the working group on plant-pest relationships.

GENERAL ISSUES

Information Exchange and Coordination of Multidisciplinary Efforts

International Board for Soil Resource Management (IBSRM)

The chemical components of farming systems cannot be investigated in isolation from or independent of essential physical and biological components. Linking chemistry with other disciplines is an important part of any research strategy for sustaining a stable food production system. A comprehensive strategy hinges on matching crop requirements to land characteristics, for in practice crop requirements are rarely met by the land. Mismatches between what the land offers and what the plant needs create stresses in crops that are minimized by human manipulation of the land and cropping system. Many stresses are fundamentally chemical, and chemical means are required to overcome them. In a sense, soil management is human intervention to rectify crop-land mismatches.

Matching crop requirements to land characteristics requires interdisciplinary cooperation and a research strategy pursued within an environment that fosters critical interdisciplinary interactions. Such a strategy cannot be developed by any single discipline; rather, it must be created by a group committed to developing technologies, cultivars, and practices that directly benefit the well-being of the resource-poor farmer. Similarly, the necessary research cannot be conducted in any one location. It must be conducted at several sites, often in several countries, with the various research projects being linked by the commonality of the soil characteristics.

A proposal has been developed for the creation of an International Board for Soil Resource Management (IBSRM) to coordinate activities to alleviate soil-related constraints in developing countries of the
tropics and subtropics. The proposal was prepared by an ad hoc internationally representative committee set up following the Conference on Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics held at Los Baños, Philippines, in 1979. The board would help establish links between soil research activities in developed and developing countries and between national and international research institutions.

The overall objectives of IBSRM would be to help ensure that soil resources will produce the food needed to support the current world population and the additional 2 billion people likely to be born during the next 20 years. The board could provide mechanisms for coordinating research on the characterization, management, conservation, and classification of soil and land resources for crop production.

The specific objectives of IBSRM follow:

- Strengthen national and international research capabilities to remove soil constraints to agricultural production.
- Assist in the development of broadly applicable methods for the elimination of soil constraints and for the extrapolation of research results.
- Stimulate both the characterization and classification of soils of the tropics and the research needed to establish clear relationships between soil properties and crop production.
- Promote coordinated research on the relationships between land characteristics and crop performance.
- Support and initiate training activities, both at the national and international level, aimed at minimizing soil-related constraints.
- Promote the optimization of land use in the tropics with special reference to soil and water conservation.
- Stimulate the application of soil research results already available through transfer of science and technology.
- Identify soil research needs and mobilize resources to meet those needs.
- Develop and implement data-processing systems to compile, collate, store, stratify, process, retrieve, translate, and disseminate information on soil characterization, classification, management, and conservation, especially in relation to crop performance.

The participants of this working group recommend that donor agencies support the establishment and operation of IBSRM.
Soil Management Research Networks

High priority should be given to the establishment of integrated soil management networks for six broad groups of soils: Oxisols-Ultisols, Vertisols, Alfisols, soils of tropical wetlands, soils of steppelands, and soils of arid areas.

The ultimate objective of soils research is to develop improved soil management systems. This is accomplished by integrating into a manageable whole those techniques that alleviate individual soil constraints. However, the product of such integration must be more than the sum of individual research components. To be valid, it must consider the various interactions and "put them all together" the way the farmer does.

Useful management systems are based on soil characterization, followed by identification of the main soil constraints and the means to alleviate them in ways that are technically feasible, culturally desirable, economically attractive, environmentally safe, and politically acceptable. The Oxisol-Ultisol network is illustrated here in some detail; highlights are presented for other soil management networks.

Oxisol-Ultisol Network These two soil types predominate in approximately 1.6 billion ha, or 43 percent of the tropical land mass. They occur mainly in two critical ecosystems—the humid tropics and the acid savannas—in which lie the bulk of the 200 million ha of new lands the world needs by the year 2000 and where opening new lands poses serious environmental concerns. These soils have generally good physical properties. Their main constraints are chemical in nature: most are deficient in major (nitrogen, phosphorus, potassium) and secondary nutrients (especially calcium, magnesium, and zinc), generally have toxic levels of aluminum, fix phosphorus at high rates, and are low in effective cation exchange capacity.

Integrated soil management practices for sustained production of these acid, infertile soils must involve site-specific evaluation of many approaches, including:

- Selection of well-drained soils in flat to gently sloping landscapes
- Selection of species and varieties of annual crops, grass-legume pastures, or tree crops that can tolerate a reasonable degree of aluminum toxicity and low levels of available soil phosphorus
- Use of land-clearing methods that minimize soil compaction and include burning to capitalize on the fertilizer value of the ash
- Use of cropping systems that rapidly establish and maintain a plant canopy to protect the soil from erosion throughout the year
- Reduction of soil acidity problems through the use of aluminum-tolerant cultivars and liming to supply calcium and magnesium requirements while decreasing aluminum saturation to tolerable levels and promoting calcium and magnesium movement into the subsoil

- Management of phosphorus fertilizers through use of the most appropriate combinations of sources; developing placement methods using rates that enhance initial and residual effects; improved soil testing methods; selection of varieties tolerant to low available phosphorus levels; and potential use of mycorrhizal inoculations

- Promotion of maximum nitrogen fixation by legumes using acid-tolerant rhizobia

- Increased efficiency of nitrogen and potassium fertilization

- Identification and correction of sulfur and micronutrient deficiencies

- Promotion of nutrient recycling through managed fallows, grass-legume pastures, and agroforestry.

Although work in the above areas continues at several research centers in the Oxisol-Ultisol regions, the amount of technology generated and transferred is insufficient to assure that these soils will be productive. An Oxisol-Ultisol network should be formed, perhaps as a component of the proposed International Board for Soil Resource Management (IBSRM).

Vertisol Network These black soils occupy about 163 million ha in the tropics, primarily in semiarid regions of India, Africa, and Latin America. The main constraints are physical; they shrink and crack when dry and swell when wet, making tillage difficult. As a result, land is often idle during the rainy season. Research needs include development of low-cost tillage methods that allow the planting and harvesting of two crops per year, studies of nitrogen and phosphorus fertilization, and the control of runoff and erosion. Support and expansion of a Vertisol network already in operation in India is considered the best avenue for progress.

Alfisol Network Alfisols in the tropics are generally reddish soils with higher native fertility than the Oxisols or Ultisols. Many of them, such as the Terra Roxa in Rondonia, Brazil, and the Kikuyu red loam in Kenya, have adequate physical properties. However, there is a broad belt of Alfisols covering most of West Africa south of the Sahel that presents a unique combination of physical and chemical soil constraints: severe erosion hazard due to high sand and gravel contents, coupled with low buffering capacity, quickly transforms an initially
fertile soil into one with severe soil nutrient deficiencies. The future of West Africa's dense populations depends largely on whether these soils, presently in bush fallow or savanna vegetation, can be managed on a sustained basis. Work at the International Institute for Tropical Agriculture (IITA) in Nigeria suggests that systems based on minimum tillage, alley cropping, and the use of managed fallows have a chance to make possible the sustained production of basic African food crops. Since the exact combinations are site-specific, high priority should be given to establishment of a network to adapt the IITA results to other Alfisol regions in Africa.

Wetlands Network Expansion of rice land in Asia is severely hampered by such soil constraints as salinity and sodicity, zinc deficiency, boron toxicity, iron deficiency, iron toxicity, acid sulfate soils, and organic soils. About 100 million ha of essentially idle land in Asia could be put into full rice production if these constraints can be overcome by varietal selection and soil management. Again, an integrated network is likely to be the most effective tool for overcoming these critical constraints.

Steeplands Network Large areas of densely populated steeplands occur throughout the tropics and subtropics in Asia, Africa, and Latin America. Farmers were originally attracted by the high native fertility of the soil, but population increases and crop intensification often lead to severe erosion. Integrated soil management research in steepland areas is almost nonexistent. It is also extremely complex, involving civil engineering and community action in addition to soil research. Soil erosion is the overwhelming concern; therefore, soil management techniques must ensure the development and maintenance of a continuous ground cover.

Arid Zones Network Large-scale irrigation projects continue to develop throughout the arid regions of South Asia, the Middle East, North Africa, and Latin America. While irrigation water management is clearly the overwhelming concern, the prevention of soil salinity, alkalinity, and waterlogging are major practical concerns. Among soil nutrients, efficient nitrogen management has high priority. Considering the high capital investments involved in irrigating arid regions, greater effort must be made to preserve the quality of irrigated land and prevent degradation.

Data Bank for Soil Classification and Characterization

The purpose of soil classification is to organize information so that it can be used to predict the behavior of soils, estimate their productivity, and identify their best use. It also enables knowledge and experience about a soil to be transferred to similar soils in other locations. There are several national and regional soil classification systems in use today, including the French, U.S., and Russian systems, as well as the FAO legend. Unfortunately, the multiplicity of systems
precludes ready exchange of soil information among nations or regions using different systems.

- To facilitate information exchange, it is recommended that a user-oriented soil data bank containing soil characterization data on benchmark soils from the tropics and subtropics be established to correlate soil chemical and other characterization data among countries using different classification systems.

Data from different soil classification systems can be correlated through a reference system based on Soil Taxonomy (U.S. Department of Agriculture 1975) that will be selected by contributing countries and used by them to derive soil management parameters from soil characterization data. The computer software to derive these relationships will be a major output of the soil data bank.

Operation of the data bank should be assigned to an international agency such as the proposed International Board for Soil Resource Management. The designated agency will be responsible for maintaining the data bank and for responding to requests for information and data sets by regions, countries, or soil taxa.

The proposed soil data bank will:

- Create a common language for international soil information exchange
- Promote the adoption of standard international procedures for soil analysis
- Enable soil classification to predict the behavior of soils, estimate their productivity, and identify their best use
- Enable the assembled information to be transferred to similar soils in other locations
- Eliminate duplication of effort.

Data Bank for Fertilizer Raw Materials

Fertilizers, especially for remote areas, are often so costly that farmers cannot afford to use them for food crops. Transportation and handling often account for 50 percent or more of the cost to farmers.

At the same time, such areas may have indigenous raw materials, especially phosphate rock, that could be economically used either directly or with minimal processing to produce more food.

Personnel trained to explore for such resources, and information about the resources, should be collected in a data bank. This data bank would not only note the existence of the resource and its characteristics but would also provide guidance on how it could be processed and used for the benefit of the host country or other countries in the region.
Capitalizing Costs

Developing countries should consider including phosphate rock and liming materials for acid soils, and gypsum for saline soils, in the capital costs of land preparation or reclamation. In addition, funding agencies should encourage these practices both to better protect their investments and to improve farmers' chances for success.

Soil additives that have long-term benefits should be included in capital costs, especially when land clearing or preparation costs approach $1,000 or more per hectare. Amortized over time, another $200 or $300 per hectare to assure optimal, long-term crop yields would be money well spent.

The World Bank has recently decided to include phosphate fertilizers as part of development costs to be amortized with other capital costs. It is hoped that this practice will be expanded to include other fertilizers and soil amendments that have long-term effects.

Manpower and Training

Training soil and plant nutrition specialists at levels ranging from technicians who formulate fertilizer recommendations or manage irrigation systems to sophisticated research scientists is a high priority. There are many soil scientists scattered throughout the developing world, but because of various constraints most of them are not as productive as they could be.

One constraint is insufficient training in techniques for relevant research. Formal university programs are often very specialized, with scientists calling themselves pedologists, soil physicists, soil chemists, soil microbiologists, soil fertility specialists, plant physiologists, and so forth. Opportunities for these scientists to work as part of a multidisciplinary team are too often limited and must be increased.

A broader appreciation is required of the need to manage soils and plant nutrients under tropical conditions. This constraint has been alleviated somewhat by formal graduate training in tropical soil management offered at several universities. An opportunity to conduct thesis research under tropical conditions, however, is essential.

Although needs in this area could be described in more detail, it is sufficient to state that training for national agricultural research personnel in soils and plant nutrition should be given greater emphasis and that programs should give scientists and technicians a broad appreciation of the main research constraints, many of which are identified in this report, as well as provide in-depth experience in one particular area.
Long-Term Field Research for Sustained Productivity

Although it is clearly understood that soils research must provide the basis for sustained food production, most research is necessarily of a short-term nature, and field plots are seldom carried for more than 1 or 2 years. There is a need for long-term trials planned for 10-20 years duration or longer, located on well-characterized, representative soils. The trials should compare alternative, economical soil management systems in terms of (1) productivity as a function of time, related to weather patterns, and (2) changes in soil physical, chemical, and biological properties as a result of the continuing application of soil management technology. Trials should be planned for long-term work, including plot design that would prevent contamination from adjacent plots.

Long-term trials are needed to obtain reliable answers to such questions as:

- Are yields really sustained?
- Are the soils degrading with use?
- Do deep-rooted crops actually recycle nutrients?
- What is the residual effect of phosphorus application?
- Does organic matter increase or decrease with different practices?
- What is the nutrient balance between additions, removals, and losses?
- What are erosion losses, and are they significant in relation to crop yields, etc.?

A network trial in the humid tropics has been proposed by the Amazon Agricultural Research Network (REDINAA). The trial includes simultaneous plantings to study intensively fertilized annual crops, low-input annual crop production, alley cropping, agroforestry, pure forestry, grass-legume pastures, and traditional shifting cultivation. Untouched forest is maintained as a control. Changes in soil physical, chemical, and microbiological properties will be measured periodically to ascertain which systems improve and which degrade soils in this particular environment at different management levels. The long-term productivity of the various systems will also be followed.

Long-term trials with large established plots enable reliable information to be obtained on the effects of soil management practices on soil productivity. The chemical plots at Rothamsted, England, for example, were established in the mid-nineteenth century. They continue to provide a reference for the effects of chemical additives on the productivity of soils. Similar plots on major tropical soils need to be established in the developing world to provide a reference for studies of long-term changes in the chemical, physical, and biological properties of these soils.

Technology Transfer Needs

Although workshop discussions were oriented primarily toward research priorities, and although most participants were research scientists,
it was agreed that emphasis should be given to the need for strengthening the transfer of technology. Importance was attached to three components.

1. Validation and adaptation of research results. Regardless of whether research is conducted at experiment stations or in farmers' fields, the technology developed needs to be validated and, if judged promising, adapted to local conditions. Emphasis should be given to characterizing the differences between soil, climatic, and socio-economic constraints in the locations where the technology originated and where it will be validated. Soil characterization and its translation into useful, local agronomic terms is the cornerstone of successful transfer of plant nutrition and soil management technology. Technology validation and its adaptation are the "bottom line" of all development-oriented research and are considered to be the responsibility of the national institutions.

2. Developing effective fertilizer evaluation services. In most developing countries, fertility evaluation services must be strengthened considerably if they are to provide accurate information in a timely fashion. Many such services are currently limited to persuading farmers to begin using fertilizers. Increased emphasis must be given to optimizing return on fertilizer investment. Fertilizer response trials must be performed in well-characterized soils in order to establish the limits to which information can be extrapolated. Soil fertility specialists need to include in their recommendations risk analysis in addition to the usual economic interpretations of yield response data. Moreover, fertilizer recommendations must be coordinated with supplies. Fertilizer companies, both private and governmental, have played a central role in promoting fertilizer use and making recommendations to farmers. While this fills the gap created by ineffective or nonexistent fertilizer evaluation services, the natural bias toward the companies' marketing interest naturally lessens the objectivity of their recommendations.

3. Private sector involvement. Both the public and private sectors will play critical roles if the above issues are to be resolved. Generally, the private sector has proved to be most effective when a product or service is to be sold, that is, when a profit is possible. This, of course, is true only if competition is encouraged.

The private or cooperative sector should be encouraged in all aspects of fertilizer production, marketing, and use whenever and wherever there is opportunity for adequate return on investment, including normal costs of marketing and distribution. Where these conditions do not exist, either public sector participation or subsidies will be required; otherwise, the poorest segment of the population will not be able to benefit.
REFERENCES


INTRODUCTION

The working group considered opportunities for making major improvements in Third World agriculture through research on plant-pest relationships and plant growth regulators (PGR). In keeping with the focus of CHEMRAWN II, the group's objective was to identify areas in which chemistry, in its broadest sense, could be used effectively. Examples of such areas include plant growth regulators, the molecular and biochemical basis for crop pest resistance and susceptibility, plant-microorganism interactions, and natural-product chemistry for pest control.

The health and productivity of plants are determined by countless biotic and abiotic interactions. Such critical processes as photosynthesis, nutrient and water uptake, and resistance or susceptibility to pests are governed by complex factors, including physiology, biochemistry, and genetics. These factors are affected in turn by an important set of interrelated farming practices such as crop rotation and the use of fertilizers, growth regulators, biological control agents, pesticides, and pest-resistant plants.

Since World War II, pesticides have played an important role in increasing agricultural productivity worldwide. Their use continues to grow because they provide effective control of a great many pests on a wide array of crops. However, benefits of pesticide use are partly offset by environmental and social problems, both actual and perceived. In some agro-ecosystems, for example, natural enemies of one group of pests are destroyed by pesticides when the target pest is controlled early in the season. On occasion, new pest problems have occurred under these circumstances, and as many as five additional pesticide applications have been needed to control them.

Collectively, pests (microbes, weeds, insects, nematodes, rodents, and birds) are estimated to reduce current world preharvest food production by 35-50 percent. The impact of this devastation, which is a natural phenomenon that will always be an integral component of field agriculture, can be reduced. However, experience has demonstrated that successful control of pests often requires more than pesticides.

It is generally understood that modern agricultural ecosystems, as man-made environments, exist in a dynamic state of imbalance and that
in order to sustain high levels of production over long periods of time, pests in the system must be closely monitored and managed using a variety of techniques. The working group considered research needed to develop safer, more effective pesticides and discussed needs and opportunities for studies on fundamental aspects of plant-pest relationships that would contribute to the development of comprehensive pest control strategies.

The group also considered the potential of plant growth regulators, (for example, plant hormones) for improving crop productivity. These substances are routinely used in a number of cropping systems to raise crop yields, and studies are under way to test their potential for controlling pest and pathogen populations. Careful research is needed to develop effective procedures, however, since plant growth regulators can sometimes have negative effects, including the stimulation of insect pest and pathogen outbreaks.

Future Prospects

During CHEMRAWN II and the subsequent BOSTID working group discussions, advances were noted in molecular biology and allied sciences that are providing new tools for determining the important details of plant resistance and susceptibility to pests and of how plant growth regulators function. Moreover, it was recognized that plant genetic engineering shows promise for applying this knowledge to advantage by, for example, moving genes for resistance from unrelated plant species into important crops or by designing control genes that would respond selectively to plant growth regulators.

While the long-term prospects for plant genetic engineering are enormous, much can be expected from plant science research in the near term as well, since the capabilities of existing plants have yet to be fully exploited. In either case, a serious limitation to progress is the lack of detailed knowledge of the biochemistry and physiology of plants. In addition, increased use of plant growth regulators and advances in pest control will require further studies in the areas of pest and plant ecology and more work in the field of population genetics as it relates to plant-pest interactions.

Recent advances in fundamental science should permit rapid progress in many of these areas. Molecular genetics, for example, offers microbial ecologists extremely effective tools for determining the biochemical and physiological bases for microbial behavior patterns in natural environments, including interactions with insects. Pest control research will be further aided by the availability of powerful chemical and analytical tools such as gas chromatography, mass spectroscopy, nuclear magnetic resonance, and high-performance liquid chromatography.

In order to make the best use of the knowledge and research tools available, however, mechanisms must be found to foster interdisciplinary research. Increasingly, applied plant science requires the efforts of interdisciplinary teams of molecular biologists, biochemists, plant physiologists, plant pathologists, entomologists,
agronomists, and others. The results of this research promise to make very significant contributions to the development of agriculture throughout the world.

PLANT GROWTH REGULATORS

Once the research to establish the utility and value of a plant growth regulator is completed, the yield gain is an incremental one, costing little more than the price of the chemical involved. The use of plant growth regulators has been extremely successful in controlling the ripening of sugarcane; increasing flow time of latex in rubber; controlling abscission of leaves (cotton) and fruit (apple and citrus); controlling sprouting of storage organs such as potatoes and onions; inducing rooting for propagation; increasing yields for fruits (grapes and apples) and vegetative products (sucrose in sugarcane); inhibiting grass growth; increasing palatability of grasses for livestock; and controlling flowering (induction for marketing, inhibition for crop yield increase, and timing for breeding purposes).

Postharvest losses due to deterioration of fruits and vegetables are substantial in tropical countries; plant growth regulators can be particularly useful in reducing these losses. Several regulatory chemicals have been used commercially to delay maturity of fruits, as in the controlled chemical ripening of navel oranges and pineapples. Growth regulators are more commonly used, however, to shorten time to maturity.

A research program on plant growth regulators is needed in developing countries. Since a thorough understanding of crop growth, development, and metabolism is required, it will be important to focus research on major crops for which much of the required basic information already exists.

Recommendations

- Highest priority should be given to development of a comprehensive understanding of the developmental biology of major world crops, from germination through harvest, and to the postharvest development and/or maturation of important tropical fruits and vegetables.

- High priority should be given to research on the use of plant growth regulators in vegetative crops (potato, cassava, sugarcane, sugarbeet) since they are spared the complexities of sexual development.

- Priority should be given to research on the effects of plant growth regulators on resistance to insects, diseases, and environmental factors such as drought, salinity, and acid soils.
A research program on plant growth regulators could be conducted in three stages:

1. Evaluate all existing commercial plant growth regulators to determine any effects on the test crop(s).

2. Evaluate experimental synthetic compounds available from industry. Appropriate arrangements should be made with the private sector to supply such experimental compounds.

3. Evaluate naturally occurring, biologically active molecules for commercial utility. Less active molecules should serve as models.

The three-stage evaluation could be successfully completed in about 5 years. Support required would be modest if a good relationship is established with a private company(ies). Governmental and plantation crop experiment stations are logical starting points for this research activity.

NATURAL PLANT GROWTH REGULATORS (ALLELOPATHY)

Allelopathy refers to biochemical interactions between all types of plants, including microorganisms traditionally placed in the plant kingdom. The interactions that occur may be inhibitory or stimulatory to one or both organisms involved. The deleterious effects of weeds on crops are well known and often exceed those attributable to simple competition for water, nutrients, air, and sunlight. Weeds may negatively affect rates of germination and growth and cause poor fruiting and flowering as well as overall loss of plant vigor. On the other hand, stimulatory effects occur among certain plants. Opportunities exist, particularly for small farmers, to exploit positive effects through intercropping. However, research by plant and chemical scientists is needed because allelopathic mechanisms are largely unknown, even when the causative chemical(s) has been identified. The following examples illustrate the extent of allelopathy.

Purple nutsedge (Cyperus rotundus) is a serious weed in 52 countries and a common weed in 22 others. It is known to cause reductions of 35–90 percent in yields of crops such as garlic, okra, carrots, green beans, cucumbers, cabbage, and tomatoes. Its allelopathic effects on several crops have been demonstrated. Including purple nutsedge, the ten worst weeds in the world are bermuda grass, barnyard grass, jungle rice, goose grass, Johnson grass, guinea grass, water hyacinth, cogon, and lantana. Although all are widely distributed in developing countries and interfere with crop yields, for the most part their allelopathic effects have not been determined. Moreover, clovers, rice, eggplant, foxtail millet, sorghum, and several cereal crops including rice have been shown to have markedly lower yields because of allelopathic effects on themselves. Research is needed to help farmers minimize the detrimental effects of allelopathy and thus increase yields.
In the area of growth promotion, corn cockle has been shown to stimulate the growth of wheat when a relatively low population is present in the field. The effect is being used to advantage in Yugoslavia. Also, plants such as maize and legumes have been selected or developed to stimulate growth and yield of other crops in mixed cropping systems. This concept should be extended to important crop plants in developing countries to help increase crop yields with minimal capital investment.

Natural products have potential as herbicides. For example, rhizo- bitoxine, an uncommon amino acid produced by a mutant strain of Rhizobium japonicum, is promising as a selective herbicide. Several natural polyacetylenes have also been shown to be effective. Research is needed to develop their commercial potential and to identify other allelopathic agents that could be used as herbicides.

The effects of weeds on soil microorganisms is just beginning to be understood. Some weeds inhibit growth and nitrogen fixation by blue-green algae, free-living and symbiotic nitrogen-fixing bacteria, and nitrifiers. Other weeds, including heather and lichens, have been found to inhibit mycorrhizae. The extent of this phenomenon in crop plants should be investigated.

Research on allelopathy in tropical agriculture will require collaborative efforts between scientists in developed and developing countries. Institutions in the United States with allelopathy research programs include Michigan State University, University of Wisconsin, University of Illinois, University of California at Santa Barbara, University of Oklahoma, and Cornell University; scientists are working on allelopathy in Taiwan, Korea, Nigeria, Senegal, India, and Mexico.

Recommendations

- Highest priority should be given to research on the use of mulches of both common weeds and allelopathic crop plants to control weeds.

- High priority should be given to research to determine allelopathic effects of common tropical weeds and crops in order to minimize inhibitory effects and to better exploit stimulatory effects.

- High priority should be given to the isolation, identification, and testing of allelopathic compounds for use by farmers in developing countries.

BIOCHEMICAL BASIS OF CROP RESISTANCE TO INSECT PESTS

Since they have coexisted with pests for centuries, many plants have evolved natural resistance mechanisms. On the one hand, resistance is often associated with less desirable plant types in terms of important
factors such as yield and taste. On the other hand, plants with high yields and other good agronomic characteristics are not necessarily pest-resistant. Even a single pest such as the Hessian fly can seriously limit the yield potential of ordinary wheat cultivars in North America. Likewise, rice crop losses to the brown plant hopper in Asia can be very serious for varieties lacking resistance. Host-plant resistance to pests can play a major role in pest management in combination with other control measures.

In breeding pest-resistant varieties, it is important to have an interdisciplinary program for rapidly screening resistant donors and for transferring resistance to suitable cultivars. Moreover, knowing precisely why varieties are resistant or susceptible to pest attacks is important. Lack of this knowledge might lead to selection and breeding for plant characteristics that have no bearing on host-plant resistance. For example, susceptibility of the rice plant to stem borers was long considered to be highly correlated with morphological characteristics such as plant height, flag leaf width, and stem diameter. However, recent investigations reveal that plant chemistry is much more important.

The continual evolution of biotypes of certain insect pest species capable of overcoming specific host-plant resistance underscores the need for a better understanding of the basis of host-plant resistance or susceptibility. In some cases, differential behavioral and physiological responses of insect biotypes to host-plant chemicals have been observed, but further studies are necessary.

Chemical defenses of plants frequently are attributed to the presence of insecticidal components, generally extracted by grinding the entire plant. This is inadequate. Both qualitative and quantitative differences in defense chemicals should be studied with respect to the individual plant parts or tissues attacked by the pest and the possible effects of seasonal fluctuations. Effects of these chemicals on pest behavior and physiology should be tested.

Research is needed to determine the genetics of resistance based on the inheritance of defense chemicals. Susceptible and resistant varieties should be compared. If resistance involves more than one defense chemical, it may be possible to develop a relatively stable type of resistance since pests are not likely to overcome sensitivity to several substances simultaneously. Proper understanding of the mechanism of host-plant resistance can lead to breeding varieties with long-term resistance. Major constraints to an interdisciplinary program for breeding pest-resistant cultivars include inadequate analytical and bioassay facilities and the lack of formal working relationships between chemists and entomologists. This is important since entomologists are generally not well versed in plant chemistry.

- It is recommended that crop improvement programs give high priority to understanding the chemical components of the genetic basis of plant resistance to pests.

Many programs dealing with major world crops are located in developing countries that do not have the necessary bioassay and
cooperative efforts, the chemical basis of host-plant susceptibility or resistance could be established, which would enable plant breeders to develop more reliable pest-resistant varieties. Experience gained from this cooperation will have application in varietal improvement in developed countries as well.

PESTICIDES AND PLANT-PEST INTERACTIONS

Pesticides will continue to be an important control technology. More judicious use of pesticides is possible if pest and natural enemy populations are monitored to determine when and how much pesticide is needed. At the same time, it is often possible to use relatively specific pesticides that destroy target pests while having minimal impact on nontarget organisms.

A need exists to develop a greater number of specific pesticides. For example, certain herbicides such as endothal will selectively kill grasses in legume crops while having minimal effects on nontarget vegetation and animals. In other cases, mite pests can be destroyed with little or no impact on beneficial insects and microorganisms.

Improved pesticide application techniques are also needed since only about 1 percent of the applied pesticide hits target organisms. One improvement has been the development of granular pesticides that reduce spray-drift problems, but other approaches must be encouraged.

Some pesticides affect crop plant physiology, altering its response to pests. For example, use of the herbicide 2,4-D on corn for broadleaf weed control resulted in a threefold increase in pest aphids and significantly more susceptibility to corn smut disease. In another case, when 2,4-D was applied to Sudan grass (Sorghum sudanense), the cyanide content of the grass increased significantly, which may have an impact on feeding animals. Additional research is needed on the indirect effects of pesticides on plant-pest relationships.

The United Nations has reported that pesticide resistance currently exists in about 400 species of pests and is one of the world's most serious environmental problems. Pesticide resistance may result in increased pesticide use as well as increased crop losses, thereby generating serious economic losses and public health problems. Mechanisms of pesticide resistance must be understood in order to develop strategies for circumventing it. Some preliminary evidence with the housefly suggests that using as many as six different pesticides in rotation can reduce the development of resistance. Other studies have suggested that the use of biological and cultural control alternatives in combination with pesticides can prevent or limit the development of pesticide resistance.

Recommendations

It is recommended that development assistance agencies evaluating research proposals in the area of pesticide use and its impact:
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- Give the highest priority to proposals to investigate policies and practices that will minimize the development of pesticide resistance.

- Give high priority to investigations on the indirect impact of pesticides and herbicides on plant-pest interactions. Herbicide use, for example, can alter a plant's physiological capacity to resist certain pests. This research should include some of the major herbicide groups and major crops such as grains, vegetables, and fruits.

- Give high priority to the development of relatively specific pesticides.

- Give high priority to development of new application technologies that enable more of the pesticide to reach the target pests.

**NATURAL PRODUCT RESEARCH FOR INSECT PEST CONTROL**

Historically, plants have been recognized as a vast natural resource of biologically active chemical compounds useful in medicine and agriculture. The earliest insecticides were plant derivatives and included nicotine, rotenone, and pyrethrins. Simple extracts of plants are used today by subsistence farmers to protect crops. The use of crude botanicals in insect control is ideally suited to the small farmer for whom conventional insecticides are often too expensive or unavailable. Also, proper use of commercial toxicants often requires apparatus, protective clothing, and knowledge of farm practices beyond the capabilities of the subsistence farmer.

Although most botanical insecticides depend on direct toxicant action, basic research has revealed many new approaches to pest control derived from detailed understanding of plant-pest interactions controlled by a plant's natural defense chemicals. Furthermore, a number of subtle defense mechanisms of plants that disrupt pest growth, development, and reproduction are now recognized. Many of these compounds are not intrinsically toxic but exert their action through the disruption of endocrine-mediated processes. Examples include insect juvenile hormone mimics from the balsam tree (Abies balsamea) and the herb, sweet basil (Ocimum basilicum). Chemically optimized analogs of juvenile hormones are now registered for commercial application, although similar naturally occurring components could be used directly by the subsistence farmer.

In addition to insecticidal and insect growth regulator chemicals, many plants contain insect antifeedants including azadirachtin from the neem tree (Azadirachta indica) and active compounds from Croton, Withania, and Warburgia spp. Other plant-derived chemicals of potential use in plant protection include attractants and repellents.
The enhanced understanding of the role of minor plant chemicals in plant protection that would result from basic chemical research into plant-pest relationships will provide new approaches to plant protection of value to the marginal farmer. Scientists in developing countries are familiar with the use of botanical preparations in medicine and agriculture and are enthusiastic about the possibility of developing and using natural or cultivated botanical resources as opposed to expensive conventional commercial pesticides. Several excellent research centers in developing countries are involved in natural product chemistry and seek linkage with counterparts in developed countries. In some instances, such scientific linkage could result in a "reverse" transfer of technology. For example, while natural insecticides and insect growth regulators might be cultivated or collected locally for use by farmers in developing countries, certain of these compounds could also serve as prototypes for improved commercial products for use in developed country agriculture.

A research program in natural products for insect pest control should have two major objectives:

1. To discover, through the systematic biological evaluation of selected botanicals, naturally occurring chemicals of potential utility for pest control in agriculture and public health protection.

2. To isolate and characterize natural compounds with insecticidal, growth regulant, antifeedant, repellent, and attractant properties that can serve as models for highly effective synthetic compounds.

Recommendation

- It is recommended that collaborative international research programs be established with support from development assistance agencies to produce and standardize simple and effective botanical formulations for use by small farmers.

Laboratories that can collaborate in the area of natural products for pest control should be identified and scientific linkages established. Through collaborative programs, collection of plant materials, bioassays, and the isolation of active compounds can be carried out more effectively. Scientists in developing countries have unique access to underexploited plant resources and much of the knowledge of their potential biological activity. The work of these scientists would be vastly augmented by strong scientific linkages to laboratories in developed countries that possess the sophisticated instrumentation usually required for isolation and identification of minute quantities of complex natural product chemicals.
Training in modern bioassay techniques should be developed as an important component of the collaborative effort. Insect and other pest test systems used for such bioassays should be comprehensive and representative of targeted pest species.

**BIOLOGICAL CONTROL OF WEEDS AND INSECT PESTS**

Biological agents such as viruses, bacteria, protozoa, nematodes, mites, and insects have long been used to control insect pests and weeds. Worldwide at least 175 pest species have been effectively controlled with biological control agents. An early success was achieved by the introduction of a wasp parasite in Mauritius in 1900 in an effort to control the lima-bean pod borer. The wasp has provided complete, permanent control of the pod borer. Another outstanding success has been the introduction of the cactus moth to control pest cacti in Australian pastures.

When a biological control agent is introduced, however, a danger exists that it may also attack nontarget, beneficial species. This problem occurred when the lace bug was introduced into East Africa but later became a pest of the sesame crop.

Some biological agents are mass cultured and selectively released for pest control. For example, the parasitic nematode *Neoaplectana carponcapsa* has been proved effective in Egypt against a number of soilborne insects, including leopard-moth borers, on apple, olive, and pear trees. Another example is control of lepidopterous pests by the use of the bacterium, *Bacillus thuringiensis*. This bacterium can be mass cultured in the tropics and subtropics for control of pest caterpillars in food crops with minimal danger to nontarget organisms, including humans.

Viruses have been used effectively to control insects, weeds, and plant pathogens. As few as four virus-infected caterpillars ground up in water and sprayed over a hectare of cabbage can effectively control the cabbage looper. Similar techniques employing viruses can be adapted for use by small farmers.

**Recommendations**

It is recommended that development assistant agencies evaluating research proposals in the area of biological pest control:

- Give the highest priority to research proposals that would improve the collection and/or culture and use of biological pest control agents.
- Give high priority to ecological studies to identify potential biological control agents.
- Give high priority to studies of the genetic aspects of biocontrol agents and their target pests.
Some biological control agents with potential for insect pest control in tropical food crops include the nematode Neoaplectana carpocapsae, the nuclear polyhedrosis virus, and the bacterium Bacillus thuringiensis. For the nematode *N. carpocapsae*, research is needed to develop methods for its use in arid tropical environments. Research is needed to develop simple techniques for collecting, storing, and applying nuclear polyhedrosis viruses for control of *Heliothis* spp. that are pests of corn, pepper, and cotton crops in the tropics. Virulent strains of *Bacillus thuringiensis* for the control of tropical caterpillar pests of food crops should be identified for use as commercial, mass-cultured biological agents. Biological agents for the control of major tropical weed species need to be identified.

**PLANT-MICROBE INTERACTIONS**

The maximum yield potential of crops is rarely approached, even for irrigated agriculture on fertile land, because of the large number of pests that infest and infect plants. The root system is a particularly vulnerable part of the plant, and all roots are infected by numerous pathogens. The effect of pathogens on yields is easily shown by growing parallel sets of plants in natural and fumigated soil in a situation where water and nutrients are not limiting. In many cases, the yield increase in pathogen-free soil is double or more.

Fortunately, in nature, the ability of pathogens to attack plants is offset by antagonistic or parasitic microorganisms. In so-called disease-suppressive soils, for example, disease does not occur or is limited even though the pathogen is present. In some cases, the pathogen may not even become established in the soil.

There is now experimental evidence indicating that the composition of microorganisms in the rhizosphere can be altered and that certain "beneficials" can be used to inhibit pathogens. The result is healthier root systems and more productive plants. Crop rotations and many other cultural practices have their basis in the indirect manipulation of soil microflora to produce healthier root systems.

Because it is not possible to alter root microflora without affecting the populations of microorganisms involved with nitrogen and phosphate dynamics, the study of root microflora must be a multi-component investigation. Understanding the ecology and physiology of antagonistic and parasitic microorganisms and identifying the principal factors responsible for their ability to affect pests should lead to their use as effective pest control agents.

The overall objective of research in this field is to develop techniques to increase crop production by manipulation of plant-microbial populations in the rhizosphere. Once key microorganisms have been identified, it should be relatively simple to adapt them to agriculture in developing countries. Genetic engineering promises improved strains and, possibly, new organisms tailored for specific purposes.
Research should be undertaken on the following topics:

- **Microbe-plant interactions in relation to pest control.** Research programs should study two elements: (1) the role of plant exudation in the inhibition or stimulation of (a) pests and beneficial microorganisms, (b) the plant itself, and (c) other varieties of plants; and (2) chemical interactions between pests and antagonistic, parasitic, or symbiotic microorganisms.

- **The role of rhizosphere microorganisms related to nitrogen and phosphate dynamics.**

- **The elaboration of plant growth regulators by microorganisms and of microbial growth regulators by plants.**

Some examples of specific research projects are given in the following sections.

**Role of Host-Host Exudates**

Most infective soilborne microorganisms survive by remaining in a dormant or resting state until a suitable host is available. For example, the resting structure of the Fusarium bean root-rot pathogen germinates in the presence of seed and root exudates. Similarly, sclerotia of Sclerotium cepivorum and eggs of Globodera yostochiensis germinate and hatch only when stimulated by exudates from the onion and potato, respectively. These survival mechanisms allow pests to synchronize their life cycles with that of the host. Alterations in quantity or quality of host exudates may greatly reduce the capacity of the pest to infect the host. Also, determination of specific constituents of exudates may enable the use of techniques to trigger activity (and death) of the pest in the absence of the host.

The composition of root exudates and consequential rhizosphere effects could be changed both quantitatively and qualitatively through foliar application of major plant nutrients such as nitrogen. Chemical foliar sprays alter the phyllosphere microflora as well as the plant physiological system, resulting in an altered rhizosphere. Such a change could have beneficial effects by reducing the pest population with resultant reduced root infestations. A better understanding of the relationships between rhizosphere microorganisms and root-infecting pathogens would help in the development of effective control measures.

**Chemical Interaction Between Host, Antagonists, and Parasites**

Many opportunities exist for using specific microorganisms to inhibit pathogens and prevent the onset of disease. However, much greater understanding of the ecology, physiology, and genetics of pathogens and
their antagonists and parasites is needed. An outstanding example of the use of a microorganism to control a pathogen is the control of crown gall, caused by Agrobacterium tumefaciens, using an avirulent strain (K-84) that produces a nucleotide bacteriocin at the site of infection. In Mexico, rootstock of plants susceptible to crown gall is dipped or sprayed with K-84 bacterium, which is easily cultured and suspended in water. Similarly, transplants of rice and other crops could be treated with beneficial bacteria with minimal disturbance to standard cultural practices. Seed companies are investigating pelleting seed with specific bacteria. Although there are many other examples, the results have not been as striking. With time, however, it should be possible to identify the microorganisms that play important roles in protecting plants from pathogens. Then it may be possible to develop technology to convert a disease-conducive soil to a disease-suppressive soil.

A number of microorganisms have recently been used to change the composition of rhizospheres and thereby increase plant growth and yield. Pseudomonads, for example, have been found to inhibit Gaumannomyces, which seriously affects wheat yields. Research in the last year suggests that specific bacteria are antagonistic to nematodes. Infection by root knot and cyst nematodes of various plants was reduced as much as 50 percent by treating transplants with certain bacterial strains. Other examples of the successful use of microorganisms to control disease include pelleting cotton seed with manure to protect against cotton blight and dipping seed in water suspensions of suppressive soil.

AGRONOMIC PRACTICES

Agronomic practices play an important role in minimizing crop losses due to pests. Examples include cropping systems (crop rotation, intercropping, and sequential and multiple cropping), use of fertilizers, management of water and crop residues, and use of improved cultivars that are high yielding, nonlodging, pest resistant, and have an intensive photo period. Practices that should increase yields, however, often encourage pests, which can cause significant net yield losses. Experience has shown that pest control must be comprehensive and include agronomic practices that are nonpolluting, compatible with other practices, and easily understood by farmers.

Unfortunately, current agronomic practices often have unexpected effects on pest populations and do not result in the desired higher yields. For example, extensive planting of high-yielding varieties of rice, with a limited genetic base for pest resistance, has been shown to encourage the development of new biotypes of rice pests, including the brown plant hopper and tungro virus. Also, heavy application of nitrogenous fertilizers has increased the susceptibility of many crops to pests. Finally, desirable plant varieties introduced from other countries may be accompanied by pests that cause even more damage in their new environment than in their country of origin.
A clear example of the problem rice farmers face relates to plant spacings. It is known that when plantings are too closely spaced, microclimates are created that are favorable to pest infestations. Densely planted rice has a closed canopy that prevents penetration of sunlight and restricts air circulation near the ground. The resulting microclimate is ideal for proliferation of the brown plant hopper, and yields are consequently reduced.

Additional data on the relationship of agronomic practices and pest incidence are needed. With knowledge of the secondary effects of agronomic practices, farmers will be better able to adapt to conditions that will minimize crop losses due to pests and maximize yield.

Research priorities in agronomic practices are (in rank order):

- Pest population dynamics in different cropping systems; for example, population dynamics of the corn borer, *Ostrinia nubilalis*, under continuous cropping or alternately with other crops in Africa, tropical Asia, or Latin America.

- The effects of predators and parasites in different cropping systems; for example, the parasitism of the rice gall midge, *Orseolia oryzae*, by the wasp *Platigaster*, as affected by early or late planting of the rice crop.

- Relationships among soilborne pests, agricultural chemicals, and plant growth under different cropping systems. For example, cabbage is infected by a soil fungus that causes club root. Chemical control is needed unless the cabbage is planted following rye or corn.

- Pesticide requirements under different cropping systems. For example, late planting of corn requires treatment of seeds with a fungicide to avoid crop destruction by downy mildew, *Sclerospora*. Early planting reduces labor and the use of fungicides because the likelihood of infection is low.
INTRODUCTION

Contrary to earlier predictions, world food production has been able to keep pace with population growth. Production disparities, however, leave many countries in severe deficit and a fortunate few with occasional surpluses. The differences are largely a result of the way economic and political systems provide incentives for increasing the efficiency of growing and marketing food. In developing countries, particularly those with serious food shortages, there has been limited emphasis on processing and marketing food or developing food industries. Most food is eaten directly by those who produce it or is exported in raw form from the region. Value is seldom added through processing and packaging and, thus, opportunities to generate employment and income are lost.

As urbanization inevitably increases, the traditional practice of producing and processing food on a subsistence basis must be upgraded. Providing adequate food for displaced populations will require more complex systems of producing, storing, transporting, and marketing food and agricultural commodities. Although transfer of modern food technologies and industrial processing plants to developing countries has frequently proved difficult and uneconomic, little research has been done on traditional technologies, which are highly developed in a number of densely populated countries.

This report summarizes a number of approaches and opportunities for consideration by AID and other donor agencies and the developing countries they assist. The working group on food science and technology examined research needed in the chemical aspects of food production, preservation, processing, storage, and distribution, especially those aspects that could help improve the quality and quantity of foods consumed by people in developing countries, particularly those sections of the population (urban and poor) with lowest nutritional status. The process of selecting and weighting these research opportunities is described at the end of the report.

Two main areas of priority are described in some detail:

1. Upgrading traditional fermentation technologies and transferring them to other locations
2. Developing better low-cost packaging materials for transportation and storage of food products in the tropics.

Other improvements in food technology that could have significant benefits in particular locations include:

- Fish preservation
- Reducing lactose intolerance and producing milk extenders from oilseeds
- Producing stabilized rice bran oil
- Improving sorghum digestibility.

Group discussions were based on the following premises:

1. Developing countries currently have
   a. Resources that, although used as traditional foods, are not used with optimum effectiveness.
   b. Natural resources that are under- or unused but that could be effectively used as foods or transformed into foods and food ingredients.
   c. Potentially valuable food processing and agricultural wastes that are presently discarded but could, if recovered, help improve a community's economic position.

2. Chemical technologies exist now, or will in the near future, that
   a. Could be directed toward improving the safety, nutritive value, storage life, etc., of traditional foods.
   b. Could lead to lucrative use of under- or unused and wasted food resources and by-products, with concomitant nutritional and economic benefits.

The working group did not attempt a comprehensive study of research needs in all areas of food science and technology; however, within the time available, it assembled the best ideas of an experienced group of specialists involved in various aspects of food science and technology. Current priorities and new directions based on recent work are indicated for those problems that are most susceptible to resolution, through research and development, for the benefit of the greatest number of people in the developing world.

Participants also identified institutions conducting research in each of the topic areas. A list of these institutions and research contacts, where known, appear at the end of each section. The list is by no means complete but rather includes the institutions and individual researchers known to members of the working group.

Selection of Topics

Establishing a suitable food industry is an urgent priority in many developing countries. The introduction of modern industrial food
processing plants is often unsuccessful because of high costs, consumer resistance, quality control problems, and reliance on imported components. Traditional technologies, especially fermentation procedures, play an important role in meeting food needs but have received little research attention. Research on small-scale processing and on upgrading traditional methods should receive priority until the benefits and economies of larger scale modern processes are well established.

Priority research topics were selected from:

- Recommendations for action offered by the papers presented at the CBEMBAWN II conference, and by the 63 poster-session papers submitted to the conference
- Recommendations and ideas that emerged from conversations of members of the working group with scientists attending the conference
- Discussions among members of the working group in the course of their post-CBEMBAWN deliberations.

It was initially decided to examine the following seven groups of commodities to identify problems and opportunities for intervention and research:

- Fish and other aquatic food resources
- Fruits and vegetables
- Meat and milk
- Oilseeds and legumes
- Cereals and grain legumes
- Roots and tubers
- Water

The availability of water of sufficient quantity and quality, both for industrial use and home consumption, continues to be one of the most serious constraints. However, the group agreed not to discuss water availability as a separate topic because it fell outside the expertise of most of the working group members and would be covered by the working group on aquaculture.

Research priorities in each commodity category were discussed and were then ranked in order of priority according to an objective numerical analysis (see "Evaluation and Ranking of Priority Research Topics"). It became evident that two additional areas of research were required that were common to all seven categories: (1) applying fermentation processes to produce, process, and preserve food, and (2) packaging materials for the tropics. The latter emerged as a priority because of its general importance to all commodities, because chemical research can help solve problems in development of tropical packaging materials, and because it would not be treated by the other working groups.

Attention to the nutritional problems of sub-Saharan Africa, and to the need to stimulate growth in the fledgling African food industry by
upgrading traditional food processing technologies, were particularly recommended.

It was also agreed that in the Indian subcontinent, where problems are different from much of the tropics because of differences in food production in subtropical areas and because of the sophistication of the Indian food industries, special note should be made of the need for research on fruit and vegetable production and preservation as these are disproportionately important problem areas.

FERMENTATION PROCESSES

Biological Enrichment of Foods

It is well recognized that protein in food staples can be improved by enrichment with amino acids: for example, cereals with lysine; legumes with methionine and cystine; and maize with tryptophan and lysine. It is also known that people who consume principally polished rice are often borderline in their intake of thiamine and the B-vitamins and that people who eat principally maize often lack niacin. Vitamin and essential amino acid enrichment can be achieved by adding synthetic amino acids or vitamins, but this process increases cost and is often logistically impossible.

Biological enrichment of traditional foods—a process that requires no expenditure for the purchase of amino acids or vitamins—is an alternative. Foods, particularly fermented foods, can be enriched biologically if the proper microorganism is used. *Amylomyces rouxi* and *Endomycopsis burtonii* (found in Indonesian tapè) synthesize thiamine, thereby increasing it 300 percent and selectively increasing the lysine content of rice by 15 percent. *Klebsiella* spp. in Indonesian tempeh synthesizes vitamin $B_{12}$. It has also been used to enrich Indian idli where there is evidence that *Leuconostoc mesenteroides* increases methionine content. *Rhizopus oligosporus* (the Indonesian tempeh mold) synthesizes riboflavin, pyridoxine and niacin, while lysine-synthesizing yeasts are available for breadmaking.

There are hundreds of edible molds, yeasts, and bacteria used in food fermentations throughout the world, many of which have unique synthetic abilities for producing enzymes, essential amino acids, and vitamins. Only a few have been thoroughly studied because of the difficulty of working with mixed cultures and because analytical techniques for determining minute amounts of complex organic molecules have only recently become available.

Means now exist to survey organisms known to produce essential food nutrients and to identify strains that produce larger amounts. This is a prerequisite to the application of new biotechnological techniques in the food industry.

It is therefore recommended that:

- A central culture collection be established (perhaps as a subsidiary of the World Culture Collection in Brisbane, Australia) for deposit of all available food fermentation
organisms, and that a laboratory or a network of laboratories be established to study these cultures and systematically catalog their capabilities for producing enzymes (such as amylases, proteases, and lipases) and for synthesizing essential amino acids and vitamins.

- A bulletin be published listing microorganisms available from the culture collection and stating their special synthetic capabilities and preferred substrates. Organisms with high-yielding capabilities should be made available for use in the biological enrichment of fermented foods wherever the need exists.

- Because breads are now consumed worldwide, a special research project should be established to study the use of newly available lysine-synthesizing yeasts for breadmaking in developing countries.

Production of Breads Without Use of Wheat or Rye Flours

There is considerable interest in the production of breads in areas where wheat or rye are unavailable or must be imported. Centuries ago the Indians developed a fermentation process in which rice and a legume are made into leavened breadlike cakes (idli and dosai). The process involves soaking rice and black gram dahl (or soybean cotyledons) separately and then grinding them with water to form a batter that is fermented overnight with a starter culture. The dough rises due to the carbon dioxide produced in the batter through the action of the bacterium Leuconostoc mesenteroides and is steamed or fried as a pancake. This fermentation process could be adapted to other starch substrates or legumes.

- It is recommended that a research project be organized in Africa and Latin America to adapt the Indian fermentation process, substituting cassava starch for wheat or rice, to produce leavened breads or pancakes. Such a process will have two beneficial effects: (1) it will provide new breadlike products to consumers of cassava, and (2) the products, being a combination of starch and a legume (mung bean, soybean, groundnut, etc.), will have a much higher nutritive value for those who depend on cassava as a major staple in their diet.

Nutritional Significance of Fermented African Cereal Grain, Yogurtlike Beverages, and Porridges

The diet of hundreds of millions of African people is based on cereal grains such as maize, sorghum, and millet, and tubers such as cassava. Nigerian oyi, Kenyan uji, and West African gari are fermented to yield
yogurtlike beverages, porridges, and meals. Research on these traditional fermentation processes has only begun, having received relatively minor attention compared to more conventional food production and processing research.

- It is recommended that traditional African cereal grain fermentations be studied to determine their essential microorganisms; changes in proteins, lipids, and other components during fermentation; optimum conditions for fermentation; and stabilization of the product. When these fermentations are better understood, they can serve as model systems for designing similar fermentations in other parts of the world where they can help improve the nutritional status of low-income people.

Effect of Processing and Fermentation on the Content of Mycotoxin in Cereal Grains and Legumes

Most cereal grains and legumes in the developing world contain varying amounts of mycotoxins such as aflatoxin. Fermentations with *Rhizopus oligosporus* and *Neurospora sitophila* in Indonesian tempeh and oncom are reported to cause a reduction in the *Aspergillus flavus* activity and aflatoxin content of substrates such as peanut (groundnut) press cake by as much as 50 percent (Winarno 1979). Mycotoxin control is of great importance to human health.

- Research is needed to determine how various food fermentations affect the natural content of mycotoxin in various substrates. The study should include a search for the mycotoxin, if any, produced by accepted "edible" strains of microorganisms used in food fermentations around the world.

Separating Coconut Oil and Protein by Fermentation

Production of high-quality coconut oil and recovery of high-quality protein from the meat in a form suitable for human consumption remains a challenge for food researchers (see also National Academy of Sciences 1974). The traditional dry copra process, in which the endosperm is extracted from split nuts and dried to produce copra, involves pressure extraction of the copra oil with varying amounts of heat. The resulting press cake contains protein, sugar, vitamins, minerals, and some residual oil.

Copra is usually shipped in international commerce prior to processing and is frequently infected with molds and infested with insects. There is no premium on quality because the oil is used primarily for soap manufacture rather than edible oil. As a result, the oilseed cake is fit only for animal feed, and the oil has to undergo careful refinement before it can be used in cooking.
If the oil is efficiently extracted, defatted coconut press cake contains as much as 20 percent protein of good quality but has a high fiber content that must be removed. It is doubtful that traditional methods of drying copra can be sufficiently refined to yield ingredients for human foods. However, copra protein is much more needed in the countries of its origin than in industrial countries where it ends up as animal feed. Moreover, coconut protein is unique among vegetable proteins in that it coagulates when heated, like egg protein, and can therefore be used as a substitute for undenatured egg protein by the food industry.

An alternative method of producing food-grade oil is wet processing (Hagenmaier et al. 1973). Fresh coconut meat is removed from the shells and immediately processed to oil and protein under sanitary conditions. Wet processing is the basis of the desiccated coconut industry, which shreds, processes, and dries coconut. The product is nutritious, but it is expensive and is therefore used mainly as a condiment. Costs are high because the process has to be done carefully with heat treatment to hold Salmonella organisms to acceptable levels.

Grinding fresh coconut meat with water and filtering the mixture yields coconut milk, an emulsion containing oil and soluble protein. Experiments have demonstrated that certain bacteria will grow in coconut milk, break the emulsion, and separate the milk into excellent-quality coconut oil and a high-quality, relatively undenatured protein (Puertollano et al. 1970). The above fermentation, which uses lactic acid bacteria, has an advantage over other wet processes in that it lowers the pH, which makes the substrate less hospitable for the growth of other toxin-producing organisms such as Salmonella and therefore eliminates the need to heat the substrate. As a result, the oil is protected from oxidation and rancidity, and the protein is protected from denaturation, making both products potentially more valuable. The process, however, has yet to be applied on a pilot scale. Research with other organisms could result in more efficient ways of separating oil and protein to make commercial wet processing economic.

A pilot plant for wet processing was established in the Philippines about 10 years ago; however, the process did not employ fermentation and was abandoned due to technical and economic problems. Current needs, new market opportunities, and the potential of fermentation processes are encouraging and make further research particularly attractive and potentially important.

- It is recommended that research on wet processing of coconut be conducted with the following objectives:
  - Develop the most efficient methods of grinding coconut meat with water to extract maximum oil and protein.
  - Develop the most efficient methods of removing insoluble fiber from the milk and the most economic method of recovering edible solids from coconut.
  - Screen acid-producing organisms for those most effective at breaking the emulsion and separating coconut protein from oil, water, and other components.
Improving the Protein Value of Cassava by Fermentation

Cassava is a staple for millions of people. With a protein content of only 1-2 percent, however, cassava cannot satisfy dietary protein requirements.

In fermentation of Indonesian tapé ketella, cassava tubers are peeled and steamed; a mold (Amylomyces rouxii) and a yeast (for example, Endomycopsis burtonii) overgrow the cassava tubers. The microorganisms use a portion of the starch, thereby increasing the total protein content of the food to 3-4 percent and even higher if inorganic nitrogen is supplied. Lysine and thiamine (vitamin B₁) are selectively synthesized. The cassava develops a sweet-sour flavor that is highly acceptable to Indonesians. The final product is consumed directly or is sun dried and used in soups (Hesseltine and Wang 1981).

- It is recommended that a research project be established in areas of Africa and Latin America, where cassava is eaten, to determine if the fermentation process that produces Indonesian tapé ketella might be adapted to produce a product from cassava that has improved protein value and is acceptable to the people in these areas.

Meat-Flavored Sauces, Pastes, and Meat Substitutes

Although there is a great need for protein in the diet, meats are frequently too expensive for many people. Technology exists, however, to produce meatlike vegetable protein products from soybean, groundnut, coconut, and similar oilseed press cakes. A by-product of the huge international vegetable oil industry, press cakes have been used traditionally as animal feeds. Similarly, vegetable protein hydrolysate cubes are widely used in African cooking. These cubes could be produced locally from press cakes, cereal grains, and legumes, but they are generally imported.

Processing could be done locally by hydrolysis with hydrochloric acid, followed by neutralization with sodium hydroxide, yielding a salty meat-flavored sauce or paste. However, a much higher quality product, organoleptically and nutritionally, can be obtained using the fermentation processes that produce the well-established Chinese soy sauce or Japanese miso. These fermentations use amylases, proteases, and lipases produced by Aspergillus oryzae and Saccharomyces rouxii.

Currently available extrusion processes should be adapted to produce culturally acceptable textured products that can be marketed as meat extenders and substitutes in developing countries. This should be done in conjunction with the private sector to ensure that the products are marketable.

Another low-cost method of introducing meatlike texture into cereal grain/legume/oilseed press cake substrates is the Indonesian fermentation in which molds such as Rhizopus oligosporus or Neurospora sitophila overgrow the substrate to produce a firm, meatlike cake (oncom) that can be sliced or cut into chunks for use in soups. Although these
products are highly acceptable in Java and have shown a remarkable degree of acceptability among American vegetarians, they are largely unknown in Latin America, the Middle East, and Africa, where the need for low-cost, protein-rich meat substitutes is greatest.

- It is recommended that a research project be established in each of the major geographic areas of Africa, the Middle East, and Latin America (perhaps in conjunction with private enterprise) to produce vegetable–protein meat substitutes in experimental or pilot-plant quantities and to determine costs of production and product acceptance by local consumers. The objective is to use locally available, low-cost raw materials such as oilseed press cakes and cereal and legume by-products to produce meat-flavored sauces, pastes, and meat extenders or substitutes. In addition to improving protein nutrition, it would help to develop a small, local food industry.

**Acid Fermentation and Pickling of Tropical Fruits and Vegetables**

In temperate regions, a variety of traditional processes have been used to preserve and store fruits and vegetables over the winter. In many parts of Europe, Asia, and North America, cabbage and other brassicas are made into sauerkraut or its equivalent by acid fermentation, with or without salt or other condiments that have antibacterial qualities. Pickling vegetables with vinegar and preserving fruit with sugar are standard, well-established, low-cost processes used in rural areas to preserve food against future shortages.

These technologies have been used very little in the tropics where fresh fruits and vegetables are often available year-round. Exceptions are found on the Indian subcontinent and in Southeast Asia, where Chinese methods of preservation are used in some societies. As a result of urbanization, the poor are increasingly separated from sources of fresh fruits and vegetables. Inexpensive, simple methods of pickling or acid fermentation could enable them to take advantage of seasonal gluts.

- Research is needed on methods of preserving tropical fruits and vegetables. Organisms for acid fermentations should be identified and simple pickling techniques tested.

**Institutions and Contacts**

- American Type Culture Collection, Rockville, Maryland, USA (R. Donovick)
- Centro Internacional de Agricultura Tropical, Cali, Colombia (Dr. Cook)
- Cornell University, Ithaca, New York, USA (K. Steinkraus)
- Federal Institute of Industrial Research, Oshodi, Ikeja, Nigeria (Dr. Corlioso)
PACKAGING MATERIALS FOR THE TROPICS

There is a widespread need for improved packaging materials in developing countries to increase the quality of foods in storage, transportation, and marketing. Perishables such as fruits and vegetables are spoiled by mechanical bruising during transportation when not packed in proper materials. Durables such as cereal grains, processed flours, and dried fish are readily subject to spoilage and weevil infestation when packaging materials are permeable to moisture and pests or microorganisms.

Packaging materials are frequently designed for foods produced and consumed in temperate climates. These materials may not be suitable for the high heat and humidity of the tropics. Thus, there is a particular need to review the wide variety of packaging materials and technologies available in tropical countries. The materials sector is highly developed in some countries and less so in others. Development and wider use of locally available continuous-sheet polymers (plastic, cellophane, or chitosan) and corrugated cardboard analogs using local fibers could be very important. In many cases, there is need for
improved control of permeability to moisture and pests or microorganisms. Treatment of packing materials with degradable pesticides or spoilage retardants could also help reduce food losses.

Recent work has been conducted on sulfur-impregnated composites made from banana fibers, coconut husks, rice straw, or sisal residue in Costa Rica, the Philippines, and the Pacific region. Sulfur impregnation can produce materials that are both impervious to moisture and microorganisms and pest resistant (Bryant 1983) and that could therefore be adapted for use in food containers. Another local material is paddy straw, which is widely available and frequently burned in fields because it is uneconomic to store or transport. It has been used to make bags for handling and storing potatoes and other vegetables. Tests at the Punjab Agricultural University in India indicate that bags made of paddy straw absorb shock better than traditional jute bags, which are also more expensive (Agency for International Development 1983).

It is recommended that discussions to examine opportunities for research on packaging materials be arranged among developing country scientists and marketing and packaging specialists from industry, government agencies, and academia. The group should review the state of current knowledge and experience and identify promising research topics. Locally produced, low-cost, readily available packaging materials would help improve food availability by reducing losses while creating employment and improving health and nutrition in all sectors of developing country populations.

Institutions and Contacts

• DuPont Chemical Corporation, Wilmington, Delaware, USA
• Massachusetts Institute of Technology, Nutrition and Food Science, Cambridge, Massachusetts, USA (Dr. Marcus Karel)
• Michigan State University, Department of Packaging, East Lansing, Michigan, USA
• Metal Box, Calcutta, India
• Nuclear Institute for Agriculture and Biology, Faisalabad, Pakistan (Dr. S. H. Mujtaba Naqvi)
• Packages, Ltd., Lahore, Pakistan
• Punjab Agricultural University, Punjab, India (M. M. Kashyap and Amar Singh)
• Rutgers University, New Brunswick, New Jersey, USA (Dr. Gilbert)
• University of Delaware, Department of Food Science, Newark, Delaware, USA (Dietrich Knorr)
• University of Washington, Department of Food Technology, Seattle, Washington, USA
• University of Washington, Department of Forest Resources, Seattle, Washington, USA (Dr. Ben Bryant)
Major losses occur with traditionally processed fish products, particularly with sun-dried, smoke-dried, or salted-and-dried fish. Although these very different products are often specific to a region, each can be referred to as a dried product. (This section is based on Chapter 6 of Postharvest Food Losses in Developing Countries, 1978, National Academy of Sciences, Washington, D.C., USA.)

Traditional Technologies

**Drying** The most widely used technique for preserving fish is sun drying. The fish are simply spread on the beach or a mat and allowed to dry. However, wet fish are subject to attack by blowflies, mainly Chrysomyia spp., whose burrowing larvae cause damage and spoilage. Blowflies also are dangerous carriers of pathogenic organisms, particularly since infested beaches are often contaminated with human feces as a result of limited public sanitation facilities. Even the dried fish are subject to attack by Dermeestes beetles, and a wide range of other insect pests and mites also attack drying and dried fish.

**Salting** Preliminary salting is often used to enhance the quality and acceptability of naturally dried fish. Salting is achieved by stacking the split fish with dry salt between the layers or, preferably, by immersing the fish in brine. Salting speeds up water removal from the flesh and reduces the time necessary for air or sun drying. In the case of oily fish such as sardines, where prolonged drying leads to discoloration and rancidity, a 15-minute immersion in saturated brine reduces drying time by half. Presalted, dried fish can be kept in fair condition for 6 months, while unsalted controls go rotten or moldy.

Salting is also a chemical method of bacteria and insect control. Flies will not attack fish that have been brined before drying, and the rate of attack by beetles is inversely proportional to salt concentration. One of the most difficult problems with salted, dried fish is to control reabsorption of moisture from humid atmospheres after processing. For this purpose, proper packaging is required.

**Smoking and Smoke Drying** Smoke drying is widely used in Africa for a variety of foodstuffs, many of which are suspended for a period over cooking fires as a means of deterring insect infestation. In the Lake Chad area, fish may be partially dried in the sun and then covered with grass or papyrus, which is set on fire and the fish scorched and charred to form a hard, protective outer surface. Some fish may be smoked over a grid or fire, or simple kilns may be employed.

These methods, however, offer little protection against insects and may result in additional loss from charring and burning. The insect pests lay their eggs in the flesh before and during drying. In thick-bodied fish they are deterred during smoking, but larvae already present penetrate the deeper parts of the fish where the heat and smoke cannot reach.
Packaging A certain amount of spoilage results from storage of improperly processed products, which causes direct losses. Products attacked by insects range from those with high water content and a storage life of 1–2 days to hard-dried products with shelf lives of several months. Important economic losses of dried fish result from crumbling during storage and distribution. Poorly dried fish are fragile; if roughly handled or vibrated on overloaded trucks on poor roads, they will crumble to a powder. Prior insect attack weakens the structure and can result in a mixture of fish powder and insect frass. With poor packaging, there can also be direct physical losses and, although fish powder has a market, there are always economic losses. Packaging materials that provide adequate protection of fish during storage and transport must be developed (see recommendations in "Packaging Materials for the Tropics").

Improving Traditional Technologies

It should be stressed that the following techniques must be considered in the context of local circumstances and that introduction of these technologies to new or different areas requires adaptive research and development.

Drying, Salting, and Smoking The fish must be elevated to keep insects away and to reduce the drying time. Simple racks constructed from local materials work very well. In case of rain, preparations should be made to cover the drying fish (as an alternative to moving them from the racks under cover). Plastic sheeting is inexpensive, effective, and generally available for this purpose. In Zambia and in West Africa, this method of drying freshwater sardines is combined with a period of drying in a smoking oven. Salting is also used to speed up the process. The availability of good-quality salt at reasonable cost is an important aspect both of technology and government policy, since salt is frequently a monopoly.

- The effect of salt levels in the diet, particularly of small children, limits its desirability as a preservative. Development of safe and effective chemical alternatives is highly desirable.

Chemical Controls A variety of technologies, old and new, have been developed to improve on simple sun drying to reduce blowfly and beetle infestation. Where fresh fish are subject to blowfly damage, for example, losses can be significantly reduced by dipping boxes of small fish in an inexpensive insect-repellent solution. There are a number of other chemical treatments available, but most if not all impose potential hazards to the consumer. There currently is no chemical means for controlling insects that can be recommended and applied on a commercial scale without this health hazard.
Research is urgently needed on low-toxicity chemical treatments to apply to all types of fish preservation. At present, the use of contact insecticides should be considered as a last resort, and only where one or more of the following conditions applies:

--- No other means of coping with the pest infestation is as practical or economic.
--- The techniques employed are simple and foolproof.
--- The treatment uses insecticides of low mammalian toxicity at dosage rates that leave residues within the tolerance limits set by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO).

Refrigeration and Ice  Because of the strong preference for whole, fresh fish, there is a major interest in using refrigeration and ice to extend storage life. With ice, tropical species (i.e., those actually living in warmer water, rather than in cold water in tropical regions) are believed by many scientists to keep longer, on average, than cold-water species. Shelf lives up to 45 days have been recorded for some species, and 20-30 days is common. This longer shelf life is thought to result from a deterrent effect of the greater temperature difference between ice and warm-water fish on spoilage microorganisms and tissue enzymes. However, a recent review of storage of fish on ice (Lima dos Santos 1981) concludes that there is insufficient evidence to support this hypothesis.

There appears to be little if any advantage in deheading and gutting tropical species for cold or chill handling. Further handling creates additional hazards, and the intact fish is commonly preferred in the local market. In much of the developing world, conventional refrigeration technology is uneconomic, particularly where it is most needed—on fishing boats.

Technology for solar- and wind-powered cooling and ice-making equipment is still relatively young. One promising development is the generation of electricity by floating devices that harness energy in wave movement.

• Research on the effectiveness of different degrees of cooling or the keeping qualities of tropical fish is needed to establish objectives for alternative cooling technologies. Development of renewable energy sources for this purpose should be encouraged.

Fermentation  Recent developments have been reported for preserving fish as fish silage, fish cheese, and low-salt fermented fish (using added cereal "ragi" in Southeast Asia). Traditionally, fermented fish have been widely used in Southeast Asia as nuoc-mâm, patis, nampla, or their local equivalents, but the high salt content has limited its use, particularly by young children. The development of low-salt fermented
fish could extend the protein supply by making it possible to use a condiment in larger quantities as a protein supplement wherever this variety of marine product—one in which the source species is unidentified—is acceptable.

- Research is recommended to develop low-salt fermentation technologies for fish preservation.

REDDUCING LACTOSE INTOLEANCE AND DEVELOPING MILK EXTENDERS FROM OILSEEDS

In most Asian and African people (as well as some Caucasians), the ability to digest lactose in milk is greatly reduced around the time of weaning when children lose the ability to produce the gastric enzyme lactase. Instead of providing nutrition to the child, undigested lactose is converted to carbon dioxide by bacteria in the intestines, causing serious discomfort and flatulence.

Many lactose-intolerant people can digest milk when it has been fermented or is taken together with some cereal products; the lactase is supplied by lactobacilli in the milk product or in the cereal. A recent study at the University of Baroda in India observed that even before complete weaning, breast-fed infants with severe intolerance respond to administration of a teaspoonful of yogurt and honey before bottle feeding. An important limitation, however, is the risk of botulism associated with feeding unpasteurized honey to small children. Honey, or any sticky source of sugar, readily traps ubiquitous Clostridium botulinum spores from the atmosphere. Young children, particularly those whose gastric systems are not yet fully developed, have conditions in their small intestines that are especially favorable for growth of the organism and the production and absorption of the toxin.

- Research is needed to develop simple, safe, and inexpensive preparations to reduce the effects of lactose intolerance. Research should aim at identifying organisms, processes, and, in particular, dry, stable, and safe products that could be easily stored and widely disseminated.

Aqueous extracts of soaked, mashed oilseeds (such as soybeans and groundnuts) contain soluble proteins, amino acids, and some oil. The extracts are a valuable substitute for milk for weaning children. Because of the simplicity of the process and the relatively low cost of the starting materials, in many countries this process could supply up to 70 percent of milk requirements at substantially less cost than whole milk.

- Research is needed to improve oilseed processing technology, to identify better ways of extracting more of the nutrients, and to apply it to the variety of oilseeds available in many parts of the world.
Institutional Contact

- University of Baroda, Baroda, India (Dr. Rajalakshmi)

PRODUCTION AND STABILIZATION OF RICE BRAN OIL

Up to 700,000 tons of edible rice bran oil can be added to the world food supply if economical methods of rice bran stabilization (inactivation of fat-splitting enzymes in rice bran) can be applied. Extruder-cookers have been found to be effective bran stabilizers (Enochian et al. 1981), but existing extruders are too large for use in typical small rice mills found in developing countries.

- Research is recommended to design and field-test a small, inexpensive extruder-cooker suitable for stabilization of rice bran produced by small, two-stage rice mills that have the capacity to process 2 tons per hour of paddy or less, yielding 100 kg of bran per hour.

Institutional Contact

- Korean Institute of Science and Technology, Seoul, Korea

IMPROVING SORGHUM PROTEIN DIGESTIBILITY

Small children have difficulty digesting sorghum protein and carbohydrates, perhaps because of tannins in the seed coat that are difficult to remove in processing. This problem reduces the value of sorghum, although it is a staple in many arid regions. Recent research shows that digestibility can be increased by thermal and enzymatic treatment. Simple cold-water extraction of tannins from sorghum has been traditionally performed by North American Indians.

- Research is needed to study the causes of poor digestibility of different varieties of sorghum and to develop effective processing methods to increase its digestibility and nutritional value.

OTHER TOPICS

A number of other topics were discussed by the working group. While these were given lower priority than the topics presented above, recommendations in these areas are included here because of their potential importance in particular locations.
Fish and Other Aquatic Resources

Amino Acids as Fish Attractants  Certain amino acids are powerful attractants for some species of fish. Many fish can detect minute quantities of dissolved chemicals in the water. In some species, this ability is used to locate food through the detection of amino acids produced by decaying matter or secreted by underwater plants and animals. Amino acid preparations could be used as very effective bait to improve the fish catch.

- Research is recommended to identify amino acids that act as effective fish attractants in tropical locations for particularly desirable species. Research is also needed to improve the quality and quantity of amino acid preparations for use as attractants while reducing their cost.

Institutional Contact

- Central Research Laboratory, Ajinomoto Company, Inc., Kawasaki 210, Kanagawa, Japan (Takekazu Akashi)

Deboning Trash or Waste Fish  In many areas large quantities of fish are available but are not eaten, either fresh or preserved, because they are not enjoyed or preferred by the local people. Such fish frequently are discarded because it is not economic to convert it into animal feed, fertilizer, and so on. Recent studies of fish-eating habits have shown that consumer acceptance improves if undesirable fish are processed to conceal their identity (for example, fish balls made of minced fish, or fish fingers or sticks). However, because processing costs are high, these products are either made in the home from usually eaten species or are supermarket luxuries for the affluent. Recent engineering studies have made progress toward developing inexpensive, small deboning machines for use in small-scale processing plants in developing countries.

- Research is needed on the chemical composition of deboned products from various sources of fish and on improving quality control of the process.

Institutions and Contacts

- National Fisheries Institute, Science Division, Washington, D.C., USA (Roy Martin)
- National Marine Fisheries Service, Box 12607, Charleston, South Carolina, USA 29412 (Lloyd Regier)
- Terje Strom Institute of Fishery Technology, Tromso, Norway (Torger Borreson)
- University of Massachusetts Marine Station, Gloucester, Massachusetts, USA 01930 (H. O. Hultin)
FAO-Sponsored Research on Fish and Aquatic Resources in Developing Countries

Comparatively little is known about underused species of tropical marine fish—basic information that is essential to improved use, storage, and processing technologies. A recently launched FAO-sponsored research program is designed to collect and establish the nutritional, biochemical, and rheological properties of traditional, under- and unused species of fish and other aquatic resources in developing countries, and to establish data on foods produced from currently used species. The program will also focus on methods of food preparation, raw material harvest, consumption patterns, and fish avoidance. Unfortunately, the program has very limited coverage of tropical waters. Moreover, the recent extension of territorial waters and economic zones makes it important for developing countries to know what their aquatic food resources are.

- Support is recommended for extending the coverage of the FAO program in tropical territorial waters.

Institutional Contact

- Food and Agriculture Organization, Fisheries Division, Rome, Italy (Antonio da Costa)

Preservation and Storage of Fruits and Vegetables

Antibiotics Antibiotics have been used successfully to retard fruit spoilage in Pakistan, where tiny amounts applied to oranges have prevented entry of unwanted organisms and have prolonged storage life by months without actually penetrating the fruit or being consumed.

- More research is needed on the types and amounts of antibiotics that can be used to retard spoilage. Potential dangers such as development of resistant strains of organisms must be explored before this promising technique can be widely used.

Naturally Occurring Plant Insect Repellents Naturally occurring plant insect repellents are prevalent in nature and are widely used in traditional storage technology. Although quite effective in its evolved form, this technique has not been studied systematically. Furthermore, it has been shown to be less effective with new, high-yielding crop varieties that differ from the older varieties they have replaced. Alternatives are needed, especially by the poor. Further information about natural plant substances is presented in the report of the working group on plant-pest relationships.

- Research is recommended on naturally occurring repellents for use in food storage.
World production of oils and fats is only just keeping pace with population increases, and the supply of oils for human consumption in many developing countries is insufficient. The price of edible oils is relatively high; nevertheless, handling of oils and fats is substandard and enormous amounts are wasted. Unlike other food commodities, fats and oils oxidize rapidly and become rancid with characteristic unpleasant odors. In developing countries rancidity is actually encouraged by the catalytic action of metals with which the oils come in contact in storage containers, piping, taps, and valves. Rancidity could easily be avoided by replacing metal parts and lining storage containers with noncatalytic material. Although large returns can be anticipated, relatively little research has been done in this field in developing countries.

Primary processing—particularly that of coconut oil—is often done under crude conditions, on the assumption that the poor-quality oil will be refined after shipping. Enormous losses result.

- Research is needed to determine the optimum time and place to process oils. Research is also needed to improve the use of preservatives and antioxidants, especially for processing minor tree oils and oils from plants (shea-nut, palm kernel, melon seed, winged bean, etc.). Guidelines for handling, storing, and transporting oils and fats should be made widely available.

Institutions and Contacts
- Council for Scientific and Industrial Research, Food Research Institute, Accra, Ghana
- Lever Brothers, Kuala Lumpur, Malaysia (J. Moolayil)

Cereals and Grain Legumes

Composite flour programs need improved methods for the quantitative determination of different flour ingredients and their sources. Results obtained so far, based on electrophoretic differentiation and on quantification of proteins and fatty acids using gas chromatography, have not been sufficiently accurate.

- Research is needed to develop an analytical methodology, based on these techniques, that is applicable to binary and tertiary mixtures of flours. This work will probably be done in industrialized rather than developing nations by such organizations as the American Organization of Agricultural Chemists (AOAC).
EVALUATION AND RANKING OF PRIORITY RESEARCH TOPICS

Research projects were ranked according to their perceived importance and urgency following the weighting system developed by Czayka and Jones (1971). This procedure assigns weights to different aspects of the project that lead, eventually, to the compilation of a cumulative index for the relative importance of each project. Although only the projects assigned the highest priority are described in detail, all projects are listed.

Criteria and Their Weights

Three categories of criteria were used to evaluate the importance and merits of each project. Factors or questions considered in the evaluation are listed under each criterion. Percentage weighting is in parentheses.

- Social Importance (40)
  -- Number of people affected by the problem (15)
  -- Cultural compatibility of the planned approach to the problem (e.g., specific food habits of the target population) (15)
  -- Time required for a solution to have a practical effect (10)

- Economic Implications (35)
  -- To what extent would a solution reduce food cost? (15)
  -- To what extent would a solution increase availability of food? (10)
  -- To what extent would a solution increase incomes? (5)
  -- What is the magnitude of scale, the technological complexity, and the financial investment needed to implement a solution? (5)

- Operational Considerations (25)
  -- Availability of the required natural resources (5)
  -- Availability of the required technical resources (2)
  -- Government support for the specific project (5)
  -- Availability of infrastructural, financial, and organizational resources (10)
  -- Magnitude of required extension force (3)

Following discussion, 14 research topics were selected and subjected to the numerical evaluation process by allotting an agreed weight of 1-5 in each of the above categories (see Table 1). Of the 14 topics, the following 9 were rated as meriting highest priority:

1. Coconut/copra processing for high-quality oil and protein
2. Upgrading cassava processing
3. Packaging materials for the tropics
4. Rice bran stabilization and oil extraction
These 9 topics were then ranked, by geographic region, according to the likelihood that research would produce fruitful results in a reasonable period of time (see Table 2). Based on these results, the topics were reordered in a final overall ranking, as follows:

1. Fermentation processes applied to tropical foods, and
2. Packaging materials for the tropics
3. Fish preservation
4. Milk extenders from oilseed press cakes
5. Coconut/copra processing for high-quality oil and protein
6. Upgrading cassava processing, and
7. Rice bran stabilization and oil extraction
8. Improving sorghum digestibility
9. Reducing lactose intolerance
<table>
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<th>Section</th>
<th>Topic</th>
<th>Significance (X x 1-5)*</th>
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<tr>
<td></td>
<td></td>
<td>Social (%)</td>
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<tr>
<td>Fish</td>
<td>Fish preservation</td>
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<tr>
<td>Fruits and</td>
<td>Preservation by new antibiotics</td>
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<tr>
<td>Vegetables</td>
<td>Insect repellents</td>
<td>60 60 10</td>
</tr>
<tr>
<td>Meat and Milk</td>
<td>Reducing lactose intolerance</td>
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<tr>
<td></td>
<td>Oilseed milk extenders</td>
<td>60 45 30</td>
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<tr>
<td>Oils and</td>
<td>Rice bran stabilization and oil production</td>
<td>60 75 30</td>
</tr>
<tr>
<td>Legumes</td>
<td>Coconut processing by wet fermentation</td>
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<tr>
<td></td>
<td>Meat substitutes from press cakes</td>
<td>45 45 40</td>
</tr>
<tr>
<td>Roots and</td>
<td>Upgrading cassava processing</td>
<td>75 75 40</td>
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<tr>
<td>Tubers</td>
<td>Effect of fermentation on mycotoxin levels</td>
<td>60 75 30</td>
</tr>
<tr>
<td>Cereal and</td>
<td>Yogurt substitutes</td>
<td>60 60 50</td>
</tr>
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<td>Grain Legumes</td>
<td>Improving sorghum digestibility</td>
<td>60 30 30</td>
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<tr>
<td>Fermentation</td>
<td>Improving traditional fermentation processes</td>
<td>60 60 30</td>
</tr>
<tr>
<td>Packaging</td>
<td>Developing packaging materials for the tropics</td>
<td>75 75 20</td>
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</table>

*For each category, the group assigned a weighting of 1-5 according to the agreed relative importance for the particular topic.
### TABLE 2 Likelihood of Success of Research in Priority Topics, by Region

<table>
<thead>
<tr>
<th>Topics</th>
<th>Africa</th>
<th>Malaysia/Indonesia</th>
<th>Pakistan</th>
<th>India</th>
<th>Latin America</th>
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<tr>
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<tr>
<td>Fish Preservation</td>
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<td>7</td>
<td>8</td>
<td>6</td>
<td>8</td>
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<tr>
<td>Milk Extenders</td>
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<td>7</td>
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<tr>
<td>Coconut/Copra Processing</td>
<td>6</td>
<td>9</td>
<td>5</td>
<td>7</td>
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<td>Upgrading Cassava</td>
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<td>9</td>
<td>5</td>
<td>5</td>
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<td>5</td>
<td>5</td>
<td>6</td>
<td>28</td>
</tr>
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</table>

Likelihood of success: 5 = least; 10 = greatest.
REFERENCES


Bryant, B. 1983. Personal communication, College of Forest Resources, University of Washington, Seattle, Washington, USA.


The working group examined opportunities and constraints for expanding the use of aquaculture and integrated farming systems, particularly for small landholders and subsistence farmers in developing countries. The chemical aspects of these systems merit special attention since residual pesticides may hamper the use of agricultural wastes, a critical element in aquaculture and integrated farming. For example, mixed species of carp are grown in China, India, and Malaysia using animal manures and wastes. These systems provide impressive annual yields ranging from 5,000 to 8,000 kg/ha. The principal reasons for this productivity are the use of mixed species of fish with different and noncompetitive feeding niches and the range of natural manure-generated fish foods developed in the pond.

Excellent fish yields have also been obtained through combined duck and fish culture, through fish culture in ricefields, and through rotational systems in which vegetable gardens alternate with duck and fish ponds. In each of these systems, one crop makes use of nutrients in the residues of another. Persistent chemical pesticides would threaten the extraordinary productivity of this symbiosis.

The integrated cultivation of two dietary staples, rice and fish, is a traditional practice in many parts of South and Southeast Asia, and one that represents a sophisticated use of limited resources and abundant family labor. Ricefield fisheries, particularly cultural as opposed to capturial types, have the potential to satisfy part of the demand for inexpensive animal protein and provide a cash income for small farm households.

Despite their antiquity, potential, and widespread occurrence, ricefield fisheries are poorly documented and remain little understood scientifically. If rice–fish production is to achieve an important role in rural development in the humid tropics, basic research to solve problems and remove constraints must be conducted on a wider basis.
Research in this area can benefit two groups. Those now using their ricefields for fish culture can gain improved techniques or more productive fish species; for rice farmers not now raising fish, information on initiating their culture can be provided, including necessary modifications in current practices and potential economic benefit. Priority in applied research programs on integrated rice-fish farming should be given to the following research topics, which are discussed in detail below: system information, fish species, and principal constraints.

System Information

Rice-fish farming is an ancient resource system and a traditional activity for many small farmers. Since a considerable body of empirical knowledge exists, efforts to upgrade or modernize ricefield fisheries should be based on modifying existing, locally familiar systems rather than eliminating them in favor of new and generally untested techniques. Research needs include:

- Development of a typology of traditional rice-fish systems, including a survey of their geographical range
- A study, for each farming type, of the components and functions of the system in terms of energy and materials flow, optimal use of farm space, temporal synchronization of various farm activities, management and sociocultural inputs, and linkages with off-farm resource systems
- Cost-benefit analyses on a range of existing small-scale, rice-fish farms to evaluate the profitability of incorporating fish cultivation in the small-scale rice farm and to assess the often conflicting resource needs, risks, and priorities of the poorer rural household.

Fish Species

There is no universally acceptable fish for use in the wide variety of wet rice-farming systems that exist. Therefore, fish species suitable for rice-fish farming should be identified.

- Research is urgently needed on fish biology, to develop seed supply, and to determine stocking rates and densities, stocking size, and the best species composition for polyculture. Fish that are culturally acceptable, fast-growing, and have a relatively high tolerance for agricultural chemicals should receive special attention.
Principal Constraints

Rice Varieties  High-yielding varieties of rice mature in 90-115 days, compared with 120 days or more for traditional varieties. This abbreviated maturation period may present problems in growing fish to harvestable size, although it does not inhibit the cultivation of fingerlings for later stocking in fish ponds.

Land Preparation and Fertilizer Use  Poorly timed land preparation for rice cultivation may harm fish exposed to toxic substances released by decaying organic material in the soil. Moreover, fish cultivation in ricefields requires that nitrogen application be increased by about 50 percent to maintain rice yields. Incorrect application leading to high nitrogen concentrations in water may retard fish growth.

- Research is needed on the synchronization of rice and fish cultivation and on fertilizer management practices required to achieve optimal yields of both.

Management of Rice Pests and Diseases and Weed Control  Pesticides have three main properties that determine their value in pest control: (1) chemical stability, (2) absorption properties, and (3) toxicity. Because of their high chemical stability, many pesticides are persistent. Chlorinated hydrocarbons, for example, are very stable, with estimated half-lives of 10-15 years. Most pesticides are insoluble in water but are highly soluble in organic solvents. They are also retained in biological tissues, when absorbed through gills, lungs, integument, and alimentary canal. This is particularly true for chlorinated hydrocarbons.

Far from being specific to insect pests, most pesticides have a broad spectrum of toxicity, including fish and other aquatic animals, and agricultural chemicals used on rice may harm fish or people who eat fish. The persistence of pesticides in the ricefield environment is a long-term constraint to paddy fish cultivation. If insecticides that degrade rapidly are used, a system that shifts fish back and forth between a dooryard pond and the ricefield could prove suitable. Root-zone and other chemical application technologies that avoid water contamination may also be suitable.

- Research is needed to develop chemicals for pest control in rice-fish farming and to determine the appropriate rate, timing, and mode of application required to minimize residual persistence and potential toxicity to fish.

Water Management  Successful fish cultivation in ricefields requires a standing water depth of 15-20 cm in the paddy and 50-60 cm in ditches. Thus, a supply of water beyond that required for rice-growing must be ensured for fish cultivation. This can be a major constraint. In West Java, for example, a centrally controlled water supply is geared to the
needs of rice, not fish cultivation. Water is cut off completely during the fallow month. In addition, demand for water from other agricultural users as well as from industrial and domestic consumers is increasing.

- Research to overcome water supply constraints should focus on control, quality, and quantity of water and on the appropriate symbiotic relationship between central dooryard ponds and paddy fields.

Cage and pen culture of fish in Southeast Asian lakes has expanded rapidly in recent years; however, water pollution has seriously affected the industry. For instance, in Laguna Lake in the Philippines, agricultural runoff, domestic sewage, and industrial wastes have caused plankton blooms that have resulted in fish kills. The effects of both heavy metals and pesticides on cultural fishes have not yet been assessed.

- Research is needed to better understand lake pollution and its effects on fish culture. The results will help aquaculturists and policymakers take appropriate steps to prevent or minimize fish kills and guarantee the safety of the catch for human consumption.

SHRIMP CULTURE

Shrimp is a highly valued commodity that is in constant demand in both local and foreign markets. Several developing countries in Asia, Southeast Asia, and Latin America have the resources to develop shrimp culture to satisfy the demand.

Shrimp or prawn culture in many developing countries is carried out in traditional ways. Most shrimp farmers still depend for stock on an often inadequate wild catch of fry or juveniles. Although production of shrimp in hatcheries has become a subject of extensive research, little headway has been made.

Research Status

Penaeid Shrimps There are several species of penaeid shrimps that are suitable for cultivation, namely, Penaeus monodon, P. semisulcatus, P. japonicus, P. merguiensis, P. indicus, and Metapenaeus ensis. These species are found throughout the Philippines and in some neighboring Southeast Asian countries. P. monodon has received the most research attention as it is the fastest-growing, the biggest, and the most expensive species. A 1-g juvenile can attain a weight of more than 100 g in 5 months when reared at low density. Most of the research on P. monodon has involved hatchery and related subjects, including biology, reproduction, food and feeding, broodstock development, sexual maturity, fry collection and transport, and nursery management. Some work has been done on pests, diseases, and postharvest management.
Work in pond culture and management for adult shrimp has been relatively limited. Although Taiwan has developed advanced techniques both in hatchery and grow-out pond management, including operation and management of intensive culture systems, these technologies have not yet diffused to most other developing countries. Thailand has had some success in promoting traditional culture of shrimp in ponds; however, stock still comes from the wild.

Study of other penaeid varieties is in its infancy, but some basic studies have been done on biology, salinity tolerance, feeds, and feeding habits.

**RESEARCH NEEDS:**

- Improved engineering and management for grow-out at low density and low-level inputs. Monoculture and polyculture systems with species such as milkfish should be studied.

- Improved broodstock management, including development and reproduction, nutrition, stocking densities, maturation in ponds, and control of cannibalism.

- Improved hatchery management, including production and rearing of *P. monodon* larvae.

- Development of natural feeds such as algae and agricultural wastes, including manures, as substitutes for formulated rations in grow-out ponds.

**Prawn (freshwater shrimp)** There are several species of *Macrobrachium* with potential for culture, including *Macrobrachium rosenbergii*, or giant prawn, and the smaller species *M. lanchesteri*, *M. lancefrons*, and *M. idella*. The giant prawn is fast-growing and has received the most attention in research. Major drawbacks are its large head and its cannibalistic nature.

Most prawn research has concentrated on biology, larval rearing, and hatchery techniques. There are now small- and large-scale hatcheries, both private and government, in such places as Thailand, Hawaii, Central America, and on some Pacific islands.

**RESEARCH NEEDS:**

- Transfer of larval-rearing technology to developing countries, with emphasis on techniques suitable for village use.

- Use of natural feeds and agricultural wastes as substitutes for formulated rations in grow-out ponds.

- Evaluation of polycultures with silver carp or other phytophagous fishes that complement bottom-feeding prawns.
- Genetic improvement of M. rosenbergii to enhance domestication and yield a smaller head. Other prawn species should be screened for culture potential.

Several existing hatchery and pond cultural systems that range from low- to high-input levels can be developed for shrimp or prawn. The low-input systems are intended for small farmers at the village level, while semi-intensive and intensive systems are more appropriate for large investors prepared to take greater risks.

ORGANIC WASTES AS FISH FEED

Increasing competition for food in most developing countries requires that supplies suitable for humans not be fed to fish or other animals. This emphasises the need to increase the use of organic wastes for fish production, a purpose for which aquaculture is particularly well suited. Appropriate organic wastes that may be available in integrated farming systems include:

- Animal manures
- Crop residues
- Domestic wastes
- Composted or fermented plant, animal, and human wastes or effluents from biogas units.

Integrated farms with fish ponds fertilised by organic wastes provide a means of producing animal protein with no added feed costs. Although a number of wastes have been tested for use in aquaculture, more comparative information is needed on the value of various treated and untreated agricultural residues. In addition, it may be practical to use manure to culture midge larvae, annelids, or Moina for use as fish food.

Applied research programs should focus on the following:

- Information on how wastes such as animal manures are assimilated by fish. The contributions of microbial production to these systems is just beginning to be recognised and has not yet been controlled or manipulated to optimize production. Some waste is consumed directly, but a considerable portion is converted first to microalgae that is then consumed by fish.

- Information on the effectiveness of various fish species at capturing and digesting microalgae less than 10 microns in diameter, a size class that includes most of the green algae in phytoplankton blooms. The most effective filter-feeding adult fish is the silver carp (Hypophthalmichthys molitrix), which, because of its large size, may be one of the most important food sources in future aquaculture. The planktivorous tilapia should also be investigated in this regard. In addition, the digestibility and nutritional value of the ingested algae cells should be examined.
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- Information on polyculture systems for small farms that use various types of organic wastes. Relatively few species combinations have been thoroughly tested. Those combinations needed to optimize production are site-specific and relate to particular wastes and other available inputs.

- Information on recycling organic wastes in brackish or seawater ponds. The use of such ponds opens unused coastal saltwater sites and abandoned areas with salt-laden soils. The impact of expanded research in this area can be great; it has the potential to reduce competition for use of limited freshwater in many areas.

- Information on the use of biogas digester effluents as a food source for aquaculture systems. Raw manure and the effluent from anaerobic digesters should be compared. Although chemical analyses are available, the relative economic potential of these alternatives has not been determined.

- Research to develop appropriate chemical or microbiological procedures to enhance digestibility and food value of crop residues such as straw. Relationships between fish yields and organic and chemical compositions of various waste products should be determined.

- Studies to compare survival or incidence of parasites and pathogens in fresh animal wastes versus digested or composted animal wastes. Methods for reducing health risks need to be developed.

- Development of low-level technologies for the culture of indigenous species of fish food organisms such as midge larvae, annelids, and Moina. Technologies for the culture of live feeds such as Artemia have been developed but require expensive facilities that the average fish farmer cannot afford.

ALGAE AND AQUATIC PLANTS AS FISH FEED AND FERTILIZER

Algae and other aquatic plants are underused but potentially important sources of feed and fertilizer. Most aquatic species are capable of greater productivity than conventional crops. Furthermore, when grown on wastes in integrated systems they do not compete with food crops for fertilizer, water, or arable land. Their abundant growth in the humid tropics, without need for intensive cultivation, make them a promising addition to current feed sources. Moreover, algae and aquatic plants have the capacity to renovate wastewater through the uptake of dissolved nitrogen and phosphorus, which are major pollutants in the surface waters of most agricultural areas.

On the other hand, aquatic weeds can infest irrigation canals of large-scale agricultural schemes, causing a decrease in water flow,
siltation, and water loss through transpiration. In addition to seriously limiting irrigation efficiency, they may also affect waterborne disease vectors. For example, aquatic foliage at the water surface enhances mosquito breeding by protecting the larvae from wave action or small larvivorous fish such as Gambusia. Aquatic plants also harbor the small intermediate host of Schistosoma spp., which finds sheltered habitats with rich supplies of food and surfaces for depositing eggs.

Chemical pesticides and herbicides are used in many countries to control algae and aquatic weeds but are toxic to fish and other aquaculture organisms. They are becoming more expensive and less effective due to the development of resistant strains. Rational use of algae and aquatic weeds would eliminate these costly control measures and concurrently increase the profitability of small farming operations.

Biological control of algae and aquatic weeds by using fish has considerable potential. Phytophagous fish such as the grass carp (white amur), in combination with an omnivorous bottom feeder such as the common carp and a larvivore such as Gambusia affinis, could be used to control aquatic weeds, eliminate mosquito larvae and bilharzia snails, and also provide animal protein to the food supply. Where aquatic plant life is more sparse, stocking Oreochromis (formerly Tilapia) niloticus at 2,500–5,000/ha will control filamentous algae, some higher plants, and mosquito larvae.

Microalgae, which occur naturally in ponds fertilized by animal manure, can be harvested as a source of feed protein. This is particularly true of the highly digestible, filamentous blue-green algae, which are rich in protein and can be filtered directly by simple straining techniques. The small green algae and coccoid blue-green algae can be removed by chemical flocculation and flotation or sedimentation.

- Research is needed on the use of naturally occurring polymers such as chitosans that can be used to harvest algae. Special attention should be given to adverse effects of chemical coagulation on digestibility.

Naturally occurring aquatic plants (such as duckweed and Azolla) can be used as organic fertilizer and animal or fish feed. High-yielding plants such as water hyacinth can be used for methane generation, particularly in combination with manure slurries. Nitrogen-fixing, blue-green algae can be cultured in shallow ponds using simple techniques; and significant increases in soil nitrogen can result from deliberate algae cultivation using supplemental phosphate.

- Research is needed to develop optimal systems for using these resources.

Combinations of fish species can be used in irrigation projects to control aquatic weeds, reduce waterborne disease vectors, and supply food protein.
Site-specific research is needed to test different combinations of fish species for effectiveness.

CONTROL OF FISH REPRODUCTION

Tilapia are among the most important food fishes adapted to aquaculture in the tropics. In Southeast Asia, tilapia are fast gaining importance and popularity because of their rapid growth, ease of handling, and economy of culture. A major problem in tilapia culture is its tendency to overpopulate ponds, thereby stunting their growth.

Tilapia populations can be controlled in various ways. One particularly promising method employs sex hormones such as methyl testosterone to induce sex reversal or gonad sterilization. Although hormone techniques for sex reversal in tilapia have been successfully applied by a number of workers, the techniques have not been used to induce sterilization.

Research is needed on use of hormones to induce gonad sterilization in tilapia. Specifically, research should focus on solutions to two problems encountered in the sex reversal method: (1) nest building by males, and (2) accidental reproduction with the entry of "wild" fish into the fish ponds.

INTEGRATED FARMING SYSTEMS

Exploitation of Swampy Areas

Most swampy areas in the tropics and subtropics, especially in Southeast Asia, are underused, while people in rural areas have no agricultural land. Better drained and irrigated lands are frequently converted to commercial plantations, lessening opportunities for poor farmers. Conversion of swamps to agricultural land would provide options for these farmers.

Exploitation of only 10 percent of the estimated 200 million ha of swampland worldwide could provide land and employment for as many as 10 million farmers on farms of 2 ha. With good management, each hectare could produce 5 tons of food (3.5 tons of cereals, 1.5 tons of animal meat such as fish, duck, or chicken).

Southeast Asian swamps are mostly Histosol soils covered by brown-black water and dense vegetation. Chemically, the soil and water are low in pH and dissolved oxygen. Development of these swampy areas presents engineering problems of drainage and irrigation that must be solved. Soil and water fertilization is required.

Many efforts have been made to farm swampy areas, but almost all have used monocultures (such as rice or fish ponds) that fail to achieve desired yields. Alternatively, integrated farming systems that are based on traditional techniques adapted to these areas could be tried. Rice-duck-fish systems merit special attention.
Research is needed to adapt traditional farming methods to swamplike environments. Specifically, it will be necessary to determine the best approaches to fertilization of both soil and water, to find the most productive rice varieties, and to select appropriate species of duck and fish. Efforts should be made to use indigenous resources and to design systems that recycle by-products to the greatest extent possible.

Biogas Technology

The cost of constructing a biogas plant is substantial, and the return on investment is often not sufficiently attractive if product use is confined to biogas as fuel and to sludge as fertilizer. If sludge is used as a feed component, economics improve considerably. However, there is strong reluctance to feed sludge to animals as there are doubts about its efficiency as feed and concerns about the risk of disease.

Existing designs for biogas units are not satisfactory for use by small farmers. The floating canopy (Indian) type is too expensive and inflexible. The Chinese liquid displacement type is less expensive but requires skilled artisans, particularly when concrete is used. Gas leaks are a common problem.

Research is needed on the use of inexpensive alternative materials for construction of digesters and to develop alternative uses for sludge. Three areas merit attention:

- The use of polyvinyl chloride (PVC) and similar plastics for the construction of plug-flow tube digesters. Plastics are available in large towns in many countries, but technologies for fabrication of tubes must be developed.

- The use of tent digesters consisting of a plastic canopy over an unlined ditch or trench. These digesters may be appropriate in some situations, but methods of sealing trenches and techniques for securing the canopy must be improved.

- The implications of feeding livestock with different concentrations of biodigester sludge and using effluent as fish pond fertilizer. Animal productivity and disease transmission should be assessed.

Poultry

In the wet tropics, ducks appear to have a number of advantages over chickens: they adapt better to wet and humid conditions and have greater resistance to disease. Moreover, ducks can consume liquid diets (such as molasses and sugarcane juice), and they can harvest algae and water plants in situ. Ducks confined over water have faster growth, better health, and improved feather quality than those raised
on dry land. Furthermore, feed wastage is avoided since residues or spillage from feeders are consumed by fish. Disadvantages of ducks include social prejudices that are reflected in lower egg and meat prices.

Greater effort should be made to improve the productivity and efficiency of ducks.

- Studies should be conducted on the comparative productivity, efficiency of resource use, and adaptability of ducks compared to chickens in wet tropical environments. Parameters to be measured should include socioeconomic and technical criteria. Both egg and meat production should be assessed based on tropical feed resources.

STABLE CARBON ISOTOPE TRACER TECHNIQUES IN AQUACULTURE

A research technique that offers great promise for improving food production in aquaculture is the use of stable carbon isotopes as naturally occurring tracers of nutrients in the food web. The technique is based on the following relationships:

- The carbon atoms in all plants and animals consist of two stable isotopes (\(^{13}\)C and \(^{12}\)C).

- The isotope ratio in a particular plant type is a predictable quantity determined by the photosynthetic pathway of that plant type (C\(_3\) or C\(_4\)). For example, the isotope ratio expressed as \(^6\)C in plankton algae is different from that of corn or soybeans. Such differences can be measured by mass spectrometry.

- The isotope ratio of animal flesh reflects the ratio in the food it has eaten. For example, studies in Illinois showed that a change in the food of tilapia from plankton algae to corn stillage (residue from alcohol production) was reflected in the tissues of growing tilapia within a matter of weeks.

This technique is significant in that it can be used to measure the contribution that each of several foods (supplied feed, organic fertilizers, algae, etc.) makes toward the growth of cultured animals. With this tool, researchers and pond managers can adjust feeding regimes, manuring rates, or other management procedures to enhance production using the most efficient or economical foods. Such knowledge will be increasingly critical as competition for grains, fish meal, and other commodities increases, and feed costs reach half the operating expense of a typical fish farm.

Evidence is accumulating from aquaculture research that commercial rations supplied as primary food may be nothing more than expensive substrates for natural foods (i.e., plants and microorganisms) that turn out to be the primary food source for the cultured animal. Data
from research in Israel, for example, showed isotopic ratios in prawn flesh reflecting use of natural foods, whether the primary input was manure or expensive, formulated prawn rations.

These preliminary studies indicate that the natural carbon isotope technique can be a powerful tool for research and development in the following areas:

- Determining the relative contribution of manure-based (heterotrophs) and photosynthetically based (autotrophs) foods to an aquaculture system
- Determining the relative use of specific types of foods (supplied feeds, algae, manures, or composted, fermented, or digested wastes)
- Evaluation of the effects of specific changes in feeding regimes, manuring rates, or purely physical changes in pond environment
- Evaluation of the effectiveness of different combinations of natural and supplied feeds. Some agricultural wastes will require supplementation with a complementary waste, or a commercial ration. It is anticipated, however, that commercial rations could often be relatively inexpensive carbohydrates rather than costly protein.

An obvious limitation of this technique is the necessity for access to a mass spectrometer and a skilled operator. However, this technique can be used at a site remote from the field experiment.

ECONOMIC AND SOCIAL ISSUES

Research on economic and social issues in integrated farming and aquaculture is likely to be important for its impact on farmers in varied environmental regimes and economic circumstances. The results of these studies will improve the effectiveness of technical research by guiding it toward features that improve its acceptability by farmers. Another effect may be allocative in nature, resulting in perhaps no significantly greater total food output but critically affecting its distribution.

Infrastructural Needs

Improved aquaculture systems will place new demands on rural infrastructure, including the need to supply specialized inputs and to process, transport, store, and sell new and often perishable food products. Requirements can be substantial for credit to construct production facilities and to finance production costs. Public regulations and organizations to specify rights and obligations for
operating aquaculture and integrated farming systems are needed. Individual entrepreneurs cannot develop the infrastructure. Potentially productive and profitable technology often fails because the need for public investment in specialized facilities is not understood.

- Research is needed to define the infrastructural requirements of aquaculture and integrated farming systems and to suggest mechanisms required to provide them.

Introduction of Complex Farming Systems

Integrated aquaculture and farming systems are based on numerous interacting subsystems. While farmers may understand the operation of a complete system, they often are unable to invest in all of the components at once. Improvements in production systems tend to be incremental, paced at a rate that permits capital accumulation.

- Development of integrated aquaculture and farming systems designed for stepwise implementation, with much flexibility for optional approaches, is needed.

- Information on farmers' managerial capacities is needed. Integrated farming and aquaculture systems are complex. Are farmers generally willing and able to undertake such systems, or is it the rare entrepreneur or financially secure farmer who is willing to experiment?

Impact on Employment and Income

It is important to know who will benefit from improved aquacultural technologies. Given the economics of intensive systems (i.e., labor and cash requirements, and economies of scale), do landless laborers stand to benefit? Research is needed to determine:

- The employment characteristics of the new systems, including the impact of change on the earnings of women. Women often manage small livestock enterprises in Asia. Does this pattern hold for small aquaculture activities?

- The profitability of specific innovations. While budget studies are sufficient for simple aquaculture projects, work is needed to analyze economies of scale for integrated aquaculture and farming systems to identify options best suited for small operations.

Absolute profit is often very high in advanced aquaculture systems, but the rate of return on investment may be unattractively low. A 2:1 financial rate of return on current inputs is a good rule of thumb as
the rate small farmers can expect, yet complex integrated systems typically offer less.

- Research is needed to determine the conditions under which aquaculture projects can be expected to succeed.

SELECTED READINGS


Advances in instrumentation for environmental monitoring and chemical analysis have played a key role in the development of new scientific capabilities described elsewhere in this report. In view of the central importance of monitoring and analysis, representatives of each working group met to discuss related general issues and specifically to assess:

- Monitoring and analysis needs relating to research topics recommended by the working groups.
- Training, organization, and management needs of applied chemistry in developing countries.

PROBLEMS RELATED TO THE CONDUCT OF ANALYTICAL RESEARCH AND MONITORING PROGRAMS IN DEVELOPING COUNTRIES

Constraints to the conduct of chemical research in developing countries, generally, and to the implementation of the specific projects recommended in this report were identified.

Servicing and Maintenance of Equipment

Inability to service and maintain modern instruments was identified as the major constraint and a constant source of irritation to scientists in most developing countries. It should be noted that the Agency for International Development, the National Science Foundation, and the United Nations Industrial Development Organization have supported recent attempts to establish self-sustaining equipment repair and maintenance centers in several developing countries (in Egypt; in Jamaica, specifically for biomedical equipment with initial assistance from U.S. National Institutes of Health biomedical engineering staff; and in Tanzania). Staff at these centers are trained on site by U.S. or other qualified engineers who then help them train students on equipment brought for repair to the center by surrounding clinical and research institutions. As the project proceeds, it is expected that
U.S. input will decrease and repair charges increase until the center becomes self-supporting. On-the-job training on actual cases is supplemented by basic electronics laboratory exercises. The working group considered this to be a promising approach to a universal problem. One problem the centers face is the ready market for trained technicians, which tends to lure them away to other jobs.

Disruptions and Variations in the Power Supply

Disruptions and variations in the power supply are common problems in developing countries. Attempts to overcome them have included installation of voltage stabilizers to smooth variations and backup generators to maintain supply. Locating the most sophisticated instrumentation in regional centers equipped with the necessary backup power systems is considered to be more cost-effective than distributing them among many laboratories. This approach has been taken in India and in several developed countries. Though not a perfect solution, it has contributed significantly to creating the necessary infrastructure for chemical analysis and has greatly enhanced analytical research capabilities.

Availability of Chemicals, Materials, and Replacement Parts

The slow, laborious, and expensive process of obtaining scientific materials and instruments from abroad could be improved by removing sales and import taxes and by providing necessary foreign exchange. These practices are in effect in several countries.

It was noted that often equipment is purchased that is much more sophisticated than that actually required for a project, which not only increases costs but also compounds maintenance problems.

Recommendations

It was recommended that:

- Repair/maintenance/training centers be established in developing countries
- The simplest apparatus appropriate to research needs be ordered and that the scientists be involved in the decision-making process
- Sales and import taxes be removed and foreign exchange provided for purchase of scientific instrumentation and materials used in publicly funded projects
Regional instrument centers (with backup power systems and trained technicians) be established for the most expensive and sophisticated equipment (mass spectrometers, argon plasma spectrophotometers, etc.)

MONITORING AND ANALYSIS NEEDS RELATED TO RESEARCH RECOMMENDED BY THE WORKING GROUPS

The primary analytical requirements of all four working groups related mainly to the analysis of mycotoxins, trace elements, and pesticides.

Mycotoxins

Expensive electronic instrumentation is not required in the analysis of mycotoxins. Thin-layer chromatography (TLC), which has been applied extensively for multimycotoxin analysis, is the technique of choice. TLC has been successfully applied in culture work, and on grains, nuts, and finished food products.

For aflatoxins, minicolumn procedures offer an ideal "field" technique. Recent reviews of the application of TLC to mycotoxin analysis have been compiled by Scott (1980, 1982).

Trace Elements

Atomic absorption spectrometry (AA) is the procedure of choice for analysis of trace elements in water, soil, plant material, and food. A recent publication reviewing the technique is available (Ihnat 1982). Redistilled solvents and specially purified water (passed through cation and anion exchange resins) are necessary, however, and provisions must be made to meet this requirement.

For anion (and in some cases, cation) analysis, the low cost, adaptability, and effectiveness of nonsegmented flow injection analysis (FIA) was noted for determinations that can be made spectrophotometrically. The technique is especially applicable to analysis of plant, water, and soil samples (Ruzicka and Hanson 1981). The method's advantages are small sample size and reagent requirements, large sample throughput, low initial costs (peristaltic pumps, injector, spectrophotometers, and chart recorders), good reproducibility, and good sensitivity. The principal disadvantage is that training requires personal experience in an existing laboratory.

Pesticides

Several options are open depending on the specific need for pesticide residue analysis and assessment. These options range from simple fish bioassay procedures for use by rice farmers, through primitive TLC procedures, to those based on gas-liquid chromatography (GLC).
TLC procedures are most generally applicable and include silica gel TLC followed by appropriate spray reagents or TLC screening procedures using techniques based on enzyme inhibition (organophosphates, carbamates) or photosynthesis inhibition (herbicides) (Mendoza 1981).

Qualitative screening for unknown pesticide residues generally requires procedures based on GLC. The general screening procedure currently used in Canada accommodates 140 compounds (Health and Welfare Canada 1973).

More sophisticated research, including the identification of naturally occurring insecticides, and studies on pesticide metabolism require much more sophisticated instrumentation.

OTHER ISSUES

Quality Assurance

It is most important in analytical methodology to have regularly scheduled quality assurance checks. These checks can include a simple exchange of samples between a number of laboratories within a country or participation in international check sample programs organized by various centers throughout the world. An example of the latter is the International Check Sample Program on Aflatoxin organized by the International Agency for Research on Cancer. Participation is free.

Communication and Training

Staying informed about mainstream ideas and developments is a major problem for scientists in developing countries. Short scientific visits or study tours provide opportunities for these scientists to attend international meetings, make and renew contacts, observe the latest developments, and check the relevance and standard of their work against that of other laboratories.

A broad and sustained fellowship program is of value in establishing and maintaining a strong scientific base in developing countries. Visiting scientist programs are most valuable as mechanisms for transferring skills, providing advice, and acting as a catalyst for new work. Support is provided for both of these programs from several agencies of the United Nations system. It is essential that these programs be maintained and expanded.

REFERENCES


APPENDIX A

CHEMRAWN II Program

CHEMRAWN II Program

International Conference on Chemistry and World Food Supplies: The New Frontiers

December 6-10, 1982
Philippine International Convention Center
Manila, Philippines

Cosponsored by:
International Union of Pure and Applied Chemistry
and
International Rice Research Institute

CHEMRAWN
Chemical Research Applied to World Needs

Affiliate Sponsors
Chemical Society of the Philippines
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International Soil Science Society
International Union of Biochemistry
International Union of Biological Sciences
International Union of Food Science and Technology
International Union of Nutritional Sciences
Day 1  December 6, 1982
Delegation Building • Third Floor • Meeting Room 1

Opening Session

Session Chairman: Dr. Nyle C. Brady, formerly of The International Rice Research Institute (IRRI),
Presently: Agency for International Development, USA

1000 Welcome by Conference Cosponsors
Dr. S. Nagakura, President
International Union of Pure and Applied Chemistry (IUPAC)

Dr. Marcos R. Vega
The International Rice Research Institute (IRRI)

Introduction of President Ferdinand E. Marcos of the Republic of the Philippines
Mr. Arturo R. Tanco, Jr.
Minister of Agriculture, Republic of the Philippines

Welcome Address
President Ferdinand E. Marcos
Republic of the Philippines

Break

Our Greatest Challenge—Feeding the Hungry World
Dr. M. S. Swaminathan
International Rice Research Institute, Philippines

Luncheon

1400 Economic and Social Factors Influencing the Use of Chemicals in Agriculture
Dr. W. David Hopper, The World Bank, USA

1440 The Future Role of Chemistry in Removing Constraints on Food Production and Utilization
Dr. Louis Von Planta, Ciba-Geigy, Ltd., Switzerland

1520 Break

1540 Physical, Chemical, and Biological Constraints on Food Production and on the Level and Efficient Use of Chemical Inputs
Dr. Thomas R. Odhiambo, International Center for Insect Physiology and Ecology, Kenya, and
Dr. P. A. Sanchez, North Carolina State University, USA

1620 Basic Chemical Research and Future World Food Supplies
Dr. Melvin Calvin, Nobel Laureate, University of California-Berkeley, USA

1700 Adjourn

1830 Reception—Delegation Building, Third Floor, Lobby
Evening reception/buffet for Conference registrants, followed by a special cultural presentation featuring music and dances from different provinces of the Philippines.
The Role of Chemistry and Biochemistry in Improving Agricultural Productivity

Day 2
December 7, 1982
Delegation Building • Third Floor • Meeting Room 1

Session A: Soil and Crop Management for Efficient Use of Water and Nutrients

Session Chairman: Sir Charles Pereira
Peartrees, England

0900 Introductory Remarks

0910 A-1 Contributions of Chemistry to Removing Soil Constraints to Crop Production
Dr. R. Scott Russell, Formerly Director of the Letcombe Laboratory, England and Dr. G. W. Cooke, Rothamsted Experimental Station, England

1010 Break

1030 A-2 Developing More Efficient Fertilizers Through Formulation, Manufacturing, and Distribution Technology
Dr. Donald L. McCune, International Fertilizer Development Center, USA

1110 A-3 Modifying Crop Performance with Growth-Regulating Chemicals
Professor Johan Bruinsma, Agricultural University, The Netherlands

1150 Discussion

1250 Lunch Break

1330 A-4 Improving the Productivity of Problem Rice Lands
Dr. Felix M. Ponnamperuma, The International Rice Research Institute, Philippines

1410 A-5 Chemical Approaches to Increasing Water Availability to Crops, Including Minimum Tillage Systems
Dr. R. Lal, Dr. A. S.R. Juo, and Dr. B. T. Kang, The International Institute of Tropical Agriculture, Nigeria

1450 Break

1510 A-6 New Developments in Chemical Control of Weeds
Dr. J. R. Corbett, FBC Limited, England

1550 A-7 Chemical Techniques for Monitoring Analysis and Avoiding Pollution of Soil and Water Resources
Dr. N. Drescher, BASF, A. G., Federal Republic of Germany

1630 Discussion

1710 Adjourn

1715 - 1915 Poster Sessions (Lobby)
Day 2

Secretariat Building • Second Floor • Meeting Room 2

Session B: Integrated Approaches to Pest Management

Session Chairman: Dr. Herwig Hulpke
Bayer, A.G., Federal Republic of Germany

0900 Introductory Remarks

0910 B-1 Principal Pests of Food Crops
Dr. J. C. Davies, Centre for Overseas Pest Research, England

0950 B-2 Principal Diseases of Food Crops
Dr. G. Rangaswami, Commonwealth Technical Adviser, Bangladesh

1030 Break

1050 B-3 Interaction Among Pests, Diseases, and Weeds in Farming Systems
Dr. John Finney, ICI, England

1130 B-4 The Biochemical Basis of Resistance in Host Plants to Insect Pests
Dr. Mano D. Pathak and Dr. D. Dale, The International Rice Research Institute, Philippines

1210 Discussion

1250 Lunch Break

1330 B-5 Naturally Occurring Pesticides and Their Potential
Dr. Ramesh C. Saxena, The International Rice Research Institute, Philippines

1410 B-6 Pheromones and Other Recent Developments in Biochemical Pest Management
Mr. Peter S. Beevor, Dr. B. F. Nesbitt, and Dr. D. R. Hall, Tropical Products Institute, England

1450 Break

1510 B-7 The Potential for the Integration of Plant Resistance; Agronomic, Biological, and Physical/Mechanical Techniques; and Pesticides for Pest Control in Farming Systems
Dr. Ida Nyoman Oka, Ministry of Agriculture, Indonesia

1550 B-8 Environmental Aspects of Pest Management
Dr. David Pimentel, Cornell University, USA

1630 Discussion

1710 Adjourn

1715 - 1915 Poster Sessions (Lobby)
Day 2
December 7, 1982
Secretariat Building • Second Floor • Meeting Room 3

Session C: The Role of Chemistry and Biochemistry in Improving Animal Production Systems

Session Chairman: Dr. P. Mahadevan
Food and Agriculture Organization (FAO) of the U.N., Italy

0900 Introductory Remarks

0910 C-1 Nitrogen Sources and Roughage in Ruminant Nutrition
Dr. J. H. B. Roy, National Institute for Research in Dairying, England

0950 C-2 The Use of Sugar Cane and By-Products for Livestock
Dr. T. R. Preston, James Cook University, Australia

1030 Break

1050 C-3 Advances in Fodder Conservation Techniques
Dr. Ernst Zimmer, Institute of Grassland and Forage Research, Federal Republic of Germany

1130 C-4 Recent Developments in Feed Additives
Dr. Z. O. Müller, FAO, Pakistan

1210 Discussion

1250 Lunch Break

1330 C-5 Biochemical and Chemical Contributions to Efficient Small-Scale Pig and Poultry Systems
Dr. L. Aumaitre, Institute National de la Recherche Agronomique, France

1410 C-6 Aquaculture Systems: Problems in Breeding and Feeding
Dr. Rafael Guerrero, III, Philippines Council for Agriculture and Resources Research and Development, Philippines

1450 Break

1510 C-7 Chemistry in the Control of Ruminant Animal Diseases and Reduction of Physical and Biological Stress
Dean Robert H. Dunlop, DVM, University of Minnesota, USA

1550 C-8 Chemistry in the Control of Animal Trypanosomiasis and Theileriosis
Dr. A. R. Gray, International Laboratory for Research on Animal Diseases, Kenya

1630 Discussion

1710 Adjourn

1715 - 1915 Poster Sessions (Lobby)
The Role of Chemistry and Biochemistry in the Preparation, Processing, and Storage of Food

Day 2
December 7, 1982
Delegation Building • Third Floor • Meeting Room 11

Session D: Contributions of Chemistry and Biochemistry to Developing New and Improved Food Sources

Session Chairman: Dr. Khaled El-Shazly
Alexandria University, Egypt

0900 Introductory Remarks

0910 D-1 Synthetic Foods: Technical, Economic, Esthetic, and Cultural Issues
Dr. Sanford A. Miller, Food and Drug Administration, USA

0950 D-2 New Protein Sources of Food and Feed
Dr. Yasuji Minoda, University of Tokyo, Japan

1030 Break

1050 D-3 Conversion of Plant and Animal Waste to Food
Professor Antoni Rutkowski, Agricultural University of Warsaw, Poland

1130 D-4 Improving the Supply, Quality, and Utility of Carbohydrates
Professor R. Rajalakshmi, University of Baroda, India

1210 Discussion

1250 Lunch Break

1330 D-5 Improving the Supply, Quality, and Utility of Fats
Mr. Joseph Moolayil, Lever Brothers, Malaysia

1410 D-6 Rumen-Protected Amino Acids
Dr. H. Offermanns and Dr. H. Tanner, DEGUSSA AG, Federal Republic of Germany

1450 Break

1510 D-7 Improving the Supply, Quality, and Utility of Proteins
Dr. S. Arai, University of Tokyo, Japan

1550 D-8 Expanding and Improving the Food Supply With Enzyme Systems
Dr. Bernard Wolnak, Bernard Wolnak and Associates, USA

1630 Discussion

1710 Adjourn

1715 - 1915 Poster Sessions (Lobby)
Day 2  December 7, 1982
Delegation Building • Third Floor • Meeting Room 12

Session E: Chemistry and Biochemistry in the Processing and Storage of Food

Session Chairman: Ms. Teresa Salazar de Buckle,
Junta de Acuerdo de Cartagena, Peru

0900 Introductory Remarks

0910 E-1 Overview of Storage and Processing
Professor J. Solms and Dr. M. Bachmann, Swiss Federal Institute of Technology, Switzerland

0950 E-2 Fish Processing
Dr. Torger Borreson and Dr. Terje Strom, Institute of Fishery Technology Research, Norway

1030 Break

1050 E-3 Progress in Preservation by Fermentation
Dr. Keith H. Steinkraus, New York State Agricultural, Experiment Station, USA

1130 E-4 Amino Acid Production and Use to Improve Nutrition of Foods and Feeds
Dr. Takekazu Akashi, AJINOMOTO Company, Inc., Japan

1210 Discussion

1250 Lunch Break

1330 E-5 Chemical and Biochemical Pretreatment of Food for Drying
Professor P. O. Ngoddy, University of Nigeria, Nigeria

1410 E-6 Studies on Heat Treatment of Wheat Grains in China
Ms. Rei-Zheng Liu, Cereal and Oil Chemistry Institute of the Ministry of Commerce, China

1450 Break

1510 E-7 Removal by Processing of Naturally Occurring Toxicants and Antinutrients
Dr. I. E. Lienert, University of Minnesota, USA

1550 E-8 Water Activity and Intermediate Moisture Foods
Dr. Marcus Karel, Massachusetts Institute of Technology, USA

1630 Discussion

1710 Adjourn

1715 - 1915 Poster Sessions (Lobby)
Day 2  December 7, 1982

Delegation Building • Third Floor • Meeting Room 9

Session F: Chemistry in the Assessment and Control of the Food Supply

Session Chairman: Dr. Bansi Amla  
Central Food Technological Research Institute, India

0900  Introductory Remarks

0910  F-1  New Developments of Cooperation Between the Chemical and Food Industries to Improve the Control of the Food Supply  
Dr. Pierre Roessler, Industrie Chimique de Mulhouse-Dornach, France

0950  F-2  Overview of Assessment and Control  
Professor R. A. N. Edwards, University of South Wales, Australia

1030  Break

1050  F-3  Effects of Nutritional Quality of Chemical Changes in Processing and Storage in Food Legumes  
Dr. Ricardo Bressani, J. E. Braham, and L. G. Elias, Instituto de Nutricion de Centro America y Panama, Guatemala

1130  F-4  Rapid Testing for Contaminants and Toxicants in Foods  
Dr. H. B. S. Conacher, Health and Welfare, Canada

1210  Discussion

1250  Lunch Break

1330  F-5  Rapid, Simple Testing for Nutrients as an Aid to Plant Breeding  
Dr. Bienvenido O. Juliano, The International Rice Research Institute, Philippines

1410  F-6  Multivariate Analysis of Raw Materials  
Dr. Karl H. Norris, Department of Agriculture, USA

1450  Break

1510  F-7  The Important Difference Between Chemical Analysis and Biological Availability  
Professor Arnold E. Bender, Queen Elizabeth College, England

1550  F-8  Problems of Correlation and Definition in Analytical Techniques  
Professor W. Baltes, Technische Universitat Berlin, Federal Republic of Germany

1630  Discussion

1710  Adjourn

1715 - 1915 Poster Sessions (Lobby)
Day 3

December 8, 1982

Delegation Building • Third Floor • Meeting Room 1

Session G: The Forward Edge

Session Chairman: Dr. Louis G. Nickell
Velsicol Chemical Corporation, USA

0900 Introductory Remarks

0910 G-1 Overview of the Potentials and Prospects in Genetic Engineering
Dr. Lawrence Bogorad, Harvard University, USA

0950 G-2 Applications of Genetic Engineering to Plant and Animal Production
Professor Jeff Schell, Max Planck Institut für Züchtungsforschung, Federal Republic of Germany

1030 Break

1050 G-3 The Application of Wide Crosses to Plants
Dean Leonard Shebeski, The International Institute of Tropical Agriculture, Nigeria

1130 G-4 Improved Conventional Strategies and Methods for Selection and Utilization of Germplasm
Dr. Donald N. Duvick, Pioneer Hi-Bred International, Inc., USA

1210 Discussion

1250 Lunch Break

1330 G-5 Biochemical and Genetic Approaches to Increased Nitrogen Fixation
Dr. Ralph W. F. Hardy, E. I. du Pont de Nemours & Company, USA

1410 G-6 The Role of Growth Regulators and Hormones in Enhancing Food Production
Dr. Louis G. Nickell, Velsicol Chemical Corporation, USA

1450 Break

1510 G-7 The Potential Contribution of Cell and Tissue Culture to Crop Improvement
Professor Otto J. Crocomo, University of Sao Paulo, Brazil

1550 G-8 Photosynthetic Activity and Partitioning
Dr. Lloyd T. Evans, Commonwealth Scientific and Industrial Research Organization, Australia

1630 Discussion

1630 Adjourn

1715 - 1915 Poster Sessions (Lobby)

1930 Banquet: Featured Speaker: Dr. James C. Ingram, World Food Programme, Italy
Banquet tickets can be purchased at the Conference Information Desk and Message Center located on the ground floor of the Secretariat Building.
Day 4  
December 9, 1982

Delegation Building • Third Floor • Meeting Room 1

Session G: The Forward Edge

Session Chairman: Dr. Louis G. Nickell  
Velsicol Chemical Corporation, USA

0900 Introductory Remarks

0910 G-9 New Approaches to Meat and Milk Production  
Dr. Virgil W. Hays, University of Kentucky, USA

0950 G-10 Biorational Design of Chemicals  
Dr. Hans Geissbuhler, Ciba-Geigy, Ltd., Switzerland

1030 Break

1050 Special Plenary Session  
Food and Energy-Interdependent World Needs  
Sir George Porter, Nobel Laureate, The Royal Institution, England

1130 Discussion

1210 Lunch Break

Afternoon field trip to the Los Baños Complex in Laguna Province,  
including a visit to the International Rice Research Institute (IRRI) and  
the University of the Philippines at Los Baños.

Don't miss the Exhibit of scientific instruments, equipment, supplies and publications

Monday December 6 - Friday, December 10, 1982  
0800 - 1800

Poster Sessions will be held on Tuesday, December 7  
and Wednesday, December 8, from 1715-1915 in the  
Delegation Building, Third Floor, Lobby.

A The role of chemistry and biochemistry in improving agricultural productivity.

B The role of chemistry and biochemistry in the preparation,  
processing, and storage of food.

C New frontiers in food production and processing, including applied biochemistry and genetic engineering.
Day 5
December 10, 1982
Delegation Building • Third Floor • Meeting Room 1

Closing Session

Session Chairman: Dr. Cyril Ponnamperuma
University of Maryland, USA

0900 Introductory Remarks
Dr. Cyril Ponnamperuma, Chairman, CHEMRAWN II Future Action Committee

0910 Opening Presentation
SPEAKER TO BE ANNOUNCED

0955 Report of Chairman of Technical Session A
Soil and Crop Management for Efficient Use of Water and Nutrients

1025 Break

1045 Report of Chairman of Technical Session B
Integrated Approaches to Pest Management

1115 Report of Chairman of Technical Session C
The Role of Chemistry and Biochemistry in Improving Animal Production Systems

1145 Discussion

1210 Lunch Break

1310 Report of Chairman of Technical Session D
Contributions of Chemistry and Biochemistry to Developing New and Improved Food Sources

1340 Report of Chairman of Technical Session E
Chemistry and Biochemistry in the Processing and Storage of Food

1410 Report of Chairman of Technical Session F
Chemistry in the Assessment and Control of the Food Supply

1440 Report of Chairman of Technical Session G
The Plenary Edge

1510 Break

1530 Closing Presentation
Dr. Norman E. Borlaug, Nobel Laureate
International Maize and Wheat Improvement Center (CIMMYT), Mexico

1645 Concluding Remarks
Dr. Bryant W. Rossiter, Chairman
CHEMRAWN II Conference

1700 Adjournment
APPENDIX B

Workshop Participants

LOUIS G. NICKELL, Velsicol Chemical Corporation, Chicago, Illinois, USA, Co-Chairman
DAVID PIMENTEL, Department of Entomology, Cornell University, Ithaca, New York, USA, Co-Chairman
MUCHTAR AHMAD, Center for Rural Development Studies, Universitas Riau, Indonesia
B. J. AMIA, Central Food Technological Research Institute, Mysore, India
IRVIN M. ASHER, Office of the Science Advisor, Agency for International Development, Washington, D.C., USA
WILLIAM S. BOWERS, New York State Agricultural Experiment Station, Cornell University, Geneva, New York, USA
BILL B. BRODIE, Agricultural Research Service, U.S. Department of Agriculture, Department of Plant Pathology, Cornell University, Ithaca, New York, USA
D. HOMER BUCK, Parr Fisheries, Illinois Natural History Survey, Kimmundy, Illinois, USA
MOHINDRA S. CHADHA, Bio-Organic Division, Bhabha Atomic Research Centre, Bombay, India
CHANG-HUNG CHOU, Institute of Botany, Academia Sinica, Taipei, Taiwan
HENRY B. S. CONACHER, Bureau of Chemical Safety, Health Protection Branch, Ottawa, Ontario, Canada
PAUL CROWLEY, Office of International Cooperation and Development, U.S. Department of Agriculture, Washington, D.C., USA
TERESA SALAZAR DE BUCKLE, Junta del Acuerdo de Cartagena, Lima, Peru
S. K. DE DATTA, International Rice Research Institute, Los Baños, Philippines
CATALINA R. DE LA CRUZ, Freshwater Aquaculture Center, Central Luzon State University, Nueva Ecija, Philippines
RAY B. DIAMOND, International Rice Research Institute, Los Baños, Philippines
MOSTAFA EL-SHERIF, Faculty of Agriculture, University of Cairo, Cairo, Egypt
LLOYD FREDERICK, Agency for International Development, Washington, D.C., USA
THOMAS T. GEORGE, Fisheries Research Centre, Agricultural Research Corporation, Khartoum, Sudan

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DENNIS GREENLAND, International Rice Research Institute, Los Baños, Philippines

RAFAEL GUERRERO, Philippine Council for Agriculture and Resources Research and Development, Los Baños, Philippines

CARL-GÖREN HEDEN, Karolinska Institutet, Stockholm, Sweden

WALTER HERATH, International Dambala (Winged Bean) Institute, Kundasale, Sri Lanka

BENVENIDO O. JULIANO, International Rice Research Institute, Los Baños, Philippines

SANTOSA KOESEMADINATA, Inland Fisheries Research Institute, Bogor, Indonesia

J. MAUD KORDYLAS, Food Research Institute, Council on Scientific and Industrial Research, Accra, Ghana

R. LAL, International Institute of Tropical Agriculture, Ibadan, Nigeria

EDWARD P. LINCOLN, Agricultural Engineering Department, University of Florida, Gainesville, Florida, USA

FLORA Z. MAJID, BCSIR Laboratories, Dacca, Bangladesh

ANDREAS MANE, Mayondon, Laguna, Philippines

IBRAHIM MANWAN, Center for Agricultural Research, Planning, and Monitoring, Agency for Agricultural Research and Development, Jakarta Selatan, Indonesia

DONALD L. McCUNE, International Fertilizer Development Center, Muscle Shoals, Alabama, USA

ROBERT H. MILLER, Department of Soil Science, North Carolina State University, Raleigh, North Carolina, USA

HASSAN MOAWAD, National Research Centre, Cairo, Egypt

JOSEPH MOOLAYIL, Lever Brothers, Kuala Lumpur, Malaysia

S. H. MUJTABA NAQVI, Nuclear Institute of Agriculture and Biology, Faisalabad, Pakistan

RICHARD NEAL, International Center for Living Aquatic Resources Management, Manila, Philippines

ENRICO D. OBIAS, Liberty Flour Mills, Maya Farms Division, Manila, Philippines

IDA OKA, Food Crop Protection, Ministry of Agriculture, Bogor, Indonesia

E. R. PARISER, Sea Grant, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

JAMES F. PARR, Biological Waste Management and Organic Resources Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland, USA

RAJENDRA PRASAD, Indian Agricultural Research Institute, New Dehli, India

T. R. PRESTON, Department of Tropical Veterinary Science, James Cook University, North Queensland, Australia

EDWARD PRICE, International Rice Research Institute, Los Baños, Philippines

G. RANGASWAMI, Commonwealth Technical Adviser (Agriculture), Dacca, Bangladesh

KANOK RERKASEM, Faculty of Agriculture, Chiang Mai University, Chiang Mai, Thailand

ELROY L. RICE, Department of Botany and Microbiology, University of Oklahoma, Norman, Oklahoma, USA
WORKING GROUPS

Soil Fertility and Plant Nutrition

Robert H. Miller, Chairman
S. K. De Datta
Ray B. Diamond
Lloyd Frederick
Dennis Greenland
Walter Herath
R. Lal
Donald L. McCune
Hassan Mosawad
Rajendra Prasad
Pedro A. Sanchez
G. R. Sandhu
Goro Uehara
Peter B. Vose
C. Stanley Weeraratne
David M. Nog, BOSTID Staff

Plant Growth Regulators and
Plant-Pest Relationships

Louis G. Nickell, Co-Chairman
David Pimentel, Co-Chairman
Irvin M. Asher
William S. Bowers
Bill B. Brodie
Mohindra S. Chadha
Chang-Hung Chou
Mostafa El-Sherif
Ibrahim Hanwan
Ida Oka
G. Rangaswami
Kanok Rerkasem
Elroy L. Rice
R. R. Ronkin
Ramesh C. Saxena
Milton N. Schroth
Loren L. Schulze
Dennis Wood, BOSTID Staff

Food Science and Technology

E. R. Pariser, Chairman
B. J. Amla
Teresa Salazar de Buckle
Aquaculture and Integrated Farming Systems

Edward F. Lincoln, Chairman
Muchtar Ahmad
D. Homer Buck
Catalina R. De La Cruz
Thomas T. George
Rafael Guerrero
Carl-Güren Häden
Santosa Koesemadinata
Flora Z. Majid
Andreas Mane
Richard Neal
Enrico D. Obias
James F. Parr
T. R. Preston
Edward Price
Kenneth Ruddle
Ernst Von Weizacker
Griffin Shay, BOSTID Staff

Environmental Monitoring and Chemical Analysis

Henry B. S. Conacher, Chairman
William S. Bowers
Mohindra S. Chadha
James F. Parr
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