TOWARD SUSTAINABILITY

An Addendum on Integrated Pest Management as a Component of Sustainability Research

NATIONAL RESEARCH COUNCIL

Digitized by Google

TOWARD SUSTAINABILITY

An Addendum on Integrated Pest Management as a Component of Sustainability Research

A Report of a Subpanel Prepared for the Panel for Collaborative Research Support for AID's Sustainable Agriculture and Natural Resource Management Program

Board on Agriculture

Board on Science and Technology for International Development

National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1992

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice-chairman, respectively, of the National Research Council.

This report has been prepared with funds provided by the Bureau for Science and Technology, Office of Agriculture and Office of Rural Development, U.S. Agency for International Development, under Grant No. DAN-5052-C-00-6037-00. The U.S. Agency for International Development reserves a royalty-free and nonexclusive and irrevocable right to reproduce, publish, or otherwise use and to authorize others to use the work for government purposes.

Limited copies are available from:

Board on Science and Technology for International Development
Office of International Affairs
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

PANEL FOR COLLABORATIVE RESEARCH SUPPORT FOR AID'S SUSTAINABLE AGRICULTURE AND NATURAL RESOURCE MANAGEMENT PROGRAM

LOWELL HARDIN, *Chairman,* Purdue University
JOHN AXTELL, Purdue University
HECTOR BARRETO, Centro Internacional de Mejoramiento de Maíz y Trigo, Guatemala
BARBARA BRAMBLE, National Wildlife Federation
PIERRE CROSSON, Resources for the Future
CLIVE EDWARDS, Ohio State University
RICHARD HARWOOD, Michigan State University
G. EDWARD SCHUH, Hubert H. Humphrey Institute of Public Affairs, University of Minnesota
G. K. VEERESH, University of Agricultural Sciences, India
ROBERT WAGNER, Phosphate and Potash Institute (Retired)

Ex Officio Members

PATRICIA BARNES-MCCONNELL, Collaborative Research Support Program, Michigan State University
LEONARD BERRY, Florida Atlantic University
PEDRO SANCHEZ, International Council for Research in Agroforestry
JAN VAN SCHILFGAARDE, U.S. Department of Agriculture–Agricultural Research Service

Staff

MICHAEL McD. DOW, *Study Director*
JAY DAVENPORT, *Senior Project Officer*
BARBARA J. RICE, *Project Editor*
CURT MEINE, *Staff Associate*
NEAL BRANDES, *Study Assistant*
NANCY NACHBAR, *Program Assistant*

SUBPANEL ON INTEGRATED PEST MANAGEMENT FOR THE SUSTAINABLE AGRICULTURE AND NATURAL RESOURCE MANAGEMENT PROGRAM OF THE U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

PERRY ADKISSON, Texas A&M University
KEITH ANDREWS, Pan American School of Agriculture, Honduras
REUBEN AUSHER, Ministry of Agriculture, Israel
WILLIAM BARCLAY, Greenpeace
KENNETH H. BARKER, North Carolina State University
PETER S. CARLSON, Crop Genetics International
HAROLD COBLE, North Carolina State University
CHARLES DELP, Consultant, Wilmington, Delaware
CLIVE A. EDWARDS, Ohio State University
ROBERT EPLEE, Animal and Plant Health Inspection Service, U.S. Department of Agriculture
RICHARD A. FREDERIKSEN, Texas A&M University
GRACE GOODELL, Johns Hopkins University
DAVID GROENFELDT, Consultant, Silver Spring, Maryland
HANS R. HERREN, International Institute of Tropical Agriculture, Benin
DIANA HORNE, U.S. Environmental Protection Agency
ROBERT HUNTER, Hunter Consulting, Midland, Michigan
WILLIAM B. JACKSON, Bowling Green State University
BARRY J. JACOBSEN, Auburn University
RHONDA JANKE, Rodale Research Center
AGNES KISS, The World Bank
MARCOS KOGAN, Oregon State University
DAVID MACKENZIE, U.S. Department of Agriculture
ELUID OMOLO, International Center of Insect Physiology and Ecology, Kenya
GENE POLLARD, University of the West Indies, Trinidad and Tobago
EDWIN PRICE, Oregon State University
ALBERT PRINTZ, Neill & Co., Washington, D.C.
GEORGE TEETES, Texas A&M University
PAUL TENG, International Rice Research Institute, Philippines
H. DAVID THURSTON, Cornell University
N. A. VAN DER GRAAFF, Food and Agriculture Organization of the United Nations, Rome, Italy
G. K. VEERESH, University of Agricultural Sciences, India

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
YENE T. BELAYNEH, Bureau for Africa, Office of Technical Resources

HARVEY HORTIK, Bureau for Science and Technology, Office of Agriculture

WALTER KNAUSENBERGER, Bureau for Africa, Office of Technical Resources

WILLIAM OVERHOLT, Bureau for Science and Technology, Office of Agriculture

ALLAN SHOWLER, Bureau for Science and Technology, Office of Agriculture

BEN WAITE, Bureau for Science and Technology, Office of Agriculture

BOARD ON AGRICULTURE

THEODORE L. HULLAR, *Chairman,* University of California, Davis
PHILIP H. ABELSON, American Association for the Advancement of Science
DALE E. BAUMAN, Cornell University
R. JAMES COOK, Agricultural Research Service at Washington State University
ELLIS B. COWLING, North Carolina State University
PAUL W. JOHNSON, Natural Resources Consultant, Decorah, Iowa
NEAL A. JORGENSEN, University of Wisconsin
ALLEN V. KNEESE, Resources for the Future, Inc.
JOHN W. MELLOR, John Mellor Associates, Inc.
DONALD R. NIELSEN, University of California, Davis
ROBERT L. THOMPSON, Purdue University
ANNE M. K. VIDAVER, University of Nebraska
JOHN R. WELSER, The Upjohn Company

Staff

SUSAN OFFUTT, *Executive Director*
JAMES E. TAVARES, *Associate Executive Director*
CARLA CARLSON, *Director of Communications*
BARBARA J. RICE, *Editor*

BOARD ON SCIENCE AND TECHNOLOGY FOR INTERNATIONAL DEVELOPMENT

ALEXANDER SHAKOW, *Chairman,* The World Bank
PATRICIA BARNES-MCCONNELL, Michigan State University
JORDAN J. BARUCH, Jordan Baruch Associates
BARRY BLOOM, Albert Einstein College of Medicine
JANE BORTNICK GRIFFITH, Congressional Research Service
GEORGE T. CURLIN, National Institute of Allergy and Infectious Diseases
DIRK FRANKENBERG, University of North Carolina
RALPH HARDY, Boyce-Thompson Institute for Plant Research at Cornell University
FREDRICK HORNE, Oregon State University
ELLEN MESSER, Allan Shaw Feinstein World Hunger Program, Brown University
CHARLES C. MUSCOPLAT, Molecular Genetics, Inc.
JAMES QUINN, Dartmouth College
VERNON RUTTAN, University of Minnesota
ERNEST SMERDON, University of Arizona

Ex Officio Members

GERALD P. DINEEN, *Foreign Secretary,* National Academy of Engineering
JAMES B. WYNGAARDEN, *Foreign Secretary,* National Academy of Sciences

Staff

MICHAEL McD. DOW, *Acting Director*

Preface

At the request of the U.S. Agency for International Development (AID), the Board on Science and Technology for International Development and Board on Agriculture of the National Research Council (NRC) convened an NRC-appointed panel and a group of experts for an open forum in November 1990 on sustainable agriculture and natural resource management in developing countries. The forum served as a departure point for 3 days of intensive follow-up discussions of research priorities. Out of these discussions, the panel was asked to provide recommendations and guidelines for establishing and managing the new Collaborative Research Support Program (CRSP) for Sustainable Agriculture and Natural Resource Management (SANREM) to support collaborative research between U.S. institutions and counterparts in developing countries. The recommendations of the full panel are in *Toward Sustainability: A Plan for Collaborative Research on Agriculture and Natural Resource Management* (National Research Council, 1991).

An ad hoc subpanel met simultaneously to focus on the importance of pest management in sustainable agriculture, especially in the developing countries of the tropics. It was asked by AID to identify specific research gaps, involving problems of global or regional importance, that AID's Bureau for Science and Technology, Office of Agriculture, could help to fill and to assist AID in determining how integrated pest management (IPM) could be incorporated into the activities of the new CRSP. A second meeting was held in March 1991 to further refine the subpanel's findings. The first meeting was chaired by David MacKenzie from the U.S. Department of

Agriculture, and the second meeting was chaired by Clive Edwards from Ohio State University.

While the subpanel's recommendations were not adopted in full by the panel, they are reported here as a matter of information. The panel favored the integration of IPM research into the SANREM CRSP rather than funding IPM work as a stand-alone activity.

Concurrent with establishing the SANREM CRSP, the U.S. Congress directed AID to devote special attention to the problem of pest management in developing countries. Specifically, Congress directed AID to assess the need for an agencywide IPM policy, set up an IPM task force, and complete a review of the pest management sector. AID also was instructed to conduct an environmental assessment of locust and grasshopper control activities in Asia and Africa. In the course of its deliberations, the subpanel focused on these directives.

In determining priorities for more effective IPM, the subpanel reviewed not only current programs, but also the conceptual basis for and evolution of IPM (Edwards et al., 1991). Although there are diverse definitions of IPM, most entail an approach to pest management that integrates a range of methods and disciplines and that considers environmental, economic, and social values in the process. The importance of better-integrated methods of resource management is increasingly recognized within the international development community, and IPM seeks to provide them.

In opening remarks at the first meeting of the subpanel in November 1990, William Overholt of AID's Bureau for Science and Technology, Office of Agriculture, outlined the following issues and questions that AID faces in upgrading its pest management efforts, and that the subpanel would take these into consideration in its deliberations:

- Host countries often suffer from poor infrastructure (for example, roads and communications), weak or nonexistent institutions (for example, research facilities), and low wages. Simply training more workers is rarely an adequate solution, and one that can create management dilemmas. How should AID strengthen institutions, taking into account the problems of increased recurrent costs to local governments?
- What kind of institutions are necessary for the programs AID should support? What kinds of human capabilities are needed? How should AID activities fit into the international efforts of U.S. universities, other universities, the Food and Agriculture Organization (FAO) of the United Nations, and other international organizations?
- Should priority be given to countries with "enlightened" policies for pest management? Should countries with high pesticide subsidies, for example, be given lower priority than those (such as Indonesia) that subsidize IPM?
- Because AID does not have a solid cadre of people to help imple-

ment programs, it relies increasingly on short-term outside assistance. Should AID strengthen its internal ability to deliver pest management programs, or should it rely on outside contracts?

- With the Consortium for International Crop Protection project scheduled to end in September 1991, about $600,000 each year will become available for pest management, with the possibility of additional funds in the future. What should AID fund with $2 million, $1 million, or $500,000 per year? Should an IPM CRSP be created to complement the SANREM CRSP?
- The pest committee of the Consultative Group on International Agricultural Research (CGIAR) recently reviewed the pest management effort of the CGIAR system and suggested that it receive increased attention from donors through the creation of an IPM network. The committee's members believe that breeding plants for resistance to pests is being given too much emphasis relative to other aspects of pest management. How should AID work though the CGIAR system to address some of these issues? How should AID coordinate its activities with other donors and organizations, including the United Nations Development Program, FAO, U.S. federal agencies, and the private sector?

Dr. Overholt also pointed out that the IPM subpanel met at an important juncture in the course of current AID pest management activities. The Vertebrate Pest Management Project, implemented through the U.S. Department of Agriculture's Animal and Plant Health Inspection Service at its Denver Wildlife Research Center, ceased operating in December 1990. AID funding for the Consortium for International Crop Protection Project recently ended, but the consortium still exists. The AID continues to support projects that involve pest management activities within existing CRSPs—especially the bean-cowpea, sorghum-millet, and peanut CRSPs—as well as within ongoing biotechnology projects, projects addressing special constraints, and non-CRSP collaborative research projects. The IPM subpanel reviewed this past and current work, and suggested structural changes for the future.

One function of this review is to recommend support and service programs for AID's regional bureaus and missions. AID operates under a wide variety of conditions, in a wide range of countries—from Central America, where the production of nontraditional export crops (such as cotton) involves heavy pesticide use, to countries where subsistence agriculture prevails and pesticide use is minimal. The mandate of the Office of Agriculture in AID's Bureau for Science and Technology is to bring scientific and technologic expertise to bear in addressing constraints on agricultural development. The problems to be solved must be chosen carefully, and preference must be given to those of regional or global importance. The IPM program for rice in Southeast Asia is widely considered one of the most successful IPM efforts in the developing world. The subpanel was specifi-

cally asked to identify features of that program that are applicable to other areas.

AID's Office of Agriculture currently considers pest management to encompass all management activities, including technical assistance to missions in countries where there are pest outbreaks, pest eradication efforts, quarantine and other exclusionary methods, locust control efforts, environmental assessments and related nonresearch activities, as well as support for research (including research on IPM). The subpanel has considered this full range of activities in its review.

Acknowledgments

The panel would like to express appreciation for the particular contributions of Keith Andrews, William Barclay, Kenneth Barker, Charles Delp, Clive Edwards, Diana Horne, Michael Irwin, William B. Jackson, David MacKenzie, Myron Shenk, N. Van der Graaff, and G. K. Veeresh in assisting staff with the writing of various sections or versions and with the editing of this report. Clive A. Edwards, Rhonda Janke, and H. David Thurston also prepared a comprehensive paper *Integrated Pest Management for Sustainability in Developing Countries* as a background document for the discussions. Clive Edwards and David MacKenzie chaired the two sessions of the subpanel.

Contents

EXECUTIVE SUMMARY 1
Impediments to Integrated Pest Management in Developing Countries, 1
Support for Pest Management from the U.S. Agency for International Development, 4
Recommendations, 6

1 CONSTRAINTS ON RESEARCH AND IMPLEMENTATION ... 9
Constraints on Effective Integrated Pest Management, 10
Technical Information, 11
Interdisciplinary Collaborative Research, 19
Socioeconomic Factors, 21
Outreach and Extension Services, 22
Policy Issues, 24

2 CONCLUSIONS AND RECOMMENDATIONS 26
Research Proposal Criteria, 27
Recommendations for Agency for International Development, 29
Policy Recommendations, 31

REFERENCES 33

Executive Summary

In developed and developing countries alike, the loss of crops to pests—including invertebrates (insects, mites, and nematodes), vertebrates (primarily birds and rodents), plant pathogens (fungi, viruses, viroids, mycoplasmas, and bacteria), and weeds—is a significant problem. As awareness of the economic costs and environmental consequences of the indiscriminate use of pesticides and other chemicals has grown, alternative agricultural practices have received increasing attention. In particular, attention to the concepts, practices, and scientific basis of integrated pest management (IPM) has expanded. IPM seeks to manage pest populations and minimize crop loss in an economically efficient and environmentally sound manner. As such, it is an important component of sustainable agriculture, although there has been insufficient implementation experience to demonstrate its effectiveness adequately.

IMPEDIMENTS TO INTEGRATED PEST MANAGEMENT IN DEVELOPING COUNTRIES

The adoption of IPM in developing nations is hindered by technical, institutional, socioeconomic, educational, and policy constraints, almost always as a result of the lack of adequate recognition of the potential of IPM as an asset to sustainable agriculture, because of the lack of demonstrable effectiveness. Governments and donor agencies rarely offer adequate support for research and development, education, or training in IPM, and these groups often fail to consider the conditions of employment of extension personnel and the legal requirements for sound pest management practices.

Technical Constraints

The principal technical constraint is the inadequate scientific understanding of the natural factors that influence the abundance of pests and their natural control agents. More information is needed for developing effective biocontrol. Biocontrols may involve the direct use of parasites, predators, and microbial agents or the use of biologically based compounds. Greater attention must be given to the screening of plants, microbes, and other organic sources of compounds (biorational pesticides) that induce resistance, actively suppress pests, or disrupt pest life processes. The elucidation of the structures, toxicity, and mechanisms of action in the compounds of biological origin is critical. Research on synthetic pesticides should focus on the development of more selective strategies for their use and on improved methods for their on-farm management.

Long-term research is needed on cultural methods of pest control, including the pest management tactics used in traditional farming systems, the effects of alternative no-till or low-till methods, and the increased use of organic fertilizers and mulches in farming systems. Research should focus on the relationships between various cultural methods, nutrient cycles, and agroecosystem biodiversity. Innovative and traditional multiple-cropping systems (including polyculture and crop rotation) should be researched for their effects on pest populations, crop losses, and intervention needs. Research also is needed on the ecology and population dynamics of both pest and biocontrol species and on the integration of pest control measures.

Biotechnology offers a variety of potentially powerful new techniques to supplement traditional methods of crop breeding for host plant resistance and to suggest areas for research on pest and biocontrol agent population dynamics and pest management strategies. Research on host plant resistance is likely to progress more rapidly with the advent of biotechnology and plant genome mapping, and new diagnostic tools are being developed to detect, monitor, and predict shifts in pest populations. However, with the increasing application of biotechnology to IPM research, much greater attention needs to be given to the basic biology of all agroecosystem organisms, to the issues of biosafety, and to the development of more comprehensive approaches to the recognition and protection of intellectual property rights. These issues need to be addressed if the potential of biotechnology to enhance IPM is to be realized.

Institutional Constraints

Research on IPM is hindered by many of the same institutional constraints that inhibit research on sustainable agriculture and natural resource management more generally. The research needed to develop and implement effective IPM programs in developing countries is necessarily site

specific, long term, interdisciplinary, interinstitutional, and international. Financial and institutional support for this research is limited and difficult to obtain, and the research often is inadequately encouraged or rewarded. If progress is to be made on the technical questions noted above, greater support must be given to interdisciplinary collaborative research on IPM.

Socioeconomic Constraints

In all agricultural regions, but especially in developing nations, the rate at which IPM is adopted is determined largely by social and economic conditions. Effective development and implementation of IPM is frequently impeded by complex socioeconomic factors, including the inaccessibility of resources (including control agents and credit), inadequate land tenure and common property management arrangements, the absence of incentives to adopt IPM, and the failure to train farmers in IPM. Research must address these issues, as well as labor constraints and risk management, and must involve farmer perceptions in planning and implementation.

Educational Constraints

Implementation of sound IPM is limited by weak extension services in most developing countries. There is a lack of trained personnel to learn about the specific problems and perceptions of farmers and to provide feedback between farmers and the research community. Technical assistance programs have focused primarily on educating research personnel in technical measures to control major pests. Moreover, because the potential of IPM is often unappreciated by government officials, there is little funding for career IPM personnel after technical assistance programs end.

Policy Constraints

Regional and national policies frequently are inadequate for, and even counterproductive to, the implementation of IPM. Regional development of IPM is hindered by a relative lack of support for sustainable development generally. There is less support given to scientific research and development than is given to technical assistance projects. There is poor cooperation among countries in programs to control the spread of introduced pests. Efforts to prevent damage from migratory pests through selective intervention are inadequate. Progress in the entire field of pest management is hindered by ineffective research and implementation programs as a result of shifting priorities in donor agencies and host governments.

Government positions on pesticides—especially regarding the extent to which they are subsidized and used in the input packages for the so-called

green revolution crops—are often major impediments to the adoption of IPM. Governments typically pay insufficient attention to several critical aspects of effective pest management including the need to reduce the introduction of pests to new regions; the need to develop quarantine rules, transport restrictions, and other pest control regulations; the need to promote research, development, and extension of appropriate pest control methodologies; the need to manage the use of synthetic pesticides and other agricultural chemicals; and the need to establish rules for large-scale pest control and emergency procedures.

SUPPORT FOR PEST MANAGEMENT FROM THE U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

To overcome these obstacles and generate greater support for the development, dissemination, and implementation of IPM, the pest management program of the U.S. Agency for International Development (AID) should demonstrate the effectiveness and advantages of IPM. It should coordinate technical, economic, social, and policy activities with IPM implementation strategies; focus on IPM training and implementation programs; and strengthen technical services related to environmental assessment, assistance with quarantine and other regulations, and related areas of policy and administration.

The agency currently supports pest management projects within existing collaborative research support programs (CRSPs) and in biotechnology, special constraint, and non-CRSP collaborative research projects. These projects deserve greater recognition and allocation of resources. The stable funding provided by CRSPs is particularly important for pest control research, technology dissemination, and implementation. IPM research should not be a stand-alone activity; it should be integrated with sustainable agriculture programs and projects. AID-sponsored research should be highly responsive to the farmer—its client—and must embrace support from beyond the traditional university community. Private voluntary organizations, nongovernmental organizations, and private enterprises should assist. AID should allocate funds for collaborative research through a program of competitive grants. Some seed money might be provided for small-scale private pest management enterprises.

Collaborative Research Support Program for Sustainable Agriculture and Natural Resource Management

The Sustainable Agriculture and Natural Resource Management (SANREM) CRSP should focus on developing new IPM technology as a fundamental aspect of its work. Research on IPM within the SANREM CRSP should be integrated with research on cropping systems, nutrient management, and the

socioeconomic context of agricultural development. Various means of technology transfer and implementation also should be evaluated. The SANREM CRSP should develop IPM cropping systems at one or more locations, while serving as a base for the building of regional and global information networks involving IPM and sustainable agriculture.

Existing Collaborative Research Support Programs

The agency should encourage existing CRSPs to focus on IPM as a major component of their commodity research. The existing CRSPs should be required to supplement IPM activities in the SANREM CRSP. AID should work through the existing CRSPs to develop site- and crop-specific IPM practices.

Collaborative Research Support Program for Integrated Pest Management

The existing CRSPs cannot cover all possible sites and problems. AID's pest management program should have the flexibility to fund research on IPM that complements and strengthens research done in the existing CRSPs. Important gaps in knowledge about IPM components—for example, particular pests, crop needs, and local cultural constraints—will require special attention from AID, either because they are important to client countries and commodities or because they contribute to solving IPM problems in client countries.

The importance of focused attention on IPM as a development objective will require additional support for research in locations not covered under existing CRSPs. The research should be undertaken administratively either through an IPM CRSP or through a suitable integrated IPM project. The advantages of the CRSP mechanism in providing stable funding, information networks, scientist-directed management procedures, training and technical assistance, and in-place oversight make it the preferable option. An IPM CRSP would complement the new SANREM CRSP and supplement the work of the other CRSPs, providing balance and breadth to AID's initiatives on sustainability in developing countries.

Nonresearch and Service Activities

The agency should devote greater attention to research on IPM, but it must also continue its important support, through technical advisory, training, and other service activities, for effective response to pests. These are the responsibility of a public agency, because returns cannot be captured by private investors, but the net economic impact is highly positive. More-

over, AID should continue to serve in its critical role as an adviser to developing countries on matters of policy and regulation (involving, for example, plant and pest quarantine, pesticide use and management, environmental assessment, movement of biologic materials, and intellectual property rights and patents), which also are important components of U.S. foreign policy and technical assistance.

RECOMMENDATIONS

The recommendations outlined below will assist AID in devising and encouraging more effective IPM programs in developing countries.

Interdisciplinary and Cross-Sectoral Collaboration

AID should provide increased support for interdisciplinary and cross-sectoral collaborative research on IPM.

Integrated pest management is an interdisciplinary undertaking, and researchers have had to confront the professional and conceptual barriers that make interdisciplinary work difficult. At the same time, successful implementation of IPM requires collaboration among scientists and farmers, farmers' organizations, agribusiness, governmental agencies, donor agencies, and nongovernmental organizations. Only a strong institutional commitment to interdisciplinary and cross-sectoral collaboration can ensure that information about and implementation of IPM will continue to expand.

Information on the Components of Integrated Pest Management

AID-supported research should yield information about the components of IPM within the context of agroecosystems.

There is considerable information about ecologically sound approaches to some components of IPM, even though many components and pests have received insufficient attention. Because IPM is highly site specific, research projects should emphasize the need for information about various agroecosystem components (such as soil and water conditions, rainfall distribution, and socioeconomic factors) and their interactions, rather than about particular pests or crop problems. In all cases much work remains to be done.

Information on the Effectiveness of Integrated Pest Management Systems

Research on IPM should include consideration of the social and economic determinants of successful implementation.

More and better information about what determines the effectiveness of IPM is critical. More specifically, there is a great need for information about the economic benefits of IPM to individual farmers as well as to entire nations. Information about the social aspects of successful implementation is needed to promote institutional support for IPM research, extension, and low-cost training of farmers.

Collaborative Research Support for Integrated Pest Management

AID should require existing CRSPs to include IPM as an identifiable component of their programs. The SANREM CRSP should include IPM as a major component. A new IPM CRSP should be established to provide a focus for future research.

In all of its collaborative research programs, AID should encourage innovative approaches to interdisciplinary IPM research. The site- and crop-specific nature of IPM and the importance of focused attention on IPM also require additional research support through an IPM CRSP or other suitable mechanism. An IPM CRSP should receive the same support given to existing CRSPs (now about $2.5 million per year), and an additional $500,000 per year should be provided for research and implementation of IPM within existing AID-funded projects. A further $1 million per year should be designated for nonresearch technical assistance and for any training CRSPs are unable to provide.

Research Proposals

AID should award research grants through a competitive, peer-reviewed process.

Research proposals should take into account the general constraints described above and should be designed to support work that strengthens the existing research infrastructure in selected countries and enhances the ability of national programs to develop and implement local IPM systems. Specifically, research proposals should demonstrate opportunities to gather information on agroecosystem components and interactions and should indicate attention to indicators of success, economic incentives, social considerations, training, institution strengthening and integration of activities, and policy concerns. Proposals should meet the following criteria:

- Relevance of agroecosystem characteristics at the research site;
- Potential to develop ecologically sound, sustainable integrated pest management;
- Potential for regional and global adaptability;
- Suitability for interdisciplinary research and the involvement of farm-

ers, extension services, nongovernmental organizations, and private volunteer groups;

- Commitment of their local government to the project and potential for linkages among institutions and sectors;
- Experience of the investigators and a knowledge base;
- Capacity for training farmers; and
- Potential for collaboration with CRSPs, national agricultural research systems, and international agricultural research centers (IARCs), and for contributing to the proposed IARC IPM network.

Policy Support for Integrated Pest Management

AID should seek to improve the policy climate for IPM by securing additional personnel, by encouraging national governments to adopt policies that facilitate and support IPM, and by adopting specific policies in support of sustainable agriculture activities that include IPM.

Within AID, increased funding and continued support should be given to IPM research and implementation. AID also should improve the policy climate for IPM through its missions in client countries. All missions should include identifiable IPM components in their food and agriculture programs. They should work with host governments to develop policies that encourage the adoption of IPM in the public and private sector for the benefit of farmers and consumers. They should also adopt policies that improve farmers' land tenure and access to other resources. Finally, AID should collaborate with other donors and AID client countries in policy actions in support of IPM and sustainable agriculture in general. Specifically, governments should be encouraged to review regional and national programs that now encourage overuse of chemicals for crop protection; establish incentives for nonchemical control tactics; and adopt regulations to govern plant and pest quarantine, pesticide use, and environmental impact assessment.

1

Constraints on Research and Implementation

In developed and developing countries alike, the loss of crops to pests—including invertebrates (insects, mites, and nematodes), vertebrates (primarily birds and rodents), plant pathogens (fungi, viruses, viroids, mycoplasmas, and bacteria), and weeds (including parasitic plants)—is a significant problem. As awareness of the economic costs and environmental consequences of the indiscriminate use of pesticides and other chemicals has grown, alternative agricultural practices have received increasing attention (National Research Council, 1989). In particular, greater attention has been given to the concepts, practices, and scientific basis of integrated pest management (IPM), which seeks to manage pest populations and minimize crop losses in an economically efficient and environmentally sound manner. As such, IPM is an important component of sustainable agriculture, which is defined as follows in *Toward Sustainability: A Plan for Collaborative Research on Agriculture and Natural Resource Management* (National Research Council, 1991):

> [S]ustainable agriculture is . . . agriculture and all its interactions with society and the greater environment . . . long-term maintenance of natural resources and agricultural productivity, minimal adverse environmental impacts, adequate economic returns to farmers, optimal crop production with minimized chemical inputs, satisfaction of human needs for food and income, and provision for the social needs of farm families and communities.

Over the years, the scientific literature has offered many definitions of IPM. This report uses the one developed by the congressional Office of Technology Assessment (1990): "The optimization of pest control measures in an economically and ecologically sound manner, accomplished by

the coordinated use of multiple tactics to assure stable crop production and to maintain pest damage below the economic injury level while minimizing hazards to humans, animals, plants and the environment." The development of IPM systems under this definition requires a working knowledge of the physical and biologic characteristics of various agroecosystem components, as well as the social, economic, and cultural factors that influence the management decisions of farmers.

Integrated pest management is not one single program of specified action, but a dynamic approach to pest management that is ecologically sound and that empowers farmers to better manage their resources. IPM is highly site and crop specific; the varieties and relative importance of pests and the threats they pose vary with location and time. Recently introduced species, migratory pests, and acquired resistance all call for special attention in any IPM program because of the possibility of uncontrolled pest outbreaks. Although it is not necessary to know everything about an agroecosystem to develop and implement effective IPM strategies, further progress in implementing IPM does require an awareness of what is known about pest management, what the alternatives are to current practices, and where the impediments are that hinder widespread adoption of IPM.

CONSTRAINTS ON EFFECTIVE INTEGRATED PEST MANAGEMENT

The key to making agriculture more sustainable—and to further the development of IPM as a basic strategy of sustainable agriculture—is to overcome the barriers to sustainability. Progress in devising new or more effective IPM programs in developing countries will require attention in five areas: technical information, interdisciplinary collaboration, the socioeconomic context, outreach and extension services, and public policy.

These areas are discussed in the remainder of this chapter, and they provide the framework within which the aims and methods of IPM research need to be considered. Research objectives should focus on constraints to overall productivity. Support must be given to multidisciplinary collaborative research and to projects that demonstrate the effectiveness of IPM. On-farm experiments and implementation should have the aim of blending traditional with modern knowledge. Farmers should be involved as close and active partners at all stages in the research, development, and education process. The complex nature of research on IPM will require the long-term commitment of resources and personnel, and additional funds will be needed to support interdisciplinary investigations.

The implementation of IPM programs in developing countries also will require greater support for activities that are not directly tied to research, including training programs, technical assistance, and advisory services.

The capacities of developing-country institutions in these areas need to be strengthened to respond effectively to short-term pest outbreaks as well as to longer term concerns about plant and pest quarantines, environmental assessments, and the regulation and management of pesticides. Although these activities will focus on the needs of farmers, they will require the active collaboration of major donor agencies and lending institutions, international agricultural research centers, national agricultural research systems, university researchers and extension agents, private voluntary and nongovernmental organizations, the U.S. Department of Agriculture, the U.S. Environmental Protection Agency, local regulatory agencies, consultants, agribusinesses, food processors, and consumers.

TECHNICAL INFORMATION

Development of IPM systems often is hindered by a lack of technical information about biologic, cultural and mechanical, and chemical control methods and about the interactions among them in managing the pests within particular agroecosystems.

Biocontrol

The use of classical biocontrol—the destruction or limitation of one organism within an agroecosystem by another—is common in developing countries. Farmers traditionally have used various biological and cultural control methods to suppress pests (Thurston, 1990). The most common techniques involve the use of crop rotation and fallows and the application of organic matter (such as green manure, mulch, and compost) to crops. However, the effectiveness of traditional methods has been altered by changes in crops and crop varieties, the increased use of fertilizers and other chemicals, changes in rotation schedules, nutrient depletion, reductions in fallow periods, and widespread deforestation (with its attendant effects on local and regional climate, soil and water resources, and biotic interactions). Although these factors are common in many developing countries, their effects on pest populations need to be analyzed and understood for each particular agroecosystem.

Strengthening the indigenous capacity of developing countries to identify, produce, and distribute information about effective biocontrol agents and cultural methods is vitally important. Local production of biocontrol agents and disease-free planting stock would allow these countries to increase crop yields, save on foreign exchange, reduce environmental degradation, and create local industries. Developing countries also would benefit from assistance in the form of training, equipment, and technical guidance for the development, production, and distribution of bacterial, viral, bacte-

Biotechnology, Host Plant Resistance, and Integrated Pest Management

Many scientists and others consider host plant resistance to insect pests a form of biocontrol. Traditional plant breeding for resistance to pests has been well supported by current programs of the national agricultural research systems in developing countries and the international agricultural research centers of the Consultative Group on International Agricultural Research. Recent advances in molecular biology allow scientists to overcome species barriers and to genetically alter plants, animals, and microbes in ways not possible in the past (National Research Council, 1990), and several organisms have been genetically altered to enhance particular traits. In the United States, transgenic plants have been studied in some 200 field trials.

Research on host plant resistance and the dynamics of pest populations should move rapidly with the advent of biotechnology and plant genome mapping. With transposon tagging, scientists will be able to locate the genes for resistance to pests and to identify the products of those genes. The genetic sequences can then be cloned and transferred to other plant species, either as gene pyramids or, as the technology develops, as quantitative trait loci to produce horizontal resistance.

The techniques of biotechnology also will help to elucidate variations in pest populations—a major problem for producing some types of resistance in some crops. Technology is now being developed to use the diagnostic techniques of biotechnology so that shifts in pathogen populations can be detected, traced, and monitored and to allow predictions of changes at the local level. These techniques also will be useful for studying the population dynamics of biologic control agents and other types of organisms that live in association with crop plants (for example, *Rhizobium* species associated with legumes).

Three important issues are emerging from the recent application of biotechnology to IPM research. The first is that there is not enough information about the basic biology of many of the organisms of interest in biocontrol. The current ability to explain the physiology and biochemistry of interorganism relationships can be described as primitive at best. The tools of molecular genetics are just now being applied to model systems, but in many cases the economically important species used in agriculture have not been included.

Biosafety is the second issue. Agricultural research, by its very

nature, requires field plot testing that can endanger public health or the environment. In many instances, biotechnology field tests are subject to regulation, even though there is little international concurrence about how and what to control. In some cases, biosafety regulations constitute artificial trade barriers for products of biotechnology. There is a great need for international coordination of biosafety principles and concepts to ensure that regulatory decisions are based on the best possible science.

The third issue is that of intellectual property rights and the protection of discoveries in biotechnology. The United States is different from many countries in providing proprietary rights to breeders for their genetic improvements to crop species. This policy has angered individuals and institutions in other countries, and it is said to have contributed to diminished cooperation in germplasm collection between U.S. scientists and foreign scientists. At the same time, the securing of intellectual property rights for local and indigenous cultural groups is an increasingly important step in the effort to conserve biodiversity, especially in the tropics. Recognition of these rights can provide critical economic benefits to local people in return for their knowledge of wild and domestic biologic resources—at a time when those resources are under increasing threats from competing land uses. Mixed signals are now being sent in the international scientific community regarding the availability of germplasm, the role of patents, and the recognition of intellectual property rights. If this issue is not resolved quickly, the international repercussions within the scientific community will be devastating.

Biotechnology offers potentially powerful means of manipulating genetic material for the development of pest resistance, but it does not shorten the time required to adapt new strains to local environments. Ten to 15 years could pass before research on pest-resistant strains of crops leads to generally available materials for farmers. AID's Office of Agriculture is planning to support plant biotechnology research, including the development of pest-resistant strains of crops, through a separate program of competitive grants.

It seems safe to conclude genetic engineering will make major contributions to IPM in the next 10 years, but this will require a greater commitment to research in basic biology, a clearer understanding of the biosafety issues involved in field testing, and a more comprehensive approach to intellectual property rights and research products.

rial, or fungal biopesticides and cultural techniques that aid the process of biocontrol. The absence of such packages is a serious technical constraint on implementation of IPM.

Research on enhanced methods of biocontrol should begin with more complete surveys of biodiversity within agroecosystems to identify beneficial organisms, their modes of action, and their potential utility in plant protection. New pest pathogens need to be identified, and the use of viral, bacterial, and fungal biopesticides holds potential. Some soil fungi, for example, inhibit plant infestation by nematodes by attacking cysts or eggs. Introduced pests have been the focus of much of the recent research in biocontrol, and concerted efforts should be devoted to identifying biocontrol agents for native pests (especially locusts) and parasites. Greater emphasis should be given to bacterial and fungal toxins for weed control. Other research needs include standardized detection and screening protocols; standardized protocols for bioassays of efficacy and toxicity of biocontrol agents; simpler fermentation techniques for preparing formulation of biocontrol agents; better formulations for candidate pathogens; and improved methods, including genetic engineering, for overcoming resistance.

Chemical Control

In this discussion, chemical control concerns the use of biopesticides, botanical pesticides, semiochemicals (natural chemicals produced by insects or by plants as signals to affect insect behavior), and other agents whose effectiveness is based on particular chemical compounds. The use of synthetic pesticides in appropriate amounts in IPM programs also is discussed.

Biopesticides

Bacillus thuringiensis, a bacteria widely accepted as a biocontrol agent, has been in use for more than 40 years to control insect pests without harming humans, animals, and many beneficial insects. However, it is being marketed commercially in developing countries with mixed results, and it is not clear that the preparations developed for use in the United States or in Europe are suitable elsewhere. Genetically engineered strains of *B. thuringiensis* that are specific for similar groups of insects have been produced to solve this problem. However, there are concerns about insect resistance as a result of widespread and careless application, and it is important that *B. thuringiensis* be seen as only one of several control options.

Plant growth promoting rhizobacteria (PGPR) hold promise when applied as seed treatments for plant pathogen control. Two products have been marketed. They have shown benefits for cotton, peanuts, and beans. Other PGPR products are being researched. PGPR can provide control by

(1) improving root efficiency (water and nutrient uptake) nodulation, production of antibiotics, and competition with pathogens for limiting nutrients or infection sites and (2) inducing resistance.

Botanical Pesticides

Three broad categories of natural plant products are used to control insect pests: botanical pesticides, such as pyrethrin and rotenone; repellents and antifeedants, such as asarones from *Acorus calamus,* azadirachtin from neem, and other isolates; and whole plants that are effective in the protection of stored grain.

Although many botanical pesticides have seen long use, few have received detailed scientific examination. The effects of azadirachtin, which comes from the neem tree, *Azadirachta indica,* have been known in India for millennia, but the pesticide has been chemically characterized only recently; it is close to being synthesized in the laboratory (National Research Council, 1992). Although many botanical pesticides are known only to local farmers and to a handful of medicinal-plant specialists, they often are locally available and could be produced and used by farmers themselves or as a cottage industry.

If botanical pest control agents are to be more widely used, many problems will have to be overcome. For example, the best known products in this class—pyrethrin and rotenone—are not persistent and they affect pests and beneficial species alike. Neem is more of a systemic repellant or antifeedant (rather than a lethal toxin) that affects plant-feeding insects, and it has no apparent effect on wasps or bees. Several other problems can be identified:

- Natural pesticide preparations often break down in heat, humidity, and ultraviolet light. Many of them are effective only in uneconomically large doses. Safe and effective extracts, such as the proteinoids from *Tephrosia,* must be developed systematically.
- More effective application methods are required. For example, many natural products are applied as a spray, and unless they are systemic, like azadirachtin, they do not penetrate stems to kill stem borers.
- Research is needed on the propagation of effective plants. Methods such as tissue culture and micropropagation must be developed to mass produce selected cultivated varieties. Production of secondary metabolites in mass culture could be possible in some cases.
- Screening of untested plants, based on local and indigenous knowledge, requires careful selection of information and better methodology. Standard, replicable, scientifically sound bioassays are necessary to determine effectiveness.

- Field use of antifeedants can be problematic. Because they tend to be pest specific and require high dose rates, antifeedants are often expensive, and insects adapt to them. Plant oils could be interesting and useful exceptions. Plant compounds that are active against oviposition, virus transmission by vectors, growth, or reproduction should be examined. Plant-derived neuropeptides (muscle contractors) could offer new research possibilities.
- Research on the safe use of all biopesticides is needed. The absence of guidelines for safety in the use and local preparation of these products is a major concern. Careful attention must be given to effects on nontarget pests and to toxicity to birds and mammals.
- Multidisciplinary research, involving teams of chemists, plant pathologists, weed scientists, nematologists, entomologists, economists, and sociologists, is needed to assess both the biologic effectiveness and the cost-effectiveness of botanical pesticide use and the acceptability of these methods to farmers.
- Research needs to be broadened to include antifungal, nematocidal, and herbicidal activity and other effects.
- The mechanisms of natural products' actions need elucidation. For complex chemical structures such as azadirachtin from neem, for example, only a portion of the molecule might be needed for active pest suppression.

Pheromones

Pheromones and kairomones are insect hormones that can be used with great specificity in the monitoring of pest populations, to trap and kill pests, and to confuse mating behavior. However, their use in biocontrol is limited by several factors. They are effective for use in monitoring and for disrupting mating behavior, but they must be combined with other agents to control pests. Analytical research on their structure and occurrence is expensive and requires sophisticated equipment. Although the specificity of pheromones allows environmentally benign control of specific pests, effective mixtures need to be developed to control several pests simultaneously. Many pheromones are unstable in the tropics. Through minor changes in chemical structure, pheromones can become inactivated or even transformed into repellents.

To be useful on small farms pheromone formulations need to be more effective and less expensive. Currently, pheromones have only limited value for individual farmers, who use them primarily in traps as indicators of the type and quantity of pests. Only limited information is available on the relationship between pheromones and host plant characteristics, the weather, their effects on natural enemies, and what happens when applications are made in mixed or intercropping situations. Because few pheromones are available commercially, use in developing countries is limited. Currently,

for pheromones to be of value to the small farmer, they must be part of a pest management package.

Synthetic Pesticides

Synthetic pesticides are often viewed as the most effective or only solution to serious pest problems in developing countries. However, the well-known problems of pest resistance, pest resurgence, secondary pest outbreaks, environmental contamination, and toxic effects make their exclusive use economically, environmentally, and socially unacceptable outside an IPM system. IPM programs can include selective use of some synthetic pesticides, but improved methods of pesticide management are critical. Unfortunately, overuse and misuse of synthetic pesticides is in many developing countries a serious impediment to IPM implementation (Edwards, 1973a,b, 1985; Edwards et al., 1980). Farmers often have little or no basic information or training before they supply synthetic pesticides. Although they often have considerable knowledge of the agroecosystems in which they work, they usually must rely on sources outside their traditional cultures for information regarding synthetic pesticides.

Mechanical and Cultural Control

Before the advent of modern pesticides, farmers controlled pests primarily through the manipulation of farming practices and materials. Attention has again turned to these mechanical and cultural methods of pest control because of their positive effects on agroecosystem stability, diversity, and productivity.

Mechanical Operations and Cultivation

Different methods of tillage and cultivation are important in pest control and should be taken into account in designing farm management systems that maximize pest control. Tillage practices influence the incidence of pests by generating changes in soil structure and biota, the location of plant residues, and the ecology of weed species. Conservation tillage can produce a different spectrum of weeds, with lower populations of species that need to have their seeds buried to germinate, and higher numbers of species that are controlled by cultivation. Similarly, reduced cultivation causes some pests to decrease and others to increase (Stinner and House, 1990).

Systematic, long-term research has begun to yield better information about the effect of tillage and cultivation methods on pest populations, but most of this research has been conducted in agroecosystems in the temper-

ate zone. In the temperate regions, moldboard plowing has long been used to invert the soil, bury crop residues and weeds, and prepare a seed bed for the next crop. Since the 1960s, however, there has been a trend toward less and shallower tilling—culminating in so-called "no-till" practices, in which seeds are planted beneath the residue of the previous crop. This can require heavy use of herbicides, but considerable research is being done on ways to minimize their use, and much of this research is applicable to tropical soils (Edwards et al., 1990; National Research Council, 1989). Many of the conservation tillage methods being developed require special machinery. It is possible that some of this evolving technology could be approved for use in tropical agroecosystems.

Nutrient Management

Plant nutrition and nutrient management techniques profoundly influence the amount of pest damage to crops. Well-nourished plants can sustain greater amounts of damage from some pests. Conversely, there is evidence that fertilizers can increase attack by other pests, leading in turn to increased use of pesticides. When fertilizers are broadcast over a field, they promote weed growth between crop rows; placement of fertilizers in the row minimizes this effect (Edwards, 1989). Fertilizers also can increase the incidence of some foliar plant pathogens, such as cereal powdery mildew and cereal aphids (Jenkyn and Finney, 1981; Kowalski and Visser, 1979). If minimal amounts of fertilizers are used, crops can become less susceptible to some pests but more susceptible to others. Organic fertilizers tend to decrease attacks by soil-borne nematodes by promoting the activity of the nematodes' fungal antagonists (Hoitink and Fahy, 1986). They also decrease attacks by invertebrate pests by increasing species diversity in favor of natural enemies and by providing alternative food for marginal pests (Altieri, 1985; Edwards, 1989; Kerry, 1988). Increased use of organic matter in the soil also can facilitate cultivation for control of weeds.

Soil Biodiversity

Biodiversity in the soil can contribute ecosystem stability by providing natural pest control. Many soils harbor a variety of natural enemies that often exist and function most effectively as interspecific guilds (Walter and Kaplan, 1990). Fungal antagonists of nematodes alone include a large variety of organisms, such as nematode-trapping or predaceous fungi, endoparasitic fungi, egg parasites, cyst parasites, and species that produce toxic metabolites (Mankau, 1980b). Such native soil organisms can sometimes prevent unacceptable levels of damage to crops. For example, Mankau (1980a) reported that, despite ideal conditions for severe problems with root

knot nematodes, Senegalese farmers can market high-quality produce (vegetables) because *Bacillus penetrans* populations provide control.

Although pesticides can disrupt soil ecosystem processes, some microbes can degrade pesticides more rapidly than is possible abiotically. The potential for microbial decomposition of persistent pesticide residues is being explored as a way to reduce environmental contamination. This is similar to the way microbes are being used in oil spills. In general, much remains to be studied on the agricultural importance of soil biota, but the usefulness of diversity in imparting ecologic and economic stability to agroecosystems is becoming more clear. Some researchers suggest that the conservation of biodiversity within the soil can be enhanced by amending the soil (with organic matter and chitin, for example) and by promoting vegetative diversity in the field (Kerry, 1990).

Biodiversity and Cropping Patterns

Multiple cropping includes traditional annual sequential cropping or crop rotation, but also a variety of such innovative practices as relay cropping (growing two crops in one field in a single season); intercropping or undersowing (growing two or more crops in the same field, usually in alternate rows); and strip cropping (growing two crops in strips wide enough to allow independent cultivation and treatment, but narrow enough for their ecologic interaction) (Francis, 1986). All multiple-cropping systems increase diversity within the agroecosystem through habitat structure and species richness. This tends to minimize the incidence of insect pests, diseases, and weeds (Stinner and Blair, 1989). Such innovative cropping patterns have considerable potential for use in integrated low-input farming systems in developing countries.

INTERDISCIPLINARY COLLABORATIVE RESEARCH

The new Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM CRSP) of the U.S. Agency for International Development (AID) recognizes the essential role of IPM in the movement toward sustainability, and it emphasizes the need for interdisciplinary, collaborative research (National Research Council, 1991). IPM research is hindered by many of the same institutional constraints that inhibit research on sustainable agriculture and natural resource management. Because IPM is site-specific, research must be undertaken and applied differently in different locations. Moreover, research is necessarily long term; investigations must often continue over a period of 5 to 10 or even 20 years. This demands an unusual degree of commitment and dedication among scientists from many disciplines, institutions, and countries.

Financial and institutional support for this research is limited and for the most part it is inadequately encouraged or rewarded. Even when there is funding, interdisciplinary groups of scientists sometimes encounter difficulty in publishing their results in technical journals, most of which concern individual disciplines. All of this adds to the difficulty in attracting young scientists to IPM research.

These difficulties must be overcome if research is to make progress on the technical questions outlined in this report. There is considerable knowledge about the effects of conventional agricultural practices on pest management (Edwards et al., 1988; Edwards, 1989), but much more research is needed on the effects of innovative alternative practices (National Research Council, 1989). More generally, research must extend the principles of IPM programs to cover whole farming systems, and especially to minimize the use of synthetic chemicals and maximize the use of less expensive cultural practices. Efforts have been made, for example, to develop models that can provide recommendations based on a simple, user friendly question-and-answer system (Willson et al., 1987).

Some pest management researchers have taken the lead in developing integrated system designs using an agroecological approach. The systems approach of the Biological Control Program of the International Institute of Tropical Agriculture expands on traditional pest management research to embrace investigations of an entire agroecosystem, including characterization of agroecosystem components, intercropping effects, pest behavior in the absence of crops (sources of reinfestation), climatic data, plant host phenology and physiology, ecosystem effects on crop yield, life cycle studies of pests and populations, natural enemy population dynamics and epidemiology, and social and economic factors. A computer model of these agroecosystem components is constructed using laboratory parameters for the factors listed above and then validated by field studies and used as a research tool to identify pest control options and needs (Yaninek and Herren, 1989).

The information required to develop models is unavailable in many areas of the world, but the models can illustrate the integrated approach toward which pest management is evolving. For models to be useful, however, and for their results to be transferrable from one agroecosystem or country to another, closer collaboration is needed between biomathematicians and pest management specialists. Better field methods for determining population dynamics and better definitions of noxiousness and damage thresholds also must be developed. In the long run, however, such efforts will render valuable conceptual insights into agroecosystem functions and practical and sustainable applications on the ground.

SOCIOECONOMIC FACTORS

In all agricultural regions, but especially in those in developing nations, the rate at which IPM is adopted is determined largely by social and economic conditions. Socioeconomic factors often discourage adoption of IPM, even where the technical expertise and knowledge are available for policy formulation and for field trials and demonstration programs. If IPM and other sustainable agriculture practices are to be widely adopted, they must be socially and economically viable nationally and individually, and planning must involve farmers, extension workers, educators, administrators, and political leaders.

The principal socioeconomic impediments to implementing IPM stem from an absence of accountability for success or failure between farmers and researchers, policymakers, and government agents. This has had many consequences. Research on traditional farming systems, many of which effectively incorporate IPM, is underemphasized (Thurston, 1990). IPM research often is not applicable or relevant to the needs of subsistence farmers. Government monitoring and surveillance personnel, on whose findings policy recommendations are based, are seldom concerned with implementation. Corruption is widely believed to be common in the seed and pesticide industries and distribution systems in a number of developing countries. Land tenure and common property management arrangements often separate the farmer with the pest problem from the individual who makes decisions or pays the bills—especially for pest management—and often impede the adoption of sustainable agricultural practices. In many developing countries, tenure is insecure or nonexistent and farmers who lack title or reliable access to land can have little incentive to make a long-term investment in land improvement.

In considering the socioeconomic constraints on IPM among the subsistence or resource-poor farmers who are AID's constituents, it must be determined whether IPM will require field-specific recommendations, or whether its objectives can be achieved through broad, standard recommendations. Because agricultural conditions vary, highly generalized recommendations might place the livelihood of individual subsistence farmers in jeopardy. Field level management decisions require an understanding of the dynamics of pest populations, accurate identification of pests and their natural enemies, adequate field-sampling techniques, knowledge of the hazards of available pesticides, sophistication in the selection of seeds, and basic familiarity with IPM options. Essentially, the socioeconomic conditions that impede IPM adoption must be approached and investigated through two types of tactics: those that demand a high degree of farmer involvement (cultural practices, use of pesticides) and those that generally require minimal farmer involvement (classical biocontrol, use of host plant resistance). If developing countries are to implement IPM, they must be encouraged to

adopt policies that are based not only on sound biologic knowledge, but on farmer acceptance; on sound economic, social, and cultural considerations; and on effective means of technology dissemination (Andrews and Bentley, 1990; Showler, 1991).

The goals of new or strengthened IPM programs must not conflict with those goals of the agricultural system generally (including the generation and stabilization of income and compliance with market-related cosmetic and quality standards for agricultural products). Programs must operate within the law. They must demonstrate to farmers that pesticide selection and application can be made on a rational economic basis and that costs can be reduced through the increased use of readily available nonchemical means of control. This is often complicated by the fact that legally obtained pesticides must compete with smuggled or adulterated pesticides, which often lack standard labels.

OUTREACH AND EXTENSION SERVICES

A major impediment to the successful implementation of IPM in developing countries is the general lack of education about IPM. Farmers, agribusiness personnel, politicians, policymakers, the general public, researchers, extension agents, and teachers all need to become better informed about IPM. The degree of educational commitment to IPM in developing countries varies greatly, but education about pests and pest management is often lacking or inadequate, even in countries where agriculture is the major national activity and where the loss of crops to pests is a significant problem.

Deficient extension resources and methods are commonly identified as major barriers to agricultural production (Goodell, 1984; Showler, 1991). Extension services in developing countries are usually weak and poorly supported. Generally, extension programs are underfunded, they lack adequate means of transportation, and personnel are poorly trained. Extension agents are often poorly paid and act as low-status generalists who are responsible not only for disseminating information, but for administering credit programs. They rarely live in the communities where they work, and they often supplement their income by working in business, agriculture, or agrochemical sales. They are believed to accept favors for encouraging the sale of agrochemical products. Often, because the sheer number of farmers who need extension services is overwhelming, the larger farms are given priority at the expense of the small growers.

Several steps must be taken to improve extension and education services: The needs of farmers must be determined and this information must be transferred to administrators and researchers; relevant and practical information, both technical and policy related, must be conveyed to farmers; farmers need to be involved in training and demonstration projects; and

public understanding of the causes and effects of environmental degradation must be improved. The dissemination of information to farmers should take local traditions into consideration. In Bangladesh, for example, a transistor radio is given to most grooms as a wedding gift, and Bengali radio programs on farming are popular. Journals in the local language should be subsidized and made more affordable to peasant farmers. Extension and education services also must reach women and children more effectively since they, too, are involved in agriculture. Women in many cultures are not readily approachable by male extension agents, and in places where women tend to be suspicious of visiting government-employed female extension agents, female volunteers from the villages should be appointed as extension liaisons. In Bangladesh, board games for children on various aspects of farming (for example, pesticide use and safety) are used as extension tools (Showler, 1990).

Encouragement of young researchers is also crucial. The quality of advanced degree programs for researchers in developing countries must be improved and ensured. Because advanced degree training of developing country nationals is often underfunded, students often are unable to plan and execute comprehensive research. In addition, many students from developing countries who study abroad are assigned research projects that have little or no bearing on the needs in their homelands.

Specialists in IPM are currently few in number or unknown in many developing countries. If those who make government policy could be influenced to give adequate support and training to extension personnel, and if IPM specialists could be trained and adequately supported, the benefits to agriculture in developing countries would be substantial and long lasting. Wherever IPM has become a reality, a cadre of self-employed or grower-group-sponsored plant protection advisers has been important. Usually public- or private-sector extension specialists who work closely with researchers have supported and trained these agents. Pest management consultants can dedicate full time to learning and applying complex IPM technologies to clients' crops, and growers pay the scout-adviser for the specialized assistance.

Extension of IPM techniques to small farmers who grow basic food crops requires innovative approaches that move beyond simple reliance on government-funded extension agents and training-and-visit programs. Excellent success with the smallholder sector has been reported in Southeast Asia in the rice IPM program of the Food and Agriculture Organization of the United Nations. This program has so far provided training to more than 350,000 farmers, at a cost of about $10 per farmer. In the Philippines, cumulative training costs from 1984 to 1990 were about $1.7 million, versus cumulative savings of $20.4 million from reduced pesticide use (these figures do not include the effect on yield, which was slightly higher under

the IPM program). IPM training programs do not simply provide farmers with rules, for example, for using economic thresholds data to initiate IPM control measures. They also organize farmers into IPM groups and train them to study the pests on their own farms. Thus empowered, these farmers become extremely effective IPM users (Kenmore, 1991).

POLICY ISSUES

As the primary funding agency for U.S. foreign assistance, AID must play a leading role in changing policy to overcome the impediments and take advantage of the opportunities described in this report. IPM involves a wide range of activities that AID can promote through new policy initiatives affecting its Washington-funded research program and its operations throughout the world. Policy, within AID and client governments, should be modified or created to address the issues of economic reform, land reform, environmental protection, conservation, synthetic pesticide and fertilizer use, public health, and education—with the goal of long-term self-sufficiency for the individual farmer. In particular, many problems with the use of pesticides have arisen as a result of inadequate, nonexistent, or unenforced policy. The need for reform in all of these areas must be recognized and addressed by governments, donor and regional organizations, international banks, educators, researchers, and farmers.

Many of the required reforms should take place at the regional level. In the broadest terms, sustainable agriculture and rural development efforts receive insufficient international support. Total development assistance has been estimated at $50.2 billion per year; in contrast, $866 billion is spent worldwide each year on armaments and defense (Sivard, 1989). More specifically, there is poor cooperation among governments in controlling the spread of potentially devastating introduced pests. Because selective interventions are inadequate to prevent damage caused by migratory pests, costly emergency spraying campaigns are required during plagues (as has recently occurred, for example, in programs to control the desert locust in Africa and southwest Asia) (Showler and Potter, 1991). Progress in the entire field of pest management is hindered by ineffective research and implementation programs. Support for research and development is far weaker than is support for technical assistance. Existing programs are crippled by high turnover in personnel and by changes in national policies and in the priorities of donor agencies. Worse, agrochemical producers and multinational corporations sometimes offer the only formal plant protection programs in a given locale. If IPM research is to be successful, it needs stable, balanced, and focused interdisciplinary research and implementation teams, and adequate resources must be given to support their work.

Other policy constraints operate primarily at the national level. Pesti-

cide subsidies in some cases promote reliance on and overuse of synthetic chemicals (Repetto, 1985). Prophylactic pesticide applications are often encouraged by crop insurance programs that compensate for pest damage only if fields have been treated. Some uniform ("package") spray treatments recommended nationwide by governments are not tailored to local conditions or to varying intensities of pest attack (Matteson et al., 1984). Governments typically pay insufficient attention to other critical aspects of effective pest management, including the need to control introductions of pests to new regions and the need to develop quarantine rules, transport restrictions, and other pest control regulations. Governments also tend to ignore the need for research, development, and extension of appropriate IPM methods and large-scale control and emergency procedures.

2

Conclusions and Recommendations

In general, implementation of integrated pest management (IPM) in developing countries is limited by inadequate financial resources, a shortage of trained personnel, and a lack of recognition of IPM's importance by the governments of developing countries or by those who work in global, regional, and country mission programs sponsored by the U.S. Agency for International Development (AID). Other factors also affect the ability of researchers, administrators, and farmers to undertake adequate research and to implement the results. To overcome these obstacles, AID's pest management program should be guided by several general objectives which

- Demonstrate the effectiveness of IPM. The economic and social advantages of IPM need to be clearly demonstrated to farmers, governments, and donors to justify the allocation of resources necessary for research and implementation.
- Coordinate IPM activities. Research is needed on ways to integrate technical, economic, social, and policy activities with implementation strategies. Interdisciplinary teams are needed to secure the active participation of individual farmers in IPM research. Competition among disciplines and a lack of professional rewards for interdisciplinary work, particularly for young scientists, hinders teamwork. Furthermore, interdisciplinary research is expensive because it generally involves large numbers of scientists.
- Focus on training and implementation. The IPM research methodology supported by AID must be relevant to a broad range of agroecosystems found within client countries, and it must feed effectively into implementation and training programs. IPM programs must have well-designed, inno-

vative training components for farmers. The rice IPM program of the Food and Agriculture Organization of the United Nations provides a good model.

- Strengthen technical services. The need for AID to provide technical services to its missions on behalf of client governments and the private sector will continue. These services include environmental assessments, assistance with quarantine and other regulations, and progress in related areas of policy and administration, including movement of plant materials, response to pest outbreaks, pesticide importation and use, training, and technology transfer.

RESEARCH PROPOSAL CRITERIA

Research on IPM (and research proposals submitted to AID) should provide opportunities to gather information in the following areas.

- Agroecosystem components and interactions. To overcome the technical constraints described in this report, basic investigations must fill in gaps in the scientific understanding of the interactions among organisms and of the effects of management techniques in agroecosystems. As steps are taken to address the social, economic, educational, and institutional factors behind successful implementation, the knowledge base on which IPM ultimately depends must be continually strengthened.
- Indicators of performance. Information is lacking on productivity, pre- and postharvest losses, the rate of adoption of IPM practices, economic factors, public health, and monitoring and characterization of environmental effects. Assessments should be made before, during, and after implementation.
- Economic incentives. Information is lacking on cost-effectiveness, profitability due to reduced losses, gains from lower inputs, and other economic benefits of IPM.
- Social considerations. Information is needed about farmers' awareness of pest management problems and whether those in the community or government agencies understand how IPM can aid sustainable agriculture. The effects of land access and land tenure on the adoption and success of IPM need to be explored, as does the status of extension workers and the means to improve it. The broader involvement of rural people in extension programs and the involvement of farmers, growers, and consumers in pest management efforts need to be brought about. Farmer perceptions should be studied for acceptability of IPM (often leading to a restatement of the problem by the researcher), farmer access to resources (such as *Bacillus thuringiensis,* clean seeds, and chemicals), and assessment of risks and identification of alternatives.
- Training. Research projects should identify and provide training

opportunities for scientists in host countries. Projects also should develop and strengthen the ability of extension services to respond to farmers' needs by applying and demonstrating IPM.

- Institution strengthening and integration. The delivery systems for IPM implementation by farmers are weak throughout the developing world. This is the case not only for public institutions, but in the private sector, where a lack of capital and disincentives for small enterprises have slowed the evolution of delivery systems and services. Institutions must be able to identify and diagnose problems, to systematize information exchange and networking, and to provide technical assistance. They must address concerns about, for example, seed laws, certification, quality control, pesticide regulations, and quarantine and movement of produce and agricultural products. Moreover, information is needed on how institutions can work together most effectively and efficiently.
- Policy concerns. National governments frequently lack a commitment to IPM, to policy analysis and guidance, and to the integration of policy aims. Research should address the influence of policy on current pest management practices in general and on the adoption of IPM in particular.

In addressing constraints in these areas, IPM research proposals should specifically demonstrate the following:

- The relevance of agroecosystem characteristics at the research site, including the agroecosystem's importance in terms of nutrient and food productivity and its susceptibility to pest losses; the likelihood of success of IPM in stemming losses to pests; and the likelihood that economic performance would be significantly improved.
- The potential of the project to offer regional and global application of research results.
- The suitability of the proposed project for multidisciplinary research and the involvement of farmers, nonvoluntary governmental organizations, private and voluntary organizations, and local extension personnel.
- The support of local government and the potential for cooperation among institutions and across sectors.
- The experience of the investigators and a base of existing research and knowledge.
- The capacity of investigators and the suitability of the project for conducting training of host country personnel.
- The potential for the project to draw on research of existing Collaborative Research Support Programs (CRSPs), national agricultural research systems, and international agricultural research centers (IARCs), and to contribute to the proposed IARC IPM network.
- The contribution of the research project to identify improved nonchemical

pest control tactics, and safer, more effective, and more environmentally sound use of pesticides where necessary.

With the proviso that research on IPM should focus on the agroecosystem as a whole, rather than on target commodities or crops alone, support could be directed to a system in which traditional crops and cropping systems are supplemented with introduced cash crops that may offer incentives to farmers. Examples of possible cropping systems suggested for research attention from this perspective include: beans, corn, and squash; beans, corn, and cassava; millet and sorghum; peanuts and sesame; potatoes and beans; bananas, plantains, and papayas; and urban vegetable production systems.

RECOMMENDATIONS FOR SUPPORT FROM THE U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

Support for IPM within AID should include initiatives in its research, nonresearch, and service activities.

Research Activities

To respond to the needs described in this report, AID should increase its support for research on IPM.

This goal could be achieved through two mechanisms: creation of a new IPM CRSP or development of an IPM project to strengthen existing programs.

If established, a new IPM CRSP should address one or more (preferably two) agroecosystems, and it should receive the same support given to existing CRSPs (now about $2.5 million per year). To supplement and complement the work of the new CRSP, an additional $500,000 per year should be provided to fund research within existing AID-funded projects on biologic or socioeconomic impediments to IPM implementation.

Support for IPM projects funded directly by AID could accomplish many of the same goals as an IPM CRSP. If this option is followed, support should be given in several areas. A single research project, funded at $1 million per year, should elucidate the necessary components of a true IPM approach to crop protection in a selected agroecosystem. Another $500,000 per year should be devoted to technical assistance activities that are not included in the full research project. Finally, additional support should be sought through additional "buy-in" funds solicited from AID regional bureaus or missions, including the possibility of Public Law 480 funds where these are available.

In choosing between these approaches, AID should consider that the IPM project is a more modest approach, at least initially. The Office of Agriculture would support and manage research and related activities through

a U.S. institution, but outside the Title XII CRSP mechanism. This would be analogous to AID's current plans to expand research on plant biotechnology. The many advantages of the CRSP mechanism—long-term funding support, experience in international collaborative arrangements, information networking, scientist-directed management procedures, an emphasis on training the local populations of developing countries, a tradition of response and a mechanism for support of mission requests for assistance (including leveraging matching funds), and in-place oversight mechanisms—make it the preferable option. An IPM CRSP would complement the new Sustainable Agriculture and Natural Resource Management CRSP and supplement the work of other CRSPs, providing balance and breadth to AID's initiatives on sustainability in developing countries.

Nonresearch Activities

Although AID should devote greater attention to research on IPM, it must also continue its important support, through nonresearch technical advisory and training activities, for effective response to migratory and exotic pests.

These activities are rightly the responsibility of a public agency, rather than the private sector. Moreover, AID should continue to serve in its critical role as an adviser to client countries on matters of policy and regulation involving plant and pest quarantine, pesticide use and management, environmental assessment, movement of biologic materials, and intellectual property rights and patents—all important components of U.S. foreign policy and technical assistance. In addition, $1 million per year should be provided for these activities, which would be similar to those provided in the past by AID's Vertebrate Pest Management Project and the AID-supported Consortium on International Crop Protection.

The AID should seek to improve the policy climate for IPM through its missions in client countries.

All missions should include identifiable IPM components in their food and agriculture programs and should work with host governments to develop policies that encourage the adoption of IPM in the public and private sector for the benefit of farmers and consumers. Although AID cannot dictate policy or legislation to its client countries, it can recommend and encourage the adoption of policy and legislation through several mechanisms. AID can present policy guidelines or models for government examination. It can offer incentives for the adoption or creation of policy and legislation (for example, through the attachment of stipulations to AID assistance). Finally, AID can encourage and, where appropriate, participate in the establishment of formal agreements, treaties, conventions, or codes of conduct.

Service Activities

To attain the goals described above, AID must continue to provide additional services in support of IPM.

Especially important are technical assistance (for example, pre- and postproject environmental assessments and related field research) and assistance in project design, project evaluation, emergency response (such as the Locust Outbreak Prevention Program), in-country definition of pest problems, short-term training in pest and pesticide management, and training in quarantine and regulatory activities. These services would benefit from an increase in the number of in-house technical staff at the AID Office of Agriculture. It would be desirable for AID to hire permanent staff who have training in ecologically sound methods and approaches to pest management.

POLICY RECOMMENDATIONS

The AID should give high priority to securing more money for IPM activities, and it should strengthen its capacity to advance IPM through additional staffing.

This will require building congressional and public constituencies for increased funding and continued support. AID should recognize, reward, and publicize its successes in IPM research and implementation, for the benefit of its foreign and U.S. constituencies.

The AID should encourage national governments to adopt policies that facilitate and support IPM.

The agency should encourage the national institutionalization of IPM. Moreover, it should require its missions to include IPM in their programs. Such policy changes could be offered as recommendations, model legislation, guidelines, or as incentives by linking AID assistance to changes in policy or legislation in recipient countries. Where appropriate, specific policies could be supported through formal agreements, treaties, conventions, or codes of conduct.

The AID should give consideration to specific changes in agency policy that support sustainable agriculture activities and that include IPM.

These changes could include the following:

- Give greater emphasis to nonchemical control tactics and to associated implementation and technology transfer model systems.
- Review regional and national programs that overuse chemicals for crop protection, and provide support for changes to implement IPM alternatives where available.
- Review AID agricultural development programs to determine whether

they lead to greater dependence on nonsustainable production practices, particularly in the promotion of cash crops and export crop commodities. An external review of agricultural project lending by the World Bank, for example, found that many projects anticipated increases in pesticide use as part of the development effort, yet IPM was rarely included in projects (Hansen, 1990).

- Require environmental impact assessments after (as well as before) project implementation. AID should consider requiring the identification of nonchemical pest control alternatives in all environmental assessments, and it should support establishment of an international information clearinghouse of nonchemical pest control methods.
- Review agency policy on issues of pesticide labeling, application methods, storage and disposal safeguards, and human health monitoring, and make these changes known to client governments. AID mission programs with clearly identifiable IPM projects will be useful vehicles for this.
- Review or assure an agency policy on the transport, release, or transfer of genetically engineered biologic materials. The guidelines developed by the Program for Scientific and Technical Cooperation (PSTC) of AID's Research and Development Bureau, which only apply to PSTC projects, should apply to all AID projects. Adequate documentation of compliance should be required before funding is released.
- Develop policies, in collaboration with other donors and AID client countries, that address issues of intellectual property rights, thereby permitting proprietary techniques and germplasm to become available to developing countries in a timely fashion.
- Refine policy on donor coordination and encourage the establishment of a consortium for IPM activities and a network of researchers, eventually leading to a "center-without-walls" linked to the Consultative Group on International Agricultural Research system.
- Create an IPM task force to increase interaction among units of AID and between AID and external agencies, institutions, and interest groups.
- Encourage nongovernmental advisory groups in the United States to highlight IPM activities and generate public support for them.
- Review priorities for the development of IPM in AID client countries in Eastern Europe.
- Re-examine in-kind assistance to promote IPM support as an agency policy.

References

Altieri, M. A. 1985. Diversification in agricultural landscapes: A vital element for pest control in sustainable agriculture. Pp. 124–136 in Sustainable Agriculture and Integrated Farming Systems, T. C. Edens, C. Fridge, and S. L. Battenfield, eds. East Lansing, Mich.: Michigan State University.

Andrews, K. L., and J. W. Bentley. 1990. IPM and resource-poor Central American farmers. Global Pesticide Monitor 1:1,7–9.

Edwards, C. A. 1973a. Environmental Pollution by Pesticides. New York: Plenum Press.

Edwards, C. A. 1973b. Persistent Pesticides in the Environment, 2d ed. Cleveland, Ohio: CRC Press.

Edwards, C. A. 1985. Agrochemicals as environmental pollutants. Pp. 1–19 in Control of Pesticide Applications and Residues in Foods, B. Hofsten and G. Ekstrom, eds. Uppsala, Sweden: Swedish Science Press.

Edwards, C. A. 1989. The importance of integration in sustainable agriculture systems. Agriculture, Ecosystems, and Environment 21:25–35.

Edwards, C. A., G. K. Veeresh, and H. R. Krueger. 1980. Pesticide residues in the environment in India. Bangalore, India: Raja Press.

Edwards, C. A., B. R. Stinner, and N. Creamer. 1988. Pest and disease management in integrated lower input/sustainable agricultural systems. Brighton Crop Protection Conference—Pests and Diseases 3:1009–1016.

Edwards, C. A., R. Lal, P. Madden, R. H. Miller, and G. House, eds. 1990. Sustainable Agricultural Systems. Ankeny, Iowa: Soil and Water Conservation Society.

Edwards, C. A., H. D. Thurston, and R. Janke. 1991. Integrated pest management for sustainability in developing countries. Pp. 109–133 in Toward Sustainability: A Plan for Collaborative Research on Agriculture and Natural Resource Management. Washington, D.C.: National Academy Press.

Francis, C. A., ed. 1986. Multiple Cropping Systems. New York: Macmillan.

Goodell, G. 1984. Challenges to international pest management research and extension in the Third World: Do we really want IPM to work? Bulletin of the Entomological Society of America 30:18–26.

Hansen, M. 1990. The First Three Years: Implementation of the World Bank Pesticide Guidelines 1985–1988. Yonkers, N.Y.: Consumer Policy Institute, Consumers Union.

Hoitink, H. A. J., and P. C. Fahy. 1986. Basis for control of soil-borne plant pathogens with compost. Annual Review of Phytopathology 24:93–114.

Jenkyn, J. F., and M. E. Finney. 1981. Fertilizers, fungicides, and sowing date. Pp. 179–188 in Strategies for the Control of Cereal Diseases, J. F. Jenkyn and R. T. Plumb, eds. Oxford, England: Blackwell.

Kenmore, P. E. 1991. Indonesia's Integrated Pest Management—A Model for Asia. Manila, Philippines: Food and Agriculture Organization of the United Nations, Rice Integrated Pest Control Program.

Kerry, B. R. 1988. Fungal parasites of cyst nematodes. Pp. 293–306 in Biological Interactions in Soil, C. A. Edwards et al., eds. The Hague: Netherlands: Elsevier.

Kerry, B. R. 1990. An assessment of progress toward microbial control of plant-parasitic nematodes. Journal of Nematology Supplement 22(4S):621–631.

Kowalski, R., and P. E. Visser. 1979. Nitrogen in a crop-pest interaction: cereal aphids. In Nitrogen as an Ecological Factor, J. A. Lee, S. McNeill, and I. H. Rorison, eds. Oxford, England: Blackwell.

Mankau, R. 1980a. Biological control of *Meloidogyne* populations by *Bacillus penetrans* in West Africa. Journal of Nematology 12(4):230.

Mankau, R. 1980b. Biocontrol: Fungi as nematode control agents. Journal of Nematology 12(4):244–252.

Matteson, P. C., M. Altieri, and W. C. Gagné. 1984. Modification of small farmer practices for better pest management. Annual Review of Entomology 29:383–402.

National Research Council. 1989. Alternative Agriculture. Washington, D.C.: National Academy Press.

National Research Council. 1990. Plant Biotechnology Research for Developing Countries. Washington, D.C.: National Academy Press.

National Research Council. 1991. Toward Sustainability: A Plan for Collaborative Research on Agriculture and Natural Resource Management. Washington, D.C.: National Academy Press.

National Research Council. 1992. Neem: A Tree for Solving Global Problems. Washington, D.C.: National Academy Press.

Office of Technology Assessment, U.S. Congress. 1990. A Plague of Locusts: Special Report. OTA-F-450. Washington, D.C.: U.S. Government Printing Office.

Repetto, R., ed. 1985. The Global Possible: Resources, Development, and the New Century. New Haven: Yale University Press.

Showler, A. T. 1990. Pesticide use and environmental pollution in Bangladesh. Pp. E1–E36 in Bangladesh Environment and Natural Resource Assessment. Washington, D.C.: World Resources Institute.

Showler, A. T. 1991. The New World screwworm fly in North Africa: Implications and eradication plans. Agriculture, Ecosystems and Environment 36(3–4):235–239.

Showler, A. T., and C. S. Potter. 1991. Synopsis of the 1986–1989 desert locust (Orthoptera:Acrididae) plague and the concept of strategic control. American Entomologist 37(2):106–110.

Sivard, R. L. 1989. World Military and Social Expenditures 1989. Washington, D.C.: World Priorities.

Stinner, B. R., and J. M. Blair. 1989. Ecological and agronomic characteristics of innovative cropping systems for sustainable agriculture. Pp. 123–140 in Sustainable Agriculture Systems, C. A. Edwards, R. Lal, P. Madden, R. H. Miller, and G. House, eds. Ankeny, Iowa: Soil and Water Conservation Society.

Stinner, B. R., and G. J. House. 1990. Arthropods and other invertebrates in conservation tillage agriculture. Annual Review of Entomology 35:299–318.

Thurston, H. D. 1990. Plant disease management practices of traditional farmers. Plant Disease 74:96–102.

Walter, D. E., and D. T. Kaplan. 1990. A guild of thelytokous mites (Acarii:Mesostigmata) associated with citrus roots in Florida. Environmental Entomology 19(5):1338–1343.

Willson, H., F. Hall, J. Lennon, and R. Funt. 1987. Market Model: A Decision Support Program from the Computer Advisory System for Horticulture (CASH). Columbus, Ohio: Ohio State University.

Yaninek, J. S., and H. R. Herren. 1989. Biological Control: A Sustainable Solution to Crop Pest Problems in Africa. Ibadan, Nigeria: International Institute of Tropical Agriculture.

RECENT PUBLICATIONS OF THE BOARD ON AGRICULTURE

Policy and Resources

Agriculture and the Undergraduate: Proceedings (1992), 296 pp., ISBN 0-309-04682-3.

Water Transfers in the West: Efficiency, Equity, and the Environment (1992), 320 pp., ISBN 0-309-04528-2.

Managing Global Genetic Resources: Forest Trees (1991), 244 pp., ISBN 0-309-04034-5.

Managing Global Genetic Resources: The U.S. National Plant Germplasm System (1991), 198 pp., ISBN 0-309-04390-5.

Sustainable Agriculture Research and Education in the Field: A Proceedings (1991), 448 pp., ISBN 0-309-04578-9.

Toward Sustainability: A Plan for Collaborative Research on Agriculture and Natural Resource Management (1991), 164 pp., ISBN 0-309-04540-1.

Investing in Research: A Proposal to Strengthen the Agricultural, Food, and Environmental System (1989), 156 pp., ISBN 0-309-04127-9.

Alternative Agriculture (1989), 464 pp., ISBN 0-309-03987-8; ISBN 0-309-03985-1 (pbk).

Understanding Agriculture: New Directions for Education (1988), 80 pp., ISBN 0-309-03936-3.

Designing Foods: Animal Product Options in the Marketplace (1988), 394 pp., ISBN 0-309-03798-0; ISBN 0-309-03795-6 (pbk).

Agricultural Biotechnology: Strategies for National Competitiveness (1987), 224 pp., ISBN 0-309-03745-X.

Regulating Pesticides in Food: The Delaney Paradox (1987), 288 pp., ISBN 0-309-03746-8.

Pesticide Resistance: Strategies and Tactics for Management (1986), 480 pp., ISBN 0-309-03627-5.

Pesticides and Groundwater Quality: Issues and Problems in Four States (1986), 136 pp., ISBN 0-309-03676-3.

Soil Conservation: Assessing the National Resources Inventory, Volume 1 (1986), 134 pp., ISBN 0-309-03649-9; Volume 2 (1986), 314 pp., ISBN 0-309-03675-5.

New Directions for Biosciences Research in Agriculture: High-Reward Opportunities (1985), 122 pp., ISBN 0-309-03542-2.

Genetic Engineering of Plants: Agricultural Research Opportunities and Policy Concerns (1984), 96 pp., ISBN 0-309-03434-5.

Nutrient Requirements of Domestic Animals Series and Related Titles

Nutrient Requirements of Horses, Fifth Revised Edition (1989), 128 pp., ISBN 0-309-03989-4; diskette included.

Nutrient Requirements of Dairy Cattle, Sixth Revised Edition, Update 1989 (1989), 168 pp., ISBN 0-309-03826-X; diskette included.

Nutrient Requirements of Swine, Ninth Revised Edition (1988), 96 pp., ISBN 0-309-03779-4.

Vitamin Tolerance of Animals (1987), 105 pp., ISBN 0-309-03728-X.

Predicting Feed Intake of Food-Producing Animals (1986), 95 pp., ISBN 0-309-03695-X.

Nutrient Requirements of Cats, Revised Edition (1986), 87 pp., ISBN 0-309-03682-8.

Nutrient Requirements of Dogs, Revised Edition (1985), 79 pp., ISBN 0-309-03496-5.

Nutrient Requirements of Sheep, Sixth Revised Edition (1985), 106 pp., ISBN 0-309-03596-1.

Nutrient Requirements of Beef Cattle, Sixth Revised Edition (1984), 90 pp., ISBN 0-309-03447-7.

Nutrient Requirements of Poultry, Eighth Revised Edition (1984), 71 pp., ISBN 0-309-03486-8.

More information, other titles (before 1984), and prices are available from the National Academy Press, 2101 Constitution Avenue NW, Washington, DC 20418 USA, 202/334-3313 (information only); 800/624-6242 (orders only); 202/334-2451 (fax).

RECENT PUBLICATIONS OF THE BOARD ON SCIENCE AND TECHNOLOGY FOR INTERNATIONAL DEVELOPMENT

Energy

Alcohol Fuels: Options for Developing Countries (1983), 128 pp., ISBN 0-309-04160-0.

Producer Gas: Another Fuel for Motor Transport (1983), 112 pp., ISBN 0-309-04161-9.

The Diffusion of Biomass Energy Technologies in Developing Countries (1984), 120 pp., ISBN 0-309-04253-4.

Technology Options

Priorities in Biotechnology Research for International Development: Proceedings of a Workshop (1982), 261 pp., ISBN 0-309-04256-9.

Fisheries Technologies for Developing Countries (1987), 167 pp., ISBN 0-309-04260-7.

Applications of Biotechnology to Traditional Fermented Foods (1992), 199 pp., ISBN 0-309-04685-8.

Plants

Amaranth: Modern Prospects for an Ancient Crop (1983), 81 pp., ISBN 0-309-04171-6.

Jojoba: New Crop for Arid Lands (1985), 102 pp., ISBN 0-309-04251-8.

Quality-Protein Maize (1988), 130 pp., ISBN 0-309-04262-3.

Triticale: A Promising Addition to the World's Cereal Grains (1988), 105 pp., ISBN 0-309-04263-1.

Lost Crops of the Incas (1989), 415 pp., ISBN 0-309-04264-X.

Saline Agriculture: Salt-Tolerant Plants for Developing Countries (1989), 150 pp., ISBN 0-309-04266-6.

Innovations in Tropical Forestry

Mangium and Other Fast-Growing Acacias for the Humid Tropics (1983), 63 pp., ISBN 0-309-04165-1.

Calliandra: A Versatile Small Tree for the Humid Tropics (1983), 56 pp., ISBN 0-309-04166-X.

Casuarinas: Nitrogen-Fixing Trees for Adverse Sites (1983), 118 pp., ISBN 0-309-04167-8.

Leucaena: Promising Forage and Tree Crop for the Tropics (1984), 2d ed., 100 pp., ISBN 0-309-04250-X.

Neem: A Tree that Could Help the World (1992), 149 pp., ISBN 0-309-04686-6.

Managing Tropical Animal Resources

Butterfly Farming in Papua New Guinea (1983), 36 pp., ISBN 0-309-04168-6.

Crocodiles as a Resource for the Tropics (1983), 60 pp., ISBN 0-309-04169-4.

Little-Known Asian Animals with a Promising Economic Future (1983), 133 pp., ISBN 0-309-04170-8.

Microlivestock: Little-Known Small Animals with a Promising Economic Future (1990), 449 pp., ISBN 0-309-04265-8.

Resource Management

Environmental Change in the West African Sahel (1984), 96 pp., ISBN 0-309-04173-2.

Agroforestry in the West African Sahel (1984), 86 pp., ISBN 0-309-04174-0.

Conserving Biodiversity: A Research Agenda for Development Agencies (1992), 127 pp., ISBN 0-309-04683-1.

Additional titles and ordering information are available from the Board on Science and Technology for International Development, Publications and Information Services (FO-2060), Office of International Affairs, National Research Council, 2101 Constitution Avenue NW, Washington, DC 20418 USA, 202/334-2688.

NATIONAL ACADEMY PRESS

The National Academy Press was created by the National Academy of Sciences to publish the reports issued by the Academy and by the National Academy of Engineering, the Institute of Medicine, and the National Research Council, all operating under the charter granted to the National Academy of Sciences by the Congress of the United States.

Digitized by Google