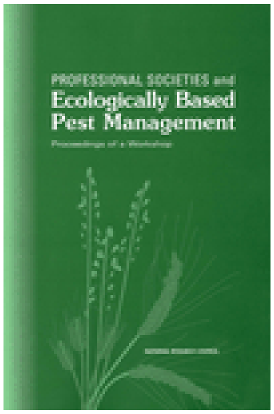

Professional Societies and Ecologically Based Pest Management: Proceedings of a Workshop

National Research Council

ISBN: 0-309-56297-X, 76 pages, 6 x 9, (2000)

PROFESSIONAL SOCIETIES and Ecologically Based Pest Management

Proceedings of a Workshop

Board on Agriculture and Natural Resources
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C.

NATIONAL ACADEMY PRESS2101 Constitution Avenue, NWWashington, DC20418

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This study was supported by the US Department of Agriculture, Economic Research Service (Agreement 59-0790-8-053); the W. K. Kellogg Foundation (Grant P0056838); and the National Science Foundation (Grant DEB-9903431). Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number 0-309-07132-1

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Printed in the United States of America

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Preface

The National Research Council's (NRC) Board on Agriculture and Natural Resources invited professional societies associated with agriculture and ecology to participate in a two-day workshop to explore leadership and a common vision for ecologically based pest management (EBPM). These proceedings describe the challenges of and opportunities for EBPM discussed by participants in the workshop.

The workshop was organized as a follow-up activity to the 1996 release of the NRC report *Ecologically Based Pest Management: New Vision for a New Century.* That study committee envisioned pest management strategies of the future based upon ecological principles and supplemented with biological, chemical, or physical inputs as necessary for safe, durable, and profitable outcomes. The study committee recognized that the shift to ecological approaches would require a substantial change from the dominant practice of product input to the primary mind-set of ecological knowledge. A foundation of ecological knowledge exists within professional societies associated with pest management, but in most cases these scientists and practitioners have diverse interests. Because a strong, unified group is necessary to build interdisciplinary, ecological systems-based approaches to pest management, the report authors encouraged professional societies to organize a forum for discussion of EBPM.

By joining together, professional societies can have a larger voice to impact the decision-making process.

Several committee members from the 1996 NRC report and leaders from a number of professional societies were solicited for their help in organizing a workshop for professional societies to explore common themes related to ecologically based pest management. Representatives from professional societies including the American Phytopathological Society, National Agricultural Biotechnology Council, Ecological Society of America, American Institute of Biological Sciences, Weed Science Society of America, Entomological Society of America, Agronomy Society of America, American Society of Animal Science, and American Agricultural Economics Association participated in the forum March 10–11, 1999, in Raleigh, North Carolina. Workshop participants included a diverse group of stakeholders: university and extension scientists, industry representatives, producers, and policy makers. The workshop was coordinated with the International Conference on Emerging Technologies for Integrated Pest Management (hosted by North Carolina State University) held March 7–10, 1999, in Raleigh, North Carolina.

The NRC workshop was designed to explore the following topics:

- approaches to gain a common perspective within and across societies for ecologically based pest management;
- barriers to research, development, and implementation of ecological approaches to managing pests;
- interdisciplinary and inter-institutional approaches to organizing pest management research and development within a university and among research collaborators (e.g., across departments, universities, and between the public and private sectors); and
- national policies to accommodate an ecological systems approach in pest management.

The two-day workshop was organized with an opening plenary session designed to communicate crosscutting themes of ecological pest management research. Eugene Odum of the University of Georgia made the keynote presentation in which he provided the audience with an overview of current agricultural practices that actually encourage pests—which provides, in part, the context and need for EBPM (Chapter 1). Ralph Hardy of the National Agricultural Biotechnology Center and Neal Van Alfen of the University of California, Davis began the session with comments describing the “vision for pest management” (Chapter 2). Miguel Altieri and Clara Ines Nichols of the University of California, Berkeley discussed the application of agroecological concepts to EBPM strategies (Chapter 3. Katherine R. Smith of the USDA's Economic Research Service shared an economist's view of EBPM (Chapter 4). Matt Liebman of Iowa State University discussed integrating soil, crop, and weed management in low-external-input farm systems (Chapter 5). Steve Lindow of the University of California, Berkeley followed with his perspective as a microbial ecologist in Chapter 6. Greg Dwyer of the University of Notre

Dame presented an overview of integrating mathematical models with field experimentation as a tool to facilitate understanding of insect-pathogen dynamics (Chapter 7). The plenary session was followed by a day of breakout sessions when participants were divided into discussion groups to promote interdisciplinary interaction and an exchange of ideas among societies and other stakeholders. These discussions were summarized in Chapter 8 from workshop transcripts and from consultations with Mary Jane Letaw and several of the other workshop organizers.

We ask the reader to remember, first, that any single workshop is necessarily incomplete and, second, that its proceedings can only report on what was said. Consequently, this report is not intended to be a thorough examination of its subject matter. All the information reported in the text emerged from the presentations made at the workshop, which were organized as a topic-by-topic synthesis of perspectives from the various fields involved with pest management. The purpose of these presentations is to highlight issues from relevant experience, identify the range of problems and challenges, and explore the opportunities that could be pursued by pest management practitioners, researchers, and professional societies. The presentations represent the views and opinions of those individuals participating in the workshop and do not necessarily represent a consensus of views or opinions, nor do they represent the deliberations of a formally constituted NRC study committee. All of the contributors have reviewed the document and affirmed that they thought the report accurately reflected the events and discussions at the workshop.

Kim Waddell
Project Director

ACKNOWLEDGMENTS

With the support of the W. K. Kellogg Foundation, the US Department of Agriculture's Agricultural Research Service, and the National Science Foundation, the Board on Agriculture and Natural Resources convened a workshop on “Professional Societies and Ecologically Based Pest Management” in March 1999 to explore ways of developing leadership and a common vision for ecologically based pest management (EBPM) among professional societies and their collaborators. Five invited papers and a keynote presentation, reflecting the diversity of disciplines associated with pest management, are included in this report. These papers identify the challenges that face EBPM, seen from the perspective of their respective disciplines, as well as the tools and contributions that these disciplines can bring to EBPM.

The Board on Agriculture and Natural Resources wishes to recognize the following individuals for their valuable assistance in organizing the workshop and their contributions to the workshop and its proceedings:

NEAL K. VAN ALFEN, University of California, Davis

MARY BARBER, Ecological Society of America, Washington, DC

GARY W. BARRETT, Institute of Ecology, University of Georgia

GERALD A. CARLSON, North Carolina State University

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GEORGE G. KENNEDY, North Carolina State University

BRUCE D. MAXWELL, Montana State University

ALISON G. POWER, Cornell University

ROBERT G. ZIMBELMAN, Federation of Animal Science Societies, Bethesda, MD

The Board on Agriculture and Natural Resources also wishes to acknowledge Mary Jane Letaw (Project Director through September 1999) for her work in the planning and organization of the workshop. The Board also wishes to thank Karen L. Imhof, Project Assistant, for her patience and assistance throughout the project, and Editor Louise R. Goines. Special thanks are due to Kim Waddell, Project Director, for his diligence and hard work in assessing and organizing the workshop proceedings.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We wish to thank the following individuals for their participation in the review of this report: May Berenbaum, University of Illinois; Joseph Headley, University of Arkansas; Lorna Michael Butler, Iowa State University; Jenny

Broome, University of California, Davis; Max Carter, Max Carter Farm, Douglas, GA.

While the individuals listed above have provided constructive comments and suggestions, it must be emphasized that responsibility for the final content of this report rests entirely with the authors and the National Research Council.

Contents

FIGURE

1

Pest Management: An Overview[1]

EUGENE P. ODUM and GARY W. BARRETT

Institute of Ecology, University of Georgia

As we document and celebrate success stories dealing with pests and diseases using ecologically based integrated pest management (combining the IPM and EBPM acronyms), we might inquire, "Why are we having to deal with an increasing number of pests, exotic species, and new diseases?" Perhaps there are some ecosystem-level approaches or overall management practices that we might undertake that would reduce the need to continue only to deal with pest species one at a time.

An increase in air travel and other intercontinental transportation is certainly a factor, but what makes the local ecosystem susceptible to invasion once a new species is introduced or a resident species suddenly erupts to become a pest? Drake et al. (1989), Elton (1958), Levin (1987), Mooney and Drake (1987), and Vitousek et al. (1987), among others, discussed "the ecology of invasions" with the general conclusion that disturbance and "open niches" contributed to making natural ecosystems vulnerable to invaders. When it comes to crops or other cultivated or domesticated ecosystems, we suggest that there are four related current management practices that encourage pests.

[1]This commentary is organized as a general response to the basic question "Why are managed ecosystems vulnerable to pests?" which was delivered as a dinner presentation by Dr. Eugene Odum at the Professional Societies and Ecologically Based Pest Management workshop in Raleigh, North Carolina on March 10, 1999.

ECOSYSTEM STRESS AND EXCESSES

Humans tend not to be satisfied with a reasonably good yield but always seem to strive for more, even recognizing that it is possible to have "too much of a good thing." When a crop plant (or the cropland itself for that matter) is forced to produce a maximum possible yield of desired products (e.g., forced increase in the harvest ratio), the plant has very little energy left to defend itself from pests. This is one of the reasons we see an increase in pesticide use. Also, growers seeking the maximum rather than the optimum will often experience overshoot or "boom and bust" crop production patterns, as occurred with cotton in the Canete Valley of Peru in the 1950s (Barducci, 1972) and in Texas in the 1960s (Adkisson et al.,1982).

An experimental study of the effect of increased egg production on disease in a small bird, the great tit, provides an analogous example of the trade-off between productivity and defense (Opplinger et al., 1996). Researchers artificially increased clutch size by removing the first two eggs laid in the nest boxes. With an increase in the clutch size by an average of one egg, the researchers observed an increase in prevalence of malarial parasites in the blood stream from 10 percent in the control females to 50 percent in the experimental females.

Given this trade-off between productivity and defense, what we should consider doing is using the same biotechnology to reintroduce some of the antiherbivore defensive capabilities that most wild plants have developed through natural selection back into crop plants. This strategy may result in lower but more sustainable yields for the crops in question.

EUTROPHICATION

Our effort to increase agricultural productivity worldwide, in order to support increasing numbers of people and domestic animals (which, in turn, excrete huge amounts of nutrients to the environment), has caused global eutrophication problems that are perhaps the greatest threat to ecospheric diversity, resilience, and stability. Global warming that results from CO_2 enrichment of the atmosphere is just one aspect of this overall perturbation. Nitrogen enrichment is also a serious threat (Henrikson et al., 1997; Vitousek et al., 1997). Excess nitrate fertilizer and other nutrient runoff favor many noxious weeds, exotic pests, and dangerous disease organisms because these organisms are highly adapted to high-nutrient environments.

The well-known red tide phenomenon is a good example of how enrichment can create a pest out of normally innocuous organisms. At their typical low densities, the red tide microorganisms in estuaries cause few or no problems. They secrete a toxin as a defense mechanism but not in concentrations that could affect fish. But when the estuary is enriched by nutrient-filled pollution, the organisms can rapidly multiply and reach densities when their defensive toxins can cause massive fish kills.

Another example recently described involves cattle in feedlots. When cows are fed enriched corn in order to increase meat yield, high levels of a virulent strain of *Escherichia coli* were discovered to persist in the lower pH environment of the cattle's digestive system. These high levels of pathogens can contaminate feed and other cattle, and can cause food-borne illnesses in humans through the consumption of the contaminated meat. When the cows were put on grass and hay diets, their gut pH levels were elevated and resulted in a 10^6-fold decrease in the numbers of this virulent strain of *E. coli* (Diez-Gonzalez et al., 1998).

CONTROL VERSUS ERADICATION

A common response to the appearance of pest species is an effort to eliminate them completely rather than reducing their numbers to a point where their impact is small. The trouble with the “kill 'em dead” approach is that it often involves heavy applications of pesticides, which often result in strong selection favoring resistant strains (the few individuals in a given pest population that have some mutation-derived differences in their metabolic pathways that confer resistance against the pesticide). More moderate measures that control but do not eliminate pest species appear to alter the relative frequency of these resistant mutations and slow the development of resistance in the pest populations. An example is the development of a rust-resistant strain of wheat accomplished by introducing a “slow rust” gene that keeps the disease at a low level, so that there is less selection pressure on the rust fungus to mutate (see Holden, 1992, for details). Therefore, reducing the overuse of a pesticide may help reduce the development of particularly challenging resistant pests.

MONOCULTURE VULNERABILITY TO PEST INVASION

For decades the goal of agriculture and agribusiness governmental departments has been to increase crop yields per unit of land by promoting industrial agriculture that involves large-scale monocultures, the use of fossil-fuel-powered machinery, and very heavy applications of chemical subsidies. One result, as documented in numerous papers, reports, and books, is the rapid increase and spread of pests (see, e.g., two reports: NRC, 1989, 1996; and two agroecology books: Altieri, 1987; Gliessman, 1998).

Fortunately, new agricultural practices involving reduced tillage, cover crops, crop rotations, strip cropping, trap crop buffers, and other diversifications that are coming into greater use do reduce pests and decrease the need for heavy pesticide use. We cite two field studies that demonstrate that “not putting all the eggs in one basket” does indeed reduce pests.

Kemp and Barrett (1989) and Holmes and Barrett (1997) demonstrated that the establishment of grassy corridors in soybeans and strip cropping soybeans with sorghum repeatedly reduced the abundance of insect pests such as potato leafhoppers and Japanese beetles, respectively. Thies and Tscharntke (1999) compared two different landscapes; one with large monocultures and one with crop fields interspersed with fallow habitat. Crop damage to oilseed rape by the rape pollen beetle was much less in the more structurally diverse landscape due to greater parasitism by parasitoids coming in from the fallow areas.

Thus, the practice of crop diversification, within and among crop types, has led to the reduction of insect pests, but also has benefited wildlife, increased soil quality, and increased net economic profits across spatial scales.

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2

Vision for Pest Management

ORIGINS OF THE WORKSHOP

RALPH HARDY

National Agricultural Biotechnology Council

We are living in interesting times with interesting changes. Some countries are cutting back on antibiotic use in food animals, and pressure is developing in the United States to do the same. This is part of a growing trend that I see of moving from a chemical input approach to an ecosystem-based approach. The following are just a few more examples that are relevant to this movement toward ecosystem approaches.

U.S. Department of Agriculture (USDA) researchers recently introduced a "competitive exclusion product" called PREEMPT. In field tests, the researchers used this product to successfully reduce *Salmonella* bacteria from 7 percent in untreated chickens to 0 percent in the treated chickens. The Food and Drug Administration approved PREEMPT for use in the poultry industry in March 1998. PREEMPT is a microbial cocktail of nonpathogenic microbes that is sprayed on newly hatched chicks, giving them resistance to *Salmonella.* This new drug preempts the growth of *Salmonella* in the avian gut before the pathogenic forms have the opportunity to reduce growth efficiency and potentially contaminate the food product. This ecosystem-based process has been licensed and is being commercialized (Hays, 1998).

Another process that is not yet commercialized, but I expect will be commercialized in the next year, is an approach to eliminate rodents from poultry farms that is more effective than currently used rodenticides. This approach involves adding an organic rodent feeding repellent to the poultry feed, thereby reducing fecal contamination by rodents in the feed, around the poultry feeding areas, and in related operations.

Another tool that is being developed for the poultry industry utilizes a proprietary cloacal plug to eliminate fecal contamination (the plug is inserted after the chickens have been killed). This technique will reduce microbial contamination of the poultry food products during processing. These three examples from the poultry industry serve to document the movement from primary and dominant use of “chemical-icides” in pest control to approaches that are more ecosystem based.

ECOLOGICALLY BASED PEST MANAGEMENT

The National Research Council (NRC) initiated a study in 1992 that was undertaken at the request of the USDA Animal and Plant Health Inspection Service and Agricultural Research Service. The U.S. Environmental Protection Agency funded the study. The NRC convened a committee composed of 14 members with environmental expertise from various disciplines, including entomology, plant pathology, weed science, and economics. The study addressed the following questions:

- Do we need new arthropod, weed, and pathogen control methods in crop and forest production systems?
- What can we realistically expect from investment in new technologies?
- How do we develop effective and profitable pest control systems that rely primarily on ecological processes of control?
- How can we oversee and commercialize biological control organisms and products?

The committee was diverse and took considerable time to identify a consensus response to the charge. The defining question was a simple one and required committee members to describe their vision for pest management in 20–25 years. The response became unanimous within one-half hour and provided the title for the report—Ecologically Based Pest Management: New Solutions for a New Century.

In its report, the committee stated that ecologically based pest management had to be safe to nontarget, beneficial organisms, as well as applicators, growers, and consumers. Clearly, ecologically based pest management (EBPM) has to be profitable if it is going to be implemented by producers. Finally, EBPM has to be durable in terms of its long-term outcome. Because the word “sustainable” is a term with so many different definitions, the committee chose to use the term “durability,” which is more appropriate for this area. Durability can refer to potential problems associated with evolution of resistance by overuse of a single management tactic. Basically, the change to ecologically based pest management will require a substantial change to a knowledge-based approach, and this knowledge has to build upon an understanding of the inherent strengths as well as the weaknesses of the managed ecosystem.

A primary objective for managing pests is to try to capture and reinforce what can be beneficial for the ecosystem. A secondary approach, if needed, is the addition of supplemental inputs that could include physical or cultural interventions. This would include a variety of biological approaches ranging from traditional plant breeding to genetic engineering and chemicals—provided that those chemicals are safe, profitable, and durable. A chemical can be included in EBPM if it can meet these three requirements and has low risks, for example, for nontarget organisms. These supplements or products should be developed and deployed to minimize disruption to the managed ecosystem, delay development of resistance, and be profitable to the producer.

This NRC report should be viewed as a big picture, one that needs considerable definition to move toward implementation. Clearly, there is a need for a cross-cut of professional organizations and their involvement in order to successfully implement ecologically based pest management systems. Ecology must be incorporated, but so must more traditional pest management disciplines—entomology, plant pathology, and weed science—collectively utilizing a systems approach.

In order to enhance our understanding of this systems approach, several experts were invited to this workshop to present the ecological aspects of their respective fields. For the second day of the meetings, the workshop participants were asked to come to the breakout sessions with an open mind, to speak, to listen, and, most importantly, to learn how we can expand and develop the ecosystem-based approach. The opportunity and the responsibility are there for us to initiate the development and implementation of ecosystem-based approaches in pest management. The professional societies can and should be the leaders in this endeavor.

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VISION FOR ECOLOGICALLY BASED PEST MANAGEMENT

NEAL VAN ALFEN

University of California, Davis

It is generally recognized that one can manage many pests using current knowledge of pest biology without needing to resort to pesticides if the crop is managed on a small scale, if there is flexibility in the crops to be planted, and if one is prepared for periodic crop failures. This is agriculture as we have known it for most of the history of humankind. It is much more difficult to raise crops on the scale needed to feed the world today without resorting to pesticides. One goal of most pest control scientists is to reduce our dependence upon pesticides, and we generally acknowledge a common set of strategies that are available to us to achieve this goal. The difficulty is that we have been unable to achieve this goal to our satisfaction. The 1996 NRC report on EBPM chronicles the successes that have been achieved in the past using the espoused principles. It also delves into why we have not been more successful in managing pests using these principles in large-scale agriculture.

The vision that is represented in this report is not new. Integrated pest management (IPM) emerged in the aftermath of Rachel Carson's 1962 book *Silent Spring* and amid serious concerns about the defeat of pesticides through the genetic plasticity of pests. From this origin, IPM adherents and IPM organizations have worked to reduce our dependence upon pesticides. Equally committed, but more poorly organized within the scientific community, are the proponents of biological control who have also been seeking to find alternatives to organic chemistry for pest management. Groups that support sustainable agriculture and organic farming are committed to a similar vision of pest management. Clearly the concepts and recommendations of the NRC report (1996) are not new nor would they have been possible without the toil of these groups of scientists and farmers during the past decades. They demonstrated the validity of the concepts. The NRC committee, however, recognized that there remain significant barriers to the widespread adoption of the vision of EBPM. Some of the existing barriers are institutional and readily resolvable, whereas others reflect our lack of knowledge of the functioning of agroecosystems.

If IPM, biological control, organic farming, and sustainable agriculture strategies include the essence of EBPM, is it fruitful to complicate the landscape with a new acronym? In reflecting on the history of the development of the pest sciences, the NRC committee felt that a new articulation of our vision of pest management was needed and that, in particular, we need to move beyond current organizational/institutional barriers. New knowledge and approaches to science also create opportunities to move beyond our traditional ways of approaching pest management. This combination of new opportunities for addressing deficiencies in our knowledge and the need to remove organizational/cultural barriers provides the impetus for articulation of a new vision and the creation of a new professional culture of interdisciplinary pest management.

LIMITATIONS

The implementation of pest management practices based upon ecological principles is limited by our lack of complete knowledge concerning the functioning of ecosystems and landscapes. This specific deficiency in our knowledge is but one of the many areas when we are limited in being able to effectively manage pests. The NRC report outlines in detail many of the areas that would benefit from additional research. Through various state and federal programs an effective infrastructure exists in the United States for the delivery of information to growers, but we often lack sufficient new information to provide growers through this system. With the exception of transgenic crops, most of the advances in pest management in recent decades have been incremental improvements of previous discoveries.

Some recent developments offer hope that greater understanding of how ecosystems function will be forthcoming. We currently know little about the microflora of ecosystems, knowing the names of only about 1 percent of them and the roles of even fewer. New detection and genotyping methods provide tools to probe these unknowns. Likewise, development of methods to handle and see patterns in complex data sets provides another window through which to explore how ecosystems function.

The lack of significant new developments in strategies for EBPM is in part due to the lack of funding for basic research in this area. Much of the funding for IPM has been directed toward development and maintenance of an extension delivery system. The USDA's National Research Initiative Competitive Grants Program and the regional IPM grants programs also provide some funding, but relative to the needs the amounts available are small. Compounding the problem is the generally low level of funding available for all ecological research. The National Science Foundation is the primary source of funds for ecological research in the United States, with most of the funding from this agency directed toward the study of natural ecosystems. There is a dearth of funding to understand managed ecosystems, such as those of agriculture and much of our forestland. One of the challenges that we face is to articulate the need for funding to study agroecosystems.

We especially need to attract ecologists to study agroecosystems. Much more basic science must be conducted on how these systems function. Attracting appropriate scientists to address these problems is as much a cultural issue as it is a funding one. Natural ecosystems hold much more interest for these scientists than do pest management issues in agroecosystems. Just as the basic molecular sciences, however, have fueled agricultural biotechnology, our future progress in understanding how agroecosystems function will be dependent upon ecologists who find the study of agroecosystems interesting and rewarding.

INFORMATION NEEDS

What new information is needed? In addition to our need for knowledge of how agroecosystems function, the committee felt that we need to identify and conserve critical bio-resources that have potential for use in pest management. We also need to have a better understanding of the mechanisms that regulate population levels of pests in ecosystems. We need additional research to develop new diagnostic tools. In other words, we need to be able to monitor events in the ecosystem as they happen, particularly to better understand the role of those organisms that cannot be easily seen or distinguished. We must develop broadbased crop management strategies that are not discipline specific. We must develop implementation and evaluation strategies, such as how to recognize and measure success. Finally, there has to be an understanding of the socioeconomic issues that influence the adoption of EBPM practices.

WORKSHOP GOALS

The goal of this workshop is to find common ground among various groups and professional societies, that will lead to joint support for our common vision of pest management, rather than to address the research needs necessary for the success of EBPM. Additional research funding, which we all agree is necessary for us to reduce our dependence on pesticides, will only come from coordinated educational programs directed toward the public and policy makers. We will be most successful if the various groups with this common vision can work together (i.e., to develop transdisciplinary research and educational approaches). As we plan for the future, we need to consider our history and adapt in order to assure that we do not repeat past errors.

HISTORICAL CHALLENGES

Historically, the pest sciences were subdivided into different groups, departments, or colleges by academic institutions and governmental agencies. Within these institutions they became isolated from each other, and often became competitors. Although there are many exceptions that can be identified, the general isolation of the pest science disciplines from each other has created sufficient difficulties that we now must seek new institutional approaches for cooperation. The recent trend in agricultural colleges of land-grant institutions has been to seek new ways to organize disciplines to reduce the types of isolation and competition that have created barriers in the past. This trend will certainly continue until we are able to assure the success of interdisciplinary programs.

Pest scientists have a common vision of the development of safe, profitable, durable pest management systems, but there have been differing views on how to implement this vision. The administration of IPM programs by the federal government has had a particularly contentious history in some states. In the past, the majority of IPM programs have been almost exclusively insect management programs with administrative barriers that have served to limit the participation of other disciplines. The recent progress that has been made in most states and institutions to make IPM programs genuinely interdisciplinary bodes well for our future ability as pest scientists to work together. Future progress of the pest science disciplines will be based upon our ability to work together to address all pest problems at a systems level. Nature does not recognize the administrative divisions that we have erected.

Our disciplinary isolation has manifested itself through the evolution of unique nomenclatures in each discipline that describe the same processes. Entomologists and plant pathologists, for example, have even developed different concepts about what constitutes biological control. Within disciplines such problems of varying definitions often arise, but they need to be addressed between disciplines for effective communication to develop. As we learn to address problems of pest management on a systems level, we will need to reconcile the different languages that we have developed.

BRIDGING THE GAP

Professional societies offer hope to serve as bridges to bring disciplines together. The nature of membership in professional societies is not competitive with each other. Unlike institutional departments that generally allow only a single affiliation, individuals belong to multiple professional societies. Members join as an expression of their interest in the discipline.

Professional societies are seeking ways to jointly sponsor issues of common interest and to sponsor joint meetings that allow their members to meet with those of similar disciplines. Joint meetings present challenges to find common ground in our different cultures. Bringing together groups that have evolved different cultures is a challenge, but if interdisciplinary efforts such as EBPM are to succeed we must bring these cultures into closer communication through more frequent interactions.

Where do we start to bridge the gap and build on common ground? We have developed a common vision of the future of pest management. We all agree that this vision must include addressing pest problems as a managed ecosystem issue rather than on an individual pest basis. Having defined a common vision makes it now possible for us to address how to achieve this vision. To achieve this vision we must not only engage all pest science disciplines but also reach out to all relevant disciplines.

SETTING THE CONTEXT

EBPM promotes the economic and environmental viability of agroecosystems by using knowledge of interactions between crops, pests, and naturally occurring biocontrol organisms to modify cropping systems in ways that reduce damage associated with pests. Coexisting crops, herbivores, predators, pathogens, weeds, and other organisms interact with one another and respond to their environment. This web of interrelated interactions also can confer stability on the system; while a pest population increases and decreases, it is subject to the checks and balances imposed by populations of the other organisms. Thus, future pest management strategies will be built upon an improved understanding of natural biological interactions that suppress pest populations, as well as identification of where the use of supplemental inputs and cultural practices disturb the managed ecosystem and how pest populations develop and adapt to these disturbances. Manipulation of these natural processes into practical and profitable strategies is key to development of ecologically based pest management.

The vision is very similar to the one that has long been articulated for IPM. Achieving the vision of ecological or integrated pest management will depend upon translation of ecological knowledge into practical and profitable strategies for managing pests in farming systems. The chapters that follow present author's perspectives on the sociological, economic, and ecological context for ecological pest management.

3

Applying Agroecological Concepts to Development of Ecologically Based Pest Management Strategies

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Most scientists today would agree that conventional modern agriculture faces an environmental crisis. Serious problems such as land degradation, salinization, pesticide pollution of soil, water, and food chains, depletion of ground water, genetic homogeneity, and associated vulnerability raise serious questions regarding the sustainability of modern agriculture. The causes of the environmental crisis are rooted in the prevalent socioeconomic system, which promotes monocultures and the use of high input technologies, and agricultural practices that lead to natural resource degradation. Such degradation is not only an ecological process but also a social, political, and economic process. While productivity issues represent part of the problem of natural resource degradation, addressing the problem of agricultural production must go beyond technological issues and include attention to social, cultural, and economic issues that account for the crisis as well.

The loss of yields due to pests in many crops, despite the substantial increase in the use of pesticides, is a symptom of the environmental crisis affecting agriculture. It is well known that cultivated plants grown in genetically homogeneous monocultures do not possess the necessary ecological defense mechanisms to tolerate pest populations that experience outbreaks. Modern agriculturists have selected crops for high yields and high palatability, making them more susceptible to pests by sacrificing natural resistance for productivity. On the other hand, modern agricultural practices negatively affect pests' natural enemies, which in turn do not find the necessary environmental resources and opportunities in monocultures to effectively suppress pests. As long as the structure of monocultures is maintained as the structural base of agricultural systems, pest problems will continue to persist. Thus, the major challenge for those advocating ecologically based pest management (EBPM) is to find strategies to overcome the ecological limits imposed by monocultures.

Integrated pest management (IPM) approaches have not addressed the ecological causes of the environmental problems in modern agriculture. There still prevails a narrow view that specific causes affect productivity, and overcoming the limiting factor (e.g., insect pest) via new technologies continues to be the main goal. In many IPM projects the main focus has been to substitute less noxious inputs for the agrochemicals that are blamed for so many of the problems associated with conventional agriculture. Emphasis is now placed on purchased biological inputs such as *Bacillus thuringiensis,* a microbial pesticide that is now widely applied in place of chemical insecticide. This type of technology pertains to a dominant technical approach called input substitution. The thrust is highly technological, characterized by a limiting factor mentality that has driven conventional agricultural research in the past. Agronomists and other agricultural scientists have for generations been taught the “law of the minimum” as a central dogma. According to this dogma, at any given moment there is a single factor limiting yield increases, and that factor can be overcome with an appropriate external input. Once one limiting factor has been surpassed—for example nitrogen deficiency, with urea as the correct input—then yields may rise until another factor, pests for example, becomes the new limiting factor due to increased levels of free nitrogen in the foliage that attracts and supports the herbivore populations. That factor then requires another input— a pesticide in this case—and so on, perpetuating a process of treating symptoms rather than dealing with the real causes that evoked the ecological imbalance.

The addition of biotechnology-based approaches in pest management is merely a new tool to be used as input substitutions to address the problems (e.g., pesticide resistance, pollution, soil degradation) caused by previous agrochemical technologies. Transgenic crops developed for pest control closely follow the paradigm of using a single control mechanism (a pesticide) that, as a strategy, has been shown to fail repeatedly over time against pest insects, pathogens, and weeds. Transgenic crops are likely to increase the use of pesticides and to accelerate the evolution of “super weeds” and resistant insect pests.

The “one gene–one pest” approach emphasized by plant breeders introducing vertical resistance or by biotechnologists developing transgenic crops has proven to be easily overcome by pests that are continuously adapting to new situations and evolving detoxification mechanisms. There are many unanswered ecological questions regarding the impact of the release of transgenic plants and microorganisms into the environment. Among the major environmental risks associated with genetically engineered plants are the unintended transfer to plant relatives of the “transgenes” and the unpredictable ecological effects.

Given the above considerations, agroecological theory predicts that biotechnology will exacerbate the problems of conventional agriculture. By promoting monocultures it will also undermine ecological practices of farming, such as crop rotation and polycultures, which are key strategies to break the homogeneous nature of monocultures. As presently conceived, biotechnology does not fit into the broad ideals of sustainable agriculture.

This production-oriented viewpoint has diverted agriculturists from realizing that limiting factors only represent symptoms of a more systematic disease inherent to imbalances within the agroecosystem. This viewpoint has also diverted them from an appreciation of the complexity of agroecological processes, thus underestimating the root causes of agricultural limitations. A useful framework to achieve a deeper knowledge of the dynamics of agroecosystems is to use agroecological principles. Agroecology goes beyond a one-dimensional view of agroecosystems and includes their genetics, agronomy, and edaphology in order to embrace an understanding of ecological and social levels of coevolution, structure, and function. For agroecologists, sustainable yield in the agroecosystem derives from the proper balance of crops, soils, nutrients, sunlight, moisture, and other coexisting organisms. The agroecosystem is productive and healthy when these balanced and rich growing conditions prevail and when crop plants remain resilient to tolerate stress and adversity. Occasional disturbances can be overcome by a vigorous agroecosystem that is adaptable and diverse enough to recover once the stress has passed. Occasionally strong measures (e.g., microbial insecticides, alternative fertilizers) may need to be applied by farmers employing alternative methods to control specific pests or soil problems. Agroecology provides the guidelines to carefully manage agroecosystems without unnecessary or irreparable damage. Simultaneous with the struggle to fight pests or diseases, the agroecologist strives to restore the resiliency and health of the agroecosystem. If the cause of disease or pests and so forth is recognized as an imbalance, then the goal of the agroecological treatment is to recover the balance. In agroecology, biodiversification is the primary technique to evoke self-regulation and sustainability.

From a management perspective, the agroecological objective is to provide a balanced environment, sustained yields, biologically mediated soil fertility, and natural pest regulation through the design of diversified agroecosystems and the use of low-input technologies. The strategy is based on ecological principles that lead crop management to optimal recycling of nutrients and organic matter turnover, closed energy flows, water and soil conservation, and a balance between pest and natural enemy populations. The strategy exploits the complementary and synergistic attributes that result from the various combinations of crops, trees, and animals in spatial and temporal arrangements. These combinations determine the establishment of a planned and associated functional biodiversity, which performs key ecological services in the agroecosystem.

The optimal behavior of agroecosystems depends on the level of interactions between and among the various biotic and abiotic components. By assembling a functional biodiversity, it is possible to initiate synergistic responses that subsidize agroecosystem processes by providing ecological services, such as the activation of soil biology, the recycling of nutrients, the enhancement of beneficial arthropods and antagonists, and so on.

In other words, ecological concepts are utilized to favor natural processes and biological interactions that optimize synergies so that diversified farms are able to sponsor their own soil fertility, crop protection, and productivity. By assembling crops, animals, trees, soils, and other factors in spatially and or temporally diversified schemes, several processes are optimized. Such processes (such as organic matter accumulation, nutrient cycling, natural control mechanisms, etc.) are crucial in determining the sustainability of agricultural systems.

Agroecology takes greater advantage of natural processes and beneficial on-farm interactions in order to reduce off-farm input use and to improve the efficiency of farming systems. Technologies emphasized tend to enhance the functional biodiversity of agroecosystems as well as the conservation of existing on-farm resources. Promoted technologies are multifunctional, as their adoption usually means favorable changes in various components of the farming systems at the same time.

For example, legume-based crop rotations are one of the simplest forms of biodiversification and can simultaneously optimize soil fertility and pest regulation. It is well known that rotations improve yields by the known action of interrupting weed, disease, and insect life cycles. However, they can also have subtle effects such as enhancing the growth and activity of soil organisms, including vesicular arbuscular mycorrhizae, which allow crops to more efficiently use soil nutrients and water.

Another practice is cover cropping or the growing of pure or mixed stands of legumes and cereals to protect the soil against erosion, which ameliorates soil structure, enhances soil fertility, and suppresses pests including weeds, insects, and pathogens. Cover crops can improve soil structure and water penetration, prevent soil erosion, modify the microclimate, and reduce weed competition. Besides these effects, cover crops can affect the dynamics of orchards and vineyards by enhancing soil biology and fertility and by increasing the biological control of insect pest populations through the harboring of predators and parasites.

Perhaps the most dramatic example of the integrative effects of a multipurpose technology in simultaneously enhancing IPM and soil fertility is organic soil management. Some studies suggest the physiological susceptibility of crops to insects is affected by the form of fertilizer used (organic vs. chemical fertilizer). Studies documenting lower density of several insect herbivores in low-input farming systems have partly attributed such reduction to lower nitrogen content in the organically farmed crops.

The ultimate goal of agroecological design is to integrate components so that overall biological efficiency is improved, biodiversity is preserved, and the agroecosystem productivity and its self-sustaining capacity is maintained. The goal is to design an agroecosystem that mimics the structure and function of natural ecosystems. These systems typically include:

- Vegetative cover as an effective soil- and water-conserving measure, met through the use of no-till practices, mulch farming, and cover crops and other appropriate methods;
- Regular supply of organic matter through the addition of organic matter (manure and compost) that results in the promotion of soil biotic activity;
- Nutrient recycling mechanisms through the use of crop rotations and crop/livestock systems based on the use of legumes; and
- Pest regulation assured through enhanced activity of biological control agents achieved by introducing and/or conserving natural enemies and antagonists.

The process of converting a conventional crop production system that relies heavily on systemic, petroleum-based inputs to a diversified agroecosystem with low inputs is not simply a process of withdrawing external inputs without compensatory replacement or alternative management. Considerable ecological knowledge is required to direct the array of natural flows necessary to sustain yields in a low-input system. The process of conversion from a high-input conventional management to a low-external-input management is a transitional process with four marked phases:

- progressive chemical withdrawal;
- rationalization and efficiency of agrochemical use through integrated pest management and integrated nutrient management;
- input substitution—using alternative, low-energy input technologies; and
- redesign of diversified farming systems with an optimal crop/animal integration, which encourages synergism so that the system can sponsor its own soil fertility, natural pest regulation, and crop productivity.

During the four phases, management is guided to ensure the following processes:

- increasing biodiversity both in the soil and above ground;
- increasing biomass production and soil organic matter content;
- decreasing levels of pesticide residues and losses of nutrients and water components;
- establishment of functional relationships between the various plant and animal components on the farm; and
- optimal planning of crop sequences and combinations and efficient use of locally available resources.

The challenge for EBPM scientists is to identify the correct management techniques and crop assemblages that, through their biological synergism, will provide key ecological services that sustain the performance of agroecosystems. The exploitation of these synergisms in real farm settings involves agroecosystem design and management that require an understanding of the numerous relationships among soils, plants, herbivores, and natural enemies. Clearly, the emphasis of this approach is to restore natural control mechanisms through the addition of selective biodiversity components within and outside the crop field, thereby creating a whole array of possible arrangements of vegetation in time and space.

4

Economist's View of Ecologically Based Pest Management

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The following comments are organized around five of the questions posed to workshop participants about the value and feasibility of interdisciplinary approaches to ecologically based pest management (EBPM) research.

HOW CAN ECONOMICS AND OTHER SOCIAL SCIENCES CONTRIBUTE TO INTERDISCIPLINARY EFFORTS AND EBPM?

Pest management is an intrinsically anthropocentric endeavor. There is no reason to manage pests other than the fact that the activity meets human needs and objectives. Decision models implicitly, if not explicitly, assume that the human pest management decision-maker is a central part of the agroecosystem being addressed. Economics, sociology, anthropology, and other potentially relevant social sciences are critical to understanding that central, human aspect of the ecosystem that is being managed. To ignore the human behavioral and economic influences on the ecosystem is to fail to fully evaluate decisions in an ecological context. Thus, it is almost a tautology to say that the social sciences contribute to EBPM.

Figure 4-1 is a schematic diagram of the pest management decision-making process. It provides a handy mechanism for illustrating how research and development of pest management options require social–scientific concepts, irrespective of whether options are screened and selected on the basis of their ecological properties or for other attributes (Reichelderfer et al., 1984).

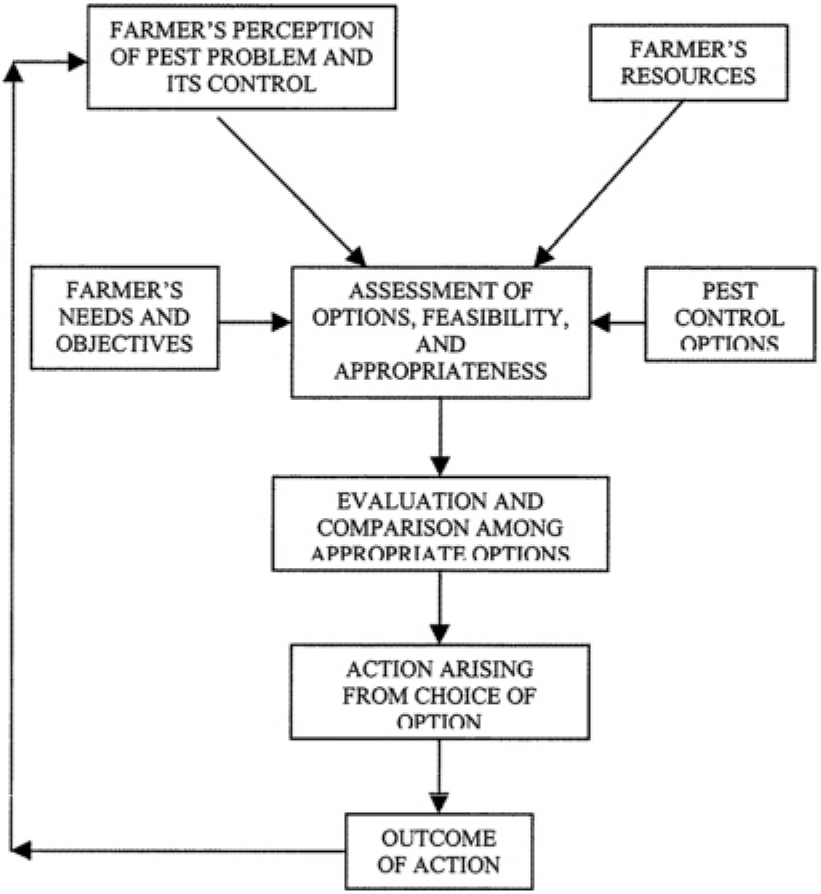

FIGURE 4-1 Pest Management Decision-Making Proposal

First, knowledge of the pest control user groups' perceptions helps to identify and define the real problems that need to be addressed in the development of programs. Second, knowledge of the user groups' resource base and the institutional framework within which the group operates—producers or those who advise them—prevents the conduct of research that might otherwise lead to the development of unfeasible or inappropriate technology. Third, the use of economic criteria to develop and refine pest control strategies helps to ensure that the end-product of the research is not only feasible and ecologically appropriate in this context but also preferable to the users' current approaches. Demonstrations of the relative economic advantages of various pest control strategies influence users' decisions to adopt or implement a particular option. This is a critical point for farmers at the strategy adoption stage. Finally, the outcome of a selected option's implementation is determined by how well the action addressed the needs and objectives of the user, which is why there is a feedback loop in the schematic. Those needs and objectives, though, are based on economic, psychological, and sociological factors, not just the technical factors; thus the importance of the human in the EBPM calculus. A tremendous range of pest management decision models has been developed and used specifically for the *design* of pest management systems that merge social with ecological considerations (Carlson and Wetzstein, 1993).

Economics plays another important role by providing a way of measuring trade-offs across species, across environmental media, and among the different functions of the ecosystem. Altieri and Nicholls (2000) discussed ecological trade-offs in agricultural ecosystems, urging that these be taken into account in pest management decision making. But there are really only a couple of currencies that can be used to measure ecological trade-offs in a consistent manner across environmental media. One is energy; and the other is money or monetary equivalents. Because pest management is anthropocentric, money seems to act as the more reasonable metric in making decisions about trade-offs. Economic theory, which allows monetary values to incorporate the dimensions of time and space, is critical for valuing or comparing the values of outcomes.

AT WHAT STAGES IS ECONOMICS USEFUL?

First, in the *planning* stage, when biological science partners are describing pest status, species identification, and distribution, and the ecological relationships that define an agroecosystem, economists can usefully survey the pest control market and identify the institutional factors that may improve the success of different ecologically based approaches. Second, the *experimental* phase is a particularly important point for economic input as approaches are being developed and tested in the laboratory or the field. If economists are not involved at this point, it is quite likely that the experiment will be designed in such a manner that the economic measures needed for assessing the EBPM system's economic feasibility cannot be attached to the outcomes of the experiment. This is a critical stage for interdisciplinary interaction.

Finally, in the *implementation* of pest management strategies, the identification of the constraints to adoption and the incentives for adoption are peculiarly intertwined with economics, psychology, sociology, and the health sciences. Here, then, the social sciences continue to play an important role in predicating the practical, on-the-ground success of ecologically successful pest management systems.

WHAT ARE THE BARRIERS TO INCORPORATING ECONOMICS IN INTERDISCIPLINARY RESEARCH AND EXTENSION?

The alleged barriers to interdisciplinary research are notorious. A standard concern is that technical language and terminology are constraints among scientists.[1] An equally weak claim is that scientists must oversimplify their own disciplinary approach for the sake of those in other fields, and that they cannot publish interdisciplinary research results in a disciplinary journal. In the context of EBPM research, this notion is conceptually absurd. EBPM researchers are dealing with problems that should be as attractive to intradisciplinary journals as they are to interdisciplinary ones. Empirical dismissal of commonly cited barriers is provided by Young (1995), whose study of a survey of agricultural economists who co-authored multidisciplinary research articles suggests that interdisciplinary research does not hinder one's professional status and, in fact, can be professionally rewarding.

This is not to say that there are no institutional barriers inhibiting interdisciplinary research. Disciplinary chauvinism is built into academe in a variety of ways (Duffy et al., 1997). Furthermore, the additional time requirements for interdisciplinary research do constitute a potential barrier to some untenured scientists who need to devote their time to research that will promote tenure. These problems may be exacerbated by academic institutions that have set time frames and predetermined levels of research productivity and types of research outlets for the consideration of tenure.

Perhaps the most serious barrier, however, is the lack of funding mechanisms for interdisciplinary works. The major competitive granting system for agriculture in this country is the USDA's National Research Initiative Competitive Grants program, which remains organized on basically disciplinary lines, despite the fact that there is encouragement and an honest attempt for interdisciplinary work (National Research Council, 1994). The peer panels in this granting program tend to be comprised solely of experts from a specific (though possibly broad) discipline—for example, the plant science panel would be comprised of plant scientists, the animal science panel by animal scientists, and so forth. It is often very difficult for a group of peers of a single discipline to judge the suitability of interdisciplinary studies while simultaneously considering other proposals that focus exclusively within the discipline. In this setting, interdisciplinary studies are at a disadvantage and face a greater funding barrier (Chubin and Hackett, 1990). If the process of peer review of proposals truly targets interdisciplinary work and money is truly provided for these types of proposals, then we can overcome those barriers quite rapidly.

[1] It seems fair to assume that if plain English cannot be used by scientists to describe technical relationships, then either (a) the technical relationships are not understood well enough to be effectively communicated to people in other disciplines or (b) the non-communicating scientist is choosing to be pretentious and insular in his/her decision to continue using jargon.

WHAT IMPACT DO PROFESSIONAL SOCIETIES HAVE WITH REGARD TO MONETARY INCENTIVES?

Most professional societies devote a considerable amount of time and energy to lobby—to secure and maintain specific sources of money from congressional granting—for very specific endeavors within their disciplines. The competitive nature of this activity is a much more severe constraint than is disciplinary culture, and can only be overcome by those societies agreeing to discontinue this type of lobbying behavior. Under the current conditions, there is little incentive for the societies to do that. There are coalitions and umbrella organizations whose missions are to increase funding for agricultural science without looking at it in a disciplinary perspective. Yet, the disciplinary lobbying continues and is something that professional societies should try to overcome in order to spur more funding for interdisciplinary research and study.

WHAT IS THE ROLE OF INDUSTRY?

Industry and other components of the private sector are funding and pursuing a greater proportion of total agricultural research and development in this country than at any previous time. This is occurring at an increasing rate and is overtaking the public sector in the amount of resources devoted to agricultural research and development (Fuglie et al., 1996). Industry does not face the same barriers to interdisciplinary cooperation that are seen in the public sector. Most businesses are organized around their marketing, basic science, and applied science divisions. With this construct, businesses are often able to create an environment where interdisciplinary work is done to produce a product.

However, due in part to intellectual property issues, scientists in the public sector may be denied access to much of the knowledge that is created in that more goal-oriented, interdisciplinary-prone process. Thus, it is important to consider the private sector at the same time that we are thinking about the roles of professional societies and the public sector in furthering the needed interdisciplinary approaches in pest management research and extension. Indeed, the impact of public research funding and related policies on private sector incentives, and the subsequent need for public sector compensation to assure public goods provision (such as EBPM), is a much needed area of future research (Falck-Zepeda and Traxler, 2000).

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5

Opportunities to Integrate Soil, Crop, and Weed Management in Low-External-Input Farming Systems

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American farmers currently apply more than 200 million kilograms of herbicide-active ingredients each year (Aspelin and Grube, 1999). Although herbicides have reduced farm labor demands, heavy reliance on chemical weed control has had a number of undesirable consequences, including ground and surface water contamination (Barbash et al., 1999; Larson et al., 1999; U.S. Geological Survey, 1999) and shifts in weed community composition toward herbicide-tolerant species and herbicide-resistant genotypes (Heap, 1999; Radosevich et al., 1997). Weed management strategies that rely more on manipulations of ecological processes and less on herbicide technology are needed to address these and other problems.

Ecologically based weed management strategies begin with the premise that no single tactic will remain successful in the face of genetically heterogeneous weed populations, range expansions by dispersing weed species, variable weather conditions, and changes in crop management practices. Rather than relying on a single "large hammer," such as herbicide technology, to suppress weeds, ecologically based strategies seek to integrate many "little hammers" that act in concert to stress and kill a wide range of weed species at many points in their life cycles (Liebman and Gallandt, 1997). By spreading the burden of crop protection over multiple, temporally variable tactics, ecologically based weed management strategies can reduce risks of crop loss and limit rates of weed adaptation to control tactics.

One approach for using ecological knowledge to increase the range of tactics available for weed management involves managing soil conditions to suppress weed emergence, growth, and competitive ability (Gallandt et al.,1999; Liebman and Davis, 2000). As a consequence of the fixed root habit, both weeds and crops are affected by soil conditions. Weeds and crops may differ in their responses to those conditions, however. Just as certain herbicides are toxic to weeds but do little or no harm to crops, certain edaphic factors may suppress weeds but have neutral or positive effects on crops.

Legume residues, composts, and manures are widely used in organic and low-external-input farming systems to maintain soil productivity. Experiments conducted with several crop–weed combinations indicate that use of these soil amendments in place of synthetic fertilizer can also reduce weed density, biomass production, and competitive ability, at the same time maintaining or improving crop performance. This has been true for sweet corn and field corn grown in competition with *Chenopodium album* (Dyck and Liebman, 1995; Dyck et al.,1995); dry bean in competition with *Brassica. kaber* (Liebman and Ohno, 1998); and potato in competition with *Chenopodium album* and other weed species (Gallandt et al.,1998). Several factors appear to be responsible for the differential responses of crop and weed species to soil amendments.

First, the substantial differences in seed size that exist between many weeds and crops (Mohler, 1996) may convey differential susceptibility to early-season stresses that limit photosynthesis and nutrient uptake. Because of greater seed reserves, seedlings of large-seeded crops, such as corn and soybean, are likely to be more tolerant of low-nutrient conditions and soilborne phytotoxins, whereas seedlings of small-seeded annual weeds are likely to be less tolerant of these and other stresses (Westoby et al., 1996).

Second, many annual weed species are better adapted than crops for rapid nutrient uptake and biomass production early in the growing season (Alkämper, 1976; DiTomaso, 1995). Consequently, under conditions of high nutrient availability, many small-seeded weeds are highly competitive with large-seeded crops, despite their lack of seed reserves. Changes in the timing of nutrient availability have been investigated for their potential to alter weed growth and competitive ability. By delaying the application of synthetic fertilizer until several weeks after crop and weed germination, the growth of weeds such as *B. kaber, Chenopodium album,* and *Veronica hederifolia* can be reduced and the yield of crops such as corn and wheat can be increased (Alkämper et al., 1979; Angonin et al., 1996). Certain crop residues, composts, and manures may serve as slow-release nutrient sources that are better synchronized with the nutrient demands of crops rather than weeds (Dyck et al., 1995; Liebman and Davis, 2000). Specific rates of nutrient release from organic soil amendments will depend on substrate quality, soil temperature and moisture conditions, and other factors, but could be regulated advantageously.

Third, crop residues, composts, and manures serve as sources of biochemicals that can affect crop and weed growth. Some of these compounds are growth inhibiting, whereas others are growth promoting. In addition to containing nitrogen, which generally stimulates plant growth, legume green manures can release a range of phytotoxic compounds (Liebman and Ohno,

1998) that may be particularly damaging to small-seeded species (Liebman and Davis, 2000). Early in the decomposition process, composts and manures may release acetic acid, phenols, ammonia, and other organic compounds at concentrations high enough to be phytotoxic (Ozores-Hampton et al., 1999; Tiquia and Tam, 1998; Zucconi et al., 1985). Alternatively, mature composts and well-rotted manures can serve as sources of growth-stimulating substances, such as indole-3-acetic acid, and humic and fulvic acids (Chen and Aviad, 1990; Valdrighi et al., 1996). Beneficial effects of humic substances on plant growth are believed to result from increased membrane permeability, greater nutrient uptake, enhanced protein synthesis and photosynthesis, changes in enzyme activity, and effects similar to those resulting from application of plant growth regulators (Chen and Aviad, 1990). For reasons mentioned previously, small-seeded weeds may be more susceptible than large-seeded crops to compost-derived phytotoxins; this needs to be tested experimentally. It also remains to be learned whether growth-stimulating substances from compost differentially affect weeds and crops. The timing and balance of growth-inhibiting and growth-stimulating effects of soil amendments merit more research.

Finally, applications of crop residues, composts, and manures may change soil microbial conditions affecting weeds and crops. Applications of fresh plant materials and manure can increase the activity of soilborne pathogens, such as *Pythium, Phytophthora,* and *Rhizoctonia* spp. (Cook and Baker, 1983; Dabney et al.,1996). Whether or not such pathogens can be managed to differentially attack weeds and crops needs to be investigated. Alternatively, organic soil amendments may reduce the incidence of pathogens attacking crops and improve their growth by increasing colonization of the root zone by beneficial microorganisms (Cook and Baker, 1983; Pankhurst and Lynch, 1995). More research is needed to determine whether such an effect could increase a crop's ability to compete with weeds.

The aforementioned soil-related factors represent only a small subset of the many components of farming systems that can be manipulated to contribute to ecologically based weed management strategies (Liebman and Gallandt, 1997). Diversification of cropping systems through crop rotation, intercropping, and cover cropping offers a particularly powerful set of tactics for managing weeds that can effectively complement soil-based approaches (Liebman and Davis, 2000; Liebman and Dyck, 1993; Teasdale, 1998). Other soil- and crop-related approaches that may serve as components of ecologically based weed management strategies include:

- tillage practices that move weed seeds and vegetative propagules in ways that reduce their survival and disrupt the timing and success rate of seedling or shoot emergence (Buhler, 1995; Mohler, 1993);
- residue management practices that promote attack on weed seeds and seedlings by vertebrates, insects, and microbes (Boyetchko, 1996; Brust and House, 1988; Pitty et al., 1987);
- soil solarization techniques that use temporary plastic tarps to alter soil conditions and kill weed seeds before crops are sown (Stapleton and DeVay, 1995);

- irrigation and fertilization practices that place water and nutrients where they are most available to crops and least available to weeds (Grattan et al., 1988; Rasmussen et al., 1996);
- use of crop densities, spatial arrangements, planting dates, and genotypes that increase crop competitiveness against weeds (Buhler and Gunsolus, 1996; Lemerle et al., 1996; Mohler, 1996; Teasdale, 1995; Teasdale and Frank, 1983; Wall and Townley-Smith, 1996).

The successful integration of soil, crop, and weed management will require active collaboration among microbiologists, biochemists, agronomists, weed ecologists, agricultural engineers, and members of other disciplines. A better understanding of weed dynamics and soil-related processes on organic and low-external-input farms, which often use diversified cropping systems, crop residues, composts, and manures to maintain soil productivity, will also further the development of integrated weed management systems. Given that private industry has little incentive to aid farmers interested in reducing the use of herbicides and other purchased inputs, public funding to support research on ecologically based weed management is highly desirable.

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6

View of a Microbial Ecologist

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Microbial ecology principles will be important in any future efforts to practice ecologically based pest management. It is clear we lack a complete understanding of a number of important issues relating to interactions between pests and crop plants as well as between pests and other microorganisms. It will be important to determine the mechanisms of interaction between microorganisms in order to know the potential for ecologically based pest management as well as the degree to which it has been achieved. A lack of understanding of these interactions limits our ability to understand the processes that occur during our efforts to implement ecologically based pest management. Unless a more thorough understanding of the ecological principals dictating microbial and plant interactions is obtained, efforts to achieve ecologically based pest management will remain empirical and will lack transferability between systems. On the other hand, by understanding particular model systems in which ecologically based management can be successfully implemented, it should be possible to develop common strategies and practices by which pest management can be relied upon in the future. Examples of important ecological principles that will need to be understood, as well as recent attempts to obtain information in these areas, will now be presented.

One of the most powerful and dramatic recent applications of technology to microbial ecology has been to address questions of population structure and population genetics. Until recently, we lacked tools to differentiate between individuals in populations of the groups of microorganisms that operate either as pest microorganisms or as biological control agents. For this reason, it was previously impossible to know whether a population of a target pest was genetically homogeneous, and therefore might be expected to react similarly to a biological control agent, or was genetically diverse and requiring more complex strategies of management such as in the deployment of plant disease resistance genes. One of the more important tools for implementing ecologically based pest management is that of the effective deployment of plant disease resistance genes. Because of a gene-for-gene relationship between resistance genes in a host plant and avirulence genes in a plant pathogen, it is important to understand the population genetics of the plant pathogen as well as processes that could lead to changes in the genetic structure of the population, since changes could lead the pathogen to overcome plant disease resistance. Because of the ease with which plant pathogens can now be spread around the world by human activities, we need to be knowledgeable about pathogen diversity throughout the globe to be able to deploy plant disease resistance genes in a way in which resistance will be durable. A good example of a detailed examination of a plant pest population has recently come from the laboratory of Dr. Jan Leach of Kansas State University, who studied the bacterial plant pathogen *Xanthomonas oryzae,* one of the most important pathogens of cultivated crops (George et al.,1997; Raymundo et al., 1999). Her analysis of the populations of this pathogen in a variety of tropical regions where rice is grown showed that the pathogen had apparently been spread widely to rice grain regions but that local variation in a pathogen population also can occur. This information is clearly applicable to regional and local plant breeding efforts to develop disease resistant rice cultivars in that it elucidates the need to include a wide variety of pathogen genotypes in selection schemes to anticipate introduction of novel pathogenic strains.

Knowledge of the population structure of soilborne pathogens is also important in implementing biocontrol procedures. For example, the soilborne plant pathogenic fungus *Armillaria mellea,* which can attack the subterranean parts of a variety of woody plants, has recently become a prominent disease problem in pear orchards in California. The recurrence of this disease might be associated with changes in cultural practices such as irrigation or fertilization but the introduction of novel virulent strains of the pathogen could not be ruled out without a better understanding of the population structure of the pathogen in the orchards. However, David Rizzo of the University of California at Davis was able to ascertain, using molecular techniques, that a limited number of genotypes of pathogen occur within a given orchard, and that large contiguous areas of trees are apparently infected by clonal representatives of a given strain of the plant pathogen, apparently originating from infections of native tree species hundreds of years ago (Rizzo et al.,1998). Thus, it appears that changes in cultural practices, perhaps increased amounts or altered times of irrigation in recent years, have stimulated a preexisting pathogen within the orchards. Without an understanding of the pathogen structure within these orchards, such conclusions would have been impossible and a focus of disease management based on cultural practices could not have been made.

The role of microorganisms in common cultural practices for pest management such as crop rotation and soil amendments can now be better understood using molecular biological tools. For example, it has frequently been observed that the incorporation of green plant residues (green manures) into soils can decrease the severity of diseases caused by soilborne plant pathogens such as *Verticillium dahlia.* Clearly, the introduction of large amounts of plant material into soils could have many effects on the composition and behavior of soil microorganisms. Although numerous descriptions of changes in soil microorganisms have been provided, it has been recognized through the work of Oen Huisman and James Davis (and others) that a common feature of soil microorganisms in sites that have become resistant to disease due to the addition of green manures is an increase in microbial activity (Davis et al., 1996). Increased microbial activity might logically be associated with increased production of antibiotics and other biologically active compounds in the soil. Without the direct measurements of microbial activity that are now possible, statements about the potential involvement of microbial communities and negative interactions with soilborne plant pathogens would remain hypothetical.

One of the most striking and influential contributions of molecular microbial ecology to the study of pest management has been to better define the composition of microbial communities in a given habitat. It is deplorable that only less than about 1 percent of the soil microorganisms found in agricultural soils can be cultured and hence studied. It seems likely that many of the unculturable microorganisms play an important role in the disease process and in maintaining plant health. While few advances in our ability to culture soilborne microorganisms have been made, it is now possible to obtain a direct assessment of their diversity and identity. Culture-independent methods of identifying microorganisms, for example, by amplification of common molecules such as 16S rRNA genes, has made it possible to identify microorganisms present in a sample. Such studies, when applied to soil microorganisms, reveal incredible levels of diversity among the unculturable microorganisms. For example, a study by Dr. Eric Tripplet of the University of Wisconsin revealed not only that high levels of diversity are found in agricultural soils but that different microorganisms are found in disturbed agricultural soils compared to undisturbed forest soils (Borneman and Triplett, 1997). Although we remain far from the goal of being able to specifically manipulate microbial communities in soils, tools are now available to assess impacts of agricultural practices such as cultivation and crop rotation.

Molecular tools of microbial ecology now enable us to obtain a better insight into what microorganisms are doing while in their natural habitats. An understanding of microbial activities in situ will be required before we can hope to routinely manipulate systems to achieve pest management. It is now possible, for example, to determine the conditions in which a plant pathogen will express virulence traits. The plant pathogen *Pseudomonas syringae* pv. *syringae,* which causes a variety of diseases including a leaf and fruit spot of cherry, damages plants by its production of a phytotoxin. The genes for these toxins have now been cloned and work by Dr. Dennis Gross of Washington State University has demonstrated that such genes are not expressed except when the pathogen is found associated with cherry (Mo et al.,1995). Furthermore, specific phenolic elicitors of gene expression when combined with sugar exudates found in host plants are sufficient to elicit toxin production (Quigley and Gross, 1994). Such detailed knowledge of pathogen behavior might form the basis for innovative strategies to evade the deleterious traits of plant pathogens by selective breeding to eliminate plant signals required for virulence.

Molecular genetic tools when applied to microbial ecology should enable us to better understand interactions between microorganisms that can confer biological control of important diseases. Whereas a number of microbial traits such as antibiotic production, chitinase production, and the production of iron-sequestering agents have all been implicated in biological control, in most cases we lack understanding of the expression of these traits in the habitats where biological control must occur. New tools have now been developed, however, that permit assessment of the level of expression of those genes implicated in biological control. For example, work by Dr. Joyce Loper of the US Department of Agriculture, Corvallis, OR, has clarified the role of iron siderophores in biological control. It was hypothesized that the rhizosphere of plants often lacks sufficient iron to allow unrestricted growth of plant pathogens prior to infection. Biological control agents, by acquiring iron in the infection court, might deprive plant pathogens of needed iron and thereby confer disease control by iron competition. By fusing iron-regulated genes involved in pyoverdine siderophore production with an ice nucleation reporter gene, Dr. Loper's group was able to demonstrate that available iron concentrations are moderately low in many soils but that iron availability in the rhizosphere was greatly dependent on the plant species itself (Loper and Henkels, 1997). This work provides a basis to predict those plant species and conditions under which control with an introduced siderophore-producing biological control agent would be expected to be maximally effective.

It is clear that a better understanding of microbial plant pests, as well as associated microorganisms that might be involved in their management, needs to be gained before ecologically based pest management schemes can be reliable. It is expected that the reliability of such management schemes will increase as we move from an empirically based protection strategy to one based on knowledge of the identity of the organisms and their activities in agricultural ecosystems.

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7

On the Use of Mathematical Models in Ecological Research: Example from Studies of Insect–Baculovirus Interactions

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Historically, mathematical models in ecology have been used largely to provide qualitative explanations for patterns in nature. A classic example of this approach was the effort to use competition models to explain species diversity (Diamond and Case, 1986). Simple competition models showed that species that utilized the same resource can coexist under the right circumstances (Begon et al.,1996). This theoretical observation, however, leads to much controversy over the general issue of whether competition structures natural communities.

This kind of general statement about nature is arguably of little importance for problems of resource management. Perhaps as a consequence, modeling efforts in many applied fields, especially pest management, have often rejected simple mathematical models in favor of giant simulation models (Onstad, 1988). Simulation models have hundreds of parameters and state variables, take years to construct, and are often so complex that they can take pages to describe. Such models represent the opposite extreme from the simple models used in academic research, in that they attempt to sacrifice understandability for ecological realism.

The last few decades, however, have seen increased interest in applied questions among academic ecologists, and the resulting research has begun to suggest an alternative use for simple mathematical models (Hilborn and Mangel, 1996). Specifically, simple mathematical models can be used as statistical hypotheses much as linear models have been used in classical statistics.

Moreover, current research suggests that many sets of ecological data cannot statistically justify complex models. That is, although nature may appear to be complicated, real data often cannot prove that more complicated models give a better description than simpler models (Hilborn and Mangel, 1996). Whether this is because nature really is simple, or because our data are noisy, is irrelevant for many practical purposes. The fact is that, if we want useful quantitative descriptions of nature, it is typically the case that we need fewer than 10 parameters.

Current work in ecological modeling thus emphasizes close connections between theory and data, and the use of mathematical models as statistical hypotheses about nature. As a result, models that were once viewed as being of only intellectual interest may well become useful in pest management. To make this point concrete, I will review my own work on a virus disease of a forest pest, the gypsy moth *Lymantria dispar*.

Ecological models of insect diseases began with a simple model by Anderson and May (1981), which started with a model for human epidemics and added population dynamics of insects and pathogens. Anderson and May used the model to make the general point that pathogens may drive the dynamics of forest insects capable of significant outbreaks such as the larch budmoth, *Zeiraphera diniana.* Further research on this and other insects has instead suggested first that single-factor explanations for forest insect population dynamics are probably generally insufficient, and second that pathogens are not always important players in the population dynamics of forest insects (Hunter and Dwyer, 1998). Nevertheless, even though the original generalization is too sweeping, features of Anderson and May's model have been useful for understanding insect pathogens.

Specifically, Anderson and May's model assumed that the rate of horizontal transmission of the virus increases linearly with the density of the pathogen. This assumption provided a useful quantitative hypothesis, and it is nonetheless interesting even though data show that it is often incorrect. For example, data for the transmission of the gypsy moth virus reject a linear model but cannot reject a nonlinear model (Dwyer et al., 1997). Additional experiments, however, suggested that this nonlinearity arises because of variability among the host insects in their susceptibility to the virus, and a model that allows for this variability can accurately predict the timing and intensity of virus epidemics (or epizootics) in naturally occurring gypsy moth populations. Surprisingly, the resulting model requires only four parameters.

Although this model arose from efforts to answer questions of basic research, it is beginning to have practical applications. For example, efforts are being made to genetically engineer this and other viruses. Consequently, a question of environmental concern is, “Will engineered virus strains outcompete wild-type strains, thereby altering the ecological balance between host and pathogen?” Because the model can predict epidemics from experimental transmission data, it can be used to assess the risks of releasing engineered strains before any such strains have been released (Dwyer et al., in press). Preliminary work has suggested that at least one deletion mutant of the gypsy moth virus is unlikely to be a superior competitor, and work is now advancing to apply the model to assess commercially produced strains of the nuclear polyhedrosis virus of the cabbage pest *Trichoplusia ni.*

More concretely, gypsy moth populations tend to be very patchily distributed, so that a major challenge for managers is identifying which populations need to be controlled and which are likely to collapse. Because the virus model can be used to predict which populations are likely to have severe virus epidemics, it can assist in identifying which populations are likely to collapse.

These studies demonstrate several advantages of using simple mathematical models. First, compared to the logistic expenses of performing experiments and collecting data, the cost of constructing, simulating, and analyzing models is very low. Second, models can allow us to extrapolate between small-scale field and lab measurements and the dynamics of populations. The gypsy-moth-virus model, for example, uses as input only the initial density and frequency of infection of gypsy moths in the field, and measurements of disease transmission and kill rates from small-scale lab and field experiments. The model can nevertheless predict the timing and intensity of virus epidemics in naturally occurring gypsy moth populations on 3–10 hectare plots with great accuracy across a wide range of densities (Dwyer et al., 1997; Dwyer et al., in press). This ability to extrapolate across scales means that the model can be used to predict the outcome of large-scale releases of engineered viruses from measurements before such releases are carried out. Third, by focusing on simple explanations for what superficially appear to be complex natural phenomena, simple mathematical models provide useful testable hypotheses. Moreover, the success of the gypsy-moth-virus model, which includes only four parameters, suggests that many natural phenomena are simpler than they initially appear.

These advantages of simple models should theoretically be even greater in pest management. This is because questions of ecological research can often be phrased somewhat qualitatively, whereas questions of pest management research are ultimately economic and thus inescapably quantitative. I would therefore argue that the infrequent use of mathematical models in pest management is due to an overemphasis on complex simulation models. In addition to being more difficult to understand, such models are inherently more expensive than the simple models that I advocate here. Complex simulation models are therefore less likely to be tested, and in turn are less likely to be discarded in favor of better models. Hopefully simple mathematical models will eventually come to be as useful in pest management as they are in ecological research.

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8

Key Components and Elements Critical to Achieving the Vision: Group Discussion Summary

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Workshop participants convened in small discussion groups to identify key components necessary for research and implementation of ecological approaches to pest management. Discussion questions (see Appendix A) were designed to explore interdisciplinary approaches that could cut across individual society interests. The groups explored a number of issues and questions: How can we advance or implement ecologically based pest management (EBPM) and its principles? What are the goals and challenges within EBPM-related research? What are the knowledge gaps for research and the institutional constraints that inhibit EBPM research and implementation? Finally, what are the opportunities that professional societies could pursue to foster EBPM research and implementation?

FINDING COMMON GROUND

Throughout the group discussions, a number of participants used the terms "EBPM" and "IPM" (integrated pest management) interchangeably.[1] However, for others, there were also perceptible differences in the uses and meanings of

[1]The terms "EBPM" and "IPM" are used in this chapter interchangeably, except in discussions exploring the specific differences between the two terms, or when workshop participants are making explicit references to one or the other term.

the terms and, as the issue was explored, the groups spent a considerable amount of time determining the conceptual differences between IPM and EBPM. In an effort to bring these views together and find some common ground, Neal Van Alfen, led workshop participants in a discussion on various perspectives surrounding the vision of EBPM.

The discussion began by exploring the use of terminology and its implications for IPM and EBPM. There was general agreement that IPM had historically been an ecologically based approach and largely still was, but there was a call for a shift in emphasis to more long-term research approaches. Several members of the discussion group voiced the opinion that IPM was a term that should be retained, since IPM is still connected to its foundation of ecological principles. Others suggested that perhaps there were reasons for change, and pointed to a similar situation from the field of forestry when a change in nomenclature and management practices (from “forestry” to “ecosystem management”) resulted in greater public recognition and acceptance. For those supporting a change in the terminology, some view IPM as having drifted from the ecological systems-based approaches—based on the perception that IPM has not adequately addressed the ecological causes of the environmental problems in today's agriculture.

If there is to be genuine progress toward the shared goal, there should be a focus on modifying the existing infrastructure to incorporate a broader base of ecological knowledge as well as new technologies, so that we can increase our rate of progress toward the shared goals of IPM and EBPM. If successful, the stage would be set for progress toward a common vision.

To further advance EBPM as a viable pest management system to farmers, the discussion participants acknowledged that farmers needed to understand the value of shifting from maximum yields to sustaining managed ecosystems. There should also be a stronger focus on issues of quality—quality of the products and of the production system. Furthermore, the definition of profitability needs to be broadened and should incorporate the environmental costs that may be forthcoming with different pest management systems. From this foundation the groups felt they were able to proceed further and identify goals for research.

Multidisciplinary research was repeatedly identified as a critical step toward addressing both component and systems-level challenges for EBPM. The complexity of managed ecosystems requires expertise and research across the range of biological and social sciences, and, in order to understand and manage the interactions between crop and pest in an ecologically sound way, researchers will need to draw upon multiple disciplines.

Another goal for EBPM is to incorporate established ecological concepts. One of the challenges in agriculture is the recognition of current limitations in modern ecology. Theory has advanced enormously in the last 10 years to accommodate large-scale, long-term experimentation, and there are a number of new methodologies being developed. One approach for EBPM practitioners to consider is to consult leaders in the ecological community who can identify what is currently possible but also what is not possible. The group acknowledged that, during discussions and workshops, participants often assume a greater understanding of ecology than is actually known by researchers and theoreticians. For example, the workshop presentations illustrate how much more is needed to identify and address critical questions that involve microbial processes before we can advance to another stage of our management strategy for soils.

PARTNERSHIPS

Professional societies are in a unique position to influence the direction and extent of research and implementation that can support ecologically based integrated pest management. Practitioners and scientists who attended the conference emphasized that collaborations should not be limited to scientists or professional societies. To be truly interdisciplinary, research should extend beyond these boundaries to other interested organizations and groups such as producers, input suppliers, nongovernmental organizations, and academic scientists.

Many participants felt that developing partnerships with industry and other groups will be essential to EBPM. For example, the workshop participants suggested that there could be partnerships between researchers/practitioners of EBPM and the plant protection industry, which has a sophisticated marketing program and, consequently, a very powerful presence in the market. The perception held by the discussion groups was that there has been much improvement in environmental sensitivity within both the consumer and industry sectors, and this sensitivity could be further enhanced via these partnerships. The same logic could be applied for other partnerships with the chemical industry, the food processing industry, and other industries that are involved in agriculture. The participants acknowledged that there would be some obvious polarization that might exist between industry views and researcher views. If and where that occurs, it might be most productive to involve a wider range of societies and organizations in facilitating the dialogue and reminding the differing parties of their common interests and objectives. The societies that represented cross-sector or multidiscipline interests like the American Association for the Advancement of Science (AAAS), Council for Agricultural Science and Technology, and the American Institute of Biological Sciences may have the best chance of bridging the gaps between the disparate views expressed.

There was also a call for partnerships with existing public interest groups that already have regional networks of stakeholders such as the sustainable agriculture working groups, which are citizen groups. These opportunities could result in additional grassroots support and infrastructure, a critical resource for public education, and raising political awareness.

A common interest in EBPM and the issues surrounding farm and rural community structure and stability can initiate other partnerships among societies representing social scientists, applied anthropologists, rural development experts, and political scientists. The issues of pesticide use and safety and environmental health concerns could bring the public health societies, such as the American Public Health Association, to a partnership. Other organizations that find issues within EBPM of interest include practitioner organizations such as the Association of Conservation Districts, Association of Farm Managers, and Certified Crop Consultants Association, public policy groups such as county commissioners, and the AAAS fellows. There are producer organizations that have a stake in EBPM, such as various commodity groups, organizations of crop consultants, processors, and marketers, including cooperatives and grocery store chains, that have a stake in IPM labeling and organic products. There are also consumer organizations, input suppliers, cooperative extensions (both the general basic extension and the IPM cooperative extension program), environmental organizations such as the Natural Resources Defense Council, federal and state departments of agriculture, the National Science Foundation, and various nongovernmental organizations, all of which represent potential partners with common interests in EBPM.

The economic principles associated with IPM and EBPM need to be fully distributed, because profitability is often seen as the primary motivation in farmers adopting a given strategy. Nonetheless, farmers are still committed to issues beyond that of profitability. Farmers are also interested in safety for workers and consumers, the durability of their production systems, and environmental protection of the land and its resources. Many also want to increase their understanding of sustainable agriculture. This combination of values makes many farmers ideal participants in any partnerships with researchers or professional societies. Given the range of farm products and farm size in American agriculture, there are a variety of opportunities that the researchers and professional societies can use to identify the issues and constraints that the farmers face in their pest management plans. This relationship would also reduce the lag time between the successful development of new pest management strategies by researchers and the consideration and application of these strategies by farmers.

On the issue of collaborators and partners, Several of the workshop participants felt that it should be much more farmer centered than it traditionally has been. There is the perception that farmers should be more involved in observing and monitoring roles in the development of EBPM strategies and approaches. If farmers were also involved in shaping the questions, they could be extremely effective in farmer-to-farmer education. Their participation and success could stimulate more participation by other farmers whose systems could provide valuable insights from further scientific study.

GAPS AND OTHER ISSUES IN CURRENT RESEARCH

The discussion groups readily identified numerous gaps in research that need to be addressed before EBPM could have broad application and acceptance in American agriculture. Many of the gaps are in disciplines that already contribute to current pest management strategies. Other gaps reflect the lack of integration of current ideas and approaches from more basic research areas, seen, for example, in contemporary ecological research in natural systems.

Finally, the groups identified research gaps in areas of agriculture that might have considerable impact on how pest management could be practiced in the future—via transgenics and organic cropping systems.

There is a call for a stronger landscape ecology perspective in pest management research because much of the dynamics of pests is determined outside of individual farm fields. Proactive approaches, such as prevention, need to be more of a focus in pest management. Research should develop a greater understanding of the nature and consequences of dispersal in pest species.

The issue of biodiversity in agricultural systems warrants further research. Many questions emerged from this area of discussion. Should managed systems be modeled after natural systems where pest species appear to be "controlled"? From an understanding of the functionality of some natural systems, is it possible to transfer that knowledge into the design of agricultural systems? How does biodiversity affect the functionality in the system? How do these questions change with different spatial and temporal scales of managed ecosystems?

It was noted that some applied areas of pest management (weed science was identified as an example) are perceived to be lacking a foundation of ecological theory. An obvious first step would be to incorporate more of the ecological theories that are relevant to pest management strategies into these applied sciences. This process begins in the classroom within these science programs, but also could become a fixed part of certification programs for pest managers. The ecologists in these applied fields can use, via their respective professional societies, the annual meetings, forums, and symposia to integrate the relevant ecological theories into their disciplines for the benefit of their fellow members.

The group also noted that more research should focus on those managed ecosystems where there are few or no pest problems as a way to understand more about what makes these systems successful. Again, if researchers more frequently included farmers in the process, and there was a stronger network of farmers involved, it is possible that researchers would find more farm systems available for study that had success in managing their pest populations.

The participants noted that a great deal more research is still needed in existing and well-developed research areas of pest management. More studies in population biology, including studies of the population genetics of both pest and beneficial species, are needed. There was also a demand for a greater understanding of the mechanisms of action of biological control agents, traditional chemicals, and some of the newer chemicals that promote systemic acquired resistance and other resistance mechanisms. Soil ecology was another research area requiring more development, particularly in the area of nutrient or waste recycling within various soil ecosystems. There was demand for more economic and sociological research contrasting different farming practices (e.g., comparing conventional and organic approaches) as well as IPM and other pest management strategies. More studies in landscape biology and conservation biology in managed ecosystems were also requested. The groups also acknowledged that, in spite of the fact that there is a call for large-scale research projects that examine the interactions of the various crops with their environment, there was still a great need for component research. Within many systems, there is much that is not understood that will require more detailed studies of individual species or phenomena.

There was considerable discussion about transgenic crops and their impact on pest management. It was noted that there is little known about the economic and ecological changes that can occur in ecosystems when transgenic crops are introduced and whether this new technology may have some cascading effects in managed ecosystems. Another gap in agricultural research that has implications for EBPM is the current level of research and data that evaluate the impact of transgenic crops in pest management strategies. Due to intellectual and business property issues inherent in the development of the different lines of these crops by the private sector, researchers in the public sector and farmers may feel left "out of the loop." There was concern that there will be a significant time lag between the studies that examine the agronomic characteristics (including pest susceptibility) of these new crop lines and the growing commercial acceptance and use of these crops. A correlative concern was that a disproportionate amount of the research dollars will be used in investigating these crops at the expense of other important studies that might further EBPM strategies.

There is a paucity of virtually every type of research in the study of organic cropping systems, and it was also noted that there is substantial variation between regions and crops in our understanding of pest management practices in organic systems. A number of local participants attending the workshop acknowledged that, for North Carolina, there are increasing opportunities and interest in organic systems, but that researchers have yet to exploit these opportunities.

Researchers' relationships with farmers could be enhanced with some changes in research methodology. There was some discussion about the difficulty of involving farmers in traditionally designed research that often involves getting farmers to commit two or more years of resources to on-farm research. It was suggested that researchers look beyond traditional agricultural statistical designs (e.g., randomized complete blocks with three years of data) and attempt to find or develop other experimental designs for on-farm research that could be more acceptable and less costly for farmers to consider.

Another development that might enhance the appeal of implementing EBPM strategies for farmers and researchers is to examine the ecological buffering capacity of IPM systems. Researchers could develop ways that this capacity would be enhanced in an effort to minimize the fluctuations that are often seen in pest populations that impact farm income in monocropping systems. A parallel corollary to this was suggested to further explore strategies used in IPM/EBPM—such as crop rotation, intercropping, and planting a diversity of crops—in order to strengthen on-farm economic buffering in an effort to reduce the fluctuations in prices and income that farmers can experience.

INSTITUTIONAL CONSTRAINTS FOR EBPM

The perceived lack of public recognition of IPM also has public and political institution-level consequences. Some participants felt that agricultural researchers do not have effective lobbying efforts on-going in Congress, and consequently their views and issues do not have a strong voice or presence, either individually or collectively. It was also pointed out that researchers and societies have not maximized the opportunity in publicizing interdisciplinary successes or the success of IPM programs in the public media. One consequence of the lack of coverage is the relatively low public awareness of IPM, particularly of the evolution and progress of these management strategies over the last 30–35 years. Participants identified public education and outreach in subject areas that included food production, processing, and related food and environmental safety issues as important areas for improvement. If this effort begins with children, there is the hope that the public, in 10–15 years, can make better-educated decisions as consumers and voters.

The lack of voice with policy makers affects funding of research projects at the national level. The participants suggested that there is a need for increased funding for EBPM programs and they noted the value of the large national projects, such as the Center for Integrated Pest Management (CIPM) project. Located on the campus of North Carolina State University in Raleigh, CIPM provides a variety of services including implementation, training, and public awareness for IPM at the state, regional, and national levels. However, the current funding climate is perceived as particularly competitive with limited resources in which any increase in funding for IPM/EBPM programs would likely result in decreased funding in some other program in the agricultural research arena. The suggestion was made that much could be learned from other countries, particularly from European countries that have developed large-scale and widely used model IPM systems, as a template for developing the political and social infrastructure for such a network for the United States.

The discussion groups explored a number of institutional factors that were perceived to inhibit EBPM research. The participants identified the current structure and organization of disciplines and departments within research universities and land grant colleges as major factors. There was a call for some level of reorganization or integration of college and university degree programs in order to facilitate interdisciplinary degree opportunities for students who will eventually become researchers and pest managers. This would also allow cross-disciplinary researchers to develop a greater understanding of interactions among pests, particularly interactions between species that fall outside one traditional discipline (e.g., interactions between insects and birds) in an effort to better predict pest impacts in managed systems. Interdisciplinary degree programs would encourage the development of EBPM, and ideally lead to an emphasis on longer term funding cycles for grants that focus on long-term experimental systems. This approach would develop a more fundamental connection between acquiring knowledge in such systems and the implementation of the lessons gained from those experiments into managed systems.

CHALLENGES WITH EBPM IMPLEMENTATION

When the discussion groups talked of the diversity of scale in American agriculture, they saw the feature as both an opportunity for a variety of research questions as well as a major challenge for applying principles of EBPM. The different commodities, the myriad of labor and ownership relationships on the farm, and the consumer market and demographics for farm products all have implications for the success of pest management strategies. It was obvious to the discussion groups that the heterogeneous nature of farming in this country makes any broad-scale approach complex and difficult to implement.

Many questions arose during this portion of the discussion. For example, when looking at the marketplace or labor pool, are we going to include groups that, traditionally, are rarely considered in this process, such as lower income groups, minorities, and/or undocumented migrant workers? What kind of recruitment approaches do we use to make sure we have an inclusive approach in our education efforts? How conceptually different are the pest management strategies of a particular commodity, say between a high-value vegetable crop versus an extensively planted grain crop?

It was noted that there should be more attention paid to the groups impacted by changes in pest management, such as farm workers and consumers. However, this concept generated more questions. How much consideration should there be of the economic consequences of EBPM implementation and of the demographics of the traditional consumer? Should we reduce or expand the current consumer base because of ecologically based considerations? Can the farmer afford to consider these options or even want to take the risk?

The discussion turned to the financial institutions that lend money to farmers and subsequently influence the pest management strategies that are considered for each crop. Are these institutions aware of the options of pest management? Do they appreciate and consider IPM practice? Do they view the risk associated with practices in a proper manner? The same questions apply to the insurance companies that are now beginning to underwrite some of these practices.

EBPM requires an effort in monitoring and measuring ecological impacts. For farmers to adopt and implement monitoring requires lobbying for more “green” programs that offer the farmer financial and political incentives to adopt ecologically sound pest management strategies. Can the current infrastructure of researchers, institutions, and advocates involved in IPM and EBPM move the policy makers into providing those incentives?

COLLABORATIVE OPPORTUNITIES AND BENEFITS WITH PROFESSIONAL SOCIETIES FOR EBPM

For professional societies, sponsoring joint symposia and meetings was identified as one way to stimulate and foster interdisciplinary study and interactions among students and researchers alike. The joint meeting between the Entomological Society of America and the American Phytopathological

Society in 1998 was viewed as a successful step in developing the kind of multidiscipline interaction between societies that will discern common goals and collaborative research opportunities for all involved.

One suggestion that would facilitate interactions between societies would be to provide free or reduced cost space to encourage exhibitors from other societies to share their goals or research interests. From this idea, it was also suggested that a similar display opportunity be offered to new and small start-up companies that have EBPM/IPM products or services that members can consider, as a way to promote interdisciplinary approaches to research and the tools available for EBPM.

Other approaches for collaboration among societies were suggested. One strategy called for a stakeholder roundtable, which involves bringing all the stakeholders together (e.g., the scientists and consumers) in an effort to forge a consensus. Public and private co-sponsorship could emerge and make recommendations reflecting common goals. These goals would likely reflect both the similarities and differences of the individual groups, but still manage to focus quite specifically on current important issues. This approach could also take advantage of university staff that are already in extension—that are already charged with delivering information to stakeholder groups. Another recommendation suggested working with society editorial boards to make sure the editors and, therefore, the whole review peer process understands interdisciplinary research, its value, and how to evaluate it in a publication format. This could enhance the dissemination of interdisciplinary studies as well as provide a tangible and acceptable measure of productivity for researchers in pursuit of tenure or promotion within their respective institutions.

The 1996 NRC report, *Ecologically Based Pest Management: New Solutions for a New Century,* identified a list of needs and tools necessary to build interdisciplinary, ecological systems-based approaches to pest management. This workshop was the first step, and it brought together professional societies, researchers, and practitioners for discussion of EBPM. Professional societies are in a unique position to influence the direction and extent of research and implementation that can support ecologically based integrated pest management. The attendees from the workshop came away with a new appreciation for collaborations and partnerships, which should not be limited to scientists or professional societies. There was recognition that the interdisciplinary research required to further develop ecologically based integrated pest management should draw upon other interested organizations and groups, such as producers, input suppliers, nongovernmental organizations, as well as academic scientists. Due to diverse goals and expectations, the challenge will be putting this into practice.

REFERENCE

National Research Council. 1996. Ecologically Based Pest Management: New Solutions for a New Century. Washington, DC. National Academy Press.

Appendixes

Appendix A

Workshop Program

PROFESSIONAL SOCIETIES AND ECOLOGICALLY BASED PEST MANAGEMENT WORKSHOP

Achieving the Vision

March 10–11, 1999

North Raleigh Hilton, Raleigh, NC

March 10, 1999

Session I:	**Introduction (plenary session)**
3:00–3:10 PM	Introduce the Charge *Ralph Hardy, National Agricultural Biotechnology Council*
3:10–3:30	Vision for Ecologically Based Pest Management *Neal Van Alfen, American Phytopathological Society*
3:30–3:50	Question and Answer Session

Session II:	**Setting the Context (plenary session)**
3:50–4:10	Applying Ecological Principles in Agroecosystem Studies *Miguel Altieri, University of California, erkeley*
4:10–4:30	How Economists View Ecologically Based Pest Management *Katherine R. Smith, Economic Research Service, U.S. Department of Agriculture*
4:30–4:50	Integrating Soil Crop and Weed Management in Low-External-Input Farming *Matt Liebman, Iowa State University*
4:50–5:10	Microbial Ecology *Steven Lindow, University of California, Berkeley*
5:10–5:30	Combining Models and Field Experimentation to Understand Insect-Pathogen Dynamics *Greg Dwyer, University of Notre Dame*
5:30–6:30	Open Discussion
6:30–7:30	Dinner
7:30–8:30	**After-Dinner Presentation and Discussion** Pest Prevention *Eugene P. Odum, University of Georgia*
March 11, 1999	
Session III:	**Key Components and Elements Critical to chieving the Vision** Group Discussions (each attendee will participate in both group discussions)
8:00–9:30AM	Research (e.g., key processes, systems science, experimental design) *Facilitator: Jenny Broome, University of California, Davis*
	Implementation (e.g., ecological productivity, teaching biological principles, adoption strategies)

	Facilitator: Lorna Michael Butler, Washington State University, Puyallup
9:30–10:00	Break
10:00–11:30	Continue Group Discussions (attendees will move to other discussion group)
11:30–12:30	Lunch
12:30–1:30 PM	Discussion Summaries
Session IV:	**Developing a Pathway for Implementation (plenary session and discussion)**
1:30–2:45	*Neal Van Alfen*
Session V:	**Synthesis**
2:45–3:00	*Ralph Hardy*
3:00	Adjourn

SESSION III DISCUSSION QUESTIONS

Key Components and Elements Critical to Achieving the Vision

Research discussion group
Facilitator: Jenny Broome, University of California, Davis

1. What are goals of ecologically based pest management systems (e.g., manipulating biological processes, stability in production)?
2. Progress in ecologically based pest management will depend upon a strong foundation of research. What are some major research gaps (e.g., development of spatial statistics and predictive models, genetic basis of pathogenicity, basis of host selection and host-range specificity, host plant resistance, monitoring methods, implementation and evaluation research)?
3. What does it mean to participate in interdisciplinary, collaborative research (e.g., joint authorship)? When does interdisciplinary/inter-institutional collaboration begin?

4. How can collaboration strengthen quality and impacts of research? How do you make it work so all partners come out as winners?
5. How should ecologically based pest management research be organized (e.g., long term ecological research studies, university, on farm) to evaluate ecological processes and accommodate site-specific variability?
6. How can practical knowledge be incorporated into the research design to improve pest management decision making in individual management systems?
7. What organizations should take the lead in establishing and coordinating collaborative research efforts for ecologically based pest management? What types of projects should be lead by the public sector? Private sector? Joint leadership?
8. What are potential roles of collaborators, including professional societies, in advancing research investments in ecologically based pest management (e.g., policy)?

Implementation discussion group

Facilitator: Lorna Michael Butler, Washington tate University, Puyallup

1. What are the goals of ecologically based decision making? How can integrated pest management be strengthened by ecological approaches?
2. What does response to Question 1 imply with regard to choices of methodologies and partners?
3. How can biological principles be used to create user-friendly decision-making systems? What are some technical and social challenges?
4. What are some factors that facilitate/discourage adoption of ecologically based pest management strategies?
5. What role will extension/consultants/input suppliers and other producers play in education, demonstration, and training of pest managers? What should be the role of the public sector? Private sector? Joint roles?
6. What is the role of collaborators, including professional societies, in advancing implementation of ecologically based pest management (e.g., policy)?

Appendix B

Program Participants

RALPH HARDY (Co-organizer) is President of the National Agricultural Biotechnology Council in Ithaca, New York. Until September 1995, Hardy was President and CEO of Boyce Thompson Institute. His broad interests include biological nitrogen fixation and photosynthesis, biotechnologies, and biobased products. Hardy chaired the NRC study committee on biological control and served on the NRC study committee that wrote the 1996 report *Ecologically Based Pest Management: New Solutions for a New Century.* Hardy received a PhD degree in biochemistry from the University of Wisconsin.

NEAL VAN ALFEN (Co-organizer) is Dean of the College of Agricultural and Environmental Sciences at the University of California at Davis. His current research focuses on developing biological control strategies for diseases in natural and managed forests. Van Alfen served on the NRC study committee that wrote the 1996 report *Ecologically Based Pest Management: New Solutions for a New Century.* Van Alfen is President-Elect of the American Phytopathological Society. He received a PhD degree in plant pathology from the University of California at Davis.

MIGUEL A. ALTIERI is Associate Professor and Associate Entomologist at the Division of Insect Biology, University of California at Berkeley. His research uses the concepts of agroecology to obtain a deeper understanding of the nature of agroecosystems and the principles by which they function. Particular focus is on the ways in which biodiversity can contribute to the design of pest-stable agroecosystems that are sustainable, economically viable, and natural resource conserving. Altieri received his PhD degree in entomology from the University of Florida.

GARY W. BARRETT is Odum Professor of Ecology at the University of Georgia. His research interests include stress effects (e.g., pesticides or fertilizers, sludge or fire) on ecosystem dynamics; mammalian population dynamics; applied ecology; agroecosystem ecology; restoration ecology; landscape ecology; ecological manpower, education, and research trends. Barrett is President of the American Institute of Biological Sciences. Barrett received his PhD degree from the University of Georgia.

GREG DWYER is the Galla Assistant Professor in the Department of Biological Sciences at the University of Notre Dame. His teaching and research focus on insect host-pathogen relationship, disease ecology, and modeling. Dwyer combines ecological field experiments and mathematical models to determine how the characteristics and interactions of individual organisms determine the dynamics of populations and communities. He received a PhD degree in entomology from the University of Washington.

MATT LIEBMAN is an Associate Professor of Agronomy at Iowa State University. His research interests include crop rotation, intercropping, and cover cropping systems; integrated production of crops and livestocks; and weed ecology and management. He received a PhD degree in botany from the University of California at Berkeley.

STEVE E. LINDOW is Chair, Microbial Biology Division in the Department of Plant and Microbial Biology at the University of California at Berkeley. His research emphasizes both molecular genetic and ecological approaches to the study of the interaction of epiphytic bacteria with other microorganisms on plants, as well as the interactions of these organisms with the plants on which they live. Lindow received his PhD degree in plant pathology from the University of Wisconsin, Madison.

CLARA INES NICHOLLS is Home Community Horticulture Advisor, University of California Cooperative Extension, Alameda County. Her research focuses on enhancing biological control of insect pests through biodiversification designs of cropping systems in urban as well as rural environments. Clara received her PhD degree in entomology from the University of California, Davis.

EUGENE P. ODUM is Callaway Professor Emeritus and Director Emeritus of the Institute of Ecology at the University of Georgia. He has pioneered ecosystem ecology beginning with his first textbook published in 1953. Elected to the National Academy of Sciences in 1970, he has received three international awards, the French L'Institut de la Vie Prize, the Tyler Award, and the Swedish Crafoord Prize. Odum received his PhD degree in Biology from the University of Illinois.

KATHERINE (KITTY) REICHELDERFER SMITH is Director of the Resource Economics Division of the U.S. Department of Agriculture's Economic Research Service, an agency that generates information and analysis vital to enhanced performance of the food and agricultural system and rural America. Her principal areas of expertise are policy analysis, particularly with respect to agricultural and resource policies, and the relationships among agricultural production, trade, and environmental quality. Smith received her PhD and MS degrees in agricultural and resource economics from the University of Maryland.

Appendix C

Forum Participants

Miguel Altieri, Division of Insect Biology, University of California, Berkeley

J. Lawrence Apple, North Carolina State University Raleigh, (International Association for the Plant Protection Sciences)

Jorge Aragon, National Institute of Agriculture, Cardoba, Argentina

Jack Bailey, North Carolina State University Raleigh, (American Phytopathological Society)

Waheed I. Bajwa, Oregon State University, Corvalis, (Entomological Society of America)

Keith Baldwin, North Carolina State University, Raleigh

Mary Barber, Sustainable Biosphere Initiative, Ecological Society of America, Washington, DC

Kenneth R. Barker, North Carolina State University Raleigh, (Council for Agricultural Science and Technology IPM Task Force)

O. W. Barnett, North Carolina State University, Raleigh, (American Phytopathological Society)

Gary W. Barrett, University of Georgia, Athens, (American Institute of Biological Sciences)

Mike Benson, North Carolina State University, Raleigh, (American Phytopathological Society)

Jenny Broome, University of California, Davis, (American Phytopathological Society)

Joe Burton, Agricultural Research Service, U.S. Departmnent of Agriculture, North Carolina State University, Raleigh, (American Society of Agronomy; Crop Science Society of America)

Lorna Michael Butler, Washington State University, Pullman, (Rural Sociological Society)

Gerald A. Carlson, North Carolina State University, Raleigh, (American Agricultural Economics Association)

N. Beth Carroll, Novartis Crop Protection, Greensboro, North Carolina

Max Carter, Max Carter Farm, Douglas, Georgia (Georgia Conservation Tillage Alliance)

Margriet Caswell, Economic Research Service, U.S. Department of Agriculture, Washington, DC (American Agricultural Economics Association)

Harold Coble, North Carolina State University, Raleigh (Council for Agricultural Science and Technology; Weed Science Society of America)

Thomas Currier, AgraSol, Chapel Hill, North Carolina

Jennifer Curtis, Natural Resources Defense Council, Carboro, North Carolina

Greg Dwyer, University of Notre Dame, South Bend, Indiana (Ecological Society of America)

Brian Federici, University of California, Riverside, California (Entomological Society of America)

Jennifer Grant, Cornell University, Geneva, New York (Entomological Society of America)

Thomas A. Green, IPM Institute of North America, Madison, Wisconsin

Ralph W. F. Hardy, National Agricultural Biotechnology Council, Clarence Center, New York

Dan Hess, Affymax Research Institute, Palo Alto, California

Maureen Hinkle, National Audubon Society, Washington, DC

Barry J. Jacobsen,, Montana State University, Bozeman, Montana (American Phytopathological Society)

Paul Jepson, Oregon State University, Corvallis

George G. Kennedy, North Carolina State University, Raleigh, (Entomological Society of America)

Kathleen Kidd, North Carolina Department of Agriculture and Conservation Services, Raleigh

Matt Liebman, Iowa State University, Ames, (American Society of Agronomy; Ecological Society of America)

Steve Lindow, University of California, Berkeley, (American Phytopathological Society; American Society of Microbiology)

Mike Linker, North Carolina State University, Raleigh, (Entomological Society of America)

Joyce Loper, Agricultural Research Service, U.S. Department of Agriculture, Oregon State University, Corvallis

Bruce D. Maxwell, Montana State University, Bozeman, (Weed Science Society of America)

H. Charles Mellinger, Glades Crop Care, Inc., Jupiter, Florida

John Miranowski, Iowa State University, Ames, (American Agricultural Economics Association)

Mike Morgan, AgraSol, Durham, North Carolina

Vince Morton, VIVA, Inc., Reidsville, North Carolina

Paul Mueller, North Carolina State University, Raleigh

Clara Nicholls, University of California, Berkeley

Eugene P. Odum, University of Georgia, Athens

Alison G. Power, Cornell University, Ithaca, New York (Ecological Society of America)

Ed Rajotte, Pennsylvania State University, State College (Entomological Society of America)

Jean B. Ristaino, North Carolina State University, Raleigh, (American Phytopathological Society)

Dave Ritchie, North Carolina State University, Raleigh

Daniel Robison, North Carolina State University, Raleigh

Katherine R. Smith, Economic Research Service, U.S. Department of Agriculture, Washington, DC

Jean Steiner, Agricultural Research Service, U.S. Department of Agriculture, Washington, DC

Mike Stringham, North Carolina State University, Raleigh, (Entomological Society of America)

Turner Sutton, North Carolina State University, Raleigh, (American Phytopathological Society)

Joe Trlica, Colorado State University, Ft. Collins (Society for Range Management)

Neal K. Van Alfen, University of California, Davis (American Phytopathological Society)

Keith Waldron, Cornell University, Ithaca, New York, (Entomological Society of America)

Wes Watson, North Carolina State University, Raleigh

Wes Watson, North Carolina State University, Raleigh, NC