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ECOLOGY AND THE AGRICULTURAL SCIENCES: A FALSE DICHOTOMY?

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Analysis of the relationship between ecology and agriculture requires an understanding of how the two areas see themselves and each other. Both disciplines have common roots in botany, chemistry, physics, and geology, and in the interactions among both biotic and abiotic factors. Agriculture has long been recognized as an applied science with interdisciplinary traditions that involve the recognition that some of its management techniques are as much an art as a science.

Agronomy was one of the earliest scientific disciplines and is also one of the most empirical: present-day agronomy has been very successful at developing methods for coaxing further productivity out of a given area of land, whether this entails studies of the effects of different tillage methods on soil porosity, the development of new strains of *Rhizobium,* or the efficacy with which specific herbicides suppress weeds under particular application regimes. Agronomists have contributed much to process-level studies in microbial ecology, soil-surface chemistry, plant physiology, and genetics; rarely have they addressed their problems in terms of the larger, complex set of organism-level interactions that define crop productivity (Russell 1966). Although agricultural practices often take such interactions into account, especially in non-intensive agricultural systems, a reliance on chemical inputs during the past 40 yr has allowed its practitioners in developed countries to ignore all but the most superficial ecological relationships in most cropping systems. Added fertilizers have obviated the need to understand soil organic matter dynamics or microbial community changes in cultivated soils; pesticide availability has often made knowledge about weed and insect life-history strategies or differential competition redundant.

Areas such as range management (Coupland 1977) and forestry (Jordan 1985, Waring and Schlesinger 1985) have long involved a close working relationship between ecologists and agronomists. Similarly, from ecology's inception, ecologists have often turned to the agronomic sciences for techniques and conceptual platforms from which to launch forays into the natural world (Tobey 1981, McIntosh 1985).

As one of the youngest of the natural sciences, ecology has only in the last decade or so begun finding solid niches in the applied world. Its emerging roles in conservation biology, land-reclamation science, forest management, and microbial biotechnology are examples of such initiatives. To test ecological theory, ecologists have historically focused on natural biological systems. The result? A body of theory that often describes biological phenomena in natural systems well (Coleman and Hendrix 1988), but that to a large extent either: (a) has not been tested or (b) is irrelevant to the intensely managed systems typical of production-level agriculture. Where ecological theory has been tested in agronomic systems, the focus is more often on questions related to environmental protection than on questions related to agronomic production, or the focus is centered on the premise that the ideal agronomic system is necessarily as close an analogue as possible to the corresponding natural system.

In recent years classically trained ecologists have begun to apply ecological concepts worked out in natural systems to recalcitrant problems in agronomy. In doing so they commonly discover: (1) a lack of enthusiasm on the part of agronomists to principles held dear by ecologists, and (2) that agricultural systems—even the annual monocultures—are far more ecologically complex than they initially appeared. These problems stem from differences in perception and approach: ecologists tend to view agronomists as strict empiricists, and agronomists tend to view ecologists as overly theoretical purveyors of the obvious. All involved tend to oversimplify the biological and physical complexity of the agronomic environment. Both disciplines have historically focused on narrow, and at times competing, goals at the practical level: agronomy mainly on crop production and ecology mainly on environmental protection. Recent breakthroughs in molecular genetics, an increasing awareness of the sensitivity of our environment to disturbances, and the emergence of sustainable agriculture, now make the acceptance of mutual goals a necessity if we are to develop a productive, ecologically sustainable agriculture and a set of truly universal ecological principles.

In part, agronomy has taken an empirical path because empirical approaches are fast and clean: it is less time-consuming to design, conduct, and interpret experiments to test which of several alternative cropping methods yield better results than it is to design and implement experiments to delineate underlying principles. Graduate and undergraduate training in agronomy has tended to be equally focused: chemistry, mathematics, biochemistry, and microbiology are established prerequisites for agronomy majors, but ecology only seldom is part of the curriculum. Courses such as Soil Conservation and Weed Ecology touch on ecological principles and provide community or system-level integration, but tend to be oriented towards specific problems, such as erosion control or herbicide efficiency. Arthur's (1895) lament that ecology was a "nomen incognitum" in the agronomic curricula of land grant institutes is almost as true today as it was in the last century.

Modern agriculture today is faced with three great opportunities and one increasingly large challenge. The challenge is the necessity to produce an economically viable crop while preserving the short- and long-term integrity of the local, regional, and global environment. The opportunities lie in on-farm applications of ecological theory, biotechnology, and intelligent computer systems. That present-day intensive agriculture is overdependent on energetic, chemical, and direct economic subsidies is now recognized by most policy makers. The push towards a sustainable agriculture is an emerging national and global priority, and will require the full participation of ecologists. R. Harwood's recent assertion (Harwood 1989) that the role of ecologists in the movement for sustainable agriculture is akin to the role of crop breeders in the green revolution is not far from the mark.

Agronomists must consider the interactions of all important biological and physical components of their cropping systems, and must integrate this knowledge at the community level if they are to meet the twin challenges of economic and environmental sustainability. The application of ecological theory to agronomic systems is central to this integration. Woodmansee (1984), in listing the attributes of sustainable systems that mimic natural ecosystems, has stressed the effects of the canopy and litter in reducing sedimentation and soil temperature. Natural ecosystems also exhibit a tight synchrony of plant and microbial activity, and have residues with wide carbon-to-nitrogen ratios during periods of plant inactivity, thus reducing losses of nutrients to the environment. The retention of nutrients within the live components of native systems and their heterogeneous rooting structures together permit a fast start-up in the spring and better soil water and nutrient utilization.

The role that biotechnology should play in the development of a sustainable agriculture makes all the more imperative an understanding of organism-level interactions in modern cropping systems. Opportunities to manipulate genomes in the agricultural community are becoming available via direct molecular techniques (Board on Agriculture 1987). While ecologists must continue to play a watchdog role with respect to potential impacts of novel genomes on the biosphere, they must also take the equally important role of suggesting specific ways in which agricultural systems can be effectively and safely managed via the introduction or alteration of particular organisms.

Altering the life history traits of a competitive weed to enable its use as an easily controlled winter cover, for example, may be a safer and more economic alternative for suppressing weeds than the strategy of developing species-specific viruses that can also attack non-target populations. Work in alternative cropping techniques has shown that weed suppresson can best be obtained when warm season–cool season crops are rotated to most effectively compete with weed development (Harwood 1989). In the area of symbiotic N_2 fixation the addition of maize-like grain characteristics to legumes that already have effective symbiotic systems may be a cheaper, quicker, and environmentally safer strategy than the development of a nitrogen-fixing maize (Paul 1988). The introduction of interruptive pheromones into a cropping system may be a safer strategy for controlling herbivorous insects than would be the introduction of superpredators. But all of these alternatives require detailed knowledge about both the organisms that inhabit agricultural communities and also—and perhaps more importantly—the ways in which they interact with each other and their environments.

How do we implement a program to introduce ecological concepts into agriculture? An analysis of the successes and shortfalls of the interdisciplinary integrated pest management (IPM) concept provides insight into ways to effect this transfer. The United States Department of Agriculture defines IPM as "a desirable approach to the selection, integration and use of methods on the basis of their anticipated economic, ecological and sociological consequences" (Allen and Bath 1980). Because of the complexity and large number of significant interactions among pests, crops, agricultural animals, and the environment, decision support systems were seen as important aspects of IPM (Haynes et al. 1980). These ranged from simple information tables to large simulation models incorporating elementary aspects of artificial intelligence (Bird et al. 1989). IPM has been a largely successful program credited with reducing insecticide use where it is practiced. Nevertheless, its success has been less than projected because the evolution of IPM did not adequately consider agronomic techniques and plant genetics nor adequately integrate ecological concepts.

Bird (1989) has suggested that the sustainable agriculture programs presently being initiated could avoid some of the mistakes made in the development of IPM by the following means:

(1) Avoid adversarial relationships among existing institutions. In some cases IPM was erroneously sold as a replacement for pesticides. Industry must be a part of a successful sustainable agriculture program.
(2) Maintain a good relationship with the original innovators. Many organic growers, environmental agencies, and people presently practicing low-chemical-input agriculture have a great deal to offer to both ecologists and agronomists.
(3) Avoid overselling a specific management practice or attempting to implement it before it is ready for adoption.
(4) Encourage interdisciplinary programs—with the mix to include ecologists, agronomists, entomologists, economists, and other social scientists—that recognize the need for basic and applied research and innovative extension services.
(5) Supply the needed research and extension resources and long-term administrative support.

We offer a sixth suggestion: alter federal policy in areas such as commodity support, set-aside acreage, and conservation programs.

Microbial ecology presents another example of a field that spans both agronomy and ecology. Major contributions of microbial ecology to agriculture over their long association include improvements in crop nutrient use efficiency, soil organic matter management, and rumen microbiology. The applications and theories of modern microbial ecology are not those of classical ecology (Chech 1987-1988), though the large numbers of organisms available and the ease of laboratory manipulation should make this an excellent field for testing ecological theory. Important practical issues await ecological input. The thrust of microbial techniques in genetic engineering, for example, and the need to understand population effects before genetically altered genomes are released to the environment should be a further stimulus to a better integration for both ecologists and agronomists.

The opportunity for the ecologist in modern agriculture, then, is to provide concepts and principles that can be used as tools to design resource-efficient agricultural systems. The development of these principles will depend on basic research aimed at understanding organism-level interactions in the agronomic environment. Agronomists have for too long ignored ecology and the benefits to be derived from integrated research approaches. Ecologists have for too long considered agronomic systems inherently uninteresting. It's time to close the gap.

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LITERATURE CITED

Allen, C. E., and J. E. Bath. 1986. The conceptual and institutional aspects of integrated pest management. BioScience **30**:658–664.

Arthur, J. C. 1895. Development of vegetable physiology. Science **44**:163–184.

Bird, G. W. 1989. Integrated Pest Management: its role in the evolution of sustainable agriculture. Michigan State University Integrated Pest Management Technical Report **48**.

Bird, G. W., T. Edens, F. Drummond, and E. Groden. 1989. Design of insect and plant pathogen management systems for sustainable agriculture. *In* C. Francis, editor. Sustainable Agriculture. John Wiley & Sons, New York, New York, USA. *In press.*

Board on Agriculture. 1987. Agricultural biotechnology: strategies for national competitiveness. National Academy Press, Washington, D.C., USA.

Chech, W. 1987-1988. The reemergence of microbial ecology. NSF Mosaic **18**:24–35.

Coleman, D. C., and P. F. Hendrix. 1988. Agroecosystem processes. Pages 149–170 *in* L. R. Pomeroy and J. J. Alberts, editors. Concepts of ecosystem ecology. Springer-Verlag, New York, New York, USA.

Coupland, R. T. 1977. Grassland ecosystems of the world. Cambridge University Press, Cambridge, England.

Harwood, R. R. 1989. History of sustainable agriculture—U.S. and international perspectives. In M. Schopf, editor. Sustainable agriculture systems. Soil and Water Conservation Society, Ankeny, Iowa, USA.

Haynes, D. L., R. L. Tummala, and T. L. Ellis. 1980. Ecosystem management for pest control. BioScience **30**:690–696.

Jordan, C. 1985. Nutrient cycles in tropical forest ecosystems. John Wiley & Sons, Chichester, England.

McIntosh, R. P. 1985. The background of ecology: concept and theory. Cambridge University Press, Cambridge, England.

Paul, E. A. 1988. Towards the year 2000: directions for future nitrogen research. Pages 417–425 *in* J. R. Wilson, editor. Advances in nitrogen cycling in agricultural ecosystems. Commonwealth Agricultural Bureaux, Wallinford, United Kingdom.

Russell, E. J. 1966. A history of agricultural sciences in Great Britain. George Allen and Unwin, London, England.

Tobey, R. 1981. Saving the prairies: the life cycle of the founding school of American plant ecology, 1895–1955. University of California Press, Berkeley, California, USA.

Waring, R. H., and W. H. Schlesinger. 1985. Forest ecosystems: concepts and management. Academic Press, New York, New York, USA.

Woodmansee, R. G. 1984. Comparative nutrient cycles of natural and agricultural ecosystems: a step toward principles. Pages 145–156 *in* R. Lowrence, B. Stinne, and G. J. House, editors. Agricultural ecosystems: unifying concepts. John Wiley & Sons, New York, New York, USA.

For reprints of this Special Feature, see footnote 1, page 1590.

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A PERSPECTIVE ON AGROECOSYSTEM SCIENCE

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OVERVIEW

Agroecosystems have perhaps the greatest impact on our lives of any ecosystem type because they provide us with food and fiber and have large impacts upon the quality of the environment. The emphasis of agricultural production is shifting from maximization to regeneration and optimization while maintaining sustainability and minimizing environmental damage. We describe a research approach that integrates information from process and field studies through the use of simulation modeling and geographic information systems to allow us to make long-term and large-scale predictions about the future of agriculture in the United States. There are numerous interactions and feedbacks that will vary as climate and management changes, which makes prediction difficult without such models. Several agroecosystem projects have been initiated in the past 10 yr that, along with continuing systems management efforts by agricultural scientists, are providing the basis for a more whole-system approach to agricultural research. Goals of ecologists and agricultural scientists are converging within agroecosystem science. This integration will help provide insight for solution of the production and environmental problems we are currently facing.

AGROECOSYSTEMS

Agroecosystems are the most intensively managed of all ecosystems, located on the most productive land and covering 30% of the earth's land area (Coleman and Hendrix 1988). Farmers have custody of more environment than does any other group (Paarlberg 1980). Because of periodic and chronic disturbances inherent in agricultural management, agroecosystems are some of the fastest changing landscapes of any ecosystem type. As a result, they have contributed significantly to the degradation of our environment while at the same time providing us with a high standard of living because of relatively low food and fiber costs. Paarlberg (1980) correctly predicted that "Those that consider ecological concern a fad will be proved wrong."

We are currently at a crucial juncture with regard to agriculture in the United States. We have relied on our vast soil natural resource, with its huge store of nutrients in the form of soil organic matter, for high levels of crop production. After 100–200 yr of cultivation