Rethinking the Vision for Environmental Research in US Agriculture

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Environmental research in agriculture is today largely reactive, focused on problems at small scales and conducted within narrow disciplinary boundaries. This approach has worked to abate a number of environmental problems created by agriculture, but it has not provided effective solutions for many of the most recalcitrant ones. Furthermore, the approach fails to position agriculture to deliver new environmental benefits that the public and policymakers increasingly demand. A new vision is needed for environmental research in agriculture—one that is anticipatory; promotes long-term, systems-level research at multiple scales; better incorporates important interactions between the biophysical and social sciences; and provides for the proper evaluation of deployed solutions. Achieving this vision will require major changes in funding strategies, in institutional reward structures, and in policies that presently inhibit collaborations across disciplinary and institutional boundaries. It is, nevertheless, time to act.

Keywords: agriculture, environmental policy, research strategies, social science, systems approach

The astounding success of American agriculture is inarguable, but with success have come unintended environmental problems. Policymakers first addressed such problems with the creation of the US Department of Agriculture's Soil Erosion Service in the 1930s, and over the ensuing 75 years, growing concerns about the environmental costs of agriculture, often embedded in conservation policy, have had a major impact on agricultural research priorities.

Today, more than a third of the nation's public agricultural research portfolio addresses environmental issues related to agricultural production (NRC 2003), ranging from nutrient contamination of ground and surface waters to the harmful effects of invasive species on US farms, rangelands, and water resources. There is ample opportunity for environmental effect: About 50 percent of the conterminous United States is used for growing crops or grazing (USDA 2000), and the economic costs of environmental problems created by agriculture are high and mostly external to producer decisions. For water quality alone, costs are likely to be in the tens of billions of dollars (Ribaudo 2003). But is today's portfolio of environmental research in agriculture on the right track? Are we on a trajectory that will solve deeply entrenched problems and promote the discovery and realization of new benefits? We think not, and we believe that it is time to redefine the overarching vision of environmental research in agriculture.

Historically, and still today, environmental research in agriculture has almost always been reactive and directed toward finding solutions to discrete problems at relatively small

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Evidence now shows that solutions for many environmental problems in agriculture, such as compromised water quality in agricultural landscapes, must incorporate the interactions between the biophysical and social sciences. Photograph: S. R. Deming.

(mostly farm- or field-based) scales. Although follow-up evaluations of whether or how research has ameliorated problems have been rare (NRC 2003), for a number of challenges this approach has appeared to work well: Conservation tillage, for example, promotes soil and energy conservation, riparian vegetation traps phosphorus runoff, crop rotation reduces pesticide use, and wetlands capture nitrates.

Nevertheless, limitations to traditional approaches to environmental research in agriculture are becoming progressively more apparent as environmental science advances toward a more systems-based understanding of landscapes and regions, develops better methods to measure performance within systems, and incorporates economic and social, as well as biophysical, approaches to understanding ecosystems at multiple scales.

Moreover, and perhaps most compelling, solutions to many environmental challenges in agriculture remain distressingly distant. Numerous advances in agriculture continue to cause environmental problems downstream or downwind, and developed solutions have been only slowly or incompletely adopted. Examples abound—food-chain pesticides; silted rivers, lakes, and reservoirs; degraded pastureland; nitrate-enriched groundwater. Researchers have developed remedies for these and many other problems, yet their solutions have often not been adopted for lack of incentives or other socioeconomic reasons, or solutions have turned out to be inadequate because they fail to fully consider the complex environmental, economic, social, and political landscape in which they are deployed. And in all too many cases researchers do not know how well a specific solution has worked because performance monitoring or follow-up assessments are not conducted—the assumption is that simply adopting certain practices will change environmental outcomes.

A further shortcoming of today's vision for environmental research in agriculture is that it only weakly addresses the potential for agriculture to produce positive benefits for the environment. More and more the public is demanding clean water, biodiversity protection, mitigation of global climate change, energy conservation, and rural amenities such as open space and recreational opportunities. Agriculture has a potentially valuable role to play in the provision of these and other benefits, which need to be properly taken into account when making policy decisions.

What is needed to refocus and stimulate environmental progress in agriculture? Nothing less than a new research vision: a vision that anticipates problems stemming from new agricultural technologies and offers integrated strategies for their solution; that facilitates systems-based approaches to understanding rural landscapes and watersheds and provides improved ways to measure environmental performance within them; and that gives appropriate incentives for agriculture to go beyond food and fiber production to deliver environmental benefits to society. This vision differs fundamentally from the one now in place.

Implementing this vision will require shifts in policy and funding to support a proactive, anticipatory research portfolio that addresses environmental challenges and opportunities at multiple scales and over short- to long-term time periods. It will also require more effective integration of biophysical research with research in economics and other social sciences, so that relevant interactions between agriculture, society, and the environment can be incorporated into solutions.

To realize new environmental benefits from agriculture, such as carbon sequestration in no-till row crops, requires a systems approach that considers ecological processes and trade-offs at multiple scales. Photograph: S. R. Deming.

Proactive, anticipatory research is essential because experience has shown that, once started, many environmental problems can be slow or difficult to reverse; sometimes they become intractable. Well-recognized examples include the use of ozone-depleting methyl bromide as a soil fumigant; high rates and inappropriate timing of fertilizer and pesticide use; release of biocontrol agents without prior, adequate risk assessment; and water and air pollution attributable to the accumulation and disposal of animal waste. Replacing established practices such as these will require research to identify effective alternatives and appropriate incentives for their widespread adoption. Anticipating and preventing future problems requires greater foresight, which must be informed by exploratory research.

How can research become more anticipatory? In part, agricultural innovations will have to be better evaluated for their environmental, social, and economic impacts before they are deployed. But perhaps more important, sufficient evaluation requires a fundamental understanding of the system in which the technology is to be used, including an understanding of the ecological interactions that the technology will affect. Furthermore, scientists need to be able to measure the environmental performance of these innovations after deployment. This requires basic environmental research to understand the system at multiple scales and locations and to develop environmental performance indicators appropriate for each.

Over the past 30 years, a more sophisticated understanding of the spatial and temporal dynamics of ecosystem patterns and processes has led to the emergence of whole new subdisciplines, including agricultural ecology, landscape ecology, ecosystem management, and earth systems science. What the new ecological science demonstrates is that downstream impacts are more complex and far-reaching than previously thought. Impacts can be additive and multiplicative, and they can even change when viewed over increasingly large spatial scales (e.g., local or regional levels versus an individual farm), over higher ecological levels (e.g., ecosystem or watershed versus species), or over extended periods of time (e.g., decades versus months or years).

For agriculture, this means that approaches intended to resolve environmental problems will be insufficient if sources and impacts are considered only over the near term and only at the level of the individual field or farm. Finding effective solutions to agriculture's environmental challenges requires multiscale, often long-term approaches.

The acrimonious debate over the link between hypoxia in the Gulf of Mexico and fertilizer use on farms in the Mississippi River basin well illustrates the need for mainstreaming approaches that integrate multiple-scale analyses. Nitrogen applied to farm fields is intended to provide plants in those fields with an essential nutrient that enhances photosynthesis and protein assimilation. Yet less than half of the nitrogen applied ends up in harvested grain; the remainder is eventually lost, either as nitrogen gas or as nitrate transported to groundwater—and nitrate can become a drinking water contaminant and eventually find its way to streams, rivers, and the Gulf of Mexico, where it causes eutrophication (NRC 2000, Rabalais et al. 2002).

Disciplinary knowledge of rhizosphere dynamics and hydrologic flow paths is important for understanding potential fates of applied nitrogen in a watershed, but a sufficient understanding of nitrate leaching also requires integration of the full suite of processes that interact to deposit and transport nitrate in the environment. Often quantitative system models can help identify the most important control points in the system, which can then be verified experimentally. By definition, this understanding requires knowledge from a wide variety of disciplines—soil and aquatic microbiology and chemistry, soil physics, agronomy, plant physiology, hydrology, and geochemistry, among others. Placing this disciplinary information into an integrated ecological context is the hallmark of a sound systems approach. But this approach requires better integration of ecological science into agricultural research programs, a change that has been slow even at land grant universities.

Another way in which research can be anticipatory is by tracking the emerging needs and values of society. The past 50 years have seen enormous and progressive shifts in national and state policies designed to sustain environmental values, embodied in laws related to clean water, clean air, endangered species, and wildlife. At the national level, policymakers have sought ways to simultaneously promote public environmental goals as well as goals related to sustaining economic vitality and the character of rural America. Examples include land retirement programs such as the Conservation Reserve and Wetlands Reserve Programs, as well as incentive programs such as the Environmental Quality and Wildlife Habitat Incentives Programs (Claasen and Horan 2000, NRCS 2003). These and other programs were recently reauthorized in the 2002 farm bill; over 14 million hectares are currently enrolled in the Conservation Reserve Program.

Ultimately, effective approaches will depend on an integration of the biophysical and socioeconomic sciences, and that integration should take place from the outset.

Interest is growing for expanding incentives to address a broader set of environmental issues, such as global warming (e.g., McCarl and Schneider 2000), which could lead to valuable environmental outcomes—stored soil carbon, for example, or reduced greenhouse gas emissions. Agricultural research has an important but as yet only partly realized role to play in the design, implementation, and evaluation of policy incentives, particularly in integrating systems-level ecological knowledge into management practices, in measuring the performance of environmental improvement activities, and in defining the economic and social incentives needed for the adoption of such practices. Recent advances in spatial analysis and geographic information systems provide a framework for integrating ecological systems knowledge into the economic and social dimensions of incentive and policy design.

Carbon storage and the many other ecological services (*sensu* Daily 1997) provided by and within agricultural landscapes are poorly recognized, largely undervalued or unvalued, and unresearched and unmeasured as services. Food production is by far the most valuable of these, but well-managed landscapes also are important: They can provide clean water, habitat for biocontrol agents and pollinators, corridors and refugia for wildlife, flood and erosion control, and aesthetic and other less tangible contributions to human welfare. Enumerating such services and understanding how they can be quantified and appropriately valued (e.g., Costanza et al. 1997, Pimentel et al. 1997) is an emerging research need with important implications for agricultural and land-use policy. To maximize the net benefits of intensively managed landscapes requires measuring and valuing potential benefits and costs and then creating the necessary incentives to achieve socially optimal levels of net benefits. At present, the research needed to do this is in its early stages, particularly research that addresses questions at the interface of the biophysical and social sciences.

A key conceptual shift in the scientific foundation for agriculture has been the recognition that to effectively address environmental problems, new practices must be based on an understanding and integration of the economic and social dimensions of these problems. Research that is strictly biophysical will yield biophysical solutions; remedies to more complex environmental challenges, however, require an equally rigorous understanding of social and economic issues such as ecological valuation, incentive programs, and cultural impediments to change. In many cases, the socioeconomic portion of a challenge is as complex and little known as the biophysical aspect, and thus requires fundamental social science research that will very likely involve the active participation of growers, consumers, and other agricultural and environmental stakeholders at various research stages. The same integrated systems approach necessary for understanding the biophysical dynamics of nitrate transformation and transport, for example, is needed to understand the political, economic, and sociological dimensions of the problem. What are the potential production costs of different management strategies, the potential environmental and social benefits gained from these strategies, and the most efficient approaches for improving the flow of environmental goods and services to society? Ultimately, effective approaches will depend on an integration of the biophysical and socioeconomic sciences, and that integration should take place from the outset.

By the early 1900s, Alfred J. Lotka and other biophysical scientists recognized the need for a systems view of agriculture that explicitly includes humans (Lotka 1925), a view that was amplified by Eugene P. Odum in the 1950s and 1960s (Odum 1984) and later by social scientists (Machlis et al. 1997). It is time now for effective research that shows how these and more recent advances can be furthered in a manner that solves and anticipates environmental problems.

A multiscale, integrated approach to research and performance evaluation as described in this article will yield greater scientific insight and more robust results. It will also produce research that is more proactive and anticipatory by providing a deeper understanding of agricultural systems. This understanding will enable scientists and analysts to more rapidly determine which new technologies or innovations or policies will cause beneficial or adverse environmental impacts, to measure and value the magnitude of these impacts, and to consequently provide a richer set of options for preventing environmental problems and for generating environmental benefits.

Long-term, basic research is essential to this vision. Research that seeks to gain a comprehensive understanding of specific types of agricultural ecosystems or landscapes cannot help but provide information needed for addressing unforeseen practical problems. The National Science Foundation's Long Term Ecological Research program illustrates this well. The program's focus on multiscale, long-term basic research in specific ecosystems (Kaiser 2001, Hobbie et al. 2003) has led to unforeseen success in contributing to a practical understanding of environmental problems, including some of those faced by agriculture (NRC 2003). At the Konza Prairie site in Kansas, for example, 10-year experiments showed that fire and grazing together are necessary for maintaining plant species diversity in tall-grass prairie; neither, by itself, is sufficient for sustaining grassland health (Collins et al. 1998). At the Cedar Creek site in Minnesota, a 7-year experiment showed that more diverse grassland plots outproduced the best grassland monocultures (Tilman et al. 2001), demonstrating a positive relationship between biodiversity and grassland productivity. In Michigan, a 10-year experiment at the Kellogg Biological Station showed the effects of different cropping systems on greenhouse gas production (Robertson et al. 2000) and suggested multiple ways that row-crop agriculture can contribute to greenhouse gas mitigation. Long-term agronomic research sites are today rare and poorly funded, but in the past they have made important contributions to agronomy and to our understanding of agriculture–environment interactions (Rasmussen et al. 1998).

Redefining the vision for environmental research in agriculture will be neither easy nor straightforward, nor is it likely to happen quickly. Funding, institutional, cultural, and policy barriers currently conspire to keep most environmental research in agriculture at a disciplinary, reactive, and local level. Funding strategies, institutional reward structures, and policies that keep different agencies and scientists from collaborating across institutional and disciplinary boundaries must be changed to realize positive results.

Agricultural intensification has brought remarkable increases in production efficiency over the past 50 years, but it has also generally enlarged agriculture's environmental footprint (Matson et al. 1997). Growth in the US population—3 million per year, at present—together with a growing global demand for food will almost certainly continue the pressure for even further intensification. Turning the national agricultural research enterprise to face forward—to help prevent future environmental problems, to create tomorrow's agricultural benefits, and to be more effective by integrating important advances and approaches from the ecological and social sciences—is a crucial national and global research need.

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References cited

Claasen R, Horan R. 2000. Environmental payments to farmers: Issues of program design. Agricultural Outlook (June–July): 15–18.

Collins SL, Knapp AK, Briggs JM, Blair JM, Steinauer EM. 1998. Modulation of diversity by grazing and mowing in native tallgrass prairie. Science 280: 745–747.

Costanza R, Cumberland J, Daly H, Goodland R, Norgaard R. 1997. An Introduction to Ecological Economics. Boca Raton (FL): St. Lucie Press.

Daily GC, ed. 1997. Nature's Services: Social Dependence on Natural Ecosystems. Washington (DC): Island Press.

Hobbie JE, Carpenter SR, Grimm NB, Gosz JR, Seastedt TR. 2003. The US long term ecological research program. BioScience 53: 21–32.

Kaiser J. 2001. An experiment for all seasons. Science 293: 624–627.

Lotka AJ. 1925. Elements of Physical Biology. Baltimore: Williams and Wilkins.

Machlis GE, Force JE, Birch WR. 1997. The human ecosystem as an organizing concept in ecosystem management. Society and Natural Resources 10: 347–367.

Matson PA, Parton WJ, Power AG, Swift MJ. 1997. Agricultural intensification and ecosystem properties. Science 277: 504–509.

McCarl BA, Schneider UA. 2000. U.S. agriculture's role in a greenhouse gas emission mitigation world: An economic perspective. Review of Agricultural Economics 22: 134–159.

[NRC] National Research Council. 2000. Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution. Washington (DC): National Academy Press.

———. 2003. Frontiers in Agricultural Research. Washington (DC): National Academy Press.

[NRCS] US Department of Agriculture, Natural Resources Conservation Service. 2003. Conservation programs. (11 November 2003; *www.nrcs.usda.gov/programs*)

Odum EP. 1984. Properties of agroecosystems. Pages 5–12 in Lowrance R, Stinner BR, House GJ, eds. Agricultural Ecosystems: Unifying Concepts. New York: John Wiley.

Pimentel D, Wilson C, McCullum C, Huang R, Dwen P, Flack J, Tran Q, Saltman T, Cliff B. 1997. Economic and environmental benefits of biodiversity. BioScience 47: 747–757.

Rabalais NN, Turner RE, Scavia D. 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River. BioScience 52: 129–142.

Rasmussen PE, Goulding KWT, Brown JR, Grace PR, Janzen HH, Korschens M. 1998. Long-term agroecosystem experiments: Assessing agricultural sustainability and global change. Science 282: 893–896.

Ribaudo M. 2003. Water quality impacts of agriculture. Chapter 2.3 in Heimlich R, ed. Agricultural Resource and Environmental Indicators, 2003. Washington (DC): US Department of Agriculture, Economic Research Service. Agriculture Handbook no. AH722.

Robertson GP, Paul EA, Harwood RR. 2000. Greenhouse gases in intensive agriculture: Contributions of individual gases to the radiative forcing of the atmosphere. Science 289: 1922–1925.

Tilman D, Reich PB, Knops J, Wedin DA, Mielke T, Lehman C. 2001. Diversity and productivity in a long-term grassland experiment. Science 294: 843–845.

[USDA] US Department of Agriculture, National Agricultural Statistics Service. 2000. Agricultural Statistics. Washington (DC): US Government Printing Office.