Long-term Agricultural Research: A Research, Education, and Extension Imperative

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For agriculture to meet goals that include profitability, environmental integrity, and the production of ecosystem services beyond food, fuel, and fiber requires a comprehensive, systems-level research approach that is long-term and geographically scalable. This approach is largely lacking from the US agricultural research portfolio. It is time to add it. A long-term agricultural research program would substantially improve the delivery of agricultural products and other ecosystem services to a society that calls for agriculture to be safe, environmentally sound, and socially responsible.

Keywords: agriculture, long-term research, sustainability, LTER, agricultural extension and education

To meet the growing world demand for food, fuel, and fiber, and at the same time sustain the environment's ability to provide economic, social, and environmental services to society, agricultural innovations are essential. Such innovations must derive from a comprehensive understanding of the long-term functioning of agricultural systems and their resiliency. Soil, water, and energy limitations pose long-standing and persistent problems for agricultural productivity, profitability, and social acceptability; for global agricultural competitiveness; and for environmental quality and security. Long-lasting solutions to these problems require a comprehensive, systems-level understanding of the linkages among basic biophysical processes and human activity, an understanding that can serve as a solid foundation for informed management and policy decisions.

This understanding can be achieved best—or perhaps only—through long-term research that integrates multiple processes, both biophysical and socioeconomic, across multiple spatial and temporal scales. Practical solutions depend on long-term research because robust solutions to many of the problems facing agriculture require evaluation in the context of climatic, social, ecological, and other factors that change on decadal (or longer) time scales. Long-term research also allows the impacts of management to be distinguished from impacts caused by long-term environmental trends such as land use and regional climate change.

Frontiers in Agricultural Research (NRC 2003), the most recent comprehensive review of the US agricultural research portfolio, identified five major challenges for US agricultural

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research in the coming decades, all of which have crucial long-term components:

1. Globalization of the food economy, which puts a priority on understanding how to optimize US advantages in agricultural productivity and resource use.

2. Emerging pathogens and other food-supply-chain hazards, which make it vital to improve our understanding and management of plant and animal diseases.

3. Enhancing human health through nutrition, which requires knowledge of the changing ways in which humans make food choices.

4. Improving environmental stewardship, which requires knowledge about delivering the environmental benefits of agriculture while reducing pollution and advancing environmental integrity.

5. Improving the quality of life in rural communities, which requires understanding the environmental and social effects of changes in agricultural market structures and land-use change.

The *Frontiers* report thus joins others (NRC 2000, 2001, 2005, Robertson et al. 2004, Boody et al. 2005) in arguing for long-term, multidisciplinary research in pursuit of answers that take longer than the typical two- to three-year grant cycle to formulate. Long-term research allows questions to be addressed against a wide range of environmental conditions; allows the inclusion of episodic events such as pest and pathogen outbreaks, the effects of which can reverberate for years; and allows the detection of important but slow-acting phenomena such as changes in soil carbon, climate, and land use, as well as the most accurate calibration and validation of ecosystem models used to forecast such changes (Hobbie et al. 2003).

Long-term, site-based research also allows diverse, nontraditional research collaborations to form more readily as investigators in different disciplines incorporate findings from others who are working in the same system. This is key for fostering research at the interface of the biophysical and social sciences, for example, and for collaborations among researchers, educators, and outreach specialists. Especially for research in working landscapes, such collaborations are essential. Agriculture is a major industry that dominates US land use, and nonconventional collaborations are needed to address the complexity of underlying relationships that affect its long-term sustainability. Many of these partnerships should involve communities that do not now interact much—production agronomists and conservationists, for example, or economists and ecologists.

The creation of an explicitly long-term research program for agriculture is now long overdue. General goals for such a program should include (a) improved understanding of agriculture from a long-term systems perspective, such that multiple management aims can be balanced against known trade-offs; (b) greater integration of the biophysical and social sciences to provide the information and insights needed to implement solutions with acceptable economic and social costs; (c) improved knowledge of geographic scalability, to ensure that solutions developed at one scale are also effective at larger scales, and to allow processes that operate at larger scales to contribute to solutions at the field and farm scale; and (d) strengthened outreach and education ties to research in agricultural ecosystems and landscapes, to improve both the relevance of research to stakeholder needs and the public understanding of these systems with their social, environmental, and management trade-offs.

Creation of an inaugural LTAR program

We call for the creation of a Long-Term Agricultural Research (LTAR) program at the federal level. Key to the early success of the program will be integration of research, education, and extension, and the involvement of growers, conservationists, and other stakeholders. Some of the most important research questions will be those that are assessed at the local scale but are of regional significance.

Furthermore, to ensure relevance to contemporary issues, constituent-based participatory selection of basic and applied science questions will be imperative. Implementation of LTAR research findings will be enhanced when stakeholders are partners from the outset. Stakeholders include farmers, landowners, resource managers, governmental agencies, policymakers, nongovernmental organizations (NGOs), and community groups such as watershed councils, development organizations, and commodity and land stewardship groups. Opportunities for working with the conservation community, which is already engaged in protecting and managing whole landscapes in which agricultural systems are embedded, will be especially valuable.

Innovative ways to engage stakeholders in science questions should include access to policy creation, joint implementation of science findings through incentives, and creation of social capital by community participation and ownership of the work. Appropriate science questions for LTAR must be systems based, interdisciplinary, and integrated from the outset for a clearer path to viable solutions. The LTAR group must thus consist of multidimensional individuals. Outreach and engagement should utilize existing regional networks. Innovative models of engagement, based in part on the ability to commit to long-term cooperative relationships, will help advance knowledge sharing.

An effective LTAR program must include multiple sites in order to capture the breadth and diversity of US agricultural production systems. Geographic, commodity, and socioeconomic diversity should be represented. For instance, in addition to covering major crops, sites should also include systems and regions dominated by large corporate holdings as well as regions with small farms, more marginal land, and mixed landscapes; the latter could include inactive farmland

and conservation easements. And full value will be realized only when multiple sites function as a network. A network allows more robust tests of common hypotheses and comparative analyses in and across different production systems, leading to a comprehensive understanding of agricultural issues.

The critical mass needed to establish an inaugural LTAR program requires a capacity for field-scale experimentation at the site level, and stakeholder involvement that exploits existing data sets and regional infrastructure. Core expenditures should be used primarily for research infrastructure and coordination, agronomic management, information management, socioeconomic assessments, stakeholder engagement, and long-term sample collection and analysis. Short-term research, which may well constitute most of the research productivity for a site, should be funded primarily through ancillary partnerships and outside funding.

A reasonable minimum useful duration for an LTAR site is 30 years, with periodic assessments and continuation based on acceptable progress. Considerations of site security and the development trajectory of the surrounding land base must thus be part of the site selection criteria. The National Science Foundation (NSF)'s Long Term Ecological Research (LTER) Network (Hobbie et al. 2003) will contribute to the success of LTAR, and appropriate elements of LTER should be incorporated into the LTAR program. For example, LTER research is largely bottom-up and location specific: at each site a group of interdisciplinary PIs (principal investigators) defines the long-term questions to be addressed by site science. Once in place, major research questions change slowly if at all, and long-term experiments are added as new questions emerge from ongoing results. Short-term studies are embedded within the long-term matrix, and some are repeated at multiyear intervals. A core set of well-defined measurements form the long-term data record and are part of the basis for making intersite comparisons. And encouraging graduate students' involvement and managing each site as a national research facility ensure participation by a wide variety of environmental and social scientists.

An LTAR program with multiple sites should be managed similarly and perhaps in partnership with LTER, but with explicit extension and outreach goals intended to involve stakeholders in LTAR science. The following hallmarks of interdisciplinary science could be required for LTAR sites:

- The focus of LTAR research is to address basic questions of potential significance to stakeholders, and from the outset stakeholders should have meaningful involvement in the process—from research design to outreach education strategies. Stakeholders should include agricultural producers, rural residents, community leaders, government agencies, the private sector, and NGOs at the local, state, regional, and national levels.

- The right mix of disciplines should be present at the start. An expansive view of the biophysical and socioeconomic disciplines is required, and systems modeling, geographic information systems, and information management should be well-integrated—they are crucial for many aspects of the enterprise, including scaling from experimental sites to regional and higher levels.

- Although long-term projects will evolve to include an expanding list of disciplines, every effort should be made to cast a wide disciplinary net at the outset, involving as many disciplines as practical in research design. The questions addressed, however, should be well focused: there will not be a place at the table for everyone.

- Research and extension should be structured around multiple subteams with interlocking, shared leadership. In addition to furthering interdisciplinarity, this helps assure leadership continuity.

- Practical matters should be resolved in advance—budget priorities, anticipated research and education/extension products, expectations for information management, commitment of people and resources, and deadlines.

- Graduate and undergraduate education and the crucial role that graduate students can play in interdisciplinary communication should be recognized and encouraged.

- Inclusion of postdoctoral students and visiting scientists provide both the opportunities for continued training and enhanced research, education, and extension of information on a global basis.

The LTAR site as a network node

The network context for LTAR is crucial—the network provides the essential resource for synergy and scaling over temporal and spatial dimensions. Two existing networks are particularly relevant for LTAR: the well-developed network of existing LTER sites, and the latent network of ongoing, long-term projects at agricultural research stations around the country. The LTAR program can play a catalytic role in bringing together this latent network. One or more LTAR sites should be part of these existing networks, and will add value to those networks by introducing unique dimensions. Additionally, the LTAR network should be closely aligned with other environmental observatories, including the nascent National Ecological Observatory Network and the emerging Water and Environmental Systems Network. All of these NSF-sponsored observatories encompass regions dominated by agriculture.

Common measurements at multiple sites are a key element for networking—they provide a foundation for scaling to regional and national levels, and are the basis for cross-site syntheses wherein ecological theory is developed and tested across gradients of climate, management intensity, biodiversity, nutrient cycling, or any of a wide variety of organizing criteria. In practice, commonality will be provided for a subset of specific measurements at a subset of sites, selected on the basis of LTAR objectives. Specific measurements and data can be obtained at current LTER sites and agricultural research stations. Nevertheless, some broad measurements such as net primary production, plant, animal, and microbial community structure, and other core measurements cut across all types of ecosystems—from terrestrial to marine and from intensively managed to unmanaged—and agricultural sites need to be full partners, especially in cross-disciplinary syntheses.

LTAR sites should conform to information management standards common to sites in the LTER network to facilitate cross-site comparisons and scale-up efforts. These standards are designed to support site and network science by (a) facilitating access to data and metadata by the scientific community and the public, and (b) ensuring the integrity, security, and usability of those data and metadata for future generations. Information management should be fully integrated with GIS from the outset. With rare exceptions, data should be made available online after a prepublication period of two to three years.

What is the appropriate scale for an LTAR site?

Historically, most agricultural and ecological experimentation has been conducted using small plots at specific sites, with little effort to examine implications of results at larger scales. However, to understand and predict the effects of factors such as climate, land use, human population, input management, water availability, and biodiversity change on the resilience of agricultural systems, it is essential to examine the effects and interactions at multiple spatial and temporal scales. An LTAR site must thus encompass the scales of important heterogeneities in farm size, soil type, land and crop cover types, and socioeconomic relationships. Larger scales are particularly important for integrated socioeconomic questions. Regional agricultural viability, for example, requires economic and institutional structures beyond the farm gate, and these resources may require that a certain number of farms exist in the region. Thus farm viability demonstrates a scale-dependent threshold effect that can have major regional socioeconomic outcomes that feed back to field- and landscape-scale biophysical processes.

Exactly how scale is addressed, including the determination of appropriate scales at a site, will depend on the system and region examined. However, certain generalizations are important. An LTAR site should be viewed from the outset as a region, and not as a single discrete site. Research might well be performed at a variety of locations: at secure, university-owned research properties, on working farms, on land leased to the LTAR site, or in communities within the region. Well-established approaches for extrapolating research results to large scales include simulation modeling and remote sensing with point or site-based measurements serving as calibration and ground-truth sites.

A call for action

Long-term agricultural research could help address a number of pressing national agricultural research priorities, particularly those questions requiring a long time frame at field and larger spatial scales. Typically these are questions that require a systems approach—virtually all of those related to the delivery of ecosystem services in agriculture, for example—and the involvement of multidisciplinary teams with strong education and extension contributors.

We identify below some immediate goals for an inaugural LTAR program related to six important topics: agricultural resilience, ecosystem services, community vitality, biodiversity, climate change, and the social and behavioral constraints to change. Each of these should be addressed at each site within an LTAR network, and include points we described earlier.

Goal 1: Agricultural resilience. Develop innovative management systems that increase the resilience of agricultural ecosystems in the face of rapid environmental and socioeconomic change. Current theory and limited empirical and case-study evidence suggest attributes of agricultural ecosystems that have shown resilience in the face of changing environmental and social conditions; these attributes include farm-scale, ecological, and market structure characteristics. Needed now is research that better identifies key attributes and their roles in protecting production from challenges that are biophysical (e.g., invasive species, infectious disease, regional climate change), economic (e.g., market shifts, industry consolidation, input prices), and social (e.g., farm demographics, public education).

LTAR research will help to provide general principles that can serve as guidelines for improving the resilience of food, fuel, and fiber production systems and thereby contribute to long-term US food and energy security. It will also promote the development of food, fuel, and fiber production systems that are able to adapt to change while maintaining environmentally sound production goals.

Goal 2: Ecosystem services. Quantify and value the ecosystem services and associated trade-offs associated with different agricultural systems. Several lines of LTAR research will contribute to a working understanding of ecosystem services: assessing the types of ecosystem services provided in different agricultural landscapes is a first step toward evaluating the trade-offs involved when managing for a particular set of services; the valuation of services is also necessary for defining trade-offs; and quantifying the value of various services to humans at both local and regional scales will require a multidisciplinary, socioeconomic approach. This research will eventually lead to a larger understanding of potential benefits and risks, allowing the identification of preferred cropping systems and helping to provide a more comprehensive means for developing conservation and other stewardship programs.

Goal 3: Community vitality. Assess the community and societal impacts and associated trade-offs of different agricultural systems and land use types within landscapes. LTAR research will contribute to our understanding of rural community vitality by addressing questions that preserve economic viability for all members of the value chain in agricultural systems. This includes the need to evaluate trade-offs that involve worker safety and health, ownership, energy production and use, environmental safety and security, and regional food security. Research might, for example, test the hypothesis that locally supported, small-scale, diverse, and sustainable enterprises improve the economic, ecological, and social capital of local communities. Ultimately this research could lead to an increase in the number of economically viable farms of different sizes and to an increase in the number of value-added processing enterprises and local input suppliers. Research could also lead to a greater number of local and regional markets in which producers and local processors capture a higher percentage of the food dollar, and help to identify optimal design and enrollment strategies for conservation programs.

In toto, we would also expect this research to contribute to the cultural sustainability of agricultural communities. Farms and ranches form a critical part of what is called the cultural landscape, areas that represent the combined work of nature and humans (UNESCO 2005). US land managers and communities must increasingly incorporate cultural history, character, and values into decisions that ultimately and deeply affect community vitality. Important aspects of cultural change can be as slow, subtle, and complex as some biophysical change, which suggests that long-term research approaches will be crucial for full understanding.

Goal 4: Biodiversity. Optimize biodiversity to improve agricultural ecosystem efficiencies, conserve and protect natural resources, and enhance on-farm profitability. To meet this goal, LTAR research must examine the relationship between biodiversity and agricultural resilience (see goal 1), and, in particular, the degree to which different kinds of diversity (e.g., rotational, plant, microbial, and insect diversity) affect ecosystem performance and profitability. Identifying the value of diversity to providing different kinds of ecosystem services, and their economic and social costs, will allow the development of agricultural systems in which biodiversity management is targeted toward specific goals such as pest protection and soil fertility, allowing low-cost biological management to enhance or offset some of today's farm operation costs.

Goal 5: Climate change. Develop agricultural systems that maximize energy conservation and reduce greenhouse gases, while investigating various forms of incentives to encourage on-farm adoption and mitigation. LTAR research is needed to identify and develop innovative ways in which agriculture can contribute to the stabilization of greenhouse gas concentrations in the atmosphere. For instance, with the rapidly emerging importance of biofuels as a means to mitigate atmospheric carbon dioxide loading and improve US energy security, research is needed now to assess the long-term social, economic, and environmental effects of what may become a large-scale restructuring of the US agricultural landscape. Research related to climate change mitigation will lead to improvements in soil quality and fertility as carbon stocks are restored, to greater efficiencies in the use of nitrogen fertilizer, and to better regional air and water quality as more carbon and nitrogen is retained on the farm. Achieving this goal will also enhance producers' ability to participate in developing carbon and greenhouse gas markets.

Goal 6: Social and behavioral constraints to change. Create a social framework that encourages and promotes the adoption of sustainable practices. LTAR research is needed to determine how structural constraints such as access to capital, agency assistance programs, and technical information affect local perceptions of the social and environmental costs and benefits of sustainable practices. There is also the need to identify behavioral factors that have a significant influence on farmer preferences and their willingness to implement sustainable practices and participate in conservation programs. Research will lead to greater public awareness of the link between food and health by drawing connections between agriculture, food quality, nutrition, obesity, and public health. This research will also lead to a greater proportion of US producers' adopting best-management practices, and thus to improved environmental health.

All of these goals have at their heart the development and promotion of agriculture that is economically competitive, environmentally sound, and of greater benefit to society than simply food, fuel, and fiber production. All share the crucial need for a comprehensive, systems-level research approach that is long-term and geographically scalable. All share the need for a long-term agricultural research effort. The time is right to add an explicit and comprehensive long-term agricultural research, education, and extension program to the US agricultural research portfolio.

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