

Long-Term Agricultural Research (LTAR):
A Research, Education, and Extension Imperative

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Innovations in agriculture are increasingly needed to secure a growing world demand for food and fiber, especially in light of the need to conserve and optimize the use of limited natural resources and to sustain the environment's ability to provide economic, social, and environmental services to society. Agricultural innovations in this context include invention, development, selection, and implementation. Increasingly these innovations must rely on a deeper understanding of the long-term functioning of agricultural systems and their resiliency. Long-lasting solutions to emerging problems related to soil, water, and energy limitations on agricultural productivity, profitability, and social acceptability, on global agricultural competitiveness, and on environmental quality require a comprehensive systems-level understanding of the linkages among basic biophysical processes and human activity, providing a solid foundation on which to base adoption, management, and policy decisions.

This understanding can be best — and perhaps only — achieved 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, and against which management impacts can be distinguished from impacts caused by long-term environmental trends such as land use and regional climate change.

The NRC's *Frontiers in Agricultural Research* report (NRC, 2003) identified five major frontiers in agricultural research for the coming decades, all of which have long-term components:

- globalization of the food economy, which puts a priority on understanding how to optimize comparative advantages in agricultural productivity and resource use;
- emerging pathogens and other food-supply chain hazards that makes improving our understanding and management of plant and animal diseases crucial;
- enhancing human health through nutrition, which requires knowledge of the changing ways by which humans make food choices;
- improving environmental stewardship, which requires knowledge about delivering environmental benefits of agriculture while reducing pollution and advancing environmental integrity; and
- 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) that have also noted the need for long-term research that engages multiple disciplines in pursuit of answers to questions that can only be addressed effectively over time periods longer than the typical 2-3 year grant cycle. Long-term research allows questions to be addressed against a wider range of environmental conditions; allows for the inclusion of episodic events such as pest and pathogen outbreaks, whose effects can reverberate for decades; and allows for the detection of important but slow-acting phenomena such as soil carbon, climate, and land use change and allows for the most

accurate calibration and validation of ecosystem models used to forecast changes in these slow-acting phenomena. Long-term, site-based research also allows diverse, non-traditional research collaborations to form more readily as investigators in different disciplines incorporate findings from others who are working in the same system; this may be especially important for fostering research at the interface of the biophysical and social sciences, for example, and for collaborations among researchers, educators, and outreach specialists.

General goals for a long-term agricultural research (LTAR) program include

1. improved understanding of agriculture from a long-term systems perspective, such that multiple management aims can be balanced against known trade-offs;
2. greater integration of the biophysical and social sciences to provide the information and insights needed to implement solutions at acceptable economic and social costs;
3. 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
4. strengthened outreach and education ties to research in agricultural ecosystems and landscapes, to improve both the relevance of research to stakeholder needs and public understanding of these systems with their social, environmental, and management trade-offs.

We nominate specific goals in the final section of this report.

Creation of an Inaugural LTAR Program

Integration of research, education, and extension, and including the involvement of practitioners, will be key to the early success of an LTAR program. 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 questions and problems, constituent-based participatory selection of basic and applied science questions will be imperative. Moreover, implementation of LTAR research findings will be enhanced by ensuring that stakeholders are partners from the outset. Stakeholders include landowners, resource managers, governmental agencies, policymakers, NGO's, and community groups such as watershed councils, development organizations, and land stewardship groups.

Innovative means to engage stakeholders in science questions 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; interdisciplinarity and stakeholder engagement provides a clearer path to more correct and viable solutions. The LTAR group must thus consist of multi-mission individuals. Outreach and engagement should utilize existing networks of regional centers. 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 U.S. agricultural production systems. And full value will only be achieved when multiple sites function as a network. A network allows more robust tests of common hypotheses in different production systems and also allows for comparative analyses across systems, leading to a substantially more comprehensive understanding of agricultural issues.

The critical mass needed to establish an inaugural LTAR program and site requires the capacity for field-scale experimentation 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 comprise most of the research productivity for a site, should be funded primarily via 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 NSF-funded Long Term Ecological Research (LTER) Network will be a significant advantage to the success of long-term agricultural research, and appropriate elements of LTER should be incorporated into the LTAR program. LTER research is largely bottom-up and location-specific: at each site a group of interdisciplinary PIs define 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 on-going results. Short-term studies are embedded within the long-term matrix, and some are repeated at multi-year intervals. A core set of well-defined measurements form the long-term data record and are part of the basis for making intersite comparisons. The encouragement of graduate student involvement and the site's management as a national research facility ensures participation by a wide variety of environmental and social scientists.

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

1. 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.
2. The right mix of disciplines should be present at the start. An expansive view of the biophysical and socioeconomic disciplines should be taken, and systems modeling, geographic information systems, and information management should be at the core — they are crucial for many aspects of the enterprise, including scaling-up from experimental sites to regional and higher levels.
3. While 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 as

practical in research design. The questions addressed, however, should be well-focused: there will not be a place at the table for everyone.

4. 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.
5. Research and extension should be structured around multiple sub-teams with interlocking, shared leadership. In addition to furthering interdisciplinarity, this helps assure leadership continuity.
6. Graduate and undergraduate education and the crucial role that graduate students can play in interdisciplinary communication should be recognized and encouraged.
7. 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 on-going long-term projects at agricultural research stations around the country. The LTAR program can play a catalytic role in bringing together this latent network. The inaugural LTAR site should be part of these existing networks and will add value to them by introducing unique dimensions.

Common measurements at multiple sites are a key element for networking — they provide a foundation for scaling to regional and national levels, and 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, it will be possible to provide commonality for only a subset of specific measurements at a subset of sites, selected with reference to LTAR objectives. The specific measurements and data that already exist can be obtained at the existing 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 undisturbed – and agricultural sites need to be full partners especially in cross-disciplinary syntheses.

As a network citizen the inaugural LTAR site should conform to information management standards common to LTER sites in order to facilitate cross site comparisons and scale-up efforts. These standards are designed to support site and network science by (1) facilitating access to data and metadata by the scientific community and the public, and (2) 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 following a pre-publication period of 2-3 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 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 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 socio-economic 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 a certain number of farms to exist. Thus farm viability demonstrates a scale-dependent threshold effect that can have major regional socioeconomic implications, and 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 that is selected. However, certain generalizations are important. First, the LTAR site should be viewed from the outset as a region rather than as a single discrete site or piece of real estate. Research might well be performed at a variety of locations ranging from secure, university-owned research properties to working farms, land leased to the LTAR site long-term, and human 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 to address a number of pressing national agricultural research priorities. Chief among these are the need to address questions that require 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 of the immediate goals for an inaugural LTAR program. They include six specific 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 each of these should fully engage stakeholders as 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 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 and fiber production systems and thereby contribute to long-term U.S. food security. It will also promote the development of food and fiber (including biofuel) systems that are able to adapt to change while maintaining productivity.

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 reaching this goal: (1) Assessing the types of ecosystem services provided in different agricultural landscapes is a first step towards evaluating the trade-offs involved when managing for a particular set of services; (2) the valuation of services is also necessary for defining trade-offs, and this will require a multidisciplinary, socioeconomic approach to quantify the value of various services to humans at both local and regional scales. This research will eventually lead to identifying preferred cropping systems based on a larger understanding of potential benefits and risks, and help 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 to meet this goal would include addressing questions related to food and fiber systems that preserve economic viability for all members of the value chain. This includes the need to evaluate trade-offs that involve worker safety and health, ownership, energy production and use, and regional-based 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 would lead to an increase in the number of economically viable farms of different sizes and an increase in the number of value-added processing enterprises and local input suppliers. Research could also lead to an increase in the number of local and regional markets where producers and local processors capture a higher percentage of the food dollar, and help to identify optimal design and enrollment strategies for conservation programs.

Goal 4. Biodiversity. *Optimize biodiversity to improve agricultural ecosystem efficiencies, conserve and protect natural resources, and enhance on-farm profitability.*

LTAR research needs to meet this goal include examining 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 towards specific goals such as

pest protection and soil fertility, allowing low-cost biological management to enhance or even offset many 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 that agriculture can contribute to the stabilization of greenhouse gas concentrations in the atmosphere, including the production of biofuel crops. This will lead to improvements in soil quality and fertility as carbon stocks are restored, in nitrogen fertilizer efficiencies, and in regional air and water quality as more carbon and nitrogen is retained on-farm. Achieving this goal will also provide producers an enhanced 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 increased 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 U.S. 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 and fiber production. All share the crucial need for a comprehensive, systems-level research approach that is long-term and geographically scaleable. 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 U.S. agricultural research portfolio.

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