Sustainable Agricultural Systems Science White Paper
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The concept of sustainability has been prominent since the 1987 report of the World Commission on Environment and Development (Bruntland, 1987). Sustainability and its relevance to U.S. agriculture were also discussed in the 1989 “Alternative Agriculture” report of the National Research Council (1989). In 1990, Congress gave the U.S. Department of Agriculture (USDA) a definition of sustainable agriculture to undergird its science programs, and USDA committed to sustainability more broadly in a memorandum issued by the USDA Secretary in 1996 (see Gold, 1999).

The core concept of sustainability is that lasting success (and avoiding crises) requires an integrated approach to producing food and other products; farm profitability; quality of life for farmers, workers, and communities; and stewardship of natural resources. That is, sustainability requires recognizing and acting upon productivity, economic, social, and environmental goals as a simultaneous set of system attributes.

U.S. agriculture has made regular improvements in annual productivity and the efficiency with which it uses certain natural resources and inputs such as fertilizer, water, and energy (Keystone Center, 2009; Tilman et al., 2001). But despite these gains and despite the stewardship orientation and efforts of America’s producers, many key environmental, economic, and social concerns related to agriculture persist or are worsening both globally and in the United States. For example, an estimated 60 percent of the ecosystem services that support life on Earth—such as fresh water; ocean fish stocks; and clean air—are being degraded or used unsustainably, with many of these changes caused in part by past management of land for food, fiber, and timber (Millennium Ecosystem Assessment, 2005). Global estimates of reactive nitrogen, climate change, and biodiversity loss are judged to have dramatically exceeded “planetary boundaries,” or critical thresholds that represent unacceptable environmental change (Rockstrom et al., 2009). In the United States, persistent concerns include loss of prime farmland, water scarcity, hypoxia in the Gulf of Mexico, reduced genetic diversity, increasing costs of production, loss of mid-sized commercial farms, threats to the health and safety of farm workers, and declining prosperity of agriculturally dependent communities (National Research Council, 2010).

Efforts to understand and address these and related concerns in isolation from one another can certainly contribute to marginal improvement along some dimensions of sustainability. The urgency, breadth, and depth of the interrelated challenges, however, call for a more integrated approach (Clark, 2007) that emphasizes the role of science in understanding the integration of the many elements into systems where understanding and exploiting linkages among elements of coupled human-environment systems can reduce tradeoffs and capture synergies.

Addressing sustainability as a multigoal synthesis is a timely and critical leap in the advancement of agriculture. It is essential to the grand challenge of meeting future demand for food in the face of changing climate within the limits of natural resources and social systems. A growing list of government, academic, and private sector efforts are creating the conditions for such a synthesis to succeed. For example:

- Companies are incorporating sustainability measures into their business strategies and supply chains and, in response, many regional, national, and global organizations and coalitions, including virtually all major agricultural commodity groups, are developing systems for documenting and advancing progress toward sustainability outcomes.
- Many professional societies are organizing symposia and publications on sustainability.
- The President's Council of Advisors on Science and Technology added the issue of sustainability to its Committee on Environment, Natural Resources, and Sustainability, and the White House Office of Science and Technology Policy (OSTP) and Office of Management and Budget (OMB) joint memorandum on science and technology priorities for the fiscal year 2012 budget included "Managing the competing demands [on land and water] for the production of food, fiber, biofuels and ecosystem services based on sustainability and biodiversity" as a key challenge.
- The National Science Foundation (NSF) has launched a multiyear Science, Engineering and Education for Sustainability investment area to address climate and energy issues.
- The USDA's Sustainable Development Council has worked over the years to help elevate sustainable agriculture in United Nations discussions by sharing examples and practices from the United States and by learning from other countries.

Current State of the Science

The National Research Council (NRC) report "Toward Sustainable Agricultural Systems in the 21st Century," effectively summarized the current state of science and practice in the United States. It documented the considerable science-based progress in American agriculture: producing more food and fiber on about the same acreage as a century ago with less labor, energy, and water per unit of output and considerably less soil erosion. It described the challenge ahead in meeting greater demands for food, feed, fiber, and biofuels despite the loss of farmland; water scarcity; declining quality of water, soil, and air; loss of genetic diversity; and rising input costs. It also cataloged concerns about the survival of mid-sized commercial family farms, farm labor conditions, food security, animal welfare, and community well-being (National Research Council, 2010; Reganold et al., 2011).

The NRC report recommended that the scientific community pursue two concurrent approaches to meet these challenges. One, an incremental approach, expands the use of improvements that many farms and ranches have made and many more can yet make that would involve the majority of production agriculture and the nation's landscapes. The other, a transformative approach, seeks to advance farming systems that balance the goals of sustainability from the outset. Examples of so-called transformative systems include organic agriculture, integrated crop-livestock systems, management-intensive rotational grazing, low-confinement integrated hog production systems, and perennial crop production for grains and biofuel feedstocks. Agroforestry, while not discussed in the NRC report, is another example. The emphasis on transformative systems is consistent with the OSTP guidance to "pursue transformational solutions to the Nation's practical challenges." While the private sector continues to make improvements, publicly supported science is required to accelerate both incremental change (particularly in social and environmental dimensions undervalued by markets) and to advance "transformative" systems that hold great potential if they are better understood.

The NRC report made five recommendations for USDA to increase its investments in science:

1. Research that clarifies economic and social aspects of current and potential technologies and management practices and that addresses issues of resilience (i.e., the capacity to absorb shocks) and vulnerability in biophysical and socioeconomic terms.
2. Integrated research and extension on farming systems that focus on the interactions among productivity, environmental, economic, and social sustainability outcomes, and how the properties of agroecosystems and the interdependencies between their biophysical and socioeconomic aspects could make the systems robust and resilient over time.
3. Long-term research and extension at the scale of watersheds and landscapes to understand the aggregate effects of farming, leading to better environmental quality, economic viability, and community well-being (which NRC recommended should be led by USDA in partnership with the National Science Foundation, Environmental Protection Agency, universities, and farmer-led sustainable agriculture groups).
4. Research in which farmers participate in farmer-managed trials and peer-to-peer education and information exchange.
5. Empirical studies of the effects of markets, policies, and knowledge institutions so that USDA can implement changes that are found to be effective in expanding the use of more sustainable farming practices and systems.

Similar trends and conclusions were noted in a comprehensive two-volume series of review papers on global sustainable agriculture published by the Royal Society of Britain (Pollock et al., 2008). Furthermore, the National Agricultural Research, Extension, Education and Economics Advisory Board (2010) recommended that USDA research focus on models for the food system that can quantify effects on land use, soil loss, water and energy use, and climate change; on producing greater quantities with emphasis on improved efficiency in the use of natural resources; and on reducing losses and waste in the food system.

Whereas the NRC report touched upon topics in marketing, civic agriculture, local foods, and community economic security, its primary focus was on the farm and the landscape more than the food system. Many scholars, particularly those from the social sciences, consider food systems and "civic agriculture" (the embedding of local agriculture and food production in the community) to be central to the concept of sustainability (e.g., Hinrichs and Lyson, 2008). For those reasons, and as further discussed below, local and regional food systems are given more attention in this paper than they were given in the NRC report.

Current Research Challenges and Proposed Research Program

USDA's science agencies have a track record of carrying out research, education, information, and extension programs in sustainable agriculture, forestry, and communities, and both longstanding and new policies and coordinating mechanisms upon which to build a new approach.

USDA science agencies address sustainability through programs focused on sustainable systems (e.g., the Agricultural Systems Competitiveness and Sustainability national program in the Agricultural Research Service [ARS] and the Sustainable Agriculture Research and Education (SARE) program in the National Institute of Food and Agriculture [NIFA]) and by incorporating appropriate sustainability dimensions into the goals of other programs. Some programs do so by explicit reference to balancing or integrating economic, environmental, and social dimensions of sustainability. Other programs do so in more general terms; for example, the mission statement of ARS' Food Animal Production national program aims to ensure a supply of animal products "produced in a healthy, competitive and sustainable animal agriculture sector" and NIFA's Agriculture and Food Research Initiative 2010 request for applications require all proposals to describe their contributions to "the potential long-range improvement in and sustainability of U.S. agriculture and food systems." The data collections of the National Agricultural Statistics Service (NASS) and research and analysis of the Economic Research Service (ERS) address many topics related to sustainability (e.g., farm economics, farm production practice adoption, environmental indicators, rural community well-being, local food systems, domestic and international food security, and organic agriculture). The Forest Service's research and development efforts have had longstanding emphasis on sustainability in resource use, environmental sciences, and forest management, and the Forest Service periodically reports on sustainability indicators in its National Report on Sustainable Forests.

USDA science is building on this foundation to enhance sustainable systems in ways too diverse to describe here. This paper describes USDA science in four areas that focus on integrating productivity, profitability, and environmental and social dimensions in ways that leverage the current state of knowledge, stakeholder interests and initiatives, Federal priorities, and unique USDA capabilities to have the maximum beneficial effect on a balanced spectrum of mainstream (i.e., incremental) and alternative (i.e., transformative) systems. These four areas are as follows:

1. Integrating sustainability issues and approaches into a range of USDA science priorities, including food security, crop and animal production and protection, bioenergy, climate change, and natural resource management.
2. Building a framework for sustainability data and information, and supporting research, education, and extension efforts to develop critical scientific and management information to fill gaps in the framework.
3. Advancing the understanding of local and regional food systems, a key part of the USDA strategy for rural prosperity and a promising market for connecting producers with consumers, many of whom are interested in farmers and land management.
4. Improving the performance of organic agriculture (the largest of the "transformative system" examples described in the NRC report).

Taken together, these strategies build upon existing strengths and unique capabilities of USDA science programs while also addressing many of the NRC recommendations.

Strategy 1: Incorporating Sustainability Issues and Approaches across Science Programs at USDA

Sustainability is a cross cutting priority across the USDA science goals. It is included in the guiding principles and in many specific strategies and actions in the Research, Education and Economics Action Plan (Woteki, 2012). Examples (in addition to those detailed in strategies 2, 3, and 4 below) include the following:

1. Goal 1A. Crop and Animal Production: Includes identifying and implementing best management practices for animal and plant systems that are environmentally, economically, and socially sound; integrating superior germplasm and best management practices into profitable, productive, and environmentally sound integrated systems for crop and animal production; and other actions described more fully below.
2. Goal 1B. Crop and Animal Health: Includes research to establish more sustainable systems that enhance crop and animal health.
3. Goal 1C. Crop and Animal Genetics, Genomics, Genetic Resources, and Biotechnology: Includes assessing new biotechnology varieties for their contributions to sustainable agricultural systems, and assessing policies and management strategies for their ability to contribute to the coexistence of different agricultural production systems.
4. Goal 2A. Responding to Climate Variability: Includes the investigation of both existing and “transformative” systems (in the sense offered within NRC 2010) to adapt to and mitigate climate change and enhance a broader set of ecosystem services.
5. Goal 2B. Bioenergy/Biofuels and Biobased Products: Includes developing sustainable, new feedstock production systems, targeting multifunctional landscapes, and models and other tools to understand and improve the effects of biofuel feedstock systems on social, economic, and environmental outcomes, including long-term productivity and ecosystem services.
6. Goal 3: Sustainable Use of Natural Resources: Includes many strategies and action items related to ecosystem services and other sustainability outcomes under both the water and landscape conservation and management subgoals. The Long-Term Agro-Ecosystem Research network, in particular, responds to the NRC recommendation for more long-term research at the scale of watersheds and landscapes.

Strategy 2: Sustainability Data, Information, and Management Systems

While sustainability goals are integrated into many USDA science programs, USDA lacks a systematic framework—a common model—for reviewing different approaches to sustainability to assess their multidimensional outcomes and effects and to make the results accessible to the public (National Agricultural Research, Extension, Education and Economics Advisory Board 2010). Producers, food companies, and coalitions working on sustainability criteria, indicators, and standards, and policymakers responsible for evaluating the sustainability effects of policies and programs all want to understand the multidimensional implications of different systems of production and different supply chains on the basis of transparent and consistent data and analyses. Being able to provide this critical information to the many stakeholder-led efforts to document and track continuous improvement is, quite likely, the single most important thing USDA can do to document and accelerate progress by mainstream production agriculture and to establish the common ground for assessing diverse approaches to sustainability.

Life Cycle Assessment (LCA) is a framework that has come into increasing use for assessing the sustainability implications of products and processes. Long used to assess the environmental effects of industrial products, LCA is increasingly being used in food and agriculture to compare the effects of different production and marketing methods, identify stages where improvements may have the biggest benefits, help producers meet requirements of U.S. and global markets, and provide transparency to sustainability claims for consumers and everyone along the supply chain (Horn and Grant, 2009). LCA will also benefit the scientific community by providing a systematic framework for identifying where data are strong and where gaps need to be filled by additional research. LCA is also being adapted to include social outcomes (Norris 2006), thereby better reflecting the multiple dimensions of sustainability.

USDA's National Agricultural Library (NAL) is leading a cross-government initiative, the "LCA Digital Commons," to develop a framework for organizing and providing access to life-cycle data and information on sustainability in agricultural supply chains. It will provide open access to transparent, quality-controlled data and documentation compatible with internationally accepted protocols for LCA.

In the meantime, however, as the NRC report has detailed, many gaps have already been identified that need to be filled, particularly the integration of economic and social consequences with biophysical data (recommendation 1) and more attention to participatory research and extension efforts on transformative integrated systems (recommendations 2 and 4). This research can also be useful for the science-based action programs of the Department by helping to provide the basis for rewarding producers for stewardship through conservation incentive programs, the development of environmental markets, or other means.

This strategy leverages several key USDA assets: the NAL's pivotal expertise in information management; ARS' ability to conduct long-term farming systems research; NIFA's programs and expertise funding participatory systems research; and NASS and ERS data and analytical resources. It also integrates well with other Federal agencies (e.g., Environmental Protection Agency and Department of Energy) that are addressing sustainability across other nonagricultural products and processes.

Current USDA Science

NAL has developed the basic structure of the framework and initial data. More data and information to populate the framework will come from a variety of existing sources (NASS and ERS data; ARS and NIFA research, education, and extension efforts; and other Federal and non-Federal sources), new research on specific priorities (e.g., biofuels, climate change, conservation, watersheds), and greater investment in integrated research and extension in participatory farming systems that focus on interactions among productivity, environmental, economic, and social outcomes.

Primary Goals

The primary goal is to provide science-based knowledge to accelerate both incremental and transformative progress toward sustainable agriculture through systems research and extension and through the development and population of a framework for understanding the sustainability (productivity, economic, environmental, and social) outcomes of agriculture, food, and forestry practices and systems.

Anticipated Outcomes

- A system for capturing and delivering data and information on environmental, economic, and social consequences of food, agriculture, and forestry systems and processes at appropriate geographic scales over the life cycle of product supply chains (NAL).
- Well-developed life-cycle inventory data on environmental, economic, and social consequences of key agriculture-related processes to fill gaps in the framework, resulting in transparent, science-based analyses to support product declarations and continuous improvement programs (ARS, NIFA, ERS, NASS).
- Development, assessment, extension, and education on incremental/mainstream improvements (e.g., soil/water/nutrient management, pest management, livestock management) evaluated for their sustainability outcomes, including all four dimensions (productivity, profitability, environmental, and social).
- Development, assessment, extension, and education on transformative systems approaches to sustainable agriculture (NIFA, ARS) including but not limited to the systems in the NRC report (2010).

Strategy 3: Local and Regional Food Systems

Developing and supporting local and regional food systems is one of five key components of USDA's strategy for enhancing rural prosperity. The Department's *Know Your Farmer, Know Your Food* initiative is its primary mechanism for accomplishing cross-USDA coordination on local and regional food systems and reconnecting farmers and consumers in order to benefit farmers, strengthen rural communities, promote healthy eating, and protect natural resources.

While the concept of "local" has somewhat different meanings to different consumers, it appears to be one promising way for farmers to tap markets that *may* be more likely to reward them for stewardship and proximity. Local food systems are a small but rapidly growing segment of U.S. agriculture, representing approximately $4.8 billion in sales in 2008 (Low and Vogel, 2011). The number of farmers markets nearly doubled in 10 years to 5,247 in 2009 and the number of farm-to-school programs grew fivefold in 5 years to 2,095 in 2009 (Martinez et al., 2010). Some sociologists and others consider local and regional food systems more important to sustainable agriculture than their numbers would indicate, arguing that the social value of closer connections between farmers and consumers is as important to the social dimension of sustainability as are production practices to the biophysical dimensions (Hinrichs and Lyson, 2008; Jordan and Constance, 2008). Local and regional food systems can be considered at one end of the marketing spectrum, complementary to the national and global supply chains whose sustainability advances will be informed by the research and data initiatives described above. Understanding where and how regional food systems are a good fit and how they complement or compete with national and global supply chains is one area of active research.

This strategy leverages key USDA assets through the cross-Departmental collaboration and coordination of the *Know Your Farmer, Know Your Food* initiative.

Current USDA Science

USDA Research, Education and Economics (REE) agencies are all active in the *Know Your Farmer, Know Your Food* initiative through leadership in its data gathering and research subcommittees, and through relevant agency programs. While some USDA programs have been supporting the development of local and regional food systems for some years (e.g., community food projects, SARE, NAL's Alternative Farming Systems Information Center, and programs of USDA's Agricultural Marketing Service), only recently has a more comprehensive analysis of regional food systems begun (e.g., ERS' primer and case study publications in 2010 and the Agriculture and Food Research Initiative's Sustainable Food Systems program, which was new in 2010).

Primary Goals

The primary goals are to inform policies and practices in local and regional food systems through research on the current and potential contributions of local/regional food systems to economic development and human well-being (including environmental and social dimensions) and the characteristics and factors that foster or limit their development and application.

Anticipated Outcomes

- Understanding the potential value and effects of regional food systems in the Northeast, and the development, sharing, and application of mapping/modeling tools to other regions (ARS, NIFA).
- Identification and evaluation of best practices, constraints, and barriers in sustainable, local, and regional food systems and public sharing of those best practices through eXtension and other means (ARS, NIFA, and NAL's Alternative Farming Systems Information Center).
- Knowledge of how market conditions and constraints affect local food system performance (ERS).
- Understanding the participation in farm-to-school initiatives, their dollar value, and their effect on fruit and vegetable consumption by school meal participants (ERS).
- Understanding the food environment factors that influence availability and selection of local food and how the availability of local foods in low-income areas affects food choice (ERS).

- Enhanced knowledge among agricultural and food system professionals, both now and in the next generation, through both formal education programs and informal youth education programs (NIFA).
- Expanded local and regional markets for new, beginning, and existing small- and mid-size farmers (ARS, NIFA).
- Improved statistical data on local and regional marketing (NASS, ERS).

Strategy 4: Organic Agriculture

U.S. organic production has more than doubled and organic food sales have more than quintupled to $22.9 billion in 2009 since the late 1990s (Greene et al., 2009). With more organic programs called for in the 2008 Farm Bill, USDA has increased its focus on the potential role of organic agriculture in achieving outcomes such as economic development, environmental services, resource conservation, climate change mitigation, nutrition, food safety, and other outcomes. This approach is consistent with the NRC report that discussed organic agriculture as an example of a system that holds promise for achieving transformative progress and a market for producers seeking higher reward for stewardship. It is also consistent with trends in the scientific community, with organic agriculture receiving more attention at professional societies (e.g., the American Society of Agronomy's Organic Management Systems section and its new monograph; Francis, 2009) and at universities (e.g., new degree programs in the past 5 years at land-grant universities in Colorado, Florida, Georgia, and Washington, plus courses and research programs at many other universities).

REE agencies have a solid basis of field science, new data, and longstanding analyses that can provide the foundation for this shift to a more science-based, outcome-based view of organic agriculture. While universities and other institutions are increasing their investments in research and education efforts that are necessarily site-specific, USDA is uniquely situated to integrate field research and extension at the regional and national levels, assess their outcomes with respect to national priorities, and integrate the efforts and results with other USDA agencies (e.g., the National Organic Program of the Agricultural Marketing Service, conservation programs of the Natural Resources Conservation Service, etc.) through the USDA Organic Working Group and other relationships.

USDA Science

ARS has invested $12.6 million in research at 20 locations that directly address organic agriculture challenges. In addition, the NAL provides information on organic agriculture, primarily through its Alternative Farming Systems Information Center.

ERS develops a broad range of economic research and analysis on organic agriculture, and organic activities are included in all three ERS divisions. The Food Economics Division is modeling consumer demand for organic food; the Market and Trade Economics Division is conducting research and analysis of organic costs and returns in major crop and livestock sectors; and the Resource and Rural Economics Division is examining the adoption of organic farming systems and the economic characteristics of the U.S. organic industry.

NASS surveys land acreage and sales of organically produced products in the Census of Agriculture. As a follow-up to the 2007 Census, NASS conducted its first-ever wide-scale survey of organic agriculture in the United States, including production of crops and livestock, production practices, production expenses, marketing practices, and value-added production and processing. Results were published on February 3, 2010. NASS also collaborates with ERS on surveys of targeted organic commodities (so far, soybeans, apples, wheat, dairy, and corn) and is working with the Risk Management Agency to develop a data series on prices received for organic crops.

NIFA funds organic agriculture through multiple programs, including the Organic Research and Extension Initiative, Integrated Organic Program, and portions of other NIFA programs such as Sustainable Agriculture Research and Education, Small Business Innovation Research, and the Agriculture and Food Research Initiative.

Primary Goals

1) Help stakeholders implement successful organic production and marketing systems in response to growing consumer demand; 2) compile knowledge to guide policies and practices regarding organic agriculture's contributions to sustainability outcomes such as rural prosperity, clean water, and climate change mitigation and adaptation; and 3) use the integrated nature of the organic paradigm as a platform for developing integrated approaches to sustainability in general.

Anticipated Outcomes

- Improved productivity and profitability of organic production systems (ARS, NIFA).
- Understanding the organic sector's effects on ecosystem services and sustainability outcomes (ERS, NIFA, ARS).
- Understanding consumer demand for organic food and the behavior of organic markets (ERS).
- Knowledge of factors that influence the adoption of organic farming systems (ERS, NIFA).
- Better data on organic production and marketing practices (NASS, ERS).
- Better coordination of stakeholder interactions (ERS, NIFA, ARS, NASS, and other USDA agencies).
- New models of research and education for integrated, transformational systems of agricultural production and marketing.

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