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Office of Science and Technology Policy
1650 Pennsylvania Avenue NW
Washington, DC 20504

Dear Office of Science and Technology Policy:

Thank you for the opportunity to provide a response to your Request For Information titled, "Identifying Sources of Agricultural Innovation." We have worked with leaders from the Agronomy, Crop, and Soils Science Societies to compile information we hope will be useful to your efforts to raise the profile of food and agriculture research in the United States.

The American Society of Agronomy, the Crop Science Society of America, and the Soils Science Society of America are dedicated to improving our knowledge of natural resource management to better manage our natural resources to meet the demands of a growing world population. Together the societies represent over 18,000 scientists in academia, industry, and government, 12,500 Certified Crop Advisers (CCA) and Certified Professional Agronomists (CPAg), and 781 Certified Professional Soil Scientists (CPSS). We are the largest coalition of professionals dedicated to the agronomic, crop and soil science disciplines in North America.

First, the Societies have each recently published our Science Frontiers, which identifies the most promising opportunities in the next decade whose investigation will establish a foundation of information that will propel the scientific discipline beyond the current state of knowledge. Each of the Societies contribute their own unique science-based solutions to the grand challenge that unites us all: *Sustainably improve the human condition for a growing global population in a changing environment.*

The Societies have also recently been engaged with the National Science Foundation on their new crosscutting initiative, Innovations at the Nexus of Food-Energy-Water Systems (INFEWS). We have collected white papers from our members to identify fundamental research questions and knowledge and technology gaps within the food, agriculture, and natural resource sciences that relates to the FEW system. Submissions are posted on a public online forum where they can be downloaded and viewed freely at any time: https://www.agronomy.org/science-policy/white-papers/browse/

In addition to our proactive efforts to identify the frontiers of innovation within our sciences, we have provided three specific examples of innovation provided by our leadership. The examples detail research gaps and critical needs for innovation in precision agriculture (including innovations in data systems), nutrient use efficiency, and major challenges from a soil science perspective.

Sincerely,

Ellen G.M. Bergfeld
Chief Executive Officer

Jean Steiner
American Society of Agronomy, President

Roch Gaussoin
Crop Science Society of America, President

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SCIENCE FRONTIERS IN AGRONOMY, CROP AND SOILS

The United Nations estimate the global population will increase to 9.1 billion by 2050, requiring at least a 70 percent increase in production to meet the demands of this population. Our challenge is to sustainably increase production of nutritious food, fiber, and reliable sources of energy while protecting shared water, soil, and air resources in shifting and increasingly uncertain climatic and socio-political conditions. The American Society of Agronomy, the Crop Science Society of America, and the Soils Science Society of America are dedicated to improving our knowledge of natural resource management to better manage our natural resources to meet the demands of a growing world population.

The Grand Challenge

One grand challenge unites us: *Sustainably improve the human condition for a growing global population in a changing environment.* Each scientific discipline and sector of the economy will offer their own unique solutions to this grand challenge.

Science Frontiers

The following science frontiers identify the most promising opportunities in the next decade whose investigation will establish a foundation of information that will propel the scientific discipline beyond the current state of knowledge while addressing the grand challenge.

AMERICAN SOCIETY OF AGRONOMY	CROP SCIENCE SOCIETY OF AMERICA	SOIL SCIENCE SOCIETY OF AMERICA
Sustainable Intensification	Crop Frontier: Crop Improvement and Adapting to Climate Change	Food, Energy, And National Security Through Soil Education
Enhancement of Ecosystem Services Provided by Agriculture	Human Frontier: Connections between Food and Health	Climate Change and Soil Processes
Socially and Economically Viable Agriculture Systems	Global Frontier: Sustainable Environmental Management	Healthy Soils, Healthy People
		Soil and Water Quality

Critical Needs

Each of the science frontiers will require cross-cutting areas of critical infrastructure to be in place.

- Augment Federal Funding for Food and Agricultural Science within Relevant Federal Agencies
- Empower and Employ the Future Science Workforce
- Cultivate the Application of Innovative, Science-based Agronomic Practices through Education and Extension
- Improve Computational Capabilities by Integrating Databases for Genetic Resources and Agricultural Research and Equip a Workforce Trained in Digital Data Infrastructure
- Promote Innovation through Partnerships between the Public and Private Sectors

More information at:
https://www.agronomy.org/science-policy/issues/science-frontiers
https://www.crops.org/science-policy/issues/science-frontiers
https://www.soils.org/science-policy/issues/science-frontiers

INNOVATIONS AT THE NEXUS OF FOOD, ENERGY, AND WATER SYSTEMS (INFEWS) WHITE PAPERS

The Societies issued a call for white papers to help inform the National Science Foundation (NSF) as they develop the research priorities for their new crosscutting initiative, Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS).

NSF aims to understand, design, and model the interconnected food, energy, and water system through an interdisciplinary research effort that incorporates all areas of science and engineering and addresses the natural, social, and human-built factors involved. INFEWS will be the first NSF program to study the interconnected food-energy-water (FEW) nexus. The need for this program is increasingly urgent, as growing U.S. and global populations, changes in land use, and increasing geographic and seasonal variability in precipitation patterns are placing an ever-increasing stress on these critical resources. NSF, through INFEWS, is uniquely poised to focus not only on the fundamental science and engineering questions at this nexus, but to train the next generation of researchers in this interdisciplinary area.

The white papers address a project, critical research question, observation, theory, or modeling activity that promises to:

- Advance an existing or new FEW systems scientific objective,
- Contribute to fundamental understanding of the FEW system,
- Facilitate the connection between science and societal needs within the FEW system.

The white papers are intended to be shared broadly with the scientific community and can be accessed at: https://www.crops.org/science-policy/white-papers/browse/

SPECIFIC EXAMPLES

Precision Agriculture and Data Systems

The impact of agricultural activities to the environment are of great concern to society and many diverse communities. Agricultural practices have evolved during the past century from horse-drawn moldboard plowing to no-till planting using GPS guided equipment. However, there is still room for improvement. Organizations such as ‘Field to Market’ are looking to further decrease agriculture’s carbon and energy footprints, decreasing inputs, and, simultaneously, increasing agricultural sustainability by maintaining soil health and minimizing water and fertilizer inputs. In other words, producers will have to become more knowledgeable in their management and optimize each input. On the field scale, this optimization will be implemented by developing and using precision agriculture techniques.

The transition to precision agriculture techniques must be strategically implemented. Few farmers understand how to take advantage of the precision agriculture equipment that that they have purchased. Few agricultural professional have the basic skills for the beginning of this new frontier. To prepare agricultural professionals in the implementation precision weed, insect, disease, genetics, conservation, and fertility management they need to learn how to integrate information from many different STEM disciplines.

In a recent agricultural enterprise industry survey (author's unpublished data), over 100 respondents rated the knowledge level for recent applicants for precision agricultural positions. Based on the results, over 50% of applicants interviewed were rated as low or deficient in:

- Operational knowledge of precision agricultural software;
- Use of basic mathematics and statistical methods to solve problems; and
- Ability to scout fields, analyze field data, and make effective agronomic recommendations.

When asked about the difficulty in locating qualified applicants the potential employers reported that is very difficult (position opened for 90+ days) to difficult (position open for 60 – 90 days). It is clear that our current and future needs additional skills that will make precision agriculture a reality.

The implementation of precision farming techniques requires the discovery of interdisciplinary techniques that rapidly and accurately define the yield limiting factors. Achieving this goal will likely require a breakdown of the silos surrounding the agricultural disciplines. Currently there are no federal programs focused on the use and development of precision techniques to sustainably increase food production. Current outreach programs are built around the skills of the trainers. Currently, the number of STEM enhanced teachers that understand precision agriculture are very limited. Expanding the recruitment STEM enhanced students will require changing the training requirements for current and future students, as well as expanding the educational opportunities available for students that did not grow up with a farming background or farming experience. Students will need fundamental knowledge in basic and applied sciences. Mathematics is the language of computers, yet most graduating seniors have a limited understanding on how to use mathematics and statistics to solve practical problems. The next generation of food and agriculture researchers will be required to have the knowledge, skills, and training in technological, computer, mathematical and engineering sciences in order to solve our grand challenge.

New precision agriculture technologies must also be developed. The following is a list of specific examples with recommendations on how the technologies must be developed in conjunction with data management systems.

1. Developing novel, targeted remote sensing and in-situ sensing technology that can be practically fielded and used in food and water system management.

   Recommendation 1.1: **Pursue development of advanced, low cost, low power in-situ and proximal remote sensing systems and sensor networks to continuously acquire, transmit, and store data on plant and soil water status and environmental conditions in the agricultural production environment.**

   Research on wireless sensors and sensor network systems is needed to enable automatic data acquisition, analysis and transformation of data to decision support recommendations for crop irrigation, fertilization and disease and pest control. Data of particular interest include soil water content and energy potential, plant water status, canopy cover fraction, canopy temperature and multi-spectral reflectance (active and passive). Rationale: Decision support systems are hobbled by lack of automatic data acquisition and wireless transmission to embedded computing systems that analyze multiple data streams to generate decision support recommendations.

Recommendation 1.2: **Pursue data standardization efforts to enable developers of decision support systems to access data from sensor systems regardless of vendor.** Research and develop of data standards that are acceptable to a wide spectrum of data users and sensor systems manufacturers is needed to remove barriers to development of advanced decision support systems for agricultural production and quality control. Rationale: Decision support systems (DSS) are hobbled by inaccessibility of data from proprietary sensor systems, slowing the development of badly needed DSS.

2. Developing novel integrated hydrology, soil, microclimate, and plant/agricultural production models that interact accurately and across traditional scales for understanding local, regional, and national impacts.

   Recommendation 2: **Pursue development of modular physical science and agronomic models that are more biologically and geophysicaly based and less empirical and which adhere to data standards that allow data assimilation from sensor systems and use by producers of decision support and sensor systems.** Research is needed to improve biophysical models of the soil-plant-atmosphere continuum so that model components can be easily shared and adapted to crop-specific model development, including tree and vine crops, vegetable crops, forage crops, fiber crops and pulse and grain crops. Decision support system rely on accurate models that can easily assimilate data from multiple sensor streams and perform the analyses that result in actionable recommendations. Existing models are not set up or designed for data assimilation and use in real time or near real time to support DSS. Data standardization will increasingly allow development of real-time data assimilation and analysis.

3. Turning this developing and pending data deluge into usable, actionable information for agricultural producers, local and regional decision makers, and citizens.

   Recommendation 3: **Support public-private partnerships to develop test beds for sensor systems, models that assimilate data from those systems and decision support systems coupled to those models.** Research and development is needed to close the loop on delivery of integrated sensing, modeling and decision support systems to agricultural producers. Fewer people are involved in production agriculture, but their educational level and ability to use modern electronic media is high. Agricultural producers need decision support systems that reduce complex data streams to actionable intelligence. The technology exists but has not been harnessed to provide on-farm decision support that allows easy understanding of decision alternatives and allows drilling down through multiple layers in an easy 3-D visualization manner to provide confidence in the recommended action. This research effort would bring together state, federal and private scientists and engineers with industrial partners to integrate the pieces and test the integrated decision support systems (sensor networks through to DSS) in real-world test beds. Because “data consumes the attention of its consumers”, the data must be reduced to visual and easily understood spatially and temporally represented action recommendations.

Nutrient Use Efficiency

Nutrients, particularly nitrogen (N) and phosphorus (P), are essential elements for life, as they are required in large amounts for plant growth. Nutrients play a critical role in an industrialized world, which has to cope with an increasing demand in crop production to match food requirements for an ever-increasing world population.

High intensity food production requires the addition of fertilizers to fill the gap between plant needs and nutrients found naturally. The downside of nutrient addition to crops is that an excess of nutrients in the environment has several detrimental consequences. Nutrient pollution is one of the most damaging economic and environmental problems in America and worldwide. Consequences range from water quality degradation (affecting drinking water supplies for humans) to ecosystem disruption and loss of resources for activities such as fishing, swimming and tourism.

Over the last decades, academic, government, non-profit and for-profit organizations have worked towards studying, documenting, and developing technologies and practices aimed at reducing nutrient pollution. While scientific, technological, and policy advances have improved nutrient use efficiency, nutrients continue to be released and discharged at concentrations that cause adverse effects to human wellbeing and the environment. Land use change, climate change and increasing human populations will exacerbate nutrient use efficiency.

Table 1 identifies key research opportunities and technology needs whereby sustainable nutrient management, based on greater efficiencies in nutrient use, can help minimize tradeoffs, and catalyze synergies to improve resilience among components of the water, energy, and food security nexus. This requires a shift in thinking from separate water, energy, and food policies to a more holistic approach to nutrient management.

More detailed information can be found in a white paper written by Andrew Sharpley et al., "Reframing Phosphorus Stewardship for Resilience in Food-Energy-Water Security," https://www.agronomy.org/files/science-policy/white-papers/2.pdf

Table 1 Examples of the roles, research opportunities and technology needs regarding nutrient fertilizer in a resilient food-water-energy nexus.

Nexus connection	The role of nutrient fertilizer	Research opportunities	Technology needs
Water and Food	Use of nutrient fertilizer has increased food grain, fiber, and livestock	Revisit dated Land Grant soil fertility recommendations.	Innovative agricultural Conservation Practices (CPs) that help protect and enhance soil structure and fertility,

	production and food security. Nutrient run-off and loss from agricultural production systems has contributed to more widespread eutrophication.	Identify critical source areas and management practices for loss. Identify and quantify legacy sources of nutrients within watersheds. Unified framework to target precision conservation. Innovative methods to recycle nutrients at farm, watershed, and global scales that reduce reliance on mined P fertilizers.	minimize nutrient loss, and increase water-use efficiency, while limiting consequences of unintended and conflicting outcomes. Unified framework to target precision conservation. Cost-effective technology to recover and recycle nutrients from manure, and wastewater (e.g., through enhanced value products) will help close the P cycle and reducing reliance on imported inorganic fertilizers.
Water and Energy	Use of nutrient fertilizers has enabled the specialization and intensification of agricultural production, as well as growth of biofuels industry (based on grain ethanol and biodiesel), increasing energy and water demand.	Quantify the impact of expanding agricultural production into marginal areas on soil erosion and nutrient loss, with longer-term tradeoffs for soil C, and ecosystem services which support food production and clean water. Revisit dated Land Grant soil fertility recommendations for cellulosic feedstock. Determine resilience of farming systems to reduced water availability and potential impacts on fertilizer use.	Ensure landscape suitability and sustainability for biofuel grain so that right biofuel crops are grown in the right place to maximize yields, whilst minimizing soil erosion and nutrient loss. Develop landscape diversity to support a greater range of biofuel crops, e.g., perennial cellulosic biofuel crops (grasses and woody plants) can help decrease nutrient loading to surface waters and increase soil C in less productive areas.

Food and Energy	Nutrient inputs to food and biofuel energy production cannot be substituted by any other chemical element.	Economic and strategic forecasting of consequences of competing biofuel and food crops for land and water resources. Global analysis of impacts of increasing food prices with tradeoffs for food security in countries reliant on food imports. Quantify production and environmental impacts of increased commodity prices that incentivize farmers to increase production and yields at the expense of conservation measures. Long-term economic impacts of incentivized farm production on soil health and water quality.	Strategic analysis of co-locating CAFOs near biofuel processing plants to utilize waste products of biofuel production (e.g., distiller's grain) as animal feed that increases P-use efficiency, minimizing nutrient losses. Cost-effective technology to generate energy from nutrient-containing waste streams, as part of a sustainable nutrient recycling strategy.

Major Challenges from a Soils Perspective

Soil is the medium -- the foundation -- of the food system and enhances the functioning capacity of the agricultural production and ecosystem. A major research and education initiative needs to be built around overcoming soil constraints, and reversing soil degradation. The term soil health has been used for this concept, but for many people this has a different connotation. Essentially, we need to grow more food on the same soils.

Growing more food will be very difficult with less water. With groundwater aquifers becoming depleted and climate change affecting surface water supplies, we need to find ways to use water more efficiently, and also enhancing the soil water productivity in crop production, together with better crop genetics.

Soil carbon offers one of the best win-win opportunities around climate change mitigation and soil productivity enhancement. We still have not yet fully explored the opportunities, like more radical enhancement of soil quality through better carbon management, especially in lower soil horizons.

Gradual soil acidification is a long-term consequence of intensive food production, but the remedy of applying a liming material can be very expensive and often dismissed by absentee landowners, so acidification continues. Sustained use of current irrigation water supplies and development of alternative supplies can result in mounting soil salinity levels that often hinder food crop growth. These are both ancient agricultural concerns, but present significant long-term threats to soil quality and food security. There are very limited marketplace resources available to advance strategies or technologies that are able to mitigate these problems; so public funding is an essential element of research. There is currently no large-scale regional/national assessment or monitoring of these two concerns, so coordination between state agencies and institutions should be a first step. Research efforts should be coordinated and targeted toward identifying agronomic management systems that include, but are not limited to, developing tolerant crops, improving water use efficiency, and enhancing the efficacy of remedial materials.