American Society of Agronomy • Crop Science Society of America • Soil Science Society of America
5585 Guilford Road, Madison WI 53711-5801 • Tel. 608-273-8080 • Fax 608-273-2021
www.agronomy.org • www.crops.org • www.soils.org

# The Food-Energy-Water Nexus in Agronomy, Crop and Soil Sciences

February 4, 2016

In the fall of 2015 the Agronomy, Crop Science and Soil Science societies put out a call for white papers to help inform the National Science Foundation (NSF) about the critical interdisciplinary research needs the societies have identified for meeting the global challenges of balancing food security for an increasing population natural resource conservation. The identification of these research priorities will help guide the focus of the new Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS) program and help inform the NSF INFEWS program leaders of areas for future funding opportunities important to our sciences.

Scientists from each of the Societies' Science Policy Committees completed their review of the white papers in early 2016 and have compiled an executive summary that represents the consensus of ideas discussed in the white papers.

The white papers will also be available on a public online forum where they can be downloaded and viewed freely. The forum will remain open and we have encouraged our scientists to continue to submit new white papers as they develop new ideas and opportunities about the food-energy-water nexus.

**Table of Contents**

# Improve Genetics, Environment, and Management in Agricultural Production

**MAIN IDEA**

Water scarcity truly defines the nexus between the escalating effects of climate change and the limits to crop production worldwide. Future agricultural production for a growing human population will be limited by rainwater and irrigation supplies, as already 75% of global freshwater is used for current agricultural production. However, the progress towards developing drought-tolerant crops operationally in field production environments has been slow. Therefore, there is a significant need for drought research that uses a combined approach between whole-plant physiology, genetics, environment, and management with the primary focus being testing hypotheses in relevant production conditions.

**FOOD-ENERGY-WATER NEXUS**

Obtaining greater efficiency from water, solar radiation, and nutrients in agricultural production will require a combination of research in genetics, environment, and management (G x E x M). This concept recognizes that no one single process or component of the overall system will be able to effectively increase efficiency, but rather synergies among components must be addressed. Understanding the G x E x M complex could increase efficiency by selecting plants for particular environments and adapting management practices to alleviate stresses during the growing season. Addressing the system-level understanding of the G x E x M complex will have enormous impact on food security and adapting agriculture to respond to climate changes.

**RESEARCH GAPS**

Incorporate multidisciplinary science into research and development efforts to improve food production and simultaneously enhance environmental quality by building transdisciplinary teams of agronomists, geneticists, plant pathologists, entomologists, weed scientists, crop advisors, soil and water scientists, natural resource managers, agricultural engineers, rural sociologists, and human nutritionists to evaluate the response of different genotypes to stress and management practices that use key physiological and phenotypic traits for sustainable crop production in variable environments.

Given the complexity of G x E x M interactions, there is a need for comprehensive, meta-scale data analysis approaches (bioinformatics) that elucidate the often subtle differences in E and M that result in large phenotypic or yield and quality differences.

Develop and implement more robust tools for assessing leaf photosynthetic efficiency and canopy interception of light to be able to screen increasing amounts of germplasm across multiple environments and management systems. Capture of solar radiation is essential to improving yields;

however, food security can only be achieved when solar radiation is converted into harvestable, high-value products.

# Big Data and Modeling for Agriculture

**MAIN IDEA**

Developing agricultural systems that respond to real-time status of soil, water, energy, and market conditions will require combining large data sets with efficient modeling algorithms. Large data management strategies and enhanced modeling will be necessary to improve viable recommendations and predictive capabilities. Implementing accurate and precise recommendations to improve agricultural systems would optimize productivity and sustainability.

The increasing volume of agricultural data can be developed into a spatial framework to achieve robust predictions of agricultural system performance at regional, national, and global scales. A large challenge is to design a spatial framework that incorporates regional data at various resolution levels and can account for the majority of environments where agricultural production takes place.

By taking this approach, such a framework can be used to evaluate productivity and environmental performance of agricultural systems more generally, informing strategic investments in agriculture and policy decisions.

Fundamental agricultural research is performed by utilizing both experimentation methods and modeling to understand interactions. However, neither experimentation nor modeling in isolation can address key questions adequately, especially system sustainability, because of the complexity and dynamic nature of agricultural systems. A quantitative description of the processes and the linkages among individual system components and their interactions is needed to apply or interpolate research results to conditions or spatial and temporal scales that are different from experiments. Integrating results from experimentation with system analysis and simulation modeling in a holistic manner is required to achieve the needed increased productivity and reduced environmental impacts of agriculture.

**FOOD-ENERGY-WATER NEXUS**

Optimization of food-water-energy issues can be achieved with system integration of experimentation, improved data stewardship, systems analysis, and modeling. Accurate models that describe water and energy use in producing food can enable more rapid development of agricultural production systems to optimize use of water and energy for individual agroecosystems.

**RESEARCH GAPS**

The primary research gap is an understanding of individual components and their interactions in the system, and predictions of their behaviors at different temporal and spatial scales. Future research should focus more on integrated approaches. Both modelers and experimentalists will benefit and our potential to address current challenges will increase substantially. In addition, such an approach has the potential to contribute to "big-data" driven science. Calibrated models have the capacity to generate big-data that can be analyzed using descriptive statistical approaches and develop decision support tools to assess risk-management and trade-offs in agriculture. In addition, such models linked to climate data and models can provide opportunities for improving real-time management decisions.

The major fundamental science research gaps are identified as (1) measurements of soil, crop, and environmental parameters to accurately describe crop growth and development and associated soil conditions; (2) integrative modeling techniques to utilize the data describing plant growth such that the model is predictive over time and space; and (3) information systems that utilize real time data to make crop management decisions.

# Soil Health

**MAIN IDEA**

Soil is fundamental to life, and yet, management of soil is often considered of low priority. The concept of soil health recognizes that effective management of soil is important for immediate food production, but also for long-term maintenance of the resource for important soil functions to continue to (a) provide food, fiber, feed, and fuel, (b) regulate water and energy flow, (c) support a large and important diversity of soil organisms, and (d) culturally enrich our human population with healthy ecosystems. The science of soil health is relatively new, as conservation agricultural management approaches can have different impacts on the widely varying number of soil types and climatic conditions around the world. Soil health management requires understanding of the properties and processes of biological, physical, and chemical components of soil that interact in complex manners over time and space. Carbon, water, and energy flows are important drivers of developing and maintaining healthy soil. The future of humankind depends on healthy soil that can provide sufficient food over a diverse landscape and control environmental quality sufficiently to allow co-existence of these two seemingly disparate goals.

**FOOD-ENERGY-WATER NEXUS**

Soil – the medium that provides support and sustenance for crops – acts as a crucial nexus between food, energy and water. It is the medium where water, gas, microbes, plants and fauna intersect. Technical issues of understanding the mechanisms, incidence, variability, and consequences of soil management are important, but socio-economic decisions of how we manage soils to function effectively without compromising future potential are equally important.

**RESEARCH GAPS**

Holistic assessments are needed of how soil managed for food, fiber, feed, and fuel production might negatively or positively impact important ecosystems processes in the short- and long-term. Management of current production systems could jeopardize our ability to manage for sustainable food production in the future with uncertain water availability and energy resources. Balanced food-energy-water management systems are needed now and into the future. Understanding the mechanisms involved is an essential part of soil health science.

Greater understanding is needed of the mechanisms, incidence, variability, and consequences of soil health management practices, in particular with regard to the interactions between water, gases, soils, microorganisms and plants. Linking the form of soil health characteristics to soil function is essential.

# Agroecology

**MAIN IDEA**

Our understanding of food production needs to expand beyond a focus on increasing yields to address issues of food access, waste, affordability, quality and healthfulness as well as larger impacts on natural resources and societal systems. In addition, these concepts need to be implemented not only in large-scale centralized production, but our approaches must encompass production on a range of scales and with the lens of a multi-functional landscape. Landscape structure design can help build more resilient food, energy, and water systems by including diversity and high biological productivity in plants, animals, and soils. The discipline of agroecology encompasses the robust scientific assessment of agroecosystems, considering aspects from the production, economic, environmental impact, and societal approaches. Agroecological research can improve our fundamental understanding of how natural and managed systems interact to produce food while protecting and regenerating limited natural resources and other valuable ecosystem services. A strategic agroecological approach to landscape design can lead to innovations that are resilient in varying climates and focus on development of sustainable human and environmental approaches that account for public health outcomes.

**FOOD-ENERGY-WATER NEXUS**

Maintaining resilience in the agroecosystem helps to support food quality, improve the efficiency of energy resources used in food production, and helps sustain water, soil, and other resources. DeLonge et al. list many connections between agroecology and the FEW Nexus in their white paper, "A Call for Agroecology in the NSF INFEWS Program." Research questions include:

- What are the links between landscape structure, soil biogeochemistry and microbiology, and food quality?
- Can soil carbon sequestration through soil management or land use changes be maximized to reduce the net climate change impacts of food systems?
- What foods can and should be grown in a future with new water resources challenges, considering both healthy food needs and energy limitations?

**RESEARCH GAPS**

Defining geographic regions where key agro-ecological principles and practices are most effective is needed to meet the challenges of conserving water resources, reducing energy consumption, and increasing renewable energy.

One challenge is to capture and store excess water at its 'highest point' in a watershed, then use it for food or energy production in water-short areas that may be separated from the capture area in space or time.

Design of biologically rich agricultural landscapes that are resilient to extreme events, such as water and energy shortages, while providing health and nutrition is needed. Applying an ecological lens to agricultural systems can improve our fundamental understanding of how natural and managed systems interact to produce food while protecting and regenerating limited natural resources and other valuable ecosystem services.

Strategic agroecological approaches to landscape design could contribute to healthy food production systems that offer multiple ecosystem services and long-term ecosystem health while being able to improve resiliency in increasingly complex food systems.

# Nutrient Use Efficiency in the FEW Nexus

**MAIN IDEA**

Nutrients, particularly nitrogen and phosphorus, are essential elements for life and are required in large amounts for plant growth. To meet 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. Phosphorus is a paradoxical input. Currently phosphorus inputs to agriculture are mined and those sources will run out at some point. Global and regional distribution of phosphorus does not correlate with need. Recycling strategies (i.e., manure, organic materials) are under-researched.

Excess application of nutrients in the environment has several detrimental consequences. Nutrient pollution is one of the most damaging economic and environmental problems in the United States 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.

**FOOD-ENERGY-WATER NEXUS**

Optimizing nutrient inputs to agricultural systems will benefit food production and water quality protection, as well as reduce energy inputs from fertilizer production.  Production of fertilizer nitrogen is an energy intensive process. Mismanagement of nitrogen and phosphorus can pollute both surface water and groundwater or result in crop deficiencies that reduce productivity and the efficient use of water and other system resources.

Sharpley et al. in "Reframing Phosphorus Stewardship for Resilience in Food-Energy-Water Security," lists key research opportunities and technologies needed to help achieve sustainable nutrient management. Greater nutrient use efficiency can help minimize tradeoffs, and catalyze synergies to improve resilience among components of the water, energy, and food security nexus. A shift in policies from separate water, energy, and food strategies to a more holistic approach to nutrient management will be needed.

**RESEARCH GAPS**

Due to the importance of nitrogen and phosphorus to the nexus of food-energy-water systems, NSF's INFEWS initiative should establish an interdisciplinary Nutrient Science program that would coordinate research efforts with existing grant-funded Research Coordination Network on Reactive Nitrogen (but have a broader scope and greater continuity) and the International Nitrogen Initiative.

Nitrogen is key to improving food production, but it also has negative impacts in the environment. Excess nitrogen in surface water runoff results in algal blooms and low-oxygen in coastal waters and rivers. Research is needed to optimize the biological benefits of nitrogen in agricultural systems, while reducing negative impacts on humans and the environment. Such research must improve the understanding of fundamental nitrogen transformations in the environment, and provide data to improve modeling of these transformations to enable real-time management responses to environmental conditions.

Fundamental research is needed to understand phosphorus biogeochemical transformations that reduce the availability of soil and applied phosphorus to plant roots. Enhancing agricultural production with lower phosphorus fertilizer inputs is possible with improved understanding and implementation of integrated crop-livestock systems. Phosphorus transformations from organic sources must be better understood to enable more efficient recycling of phosphorus from biosolids and manures.