Advancing Science for Sustainable Agriculture

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# Introduction and Background

Ensuring sustainable management of agricultural lands has emerged as an issue important to not just the farmers working the land but to stakeholders who rely on the crops and environmental services provided by the land. The common ground of all stakeholders is a desire to support an agricultural system that can persist in its ability to supply adequate food, fiber and fuel to a growing population now and in the future while protecting land and water resources and the surrounding environment. Individual stakeholders are also working toward improving specific environmental consequences related to agriculture, such as improving soil health, enhancing biodiversity and species protection, reducing greenhouse gas emissions and protecting water resources. These challenges become more difficult as climate change impacts weather patterns, requiring rapid adjustment and adaptation by farmers and the systems and technologies they rely on.

Many of these stakeholders have formed organizations to support their collective vision with collaborative convening and development of programs to support sustainability. One of these is Field to Market, a collaborative multi-stakeholder initiative comprised of over 140 member organizations, whose mission is to define, measure, and advance sustainability in U.S. agricultural production. Field to Market has developed a Supply Chain Sustainability Program to advance this mission by providing a measurement and benchmarking Platform, educational, convening and programming resources for driving continuous improvement in environmental outcomes, and a verification program for transparent documentation of participation and progress.

Over more than a decade of program development, Field to Market has aimed to remain grounded in best available science by engaging with experts to help guide, develop and review the methods and measures used for assessing sustainability. In 2016, Field to Market established a Science Advisory Council of 12 individuals with expertise in aspects of sustainable agriculture to help ensure adherence to the guiding principles and provide expertise and connections to the scientific community. Field to Market also relies on expertise from 16 member Universities, collaborations with USDA, and a system of peer-review by independent scientists for key technical and scientific elements of the program.

# Purpose

In the course of developing and implementing the program and in consultation with scientific experts, Field to Market has identified a series of research gaps – areas where advances in scientific understanding are needed to support further action on sustainable agriculture in the field. This document aims to articulate areas of research where such gaps in our collective understanding limit the development of tools and programs to engage land managers and other agricultural stakeholders in changing their practices to reduce environmental impacts. Our aim is to highlight for research funders and scientists what we see as critical areas in need of focus and investment to help drive changes in practices at the scale necessary to improve environmental outcomes on agricultural lands nationwide.

Our focus on these specific topics is informed by the scope and experience of the Field to Market program over the past decade, in particular:

* The Field to Market program is focused on providing tools that work for all farmers in the US, across a range of climate, soil, and crop management systems. In some instances, technical tool and metric development is limited because while research has been conducted on a topic, the available studies are not generalizable across soils, regions, or cropping systems. In those instances, the primary need is to expand the scope of research to investigate variability in system processes and performance across space and time, and coordinate data repositories, so that meta-analyses and model development can access the full range of information necessary.
* The Field to Market technical program relies on computer models of environmental outcomes to provide sustainability metrics. In most instances the metrics use simpler models than the research models commonly in use by the scientific community. A general area of interest is development of complex biophysical model validation, calibration and error quantification to support robust parameterizations that would enable use of research-quality models by non-experts, including development of meta-modeling or surrogate modeling approaches.
* Development of research and modeling approaches that are scalable are also a high priority.While working to achieve change at the individual field level, there is additional need to understand the region-wide impact of the practice changes. For example, a sustainability project may have documented practice changes among a small group of farmers in a watershed and be interested in understanding if those changes have had an impact on water quality at the watershed level.
* Just as important as the technical tools used, the Field to Market sustainability program requires developing guidance for partner organizations on how to work with farmers to achieve lasting, long-term conservation practice adoption. Programs also provide educational materials for farmers and agronomic advisors that indicate in straightforward terms what the impact of practice changes is expected to be on the environmental outcomes. These topics connect agronomic sciences with social sciences and economic analysis, and a significant gap is the limited scientific understanding of what motivates behavioral and cultural change in farming communities, and what are common barriers to change in farming practices.

Given these considerations and scope, we have focused on four areas that we see as priorities, where scientific progress would contribute substantially to advancing sustainable agriculture efforts in the United States. We also acknowledge areas where critical research efforts are on-going and where we support continued efforts and investment.

# Research Gaps in Sustainable Agriculture

## 1. Science to Support Cultural Transformations

Challenge: Achieving adoption of sustainable agricultural practices across large areas of US agricultural land requires reaching landowners and managers beyond the innovators, early-adopters, and scope of government programs that provide financial incentives for adoption of conservation practices. Conservation and sustainability programs often hit barriers to greater adoption when working to reach beyond these progressive growers with efforts to incentivize adoption of new practices and techniques.

While anecdotes abound, there is a lack of scientific research on identifying the barriers to adoption and the most effective strategies to overcome the barriers. We believe such research is most effective when farmers and educators are involved in the research planning and design, rather than considered only as recipients of scientific findings. Farmers are individualistic and recognize the diversity in farming, which leads to some skepticism that results seen in test plots or on other farms will work the same for them. Involving producers as participants (without requiring them to become experimentalists) and studying adaptive management can lead to more rapid insights into motivation and behavior.

This is an interdisciplinary research need, and the social barriers to adoption likely vary significantly based on the agronomic practice being recommended. Advancing research in this area would provide guidance to investments by both the public and private sector stakeholders in their efforts to meet sustainability goals by motivating and supporting change on the farm.

Research Questions**:**

* How effective are existing and emerging programs at encouraging long term change in practices? What can we learn from studying the maintenance and persistence of best management practices in areas where they have been adopted successfully? What role do social and community networks play in conservation practice adoption?
* What can we learn by understanding the impact of historical “catalyst” events such as market or regulatory changes, and severe weather events? Under what conditions do such events lead to sustained change in farming practices?
* Is there a “tipping point” or fraction of farmers in a community that, once they successfully adopt a change will lead to more widespread adoption in that community? Or a saturation point beyond which greater adoption in a specific community is unlikely? What are effective strategies for targeting adoption by specific growers who have a significant resource concern (e.g. because of their position in the landscape or other natural environmental factor)?
* Research has indicated that extrinsic motivation (e.g. payments for practices) is less effective at achieving long term change than intrinsic motivation (e.g. feeling it is the right thing to do). What influences intrinsic motivation on conservation practice adoption and sustainability awareness among farmers and farming communities?
* What role do structural barriers play in adoption of better management practices for nutrients, pesticides and irrigation water? For example, is the fertilizer storage capacity in a community a factor in how many farmers adopt split-application practices for nutrient management?
* What role do contractual barriers and incentives play – in lease agreements with non-operator landlords, bank loans, other financial services, and sourcing contracts?
* To what extent, or at what level, are initiatives by the private sector additional to government initiatives?
* Can significant forcing events in economics or policy (e.g. decision on Monarch endangered species listing) be used as opportunities to study farmer and landowner behavior and decision-making changes?
* For specific sustainability objectives, what is the most effective form of regulatory action, and who would be the winners and losers?

## 2. The Nitrogen Cycle and Sustainability

Challenge: Nitrogen (N) is a critical nutrient in plant growth and crop yield but can also represent a significant environmental concern when N not taken up in plant growth is lost to the air and contribute to greenhouse gas concentrations and air pollution (e.g. nitrous oxide, ammonia) and excess nutrients in surface water that can lead to eutrophication and water quality concerns. Nitrogen can be recycled within an ecosystem from plant growth, residues and organic amendments such as manure and compost (recycled N) or can be added from outside the system through manufactured fertilizers or nitrogen fixation by legumes (reactive N).

Nitrogen cycling through managed ecosystems is complex, and frequently research focuses on one loss pathway or factor in order to isolate the effects. However, this leaves large gaps in understanding of how combinations of environmental characteristics and management practices interact to impact nitrogen cycling. As a result, explicit actionable guidance on best management of nitrogen for farmers to minimize losses while producing a crop is incomplete. In addition, computational models and metrics to predict N loss from an agricultural field are limited by the same gap in full N cycle system research.

**Research Questions**:

* As farmers adopt practices that increase recycled N in the system (e.g. cover crops, crop residue management), what guidance can be provided on how this impacts their overall N availability throughout the year? Are revised fertilizer recommendations needed to ensure the right timing of applications in systems with residue retention and cover cropping? What recommendations do farmers follow, and what is the process for updates with new research?
* Should recommendations be revised for cover cropping systems? What does it take to make those revisions – new scientific findings, who is responsible for the process, and what funding is required?
* How is Nitrogen credit from legumes (e.g. soybean) factored into current recommendations?
* Improve ability and tools for farmers to assess the sub-field loss vulnerability of different N pathways, to guide precision agriculture adjusted applications of N. Improve understanding of how remote sensing and precision agriculture technologies can capture in-field variability in factors influencing the fate of N.
* One major environmental impact of nitrogen management is emissions of nitrous oxide (N2O), a greenhouse gas. However, research is lacking on the full GHG emissions impact of different N management practices – both how the practice impacts the nitrous oxide emissions and how it alters other management behavior that consumes energy or resources (e.g. energy for split applications of fertilizer).
* Methods to select research sites for field level studies systematically are needed in order to capture the impact of factors identified as important, in regions where data are currently limited, and facilitate model development and deployment across regions. What spatial frameworks are needed to help accelerate research across diverse agricultural systems?
* Environmental models that assess impacts of management practices on outcomes do not currently consider the risk to overall production or profitability and what measures can be taken to mitigate the risks. This leads to fertilizer decisions made as “insurance” rather than strictly based on plant nutrition requirements.
  + Recommendations on timing where the consideration in not trying to mitigate yield losses but to capture potential productivity at the right times (e.g. when rains typically occur)
  + What are the economic cost savings from precision ag and zone management approaches that match fertilizer recommendation to yield potential in a given year? Could long-term weather forecasts/seasonal outlooks be used to adjust recommendations to minimize N losses?
* A significant portion of nutrients in harvested grain are used in livestock production, which is not uniformly distributed across our agricultural landscapes. What are the implications of nutrient flows in current crop and livestock production systems for beneficial re-use and environmental losses? What approaches and technologies are needed to more effectively address risks associated with issues of spatial concentration, imbalances in nitrogen:phosphorus ratios, and asynchronous timings between manure application and crop uptake

## 3. Getting to Field scale with Water Quality Research and Data

Challenge: Agriculture in the US contributes to substantial challenges in managing water quality in surface water streams, lakes and estuaries, impacting aquatic system health and drinking water resources for communities. As mentioned in the previous section, nutrient cycling in agroecosystems is complex and research often treats it in discrete nutrients and loss pathways rather than in a comprehensive view at production field scale that would facilitate farming practice recommendations and scientific model development. Water quality challenges relate to a broad set of practices, from how organic and inorganic nutrient applications are managed to how landscapes are configured to speed or slow the movement of water. It is also subject to substantial variability based on weather events – the primary determinant of nutrient loss is runoff from rainfall. At the same time, measurements of water quality have typically focused on in-stream monitoring systems; while necessary, these measurements do not provide information that can be used in understanding individual farm field contributions to nutrient concentrations in surface waters.

The lack of field level measurements has limited the development of modeling approaches that can provide producers with individualized guidance on the nutrient losses from their operations. While both simple and complex modeling approaches exist, they are generally not well parameterized or calibrated to measured data for field scale water quality outcomes across broad regions and diverse cropping systems.

Research Questions and Needs:

* Established centralized database for collection of field scale data and assessment of important regions and agricultural systems that are not well characterized from past and current studies. This may involve coordinating among existing data repositories to create common formats and structures.
* Additional programs of field-scale data collection, specifically to fill gaps in understanding, that follow established standards to ensure the data collected can be used in meta-analyses and model development. Developing networks of data collection should focus on priority regions with a high level of resource concern.
* Improved survey statistics on fertilizer use – rates, forms and management practices, to use in landscape analyses to understand sources and solutions for water quality and researcher access to industry fertilizer use information at a level that will be beneficial to research without compromising business sensitive information.
* Best practice guidance for how researchers can successfully gain farmer trust to collect and share data for advancing research.
* Advances in the emerging technology of water quality sensors – can these be developed at the scope and scale that would enable use of data collected in model development? Can educational programs be developed to use the information collected in providing actionable feedback to farmers on how to reduce nutrient losses?
* Understanding the tradeoffs between N and P losses from specific practices and in specific regions.
* Full nitrogen budget studies that combine research on losses to water and to the air to inform our understanding of the complete N budget.

## 4. Sustainable Solutions to Pest Management

Challenge: Management of weeds, insects and diseases on agricultural lands is a major consideration in any farming operation to prevent reductions in crop yield and quality. A range of chemical approaches have been approved by the USEPA with specific requirements for applicator training and use to reduce risks from chemical use. Overall, usage of agricultural chemicals has continued to increase even as public awareness and concern about the presence of chemical residues in foods and impacts on the environment have also increased. At the same time, increased reliance on specific chemicals and increased homogenization of cropping systems has accelerated and expanded pest development of resistance, creating a management challenge for farmers.

What are sustainable solutions for managing pests that prevent damage to crops and also limit the risk to ecosystem and human health from pesticides? Two elements need to be considered to estimate risk – potential for exposure to the chemical, and the toxicity of the chemical.

Research Questions:

* What technology solutions exist to manage and reduce risk, and how can these be made feasible and affordable options for farmers to achieve greater adoption? For example:
  + Can precision agriculture be designed to automate Integrated Pest Management (IPM) strategies (Prevention, Avoidance, Monitoring and Suppression)?
  + Can engineering solutions be accelerated to reduce pesticide drift from application equipment including pesticide-contaminated dust from seed treatments?
  + How quickly can existing and emerging technology be adopted to precisely target applications to locations within a field or plant where pests are present?
  + Can mechanical seed destruction technologies assist with reducing herbicide-resistant weeds?
* How successful are resistance management strategies? For example, what is the adoption and demonstrated effectiveness of establishing refugia on farms and in regions with high adoption of seeds with herbicide resistance traits or plant-incorporated pesticides, e.g., Bt corn or cotton?
* What could be done to increase the success of refugia at providing habitat for diverse ecosystems, including pollinators?
* What are the current structural barriers to greater adoption of IPM practices? For example, to what extent do farmers find it difficult to diversify/extend crop rotations due to limitations such as seed availability, markets or prices? Is precision timing of applications limited due to trained applicator capacity and schedules?
* To what extent have pesticide risk and negative impacts been reduced as pesticide use has increased?
* What role can agricultural dealers, industry and public awareness play in surfacing challenges and solutions – for example, options to purchase seeds without seed treatments added?
* How will pests shift with climate, what is being done to prepare/forecast where challenges may arrive next? How can farmers/extension and other ag stakeholders be alerted to emerging threats?

## 5. Critical Research Programs: Opportunities and Examples

In addition to the four areas detailed above, we recognize that there remain many priority areas for research to advance sustainable agriculture. Several of these are the subject of important ongoing research programs, and so we chose not to further highlight them here. Rather, we recognize the importance and encourage ongoing investment and effort to address the challenges identified. These include:

* Research on soil health to develop standardized soil health tests, a national soil health assessment, targeted educational guidance including economic impacts to farmers, and research on understanding the dynamics of the soil microbiome and the impact of biological soil amendments. Field to Market works closely with a number of organizations active in this research and supports those ongoing efforts.
* Development of process-based crop and agro-ecosystem simulation models, including improved understanding and rapid characterization of uncertainty, and the use of machine learning for rapid calibration, and other technology improvements designed to improve reliability and usability of such tools. The agricultural modeling community has self-organized through the ongoing AgMIP (Agricultural Model Intercomparison Project) and Field to Market supports the community efforts towards these improvement models and system understanding.

# Next Steps

Field to Market is continuing to develop specific research questions and further explore the research gaps identified here by soliciting feedback throughout the Fall of 2019. In mid 2020, Field to Market will host a workshop to finalize a set of recommendations on research needs to advance sustainable agriculture in the United States. Field to Market will then work to communicate these collectively identified research needs to appropriate funding organizations. Our goal is to accelerate research investment that will contribute to closing the gaps.