AGree
Transforming
Food & Ag Policy

Towards a Knowledge Infrastructure for Science-Based Policy and Sustainable Management of Agricultural Landscapes

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Foreword

AGree drives transformative change by connecting and challenging leaders from diverse communities to stimulate policy innovation and develop initiatives that address critical challenges facing the global food and agriculture system. AGree believes we must elevate food and agriculture policy as a national priority.

AGree's work addresses four broad challenges facing the global food and agriculture system:

- Meet future demand for food;
- Conserve and enhance water, soil, and habitat;
- Improve nutrition and public health; and
- Strengthen farms and communities to improve livelihoods.

We have taken a deliberative, inclusive approach to develop a policy framework and ongoing, complementary initiatives to meet these challenges. To overcome traditional obstacles to change, we engage a broad array of stakeholders whose insights and commitment contribute to meaningful solutions. AGree's work, building on our research to better understand problems and assess options, aims to stimulate creative ideas and encourage new perspectives while fostering the linkages key to catalyzing effective action.

In this paper, three economists discuss the importance of a knowledge infrastructure for agriculture and its potential to improve on-farm decision making as well as support the sustainable management of working landscapes. The authors probe the challenges and opportunities of linking many streams and sources of data (including private data, such as site-specific biophysical data and land management practices, and public data, such as weather and climate data and market conditions) as well as models into an integrated infrastructure that maintains the privacy of proprietary information while enabling improved decision-making at multiple scales. They conclude that a well-designed voluntary system could provide participants with data and management tools that demonstrably improve a farm's economic and environmental performance while providing the public, researchers, and policy-makers with the information necessary to more effectively analyze policy tradeoffs and to improve land management policies.

This publication is part of a series intended to broaden discussion and complement AGree's consensus recommendations on policies and actions focused on food and agriculture. While the concepts presented in this paper have greatly enriched the deliberations of the AGree Co-Chairs and Advisors, the perspectives and positions do not represent consensus among them.

We hope you find this paper a helpful resource.

Deborah Atwood
Executive Director

Contents

Summary

In this paper we discuss a knowledge infrastructure that has the potential to simultaneously improve on-farm decision making as well as the sustainable management of agricultural landscapes. The utilization of precision farming and mobile technologies, together with improvements in data management software, offer expanding opportunities for an integrated data infrastructure that links farm-level decisions based on site-specific biophysical data to policy tradeoff-analysis decision tools based on landscape-scale data and models. Having joint access to such a data infrastructure would enhance private and public land management decisions and help to achieve desired environmental and social outcomes.

We describe some of the features that might be associated with a new, voluntary data system, including improved data quality and public acceptability. A well-designed voluntary system could provide participants with data and management tools that demonstrably improve a farm's economic and environmental performance. The costs of providing such services could be covered in part by reducing the use of more costly paper-based survey instruments and enumerators. However, to obtain the needed statistical representation, it may be necessary to provide monetary incentives or to require that participants in government subsidy or conservation programs also participate in the data system.

A viable data and knowledge infrastructure will require long-term financial support. We envisage a private-public partnership that supports the creation of a collaborative "pre-competitive space" for data collection and research that would support the infrastructure's development and maintenance. A key question is how both private and public resources can be pooled to achieve this goal. In our view, a coordinated pilot program funded through a private-public partnership would be the best way to test the feasibility of this approach.

Introduction

Sustainable management of agricultural landscapes is a goal that is widely shared; to maintain and improve food availability and quality while also maintaining and enhancing the natural resource base on which agriculture and all of society depend. Today, these goals are being expressed in various ways; in calls for managing "agro-ecosystems" to enhance "ecosystem services," in the need for "land sparing or land sharing" land use policies, and via the promotion of "sustainable intensification" and "climate smart agriculture."[1] To achieve such goals, farmers, ranchers, and other users of land and ecosystems need the best information, tools, opportunities, and incentives to make decisions that maintain and enhance water and air quality, soil health, biodiversity, and human quality of life now and in the future.

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Making informed decisions at the farm or landscape scales is not easy; important information is often missing or consequences are not easily identified. The relationship between land management decisions and desired outcomes is complex and requires coordination among land managers, public institutions, private sector leaders, and others in society. Recognizing these challenges, both governmental and non-governmental organizations in the United States have established an array of data, knowledge, and institutional arrangements that together constitute an "infrastructure" that supports management of agricultural landscapes. Over time, this infrastructure has evolved along with public policy towards what we will describe as "science-based policy" – that is, policy designed to achieve the goal of sustainably managing agricultural landscapes as efficiently and effectively as possible given the best-available science and technology.

The science-based approach to agricultural policy is not new. The soil conservation policies created after the Dust Bowl of the 1930s developed and encouraged soil conservation practices on farms and ranches across the United States based on the science of that era. Today those early conservation efforts have evolved into a comprehensive set of policies and programs at federal and state levels designed to manage agricultural landscapes in ways that meet both private and public goals, as embodied in the Agricultural Act of 2014 and other policies (see Box 1). As growing demands are placed on agricultural landscapes, a comprehensive approach to data, knowledge and its use for landscape management – a knowledge infrastructure – is needed.

The objective of this paper is to discuss how the knowledge infrastructure could be improved by exploiting emerging technologies together with new approaches to data acquisition and utilization. This paper provides an overview of the kinds of information needed to support science-based policies for sustainable landscape management as well as improved on-farm management, and describes the features of a knowledge infrastructure that could provide this information. Such an infrastructure should bring together the advances in agricultural sciences with the rapidly growing capabilities of data acquisition technologies, as illustrated by "big data" and "open data" initiatives.[2]

The increasing utilization of precision farming and mobile technologies, together with improvements in data management software, offer expanding opportunities for an integrated data infrastructure that links farm-level management decisions to site-specific bio-physical data and analytical tools to improve on-farm management. This has been recently referred to as "prescriptive farming" and is seen by the industry as an opportunity to better deal with the inherent risk in farming.[3] These data can also be integrated with public data at the landscape scale for research and policy analysis. Analytical tools using data at the landscape scale could provide the improved understanding needed to support science-based policy and sustainable management of agricultural landscapes.

Much of this growing volume of new data is private – for example, information about where and when agricultural operations occur, and their consequences. There is also a growing amount of public data, such as remotely-sensed data. A critical feature of the new knowledge infrastructure is that it must be able to measure, store, manage, and integrate both private and public data in ways that respect the privacy and proprietary interests of individuals while enabling diverse stakeholders to benefit from improved information and analyses. A private-public partnership could support the development and testing of data systems that improve farm-level management while also contributing to the goals of science-based policy and sustainable landscape management. We conclude this paper by identifying new initiatives for private and public data acquisition and management that demonstrate the feasibility and potential for a new knowledge infrastructure similar to what we envisage.

Box 1 | Agricultural Landscape Management Programs: Land Retirement and Working Lands

The Conservation Reserve Program (CRP) aims to conserve and improve soil, water, and wildlife resources by temporarily removing land from agricultural production (10-15 years). The USDA offers annual rental payments and cost-share assistance to farmers to establish long-term conserving cover, primarily grasses and trees, on land that has been in row crop production.

The Conservation Stewardship Program (CSP) is a voluntary program which encourages land stewards to improve their environmental performance on working lands. CSP provides financial and technical assistance to help producers adopt new practices, as well as improve, maintain, and manage existing practices on agricultural land and nonindustrial private forest land. Under CSP, participants are paid for conservation performance: the higher the operational performance, the higher their payment, based on the Environmental Benefits Index.

For a variety of other conservation programs administered by the USDA such as The Grasslands Reserve Program, Farmable Wetlands Program, etc. see: http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=landing.

Science-Based Policy and Sustainable Landscape Management

A large and growing body of scientific knowledge from agricultural, environmental, economics, and social science disciplines exists as a foundation upon which a science-based policy for agriculture can be improved, starting with the idea that agriculture is a "managed ecosystem."[4] The scientific literature has established that farmers' land management decisions affect biological and physical systems through a number of mechanisms. Some effects, such as changes in soil productivity, may be limited to the land owned by the farmer; others, such as runoff into surface waters, may appear offsite. A key insight from this body of scientific literature is that agricultural productivity depends upon and plays a key role in providing a set of "ecosystem services" ranging from food production to the provision of clean water and maintenance of biodiversity.[5]

There are two types of policies and programs being used for agricultural landscape management, often referred to as "land conservation" or "land retirement" and "working lands" policies, closely related to the ideas of "land sparing" and "land sharing" used by ecologists for wildlife management.[6] Examples of two such programs in use in the United States – the Conservation Reserve Program and the Conservation Stewardship Program – are described in Box 1.

In addition to managing agricultural landscapes, since the 1930s, agricultural policy in the United States has also sought to improve the economic well-being of agricultural households through a variety of subsidy programs that transfer income from taxpayers to agricultural producers and landowners. There are two potentially important ways that subsidy and science-based policies interact. First, subsidy policies may affect producers' land management decisions, and may either complement or conflict with the goals of sustainably managing agricultural landscapes – a point that will be discussed in some examples presented below (see Box 2). Second, science-based policies also can affect the incomes of agricultural households and landowners, and may either complement or conflict with

Box 2 | Tradeoffs between Subsidy Policies and Science-Based Landscape Management Policies: Nutrient Management, Soil Management, and Biofuels Policy

Improved nutrient and soil management have been major goals of agricultural conservation policy for decades, motivated first by the soil erosion that caused the Dust Bowl and later by additional resource concerns, including the water quality issues arising from high levels of fertilizer application. However, achieving agricultural conservation goals appears to conflict with the goals of the Renewable Fuel Standard enacted in 2007 and other policies that aim to reduce U.S. dependence on foreign oil, reduce greenhouse gas emissions, and strengthen rural economies.[12] Since early 2000, biofuels production (primarily corn-based ethanol and soy-based biodiesel) has increased over 600 percent[13], increasing the demand for corn and soy, and supporting the rise of biofuels processing facilities which have boosted local rural economic activity.[14] However, recent research has also documented unintended environmental impacts of these policies[15], such as decreases in groundwater quality and increases in surface and groundwater pollution, caused by increased use of nitrogen fertilizers and the return of land in conservation reserve programs to crop production.[16] Some of the additional nitrogen ultimately is transported to the Gulf of Mexico and may have increased the size of the hypoxic zone.[17] This policy has also been linked to higher grassland conversion which has adverse ecological impacts[18], may be encouraging farmers to allow Conservation Reserve Program contracts to expire, and may be aggravating the problem of harmful algal blooms in water bodies such as Lake Erie. An improved knowledge infrastructure would facilite the evaluation of these tradeoffs between these different economic and environmental effects of a policy promoting biofuels.

the goals of subsidy policies. Both the resource efficiency and the distributional effects of policies are important to agricultural producers and to others in society, and need to be taken into account in designing science-based policies. Indeed, there are inevitably trade-offs among the various private and public goals related to the management of agricultural landscapes. A fundamental role for the knowledge infrastructure needed to support science-based policy is to improve our understanding of these trade-offs so that stakeholders can make informed choices among policy alternatives and their likely impacts.

Assessing Synergies and Tradeoffs Among Private and Public Goals

Economics provides an analytical framework to evaluate the need for policy interventions, given sufficient physical, biological and economic data. In this framework, typically described as "benefit-cost analysis," private outcomes (e.g., farm income generated by producing and selling crops and livestock) are combined with the value of "non-market" outcomes, such as maintaining water quality and biodiversity, to determine the management strategy that yields the best outcome for society. In principle, if all policy options could be evaluated in this way, the best option could be identified. To implement this benefit-cost framework, however, both quantities and values of marketed goods are needed (e.g., quantity and price of corn produced), as well as quantities and values of non-market outputs (e.g., nutrient concentration in surface water and the environmental or health damages caused by it).

While it is straightforward to measure and value market outcomes such as the amount and value of corn produced in a given area, it is difficult to quantify and value non-market outcomes such as changes in ecosystem services (e.g. water quality). With adequate scientific understanding, spatially-relevant data and suitable measurement technologies, it is possible to objectively quantify the non-market outputs (e.g., to track and measure the nutrient concentrations and loadings in water). But in many cases, valuing non-market outputs is exceedingly difficult. For example, contamination of water by nutrients such as nitrates may have adverse impacts on human health, and it may be possible to estimate the magnitude of these effects, but it is difficult to attach a monetary value to health effects that is generally accepted by the affected people and society. Similarly, ecosystem services such as biodiversity are difficult to quantify and value in monetary terms. For these reasons, strict application of the "benefit-cost analysis" approach to the design of science-based policies faces serious challenges.

An alternative to benefit-cost analysis is what we refer to as "policy tradeoff analysis."[7] Rather than attempting to attach monetary values to ecosystem services, the tradeoff analysis approach defines a set of quantifiable economic, environmental and social "indicators" that can be used to assess the status of the agricultural landscape and outcomes associated with it. Alternative policies are evaluated in terms of the interactions among these indicators. In this approach, there is no one "solution" or best policy because different stakeholders may value tradeoffs between outcomes (indicators) differently. However, the tradeoff analysis approach has the virtue of providing the various stakeholders with the information they need to make these value judgments.

Tools suitable for policy tradeoff analysis already are in use in some aspects of agricultural policy design (see Box 3 and the discussion below). Many types of indicators have been developed for policy analysis.[8] Various measures of farm household well-being are used, such as farm income and its distribution among geographic regions and among different types of farms.[9] Measures of environmental outcomes and ecosystem services are available from direct measurements and from models, including soil quality and productivity, air and water quantity and quality, greenhouse gas emissions, and wildlife habitat. For example, the U.S. Department of Agriculture has constructed an "environmental benefits index" to assist in the design and implementation of the Conservation Reserve Program (CRP) and the Conservation Security Program (CSP) that combines a number of different environmental indicators into a summary measure.[10]

Box 3 | Examples of Farm-Level Analysis and Decision Tools

DSSAT (Decision Support for Agro-Technology Transfer) is a crop simulation model that has been in use for more than 20 years. The simulated yields are based on site-specific daily weather data, soil characteristics, and crop management activities. It is used by farm managers, researchers and policy decision makers, to evaluate how changes in crop characteristics, management and environmental conditions may impact crop yields.

AgBalance™ is an assessment tool designed by BASF to analyze the sustainability of agricultural practices on the farm and throughout the chain of production. It is based on environmental, economic, and social indicators that are aimed at helping producers balance demand with sustainable production. It can be used to assess current agricultural practices, identify areas for potential improvements, assess the impact of regulations on products and farming practices, and demonstrate the relationship between farming practices and biodiversity or resource consumption. Findings from this process can be presented to policymakers and partners throughout the food production chain.

AgTools™ - The AgTools programs(AgProfit™, AgLease™, AgFinance™) were developed to help growers assess operational investment choices with the aim of making profitable decisions. AgProfit™ can help make short, medium, and long-run investment decisions based on profitability. AgLease™ can help establish equitable short and long-run crop share and cash rent payment leases based on each party's contributions to the lease. AgFinance™ can assist in making long-run decisions on a whole farm and ranch basis based on financial rations and performance measures.

Comet 2.0™ is an online tool that provides estimates of carbon sequestration and net greenhouse gas emissions for U.S. farms and ranches. It was originally released in coordination with the Department of Energy's guidelines for the voluntary reporting of greenhouse gas emissions and emission reductions. Producers enter their current and alternative agricultural practices, and the COMET2 program then estimates changes in fuel use, fertilizer, carbon and net greenhouse gas emissions from soil and biomass for each alternative. It can also be used as an evaluation tool and can report the effectiveness of various land management systems for agricultural soil carbon sequestration.

Cool Farm Tool is an online, farm-level, greenhouse gas emissions calculator. The tool allows farmers to test alternative management scenarios and identify practices that have the potential to reduce greenhouse gas emissions. It can also calculate soil carbon sequestration. This tool was originally developed to measure on-farm greenhouse gas emissions and several multinational companies are using it to work with their suppliers to measure, manage, and reduce greenhouse gas emissions in an effort to mitigate climate change.

Farm Smart is an online environmental footprint calculator for dairy farms. Producers enter data on the farm location, feed production, herd size, ration, energy use, etc. which is used to calculate their environmental footprint. They can then compare their farm's footprint to regional and national averages. An enhanced decision support feature is expected this year (2014) that will help producers track improvements and optimize production practices in order to minimize their environmental footprint.

Integrated Farming SystemsSM is a system developed by Monsanto that provides farmers with field-by-field recommendations for ways to increase yield, optimize inputs and enhance sustainability. Monsanto has developed an iPad app that combines historical yield data, satellite imagery, field information about soil and moisture, and plant varieties to make customized variable rate seeding prescriptions for individual fields, thus maximizing the yield potential by field.

FarmSightTM is a system by John Deere that uses precision technology and wireless data to enable machine-to-machine communication, optimize machinery productivity and reduce downtime. It also includes monitors, sensors, and wireless networks that provide access to machinery and agronomic data allowing farmers can make informed management decisions.

Pioneer Field360TM Select Software, developed by DuPont Pioneer, this software combines current and historical field data with real-time agronomic and weather information to help growers make informed management decisions. Offered with this web-based software is Pioneer Field 360 Notes app, which growers can use to take notes and photos with GPS tags to track field agronomic status. The growers have the option to confidentially share information in real time with DuPont agronomists.

Smartphone Apps for Agriculture – There are myriad new smartphone apps for agriculture, ranging from farm management to commodity pricing. One example of a how smartphone apps can provide farmers with immediate management decision tools is the FieldScout GreenIndex+ app from Spectrum Technologies, Inc. With this app, growers take a picture of their crop, and the app computes a dark green color index, which can provide nitrogen application rate recommendations. This provides growers with a low-cost method for managing in-season fertility, which can improve yields, lower nitrogen costs, and increase profits. All results are georeferenced, logged, and can be emailed for archiving or further analysis.

Data and Analytical Tools to Improve On-Farm Decisions and Science-Based Agricultural Landscape Management

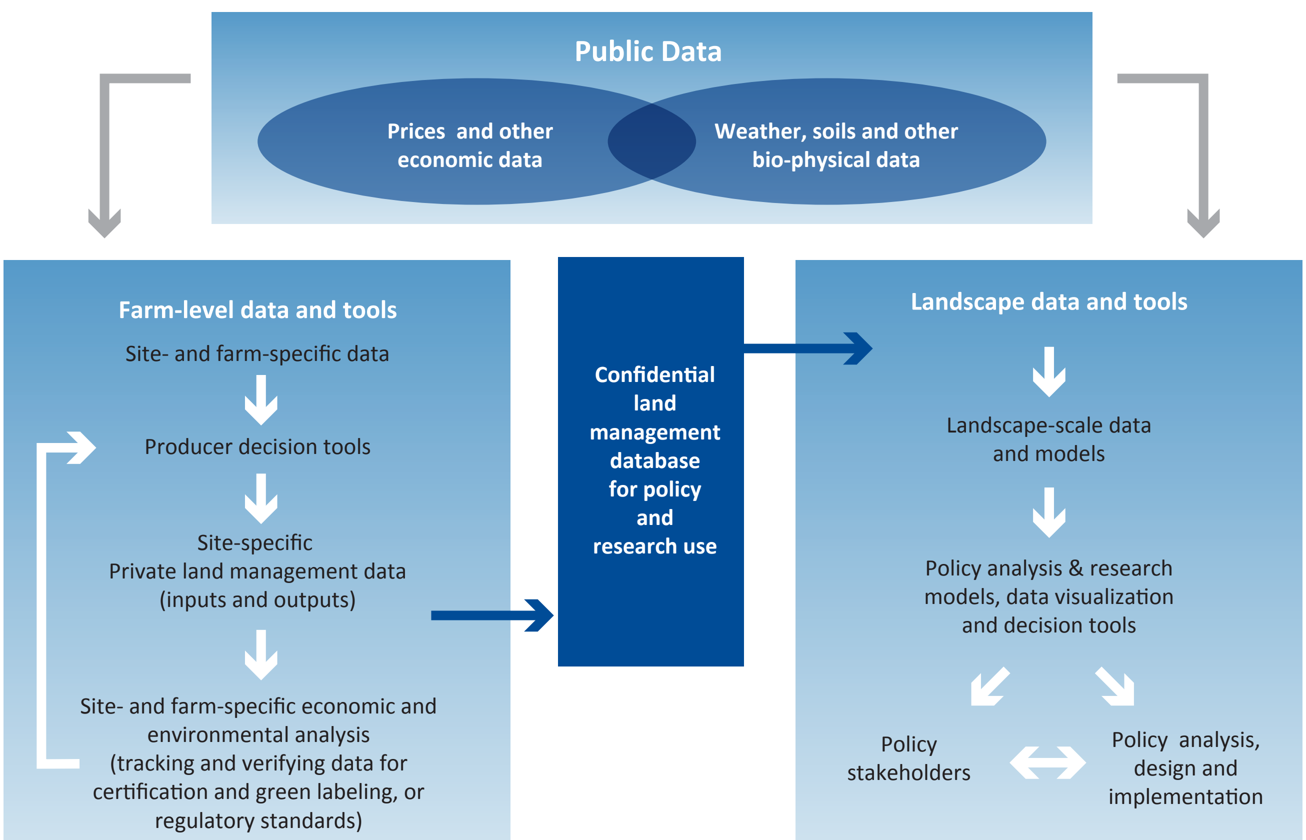
The U.S agricultural sector, like nearly all parts of our global economy, is becoming data-rich due to advances in mobile measurement and other technologies, but needs better data management and analytic capabilities to make use of the volume of data that will be available in the near future. The combination of improved data analytics and decision tools leads to another challenge: how to make effective use of these new tools to improve on-farm economic and environmental performance, and also design better policies for landscape-scale management?

Figure 1 provides an overview of the features of farm-level data and decision tools, landscape-scale data and analytical tools that support science-based policy, and their interrelationships. While farm-level decision making and landscape-scale analysis have different purposes, they both depend on both private data (site- and farm-specific characteristics of the land and the farm operation, and the site- and farm-specific management decisions that are made) as well as public data (weather, climate and other physical data describing a specific location, as well as prices and other publicly available economic data). A key question for the design of the agricultural knowledge infrastructure is how both types of data can be collected, managed, and utilized efficiently and securely.

Farm-level data and decision tools

Various farm-level data and decision tools are in use, and are evolving rapidly along with innovations in computer

Figure 1 | Linkages between data and decision tools at farm and landscape scales.



power, software, mobile information technologies, and technologies for site-specific management. The lefthand side of Figure 1 presents the generic structure of these tools, the data they use as inputs, and the outputs that are generated. Box 3 describes some of the decision tools and software that are now in use. A key feature of these tools is that they use both public (e.g., prices, weather forecasts, and policy information) and private (site- and farm-specific input use, farm size, and machinery) data to generate detailed information and outcome-based data that are useful for farm-level management decisions. This information and data can be used to monitor the economic and environmental performance of a farm operation over time and space. The value of these data for improved farm management performance should motivate producers to collect accurate information. In addition, producers increasingly need detailed management data for purposes of quality certification, e.g., for organic or sustainability certification, or to meet regulatory standards.

There are various issues that need to be addressed in advancing the use of these tools for management, certification and related purposes:

- How to make data acquisition and analytical tools appropriate for and easy to use by farm-level decision makers (both farmers themselves and organizations that provide management services);
- How to facilitate the use of data and management tools through effective outreach programs that communicate the value of the tools and the importance of the data for private and public uses;
- How to improve methods for the evaluation of data quality and the accuracy and reliability of the analytical tools; and
- How to ensure the confidentiality, security, and appropriate use of private data when it is shared, either for private decision making purposes or for research and public policy analysis.

Privacy concerns have been the subject of recent discussions among farmers and commodity organizations as they explore the use of new technologies and big-data analytics.[11]

Regional data and models for landscape management and policy tradeoff analysis

Besides the use of site- and farm-specific information for financial planning and analysis of net returns of the farm operations, more and better data are needed for policy and research purposes. The right hand side of Figure 1 shows the general structure of the data and models needed to carry out landscape-scale research and policy tradeoff analysis. There are three broad categories of regional data: publicly available biophysical data, including down-scaled climate and soils data; publicly available economic data, including prices and policy information; and the confidential site- and farm-specific data obtained from producer- and industry-generated databases. As with other data currently being collected from individuals and farms (e.g., Agricultural Census, medical records), there is a need for these data to meet confidentiality standards in their storage and use for research purposes.

Box 4 briefly describes some of the biophysical and economic models that are being used for landscape-scale analysis. As with farm-level decision tools, there is a need to more systematically develop and apply methods for the improvement of these models, for example through model inter-comparison studies such as those being undertaken by the Agricultural Model Intercomparison and Improvement Project. Typically these models require spatially and temporally explicit data that are statistically representative of the farms and landscapes in a geographic region in order to provide reliable information about economic and environmental impacts and tradeoffs. Such data are not usually available for most of the United States. As a result, these models rely on the publically available information on land management collected periodically through mailed questionnaires or enumerator interviews, which usually limits the spatial dimension of the models to the county or zip code level. This situation means that models must be operated with averaged data that may fail to accurately represent site-specific environmental processes and outcomes.

Box 4 | Examples of Landscape-Scale Tools for Research and Policy Analysis

SWAT (Soil and Water Assessment Tool) is a watershed-scale model designed to simulate the quality and quantity of surface and ground water, and predict the environmental impact of land use and land management practices. It can be used to aid policymakers and land managers in assessing soil erosion prevention and control, non-point source pollution control, and regional management in watersheds.

EPIC (Environmental Policy Integration Model) is used to compare land and forest management systems and their effects on environmental indicators like water availability, nitrogen and phosphorous levels in soil, and greenhouse gas emissions. For example, based on soil type and prevailing climatic conditions, EPIC can be used to estimate the extent to which nutrients from fertilizer, such as nitrogen, are leaching into nearby river and stream networks.

TOA-MD (Tradeoff Analysis for Multi-Dimensional Impact Assessment Model) uses a statistical description of a farm population in a geographic region to simulate the adoption and impacts of a new technology or a change in environmental conditions. TOA-MD uses economic data from the population of farms (detailed input and output data) as well as data from other models (e.g., crop simulation designed to simulate what would be observed if it were possible to conduct a policy or technology adoption experiment) and is designed to analyze technology adoption/impact, ecosystem service supply, and environmental change and adaptation. http://tradeoffs.oregonstate.edu.

REAP (Regional Economic Analysis Program) is a model developed by the Economic Research Service of the USDA. This economic optimization model is used to simulate how changes in economic conditions and policy affect regional production and farm incomes. By linking this model with others such as EPIC and SWAT, REAP can also be used to project impacts of economic and policy changes on environmental outcomes.

The currently available data are inadequate for various reasons. Many of these data are collected with samples that are not statistically representative of relevant regions or populations for landscape-scale analysis; many data are not spatially or temporally explicit, are only available (released) after substantial aggregation (thus limiting their usefulness), and are often available with long time lags between when the land management decisions are made, the data are collected, and when they become available for research or policy purposes. For example, the 2012 Agricultural Census data did not become available until 2014, and then only in limited ways for the purposes of research and policy analysis. Longitudinal data are particularly important for policy research, i.e., representative samples that provide data for the same farms over time. At present, most of the data available for research or policy analysis are not longitudinal, and one of the most valuable longitudinal surveys, the National Resources Inventory, was curtailed in 2002 and since then has only been publicly available in summary (averaged) form.

Considerations for design and implementation

Two kinds of strategies could be used to create a new knowledge infrastructure, a voluntary system or a mandatory system. There are a number of advantages to a voluntary system; it is likely to generate better quality data if participants are motivated to provide accurate information, and it is also more likely to be politically and socially acceptable. For a voluntary system to work, participants need to receive value in return for the costs of participation. As noted above, this value could be a quid pro quo in the form of providing management tools and data that improve a farm's economic and environmental performance, and also provide data valuable for product quality certification or regulatory compliance – a new form of "extension service." Another approach could be to provide financial compensation for the participants' time. The in-kind and monetary compensation approaches could also be combined in various ways. The costs of a voluntary system could be covered, at least in part, by reducing the use of more costly paper-based survey instruments and enumerator interviews.

Another motivation for producers to support a voluntary approach would be to reduce the "respondent burdens" with the present system of multiple mail-based and personal interview surveys used to collect data periodically (e.g. the Agricultural Resource Management Survey, the National Resources Inventory, the Agricultural Census, and others). Under an integrated system much of the baseline information is acquired and stored once, as a part of a farm operation's ongoing management system, rather than being collected multiple times and in a time-inefficient manner. This information could be updated in a far more cost effective and time-saving way, through mobile or web-based technologies.

There would be various challenges to the implementation of a voluntary approach. First, it may not be possible to achieve the needed statistical representation of all regions and farm types needed for research and policy analysis. One way to ensure adequate representation would be to combine a voluntary system with monetary compensation for participation. Another strategy would be to require participants in voluntary government subsidy, conservation or environmental payment programs to participate in the data system.

Another major challenge would be to maintain data confidentiality and address privacy concerns. It is clear from the online financial transaction systems now in widespread use, as well as new agricultural data initiatives, that data can be securely transmitted and stored electronically (see Box 5). However, a critical issue with site-specific data is that the identity of the data source can sometimes be inferred from the location associated with the data, either because there is a small

Box 5 | Examples of Private and Public Data Initiatives

AgGateway is a non-profit consortium of businesses serving the agriculture industry promoting eBusiness in agriculture. They provide an information and communication technology link between producers, suppliers, and wholesalers in agriculture that allows a more open exchange of data within the industry and reduces duplication of data entry. AgGateway has active councils in Crop Protection, Crop Nutrition, Seed, Feed, Ag Retail, Precision Ag and Allied Providers.

On-Farm Network®, developed by the Iowa Soybean Association, works with farmers using precision agriculture tools to discover, accurately validate, and increase the use of the right combinations of inputs and practices that improve efficiency, profitability and environmental stewardship. Data are collected by the On-Farm Network and relative information is reported back to the farmer to inform on-farm management decisions. Aggregated data are also used for research purposes.

AgMIP (the Agricultural Model Intercomparison and Improvement Program) is developing data translation tools and a data management system to make climate, crop, and economic data needed for landscape-scale analysis publicly available for research and policy analysis.[19]

The National Opinion Research Center's Data Enclave is making farm-specific data from the USDA's Agricultural Resource Management Surveys available to researchers using secure, web-based technology.

Monsanto recently acquired the Climate Corporation, which has developed an analytics and risk management product that uses hyper-local weather monitoring, agronomic data modeling, and high-resolution weather simulations to provide a suite of full-season monitoring, analytics and risk management products. This tool can help farmers improve yields on existing farmland and better manage risks that occur throughout a crop season.

John Deere recently joined with DuPont combining Pioneer® Field360™ services (a suite of precision agronomy software) with John Deere Wireless Data Transfer architecture (JDLink™ and MyJohnDeere) in an attempt to provide services that will improve precision agriculture. The wireless data transfer system will make data exchanges faster and more convenient, and enable farmers to make important seed, fertilizer and other input purchasing and management decisions, based on the latest field data from their individual fields. This involves incorporating analytical data on soil types, fungicide application timing, weather patterns, and pest management.

number of respondents in a spatial unit such as a zip code area, or because spatial coordinates are associated with data. There are various ways that confidentiality can be maintained when site-specific data are used for research and policy analysis. For example, once spatially-explicit data are recorded and integrated into a database, identities of the decision maker and precise locations do not need to be known to be useful for most research and policy analysis purposes. These kinds of procedures are currently being used with confidential data such as the Agricultural Census and the Agricultural Resource Management System (National Opinion Research Center Data Enclave) as well as with non-agricultural data such as the Census of Manufacturers data collected and maintained by the Department of Commerce.

A Path Forward: A Private-Public Partnership for Better Data

We envisage innovative private-public partnerships to advance the development of a new knowledge infrastructure for agriculture in which individuals voluntarily share and use information that is valuable for them and that can be used to promote the public interest. Much of the data needed for this new system are already being collected by individuals, the federal government, and private companies, and innovative initiatives are demonstrating the feasibility of acquiring, storing and using data securely and efficiently (Box 5). Currently, various private and public entities are simultaneously engaged in development of technology and software for data collection, for collecting and storing data, and for developing analytical tools. One of the greatest challenges is determining how data that are already being collected both privately and publicly can be better coordinated to lower costs, improve quality, and more efficiently meet both private and public needs. One solution to these challenges appears to be a private-public partnership among the various organizations that have a mutual interest in assuring that the data are obtained efficiently and used appropriately for both private and public purposes. In effect, there is the need to create a "pre-competitive space" for the development of data and analytical tools that is built on the recognition that there are important public-good attributes of the data, methods, and analytical tools.

A private-public partnership for a new knowledge infrastructure could be supported by various stakeholder organizations, including producer and industry organizations, agricultural commodity organizations, the International Life Science Institute's Center for Integrated Modeling of Sustainable Agriculture and Nutrition Security, technology firms such as Google, Facebook and Twitter, and charitable foundations with an interest in agriculture. Governmental organizations also should be involved, including USDA's National Institute for Food and Agriculture and Risk Management Agency, and research organizations promoting better public data such as the Agricultural Model Intercomparison and Improvement Project. A critical issue is how long-term funding for the creation and maintenance of the data and knowledge infrastructure will be achieved. While short-term research funding can make an important contribution, on-going support will need to be provided to create and maintain the data system. Thus, a key question is how both private and public resources can be pooled to support the data and knowledge infrastructure.

A coordinated pilot program funded through a private-public partnership could develop and test innovative approaches to incentivize data sharing and facilitate data acquisition, management, storage, and utilization. Public domain software such as AgTools (see Box 3) could be made available to producers with support from agricultural extension organizations and agri-business firms. This software can be linked to a cloud-based data retrieval and storage system, such as the one being developed by private data programs like On-Farm Network and public ones like AgMIP (Box 5). In our view, this kind of coordinated pilot program, funded through a private-public partnership, would be the best way to test the feasibility of the approach to establishing a data and knowledge infrastructure for agriculture that we have outlined in this paper.

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