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Next generation data systems and knowledge products to support agricultural producers and science-based policy decision making

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ABSTRACT

Research on next generation agricultural systems models shows that the most important current limitation is data, both for on-farm decision support and for research investment and policy decision making. One of the greatest data challenges is to obtain reliable data on farm management decision making, both for current conditions and under scenarios of changed bio-physical and socio-economic conditions. This paper presents a framework for the use of farm-level and landscape-scale models and data to provide analysis that could be used in NextGen knowledge products, such as mobile applications or personal computer data analysis and visualization software. We describe two analytical tools - AgBiz Logic and TOA-MD - that demonstrate the current capability of farmlevel and landscape-scale models. The use of these tools is explored with a case study of an oilseed crop, *Camelina sativa*, which could be used to produce jet aviation fuel. We conclude with a discussion of innovations needed to facilitate the use of farm and policy-level models to generate data and analysis for improved knowledge products.

1. Introduction

In the introduction to this special issue, Antle et al. (2016b) discuss the critical need for data, models and knowledge products that provide user-friendly data acquisition and analytical capability for decision makers. The use cases range from farm-level decision support, to the agricultural research community and donors making research investment decisions, to policy decision makers whose goal is the sustainable management of natural resources. Janssen et al. (2016) provide examples of data and information technology structures that illustrate how private and public data components could be developed for such use cases. Jones et al. (2016) argue that the most important current limitation is data, both for on-farm decision support and for research investment and policy decision making. One of the greatest data challenges is to obtain reliable data on farm management decision making both for current conditions and under scenarios of changing bio-physical and socio-economic conditions.

This paper discusses how farm-level decision models can be used to support farm decision making and to provide data for landscape-scale models for policy analysis. In the second section of this paper we provide an overview of the kinds of information needed to support science-based policies for sustainable landscape management as well as improved on-farm management. We describe how existing decision support tools could be used to develop a data infrastructure that can provide this type of information. In sections three and four we describe a landscape-scale policy analysis tool (TOA-MD) and a farm-level decision support tool (AgBiz Logic) that could be used to support landscape scale and farm level decision-making. Section five illustrates the use of these tools with an analysis of the economic potential for a new oilseed crop, *Camelina sativa*, to be incorporated into the winter wheat-fallow system used in the U.S. Pacific Northwest. In the concluding section we discuss the challenges that will need to be addressed if these and other similar data and modeling tools are to be integrated into data and modeling platforms that could support new knowledge products for both farm and policy decision makers.

2. The need for better data, models and knowledge products

Both governmental and non-governmental organizations have established a wide variety of data, knowledge and institutional arrangements that together constitute an “infrastructure” that supports management of agricultural landscapes. This physical and institutional infrastructure differs greatly around the world, but all have in common the very substantial challenge of acquiring timely, site-specific data and combining it with analytical tools to improve the quality of decision making from farm to landscape scales. To varying degrees, this decision making infrastructure has evolved in many countries 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.

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A large and growing body of scientific knowledge from agricultural, environmental, economic and social science disciplines exists as a foundation on which a science-based policy for agriculture can be further advanced, starting with the idea that agriculture is a "managed ecosystem" (Antle et al., 2001; Antle and Capalbo, 2002; Swinton et al., 2007). 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 (Reid et al., 2005).

There are two types of policies and programs being used for agricultural landscape management often referred to as "conservation" and "working lands" policies, closely related to the ideas of "land sparing" and "land sharing" used by ecologists for wildlife management (Phalan et al., 2011). In addition to managing agricultural landscapes, agricultural policy in many countries 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. The biofuel policy we discuss later in this paper is an example of a working land policy designed to produce environmental benefits by substituting biofuels for fossil fuels while maintaining food crop production.

These and other types of domestic and trade policies may affect producers' land management decisions, and may either complement or conflict with the goals of sustainably managing agricultural landscapes. For example, the biofuel development program investigated later in this paper shows that subsidies may be required to achieve its goals of increasing biofuel crop production, but may also reduce food crop production and increase food prices. 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 goal of 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.

2.1. Assessing policy synergies and tradeoffs

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. With adequate scientific understanding, spatially-relevant data and suitable measurement technologies, it is possible to objectively quantify the non-market. 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" (Crissman et al., 1998; Antle et al., 2014; Kanter et al., in press). 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 are already being used in research and policy design (Antle et al., 2014; Kanter et al., in press). Many indicators have been developed for policy analysis (Bates and Scarlett, 2013). 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. 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 conservation programs that combines a number of different environmental indicators into a summary measure (U.S. Department of Agriculture. Economic Research Service, 2006).

2.2. The need for better farm-level data and analytical tools

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. These farm-level data can 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 satellite imagery and weather and soil data, historical crop yields, and economic 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.

In addition to the need to be profitable and provide an acceptable standard of living for the farm household, farm decision making must increasingly respond to the requirements of environmental regulations and related public policies aiming to achieve more sustainable resource management. Farmers must also meet the demands by food companies and the public for assurance that sustainable and ethical practices are being used. All of these pressures – economic, environmental and social – create a need for better farm-level data and analytical tools.

New technologies began to provide new sources of "big data" for farm management beginning with the automation of agriculture 1990s. Machinery including tractors, chemical applicators, and

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