Agricultural Systems 155 (2017) 255–268

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

# Towards a new generation of agricultural system data, models and knowledge products: Design and improvement

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ARTICLE INFO

*Article history:*
Received 28 September 2015
Received in revised form 1 October 2016
Accepted 4 October 2016
Available online 3 November 2016

*Keywords:*
Agriculture
Systems
Models
Data
Knowledge products
Next generation

ABSTRACT

This paper presents ideas for a new generation of agricultural system models that could meet the needs of a growing community of end-users exemplified by a set of Use Cases. We envision new data, models and knowledge products that could accelerate the innovation process that is needed to achieve the goal of achieving sustainable local, regional and global food security. We identify desirable features for models, and describe some of the potential advances that we envisage for model components and their integration. We propose an implementation strategy that would link a "pre-competitive" space for model development to a "competitive space" for knowledge product development and through private-public partnerships for new data infrastructure. Specific model improvements would be based on further testing and evaluation of existing models, the development and testing of modular model components and integration, and linkages of model integration platforms to new data management and visualization tools.



## 1. Introduction

The idea of creating a new generation of agricultural system data, models and knowledge products (NextGen) is motived by the convergence of several powerful forces. First, there is an emerging consensus that a sustainable and more productive agriculture is needed that can meet the local, regional and global food security challenges of the 21st century. This consensus implies there would be value in new and improved tools that can be used to assess the sustainability of current and prospective systems, design more sustainable systems, and manage systems sustainably. These distinct but inter-related challenges in turn create a demand for advances in analytical capabilities and data. Second, there is a large and growing foundation of knowledge about the processes driving agricultural systems on which to build a new generation of models (Jones et al., 2017-in this issue B). Third, rapid advances in data acquisition and management, modeling, computation power, and information technology provide the opportunity to harness this knowledge in new and powerful ways to achieve more productive and sustainable agricultural systems (Janssen et al., this issue).

Our vision for the new generation of agricultural systems models is to accelerate progress towards the goal of meeting global food security challenges sustainably. But to be a useful part of this process of agricultural innovation, our assessment is that the community of agricultural system modelers cannot continue with business as usual. In this paper and the companion paper on information technology and data systems by Janssen et al. (this issue), we employ the Use Cases presented in Antle et al. (this issue A), and our collective experiences with agricultural systems, data, and modeling, to describe the features that we think the new generation of models, data and knowledge products need to fulfill this vision. A key innovation of the new generation of models that we foresee is their linkage to a suite of knowledge products – which could take the form of new, user-friendly analytical tools and mobile technology "apps" – that would enable the use of the models and

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http://dx.doi.org/10.1016/j.agsy.2016.10.002

their outputs by a much more diverse set of stakeholders than is now possible. Because this new generation of agricultural models would represent a major departure from the current generation of models, we call these new models and knowledge products "second generation" or NextGen.

We organize this paper as follows. First, we discuss new approaches that could be used to advance model development that go beyond the ways that first generation models were developed, and in particular, the idea of creating a more collaborative "pre-competitive space" for model development and improvement, as well as a "competitive space" for knowledge product development. Then we describe some of the potential advances that we envisage for the components of NextGen models and their integration. We also discuss possible advances in model evaluation and strategies for model improvement, an important part of the approach. Finally, we discuss how these ideas can be moved from concept to implementation.

## 2. Designing next generation models

### 2.1. A demand-driven, forward-looking approach

A first step towards realizing the potential for agricultural systems models is to recognize that most work has been carried out by scientists in research or academic institutions, and thus motivated by research and academic considerations more than user needs. A major challenge for the development of a new generation of models that is designed to address user needs, therefore, is to turn the model development process "on its head" by starting with user needs and working back to the models and data needed to quantify relevant model outputs.

The NextGen Use Cases presented in Antle et al. (this issue A) show that most users need whole-farm models, and particularly for smallholder farms in the developing world, models are needed that take into account interactions among multiple crops and often livestock. Yet, many agricultural systems models represent only single crops and have limited capability to simulate inter-cropping or crop-livestock interactions. Why? One explanation is that many models were developed in the more industrialized parts of the world where major commodity crops are produced. Another explanation is that models of single crops are easier to create, require less computational resources, and are driven by a smaller set of data than models of crop rotations, inter-crops or crop-livestock systems. Additionally, researchers are responding to the incentives of scientific institutions that reward advances in science, and funding sources that are more likely to support disciplinary science. Component processes within single crops, or single economic outcomes, are more easily studied in a laboratory or institutional setting, and may result in more publishable findings. Producing useful decision tools for farmers or policy decision-makers is at best a secondary consideration in many academic settings.

The need for more integrated, farming-system models has been recognized by many researchers for several decades, for example, to carry out analysis of the tradeoffs encountered in attempts to improve the sustainability of agricultural systems (Kanter et al., 2016). For example, Antle and Capalbo (2001) and Stoorvogel et al. (2004) proposed methods for linking econometrically estimated economic simulation models with biophysical crop simulation and environmental process models. Giller et al. (2011) describe a complex bio-physical farming system modeling approach, and van Wijk et al. (2014) review the large number of studies that have coupled bio-physical and economic models of various types for farm-level or landscape-scale analysis. More recent work by AgMIP has developed software tools to enable landscape-scale implementation of crop and livestock simulation models so that they can be linked to farm survey data and economic models (Porter et al., 2015). While these examples show that progress has been made in more comprehensive, integrative approaches to agricultural system modeling, these modeling approaches are more complex and have high data demands, thus raising further challenges to both model developers and potential users. As we discuss below, methods such as modularization may make it possible to increase model complexity while having models that are relatively easy to understand and use. Other methods, such as matching the degree of model complexity to temporal and spatial scales, also can be used. Section 3.8 further discusses issues of model complexity and scale.

While it is clear that model development needs to be better linked to user needs, it is also important to recognize that science informs stakeholders about what may be important and possible. Who imagined even a few years ago that agricultural decision support tools would use data collected by unmanned aerial vehicles linked to agricultural systems simulation models? So while model and data development need to be driven by user-defined needs, they must also be forward-looking, using the best science and the imaginations of creative scientists.

### 2.2. An open pre-competitive space for model development linked to a competitive space for knowledge product development

As Jones et al. (2017-this issue A) describe in their paper on the historical development of agricultural systems models, existing models evolved from academic agronomic research. While there was a sense that "decision support" was important, the model developments nevertheless began with research tools that were motivated primarily to better understand basic processes and effects on system performance. As long as model development is motivated primarily by academic and research outcomes, it will remain only loosely connected to user needs. Therefore, to re-orient model development towards user needs, a new set of institutional arrangements and incentives is needed. Fig. 1 presents a diagram of how these new arrangements might be organized. The figure shows the linkages between a "pre-competitive space" of basic science and model development, and the "competitive space" of knowledge product development. The concept of "pre-competitive space" grew out of the efforts of the pharmaceutical industry to collaborate on basic research while competing in product development. The arrows between these two "spaces" point both ways to represent the inevitable and important give-and-take.

The model development approach that now exists is largely missing the competitive space component shown in Fig. 1. To the extent that such a competitive space does exist, it is in the private sector where proprietary management support is being provided, and linkages in Fig. 1 from competitive knowledge product development back to data and model development are largely missing. In Fig. 2 we show how this link from private decision makers to models and public data could be made by connecting on-farm decision support tools to databases that could be used for model development and analysis (see the paper by Capalbo et al., 2017-in this issue, for elaboration of these ideas).

Facilitating a pre-competitive environment is likely to require innovations in the way research organizations operate, and may need to involve public-private partnerships (PPPs) that clearly delineate boundaries and roles in creating specific NextGen products. PPPs are one way that science and industry can collaborate to generate new applied knowledge that can feed into the creation of new business and services. In PPPs it is common that both private and public partners provide funding and jointly formulate the research questions that can subsequently be tackled by research institutes and universities. There are a number of challenges in structuring PPPs. For example, in the European Union PPPs have been regulated to avoid unfair competition. The EU regulations stipulate that there always has to be more than one private partner involved and intellectual property rights of the knowledge developed (e.g., tools, models, articles, methods) belong to the research partner, which can then license the use to private partners for commercial purposes.

An important aspect for a NextGen community of practice is openness. Open here means: first, inviting and engaging others to join and become involved; second, being ready to set priorities jointly with a broader stakeholder community (i.e. research programming, private