ARTICLE IN PRESS

Agricultural Systems xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Agricultural Systems

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

Editorial

Next generation agricultural system models and knowledge products: Synthesis and strategy

A B S T R A C T

The purpose of this Special Issue of *Agricultural Systems* is to lay the foundation for the next generation of agricultural systems data, models and knowledge products. In the Introduction to this Special Issue, we described a vision for accelerating the rate of agricultural innovation and meeting the growing global need for food and fiber. In this concluding article of the NextGen Special Issue we synthesize insights and formulate a strategy to advance data, models, and knowledge products that are consistent with this vision. This strategy is designed to facilitate a transition from the current, primarily supply-driven approach toward a more demand-driven approach that would address key Use Cases where better data, models and knowledge products are seen by end-users as essential to meet their needs.

1. Introduction

The purpose of this Special Issue of *Agricultural Systems* is to lay the foundation for the next generation of agricultural systems data, models and knowledge products. In the Introduction to this Special Issue, we described a vision for accelerating the rate of agricultural innovation and meeting the growing global need for food and fiber. The use of the new generation of models leads to 'virtual' and 'computational' agricultural research and development that can complement, and increasingly substitute for, conventional, 'on-the-ground' experimental methods. Likewise, significantly improved data and models can contribute to development of advanced farm-management systems, and by making better information available about new systems, could accelerate the adoption and efficient use of more productive and more sustainable technologies. Such data and models are also essential tools for assessing the landscape-scale impacts of technologies, evaluating policies to improve resource management, and projecting the performance of technologies under changing climatic and other environmental conditions.

In this concluding article of the NextGen Special Issue we aim to synthesize insights and formulate a strategy to advance data, models, and knowledge products that are consistent with this vision. As the papers in this Special Issue show, there are many ways that agricultural systems data and models could be improved and linked to new and more-effective knowledge products. Here we focus on the high-level insights that will help inform a strategy for moving the field of agricultural systems science to meet the NextGen goals we have identified – namely, forming the foundation for a computational agricultural science that can move agriculture regionally and globally toward sustainable systems that can meet the food security, nutrition, and health challenges of the 21st Century.

2. Closing the gaps between data, models, and knowledge products

2.1. The data imperative

Data are the foundation for all science and for agricultural systems analysis. A theme throughout the Special Issue is the need for better data from a wide range of systems and settings. Indeed, better data may be the single greatest need and challenge to achieving the NextGen vision. In the "State of Science" paper, Jones et al. found data limitations to be a common theme among the five Use Cases described in the Introduction to the Special Issue. Jones et al. argue that limitations of current agricultural system models and tools are mainly rooted in inadequate data, and that data limitations are far more important than gaps in basic science understanding and conceptual approaches. Moreover, data limitations restrict predictive capabilities, and this in turn erodes model credibility among users, a key point we return to below. Existing models could address many important Use Cases with better data.

Antle et al. (in this issue) also emphasize the challenge of the need for better data and identify it as a key element of both the 'pre-competitive

http://dx.doi.org/10.1016/j.agsy.2017.05.006

0308-521X/

space' of data and model development as well as the 'competitive space' of knowledge product development. They describe an approach that would integrate on-farm decision support systems with landscape-scale data and models for policy decision support. Capalbo et al. (in this issue) elaborate an example of this approach using existing models that could be linked with current information technologies. A key issue in implementation of obtaining better data for models is how to create incentives for farmer participation, as well as the participation of the private-sector knowledge product industry that is rapidly advancing.

Data is also a main theme of the paper by Janssen et al. (in this issue). They find a need for both technology and data innovations to meet the needs of the Use Case personas. They describe opportunities to improve data inputs into models through better utilization of existing and new sensor and data collection methods, including remote sensing, crowdsourcing, and mobile technology. They also discuss new tools to generate, archive, access, analyze, visualize, and interpret model inputs and outputs. The paper by Donatelli et al. (in this issue) emphasizes the need for better data to improve the quality and availability of data for pest model inputs and evaluation. They also note that ongoing climate change means that existing data on yield losses from pest damage are becoming obsolete, illustrating the challenges of incorporating non-stationarity into on-going agricultural model development.

The paper by Hwang et al. (in this issue) on incorporating genetic information in crop models highlights the need for a different type of data to improve crop model capabilities. Geneticists and plant breeders typically conduct experiments using a large number of genotypes (e.g., hundreds during their process of germplasm selection for new varieties), while agronomists and crop modelers typically include only a few genotypes combined with different environments and management. Incorporation of genetic information in crop models will enable the models to better simulate interactive genetic, environment, and management effects on production (GxExM), and to do this without having to collect additional data to estimate genotype-specific parameters as is the normal practice now (see White and Hoogenboom, 2010; Messina et al., 2006; Hammer et al., 2006). Characterizing genotype-specific parameters is becoming practical due to the inexpensive and rapid genotyping now widely available to research organizations and the private sector. As pointed out in Hwang et al. (in this issue), data are needed that include a wider range of diverse genotypes combined with a range of environments to develop relationships needed to incorporate gene-based features in crop models. For this reason, extensive collaboration is needed between crop modelers, geneticists, and breeders to design the relevant experiments and obtain appropriate genotype and phenotype response data to use in developing and evaluating the models.

2.2. Closing the gap between models and users

The papers in this Special Issue as well as stakeholder consultations by the NextGen author team and by the Agricultural Model Intercomparison and Improvement Project (AgMIP) show that a second key challenge to be addressed is the gap between models and users. This gap manifests itself in several ways.

First, the Use Cases introduced in the Introduction to the Special Issue, as well as many other Use Cases, demonstrate that most users of model outputs do not need or want direct interaction with models; rather, they need to be able to access information in ways and forms that are useful to them. Whether decisions involve farm-level management or high-level policy, it is necessary to take into account the biophysical and economic context in which the relevant systems are operating. Yet, the review of the agricultural systems models in the background papers shows that few, if any, current agricultural systems models are designed to link efficiently to context-specific data and to work with user-friendly applications.

A second gap between models and users identified by stakeholders concerns the credibility of agricultural systems models. Stakeholders emphasize the need for transparent evaluations of agricultural models so that the models will be accepted as part of the evidence base for making farm management decisions and for policy formation. To achieve this goal, several papers in this Special Issue emphasized the need for context-specific analysis to provide evidence of model capabilities and evaluation of model uncertainty. Quantification and communication of uncertainties related to data, parameterizations, and scenarios can contribute to building confidence in agricultural models.

Third, many users now need to know more outcomes than crop yields alone. The goal of assessing system sustainability has extended the scope to include economic and environmental outcomes, as well as other consequences for human well-being such as nutrition and human health. These dimensions add even greater data demands, and are hampered by the less-developed state of quantitative models for some outcomes such as nutrition and health. As a result, current modeling studies often resort to ad hoc procedures, such as using simple empirical models when process-based models are not available.

Spatial and temporal scales are also related to relevance. Detailed studies of "representative farms" or "case studies" cannot be credibly used as the basis for policy decision-making that necessarily must consider larger geographic regions and significant proportions of human populations. Designing comprehensive 'systems' models remains a major challenge to be addressed by 'out-scaling' of better inter-operable model components.

3. NextGen strategy

Our strategy for the next generation of data, models, and knowledge products is based on the insight that to achieve the NextGen vision, agricultural system research must transition from a primarily supply-driven (i.e., science-driven) approach, toward a more demand-driven (i.e., end-user or stakeholder-driven) approach. This re-orientation is necessary to guarantee that the key gaps identified above will be addressed, and it is needed to garner financial support for investments in NextGen data, models and knowledge products. In our estimation, NextGen developments for agricultural systems will not be supported primarily through conventional funding for basic or applied science. Rather, the needed investments increasingly will be made to address key Use Cases where better data, models and knowledge products are seen by the ultimate users as essential to meet their needs. We expect these investments to be made by both public and private-sector organizations willing to support important Use Case applications.

These investments in NextGen should be implemented through an elaboration and extension of AgMIP's two-track science approach (Rosenzweig et al. 2013) that incorporates the key insights outlined above. The two-track science concept is based on parallel and coordinated activities that involve: (1) improvement of data and models through systematic inter-comparison, improvement and integration; and (2) application of models to important Use Cases. NextGen adds to this two-track science concept the recognition that there are two ways that these developments can be made, i.e., in the "pre-competitive" space of data and science developments that are public goods, as well as in the "competitive space" of knowledge product developments that are largely private goods, but that can also provide important data as well as insights into what elements of model development are most useful to decision-makers. Thus, by combining AgMIP's emphasis on both science and application of data and models with NextGen insights, we arrive at a new conceptual model for data and model improvement and application that involves both pre-competitive elements