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Next generation agricultural system data, models and knowledge products: Introduction

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ABSTRACT

Agricultural system models have become important tools to provide predictive and assessment capability to a growing array of decision-makers in the private and public sectors. Despite ongoing research and model improvements, many of the agricultural models today are direct descendants of research investments initially made 30–40 years ago, and many of the major advances in data, information and communication technology (ICT) of the past decade have not been fully exploited. 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. The Special Issue is based on a "NextGen" study led by the Agricultural Model Intercomparison and Improvement Project (AgMIP) with support from the Bill and Melinda Gates Foundation.

1. Introduction

Agricultural system models have become important tools to provide predictive and assessment capability to a growing array of decision-makers in the private and public sectors. Despite ongoing research and model improvements, many of the agricultural models today are direct descendants of research investments initially made 30–40 years ago, and many of the major advances in data, information and communication technology (ICT) of the past decade have not been fully exploited. This state of science is explained in part by the inevitable lag between invention of new ICT tools and their application, but also by an underinvestment in agricultural research, particularly in non-proprietary public good research, and in research aiming to improve the well-being of poor, smallholder farm households in the developing world. At the same time, the private sector continues to utilize ICT developments – such as the recent advances in site-specific management and in the use of "big data" – to improve productivity in large-scale commercial agriculture. Even in commercial applications, advances in data are rapidly exceeding analytical capability. Moreover, these proprietary developments are not contributing little to the publicly available data, models or ICT tools for agricultural systems analysis.

These trends are resulting in a large and growing gap between the potential uses of agricultural system models, particularly in the developing world, and their actual use. This gap between actual and potential model developments and uses presents an opportunity to invest in a new generation of agricultural systems models that could dramatically improve the quality of information available to agricultural decision-makers on the farm, as well as for those making private and public investment and policy decisions.

The purpose of this Special Issue of *Agricultural Systems* is to lay the foundation for the next generation of agricultural systems models and knowledge products. The Special Issue is based on a "NextGen" study led by the Agricultural Model Intercomparison and Improvement Project (AgMIP) with support from the Bill and Melinda Gates Foundation. One of the distinguishing features of the NextGen study methodology was to move from the conventional "supply-driven" approach to model development in which scientists develop models as research tools – to a "demand-driven" or "user-driven" approach that bases data and model developments on the information and decision making needs of the user community. To operationalize this demand-driven approach, the NextGen study began by constructing a set of Use Cases for the development of papers by the study team. These Use Cases were discussed and supplemented by participants at a NextGen stakeholder workshop, where the study papers were presented and discussed. The first of these papers reviewed the state of agricultural systems science and its implications for NextGen models and knowledge products, while the second and third papers discussed various aspects of model and information technology advances.

A second distinguishing feature of the NextGen study was to recognize the need for user-friendly knowledge products, i.e., tools that facilitate the use of model outputs. Knowledge products could take the form

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of cloud-based analytical tools and mobile technology "apps" or other user-defined forms that would enable the use of the models by a much more diverse set of stakeholders than is now possible.

A third distinguishing feature of NextGen is to devise a proactive strategy to move the agricultural systems modeling community's research agenda in a direction consistent with the NextGen vision. The final paper in this Special Issue synthesizes insights from the articles in this issue and then proposes a NextGen roadmap.

2. The NextGen vision: accelerating innovation with computational agricultural science

Our vision is for a new generation of agricultural systems models and knowledge products that can help accelerate the rate of agricultural innovation and meet the global need for food and fiber. Given the stresses now being placed on the air, land, water and genetic resources on which human life depends, these innovations also must help reduce environmental impacts and enhance the resilience of food systems under changing climate conditions. We foresee the use of the new generation of models leading to "virtual" and "computational" agricultural research and development that can complement, and substitute to some degree, for conventional on-the-ground 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.

This vision for second-generation models is consistent with research on the past and likely future sources of productivity growth and increases in food commodity production. Research shows that since the agricultural revolution of the mid-20th century, the rate of productivity growth in agriculture has averaged about 2% per year, but this average masks large differences between the high and low-income countries, with productivity levels and growth particularly low in Africa. There is also evidence suggesting that cereal yield growth has been declining over the past several decades. To achieve the goal of sustainable agricultural growth, productivity increases will need to be based on more productive use of genetic resources, land, water, labor and other inputs, not from increasing the amount of land in agriculture or from increasing the use of fossil fuel-based inputs.

The current method for developing innovations in crops, livestock, and agricultural management is based almost entirely on conventional, time- and labor-intensive experimental methods in which new varieties and management practices are evaluated using field-scale experiments that may last for years. On-farm management decisions still depend largely on individual farmer knowledge acquired through personal experience, supported in some cases by "expert" or more formalized decision support. These processes are slow to improve, even with advances in genetic techniques and information technology, and become less effective in environments of increasing uncertainty due to climatic and other changes. Taken together, these conditions suggest that, with appropriate investments, it may be possible to use simulation experiments carried out with models to greatly reduce the need for trial-and-error learning, focusing field experiment to develop capabilities and increase the robustness of simulation tools. These advances could increase the rate of agricultural innovation, and also increase the rate at which these innovations are successfully adopted and implemented on farms.

3. Connecting people and models: use cases and knowledge products

There was a consensus among the NextGen study team as well as the participants of the NextGen stakeholder workshop that the next generation of agricultural systems models must be driven by the information needs of diverse stakeholders. To address this challenge, the NextGen study team developed a set of Use Cases to guide their work. The stakeholder workshop validated the authors' Use Cases and developed additional ones that reflect the diverse array of potential users of knowledge products supported by agricultural systems models. The five Use Cases proposed by the NextGen study team guided the critical assessment of the current state of agricultural systems models and the team's thinking about new developments in models and knowledge products.

The Use Cases were created to represent the array of likely users of knowledge products that are linked to NextGen models and data. The five use cases represent two types of farming systems:

3.1. Small-holder farms

Small-scale semi-subsistence farms typical of much of Africa and South Asia and other developing regions, many of which produce a mix of subsistence crops, cash crops, livestock, and, in some areas, aquaculture.

3.2. Commercial crop enterprises

Large-scale commercially-oriented crop farms typical of the industrialized countries including the United States.

The Use Cases are designed according to the four criteria indicated in Table 1. Narratives further defining the Use Cases are presented in the Appendix A.

Table 2 summarizes a number of agricultural system model features that are suggested by the Use Cases. These have important implications for the design of models and knowledge products.

- All of the small-holder use cases (1–3) require whole-farm models, and decision-makers in the commercial crop use cases (4 and 5) are likely to want whole-farm information as well, even if the specific use case (e.g., precision nitrogen application) does not require it.
- All cases need spatially referenced data, but the spatial scale of the data needed varies by case, and all cases need season-specific data. Some farm-level users will need within season data (e.g., for pest management or precision nutrient application).
- All of the Use Cases need biophysical production outputs and economic outputs. The need for environmental and social outputs is case-specific.
- Most, if not all, of the personas in the Use Cases would want to access model outputs via a dashboard application that would probably run on a laptop or larger tablet to facilitate visualization and integration of outputs with other applications and data, although some farm decision-makers or farm advisers might only want mobile applications.
- Only one of the Use Cases might want direct access to model output (the scientist Use Case 2).

In our view, this last point is a key revelation for modelers: only one of the personas (the scientist) might want direct access to model output. Moreover, even among the scientists themselves, it is often the case that one user (say, an economist) does not require the output of another model (say, a crop model) in the form it comes out of the model, but would rather have the output put into a format suitable for further manipulation. As these use cases illustrate, this is even more so for non-scientist users: there are few if any users that require direct access to the model output.

As we note below, the paper by Jones et al. (this issue) on *The State of Agricultural Systems Science*, documents that the agricultural models currently available do not meet all of the needs of the five Use Cases. Some provide field-scale predictions of crop responses to management decisions under specified climate conditions. Others provide whole-farm analysis capabilities, but few if any make model outputs accessible through user-friendly means, such as web-based dashboards, that allow

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