Integrated modeling with experimentation: systematic and quantitative research that allows applications and predictions at different temporal and spatial scales.

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Agriculture research deals with every component in the food, water and energy system. Understanding of individual components in the system and their interactions, and predictions of their behaviors at different temporal and spatial scales require quantitative descriptions of their processes and simplified but holistic reproduction of the system. The answer to this call is integrated simulation modeling and experimentation. Neither experimentation nor modeling in isolation can address key questions adequately, especially system sustainability, because of the complicity and dynamic nature of the system. In addition, decision support tools based on validated models are critical to decision making of the system.

As an applied science, agriculture research has traditionally emphasized on experimentation that is based on the principle of treatments under controlled conditions and conclusions from comparisons. We have so far acquired much qualitative understanding of individual components of the system under their predefined conditions or system boundaries. Many times, however, we still lack quantitative description of the processes and the linkages among individual system components and their interactions are still less understood. This has greatly constrained us from applying research results to conditions that are different from experiments or predicting system outcomes at spatial or temporal scales that are different from experiments. One of the consequences of the constraint is the lack of power for prediction, especially for processes that are beneficial in short run or to local areas but may be detrimental in the long-run or to neighboring regions. Below are a few of many examples. The constant increase of greenhouse gases in atmosphere and current global warming is believed to be partly related to industry revolution that started a century ago (McLamb, 2011). Human being might likely choose different strategies for development if we could predict such consequences at the beginning. Severe soil and ground water contaminations by agro-chemicals that have occurred in many places in the world are direct consequence of adoption of practices that are beneficial in short-term but detrimental in the long-run (USEPA, 2015; Kidd 1999). Policies would likely be different if policy makers were informed well in advance about possibility of such outcomes.

To take on the next challenge we are facing within the food, water and energy nexus, which is global food security, clean water, and renewable energy, research must put more emphasis on the interactions of components in the system and quantitative and mechanistic understanding of their processes. Along with experimentation, system analysis and simulation modeling will reproduce the system using quantitative descriptions and predict system outcomes under different execution scenarios and boundary conditions. Such integrated research scheme will enable best use of experimental results, and test and verify experimental findings through reproduction of experimentation in a virtual world, identify knowledge gaps and missing links in the system, and apply experimental findings to different temporal and spatial scales. The reconstructed system will help guide management strategies and search for optimization or mitigation solutions (Lovenstein et al, 1992). This will also enable to balance short-term gains with long-term losses, one area benefits with other area damages, and make policies with reliable anticipation. Such integrated research will also play an important role in training new generations of researchers to have it as new routine methodology and apply it widely.

One such an examples of integrated modeling-experimental approach to problem solving is given below. Dietzel et al. (2015) used 6 years of high-resolution experimental data to calibrate a cropping systems model (APSIM) and then used the model to estimate water use and efficiency from a system-level perspective for Iowa. This study showed that the optimum in-season precipitation amount to maximize systems water use efficiency is 430 mm and 320 for corn and soybean based-cropping systems. Above these precipitation levels, the corn and soybean yields did not increase further, but the water loss from the system via runoff and drainage increased substantially, leading to a high likelihood of soil, nutrient, and pesticide movement from the field to waterways. This example shows how a coupled experimental-modeling approach can help us deal with complex production and environmental questions.

From an end-user perspective, the development of information technology has not only made it easier to reach a wide audience with information at any time, but also led to integration of multiple data layers based on location information. Crop management decisions require research data plus up-to-date information on weather, input prices, and market information. By integrating research database with local weather information or real time marking pricing for a location, science-based decision-making will be simplified. Therefore, integrative modeling-experimentation approaches will facilitate decision-making process not only at local-scale but, if well calibrated, impacting at a larger scale.

In summary, we strongly believe that future research should focus more on integrated approaches. Both modelers and experimentalists will benefit and our potential to address current challenges will increase substantially. In addition, such an approach has the potential to contribute to “big-data” driven science. Once models have been calibrated for local conditions, they have the capacity to generate big-data that can be analyzed using deceptive statistical approaches and develop decision support tools to assist risk-management and trade-offs in agriculture.

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