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Models, Processes and Their Interactions in Cropping Systems

Challenges for the 21st Century

Lajpat R. Ahuja, Kurt C. Kersebaum, Ole Wendroth, Editors

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Preface

Overview of Modeling processes and Their Interactions in Cropping Systems

Recently observed environmental trends regarding water and soil quality, climate change with extended drought and heat waves (Trnka et al., 2013, 2019), extreme weather events (Trnka et al., 2014), and irrigation water shortages due to urban use require continual adaptation and optimization of agricultural systems through changes in cropping and management. Moreover, the increasing world population and changing diets will raise global food demand by 100–110% from 2005 to 2050 (Tilman et al. 2011). To double food production by 2050, average annual growth rates in crop production of 2.4% (non-compounding rate) would be required (Ray et al. 2013). Considering the limited land resources and the increasing competition for productive land between food, fodder, and energy production, this increase in crop production must be achieved from the same or less land compared with today (Godfray et al., 2010; Zabel et al. 2014). The advancement of science and technology to achieve these changes requires cutting-edge field research, using a quantitative whole-systems approach.

Agricultural systems are composed of physical, biological, and chemical processes of soil, water, plant, climate, their complex interactions, and their management. The whole-system framework is designed for evaluating the impact of management practices and climate on soil water and nutrient dynamics, biomass production, and environmental quality. In this framework, process-level models integrate interdisciplinary knowledge with field research to evaluate management options and to create well-adapted agricultural management systems. The models help to: (a) integrate field research results in terms of the fundamental theory and concepts that are broadly applicable beyond the site-specific empirical relationships; (b) predict crop and soil process dynamics from knowledge of the fundamental drivers that determine the environment and plant growth under different climates, (c) transfer experimental findings to longer term weather conditions beyond the limited duration of field experiments and to soil types and climates diverging from the experimental plots, and (d) use extended results to develop broad-based precision management decision support tools or simple management guidelines for producers and other users, who may link them to economic and social considerations. The models also promote precision management of spatially variable soils (Kersebaum et al., 2005), help assimilate real-time information about soil and crop conditions obtained with remote or ground-level sensors (Wallor et al. 2019) and allow an in-depth analysis of complex policy or management decisions. As a result, the models are continually improved and serve as an evolving theoretical backbone of complex agricultural system research, decision support, and information transfer.

System modeling has been a vital step in many engineering disciplines. A lot more work is needed to bring agricultural system models to the level of physical and hydraulic system models and to enhance their structure and usability. However, agricultural system models have matured enough that, with some good data to serve as reference, they can be used for many practical applications in research and management (Ahuja et al., 2002; Ewert et al., 2015; Jones et al., 2003; Matthews & Stephens, 2002; Michalczyk et al., 2014; Stöckle et al., 2014). The effect of management practices regarding tillage or no-till management, different crops and cultivars, crop rotations, organic and mineral fertilizers, water supply, and natural or tile drainage on production and water quality can now be modeled (Anapalli et al., 2005, 2015; Andales et al., 2003; Ma et al., 2000; Malone et al., 2017; Wendroth et al., 2019; Yang et al., 2019). Their integration with field research will expose knowledge and conceptual gaps in the models that will then stimulate new research (Rötter et al., 2018). The International Service for National Agricultural Research (2004) made a case for applying modeling tools and processes in planning and implementation of natural resources research and making sense of the vast amount of data. The CGIAR Science Council (2005) noted in their research priorities:

> Modeling and the ability to combine data from different sources, promises to revolutionize understanding of processes affecting management of natural resources. Thanks to strategic accumulation of data, tools, and modeling resources in the coming decade, one can expect the development of a more predictive approach to agriculture.

Integration of field research with system models has the potential to significantly enhance the efficiency of agricultural research and raise agricultural science and technology to a higher level, leading to improved production and protection of the environment. Agricultural system models are also used in hydrological, climate, and ecological research and management.

The National Academies of Sciences, Engineering, and Medicine (2019) have released a new report that identifies the most promising scientific breakthroughs that are possible to be achieved in the next decade to increase the