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Cross-scale modelling of cropping systems: From gene/genome to landscape in era of big data

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Abstract: Cropping systems modelling began by modelling key crop and soil processes at plant and field scales, aiming to understand how these processes respond to environmental and management drivers to determine crop yield. It has progressively evolved to models that simulate crop-environment interactions, multiple crops and crop rotations combined with more complex management specifications, with much broader objectives of predicting crop systems productivity, understanding soil water and nutrient cycling and impact on the environment. In recent years, the focus of cropping systems modelling has further expanded to evaluate impact of climate change on crop production and food security, to identify strategies for adapting to climate change and mitigating negative impacts of crop production on the environment. The evolving applications inevitably necessitate extension of the knowledge domain behind the cropping systems modelling together with supporting data, which however, has not happened to match the demand. Paradoxically, data to support model improvement and new model development are very limited in the era of big data.

Cropping systems modelling can serve as an effective means to integrate multidisciplinary knowledge and data, identify gaps in them, provide a functional link between relevant science disciplines, and support development of targeted applications to assist in decision-making. The essence is to achieve 'functional' integration of cross-domain knowledge and translate them to solutions for a wide range of real-world problems. The knowledge domain of cropping systems modelling has so far been mainly restricted to ecophysiology, agrometeorology and soil physics, which needs to be extended to meet the new demands. For design of novel crops and enhancing molecular breeding, new understanding of genetics and functional genomics need to be added. To evaluate productivity, soil fertility and environmental impacts at landscape scale, an understanding of the key soil and landscape processes in a spatial context need to be integrated. The former requires genomic data to be processed in a way to capture gene functions that determine physiological traits linked to the simulated physiological processes. The latter demands soil and landscape data that describe functional properties linked to simulation of key soil processes for water and nutrient cycling. Such a framework will enable cross-scale modelling of cropping systems from gene to landscape scales (Figure 1).

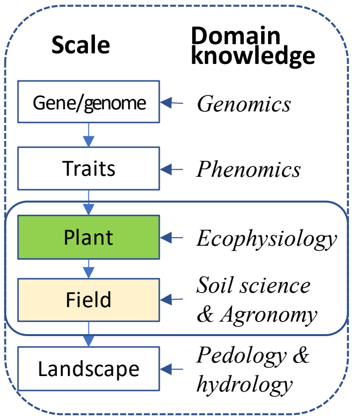

Figure 1. Scales and domain knowledge integration in current (inner box) and future (outer box) cropping systems models

Here it is argued that the 'functional' integration of multidisciplinary knowledge in the cross-scale modelling framework can significantly accelerate science advances and cross-disciplinary applications. Such a framework encourages a new conceptualization of model components to develop functional linkages across scales, enables systems components to interact and impact on systems behavior in response to external drivers. 'Functional' integration leads to surrogate approaches that capture the function while ignoring unnecessary details. It facilitates targeted data collection and overcomes the dilemma of lacking useful data in the era of big data. It can serve as the knowledge domain for AI modeling (e.g. machine learning) to further interpret the 'big' data.

The APSIM farming systems model (https://www.apsim.info/) is used to demonstrate 'functional' integration in three areas. The first area focuses on integration of gene-trait understanding to enable simulation of genotype performance across environments. The second illustrates how a simple spatial extension has enabled catchment scale modelling of productivity and environmental impacts. The third area highlights how an inverse modelling approach uses APSIM as knowledge domain to derive soil functional properties that are otherwise difficult to measure.

Keywords: *Multiscale agrosystems, knowledge integration, model conceptualization, data inversion*