Exploring FSPMs and crop models complementarities in up-and down-scaling from plant to field with a focus on modelling crop mixtures (Keynote)

Marie Launay, Noémie Gaudio

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Marie Launay[1], Noémie Gaudio[2]

[1] *US1116 AgroClim, F-84914, Avignon, France*
[2] *University of Toulouse, INRAE, UMR AGIR, F-31326, Castanet-Tolosan, France*

For correspondence: marie.launay@inrae.fr

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Crop mixtures for a sustainable agriculture

Increasing plant diversity in agriculture, in order to promote natural regulations, is suggested as a pathway towards more resilient and sustainable production systems. These natural regulations allow agroecosystems to provide ecosystem services that are broader than production alone, e.g. improvement of water quality (especially by reducing the use of chemical inputs) and soil fertility, or increasing biological pest control. At field scale, plant diversity can increase by using species mixtures such as in intercrops. Even if the agronomical advantages of these diversified systems were highlighted, several questions remain regarding their management and their integration in cropping systems to reach the ecosystem services targeted.

Modelling approaches to represent crop mixtures

Modelling their functioning is both a tool for understanding and a tool for testing hypotheses to support the agroecological transition. The main modelling approaches developed to study intercrops are process-based models at the plant scale (among which FSPMs) and at the crop scale (crop models) (Gaudio et al., 2019). Most of these models were adapted from models dedicated to isolated plants or sole crops. Modelling intercrops and ecosystem services they are designed for involves changes in the modelling approaches which are i) modelling plant-plant interactions (competition, complementarity, facilitation) and the impact of the environment and agricultural practices on these interactions, and ii) modelling the way these processes contribute to the functions and then to the ecosystem services targeted. Here we will focus on FSPMs and crop models complementarities.

Complementarity of the modelling approaches to understand crop mixtures functioning

From a strictly ecophysiological point of view, some processes are particularly determining in crop mixtures because they largely explain their functioning and performance, especially competition (for light, water and nutrients), complementarity (spatio-temporal and niche ones), phenotypic plasticity and facilitation. To represent these driving processes, different modelling approaches co-exist, from the most mechanistic and spatially explicit to the most empirical.
However, the environment, whether technical, pedoclimatic or biotic, also modifies the nature and intensity of these plant-plant interactions. Therefore, the capacity of models to take these plant-environment interactions into account appears to be crucial when it comes to building and thus evaluating the performance of mixtures to provide one or more ecosystem services.
Through various examples, we show how mobilizing the complementarity between crop models and FSPMs allows to better understand and simulate the functioning of crop mixtures.
In FSPMs, the result of plant-plant interactions is an emergent property of the models (Gaudio et al., 2019). Then, some FSPMs enable to quantify ecological processes (Zhu et al., 2015)

or given functional traits (Barillot et al., 2014) involved in intercrops performance or resource use efficiency (more often light). Then important processes highlighted by FSPMs can be summarized by functional relationships in order to be included in crop models (Barillot et al., 2011). In crop models, agricultural practices influence crop environment such as soil fertility and water availability, modifying the pedoclimatic context in which crop mixtures may adapt according to their complementarity and/or plasticity properties (Corre-Hellou et al., 2009). Thus, crop models are able to provide inputs to FSPMs, i.e. a quantified and dynamic description of the abiotic constraints within which crop mixture grows. In addition, when facing the question of crop mixtures and their skills, FSPMs and crop models face common issues, and sometimes share solutions. Other approaches such as qualitative hierarchical aggregative modelling may also be relevant when the goal is to qualify the factors that are involved in these complex ecosystems' functioning.

Towards ecosystem services assessment

It is even possible to use such modelling tools to co-construct agrosystems that are likely to meet the expectations of agricultural sectors, based on the fine interactions between plants, and between the plant and its biotic, abiotic and human environment. However, predicting how management activities and changing future conditions will alter services is made more complex by the interactions among multiple ecosystem services (trade-offs, synergies, etc.) (Agudelo et al., 2020); the more widespread use of biophysical models (FSPM, process-based models) for the estimation of ecosystem services could probably provide access to the physiological processes, or even the traits, behind the interactions between ecosystem services. Simulating ecosystem services provided by intercrops also requires taking into account their inclusion into crop rotation and the effect of the environment on the long term. This could be achieved by coupling knowledge brought by FSPMs and crop models, but also using more qualitative models based on farmers' expertise (e.g. Martin et al., 2019).

From a detailed understanding of the plant-plant processes within crop mixtures to the expression of the ecosystem services they can supply on different spatio-temporal scales, the complementarity between FSPMs and crop models is a relevant tool that should be better explored in the future.

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