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"Multi-functional **farming systems**
in a **changing world**"

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FSD5

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FOREWORD

Eight years after the launching of the FSD (Farming Systems Design) initiative in Catania (2007), the European Society for Agronomy (http://www.european-agronomy.org) has been mandated to organize its fifth symposium with the specific objective to strengthen the interdisciplinary and methodological focus of FSD. The overall objective is to promote research and capacity building on methodologies for the analysis and design of Agricultural Systems on a worldwide level. The research focus of this FSD community is the farm system level, the interactions and feedbacks at lower and higher levels of integration and the tools and methods required for understanding and implementing multi-functional farming systems expressing good trade-offs between agricultural production and ecosystems services. In a time when challenges for farming systems are increasingly defined by other systems operating at higher scales (food security, climate change, natural resource conservation, poverty alleviation….) it is important to keep an active scientific community sustaining innovation and capacity building on farming systems and their interfaces with those embedding systems and global issues.

These proceedings are aimed to serve as a compendium of the on going research in the FSD domain when considered worldwide and across the various sectors of agriculture (including fish-based systems). They include all the presentations (orals and posters) selected by the Scientific Committee of the 5th Farming Systems Design conference held in Montpellier (France) from September 7 to 9, 2015 (http://fsd5.european-agronomy.org/). A part of these communication have also been selected to compose special issues of major journals in the domain (Agricultural Systems and European Journal of Agronomy) and others will give raise to individual submissions in other journals.

The major achievements and challenges of the FSD approach are browsed through the 6 short sessions of the symposium "Farming Systems Design in Action: Methods, Achievements and Challenges" and are further developed and illustrated in the thematic sessions covering:

- *The grounds of the FSD approach* in quantitative analysis of crops (session T1. Assessing performances and services of cropping systems) and farms (T2. Assessing performances and services of farming systems).
- *The research frontiers on methodologies* for systems experiments at field level (W3. Cropping systems design: what can we do with field experiments and expert knowledge?), support of transition pathways at farm level (W4. Farms in transition), integrated analysis (T7. Scaling up from farm to landscape and multiscale scenario analysis of agricultural systems) and design (T8. Co-design and co-innovation with farmers and stakeholders) of agricultural systems.
- *A specific focus on crop models* (T3. Crop modelling and yield gap analysis for agricultural systems analysis and design) *and farm models* (T4. What's new with bio-economic models for the analysis and design of agricultural systems?) and the way they can be developed and used to sustain system's analysis and design.
- *Three typical challenges* on which the multi-scale and multi-domain FSD approach is likely to bring significant breakthrough: T5. Designing Climate Smart Agricultural Systems; T6. Designing sustainable agricultural systems with legumes; W6. Pathways for sustainable intensification of African agriculture?
- *Applications of the FSD approach to specific types of farming systems*: W1. Animal-based systems and crop-livestock interactions at farm and territory level; W7. Aquaculture systems, W2. Annual crops based systems; W5. Silvo-arable and silvo-pastoral systems.

Prof. Jacques Wery

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Farming system models for supporting farm resilience: research needs, gaps and promising approaches

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1 Introduction

It is important to increase the resilience of food production systems in the face of a changing climate, land scarcity, and changing demographics and market conditions. As farm resilience is a high-level system property emerged from social-ecological interactions, its direct measurement is difficult because it requires measuring the thresholds or boundaries that separate alternate stability regimes of the farm system. However, systems' modeling for supporting agricultural resilience is still in an early stage. Through critical review of state-of-the art literature, this study aims at highlighting the new requirements of agricultural system modeling as they apply to management for farm resilience, limitations of contemporary agricultural systems modeling approaches, and promising directions for future research on the field.

2 Materials and Methods

By review of previous conceptual works on socio-ecological systems' resilience, we conceptualized 11 criteria for evaluating models' suitability for farm resilience studies, which include the capability of the modeling approaches to (1) represent social-ecological complementariness, (2) have long-term perspective, (3) manage uncertainty, (4) capture global-local linkages, (5) mediating participation, (6) capture cross-scale feedback loops, (7) explain human behavior including (8) social learning and adaptation, (9) capture farm heterogeneity, (10) anticipate multiple farm performance allowing trade-off assessment, and (11) sensitive to biophysical, economic and social drivers. Using these criteria we evaluated a mass primary literature on farming systems models to assess strengths and weakness of six main farming systems modeling approaches, and conducted comparative analysis across the methods.

3 Results - Discussion

Farm nutrient balance model accounts farm nutrient balance based on the consideration of major material inputs and outputs. As several of these fluxes are difficult to measure (e.g., leaching, erosion), transfer functions are commonly used. Internal nutrient flows between farm production units are also measured (Smaling and Fresco, 1993; Den Bosch *et al.*, 1998a; Den Bosch *et al.*, 1998b; Lesschen *et al.*, 2007), the popular nutrient balance accounting framework, produces farm nutrient balances and some farm agronomic and economic indicators. However, due to practical difficulties in measuring nutrient flows tied with soil processes, balance of soil nutrient reserve are still poorly considered. By capturing farm nutrient balance as a snapshot in time only, the analysis offers no long-term perspective. This ignores the residuals effects of fertilizer uses, long-term soil carbon cycling, and livestock or tree production cycles. Although human components exist as system entities and are connected to farm environment via nutrient flows and management activities, no decision making mechanism is included.
Farm system dynamics model deals with internal stocks (production units of the farm) and flows (nutrients and water), associated feedback loops and time delays that affect the behavior of the entire farming system. The substantive nature of feedback loops can be either material or information links, thus create multi-directional cause-effect relationship between biophysical and social observables (Shepherd and Soule, 1998; Sendzimir *et al.*, 2011). These models can mimick the actual farm components and interinfluences, thus is perceivable by stakeholders. The models are able to perform nonlinear behavior and dynamic complexity of the farm in sensitive to change in values of observables. However, the structures of stock-and-flows and feedback loops are predefined and fixed during simulation runs, ignoring the adaptive farmers' decision on modifying the nutrient network structure to utilize subsidiary effects among farm components. Thus, the modeling approach cannot model structural adaptation of the farm to change that is essential in farm resilience. The model also can operate the system dynamics at one aggregated scale and less capability to capture heterogeneity within and between farms.
Fixed-structure integrated farm modeling frameworks couple the sub-model of static farm nutrient stock-and-flows with those of soil-crop dynamics and socio-economic processes that allow information exchange for forming feedback loops between farm nutrient cycles, crop and livestock productivity and socio-economic dynamics (Giller *et al.*, 2006; Giller *et al.*, 2011). However, its limitation to understanding farm resilience is that: the within-farm interactions and feedback loops are not the subject of farmers' adaptive decisions; they are rather fixed and unspecific to nutrient cycle management/design context. Thus, farm's structural adaptive behavior to major change in external drivers is not endogenous explained by this modeling type. Multi-agent system (MAS) models represent the coupled human-environmental system is described through autonomous 'agents', which can be defined to represent actors and acted-upon entities such as households, farm production units, offer a system tool for understanding the complexity of energy, nutrient and material flows that result from rich interactions and feedback among social and natural processes (Bousquet and Le Page, 2004; Gaube *et al.*, 2009). As separate loci of control in the human-environment system, agents act autonomously, and interact with other agents, in an ever-changing system. MAS is strong in supporting interdisciplinary between natural and social sciences. MAS is based on complex adaptive system theory that is nowadays well-suited for representing ecological systems, social systems, and human-environmental systems; thus it becomes a paradigm shared by ecological and social sciences (Bousquet and Le Page, 2004; Scholz, 2011). By mimicking actual entities in the real human-environment system, MAS allows for an intuitive

representation of the environment and of the embedding of human actors in a socially, ecologically, and spatially explicit setting. As MAS displays large-scale outcomes that result from interactions and/or learning among individual entities, it allows an adequate representation of micro-macro relationships and a strong ability to model social learning and adaptation (Kelly *et al.*, 2013). However, MAS models for understanding farm resilience and transition scenarios is still in a very early stage of development. To be able to assess farm resilience and support farms' transition to resilience, MAS models developed have to meet the following key requirements, which have not been addressed by current MAS research community: (1) *capture resilience-relevant properties* (i.e. buffering capacity, critical thresholds and tipping points), (2) *model change in slow variables as the endogenous processes*, (3) c*apture social-ecological feedback loops at different levels*, (4) *explain farming practices, which create subsidiary linkages between production units, or between farms as the subject of farmers' decisions*, (5) *parsimonious representation of socio-biophysical processes, (6) appropriate model validation* and (7) *better contextual robustness* (i.e., less dependent on site-specific assumptions, more applicable to a wide range of contextual variation and management options).

Table 1. Comparative assessment of contemporary farming system modeling approach with respect to criteria for farm resilient research. Note: detailed narrative insights of the table cells do not show.

Criteria	Nutrient balance models	System dynamics models	Bayesian Network models	Bio-economic models	Coupled component models	Multi-agent system models
Interdisciplinary	weak	strong	medium	weak	weak	strong
Long-term perspective	no	strong	no	weak	strong	strong
Uncertainty management	no	weak	strong	no	unclear	medium
Local-global perspective	no	no	no	weak	strong	strong
Participation mediation	weak	strong	strong	weak	unclear	strong
Multi-scale feedback loops	no	no	no	no	unclear	strong
Actors' behavior	no	weak	strong	medium	no	strong
Social learning and adaptation	no	no/weak	no	no	no	strong
Farm heterogeneity	medium	medium	no	weak	strong	no
Multiple farm performance	strong	strong	no	medium	strong	strong
Driver sensitive						
- Biophysical	weak	weak	weak	weak/medium	strong	weak
- Economic	weak	strong	medium	strong	weak	strong
- Social	no	medium	strong	weak	weak	strong

4 Conclusions

Agro-ecosystems modeling has gone through more than 40 years of development. Although a great deal of knowledge and tools about economic and biophysical processes exist, agricultural system modelling science hardly ever seeks to develop modelling frameworks and tools to support farm resilience management. The result of our meta analysis found that none of developed farming system models are sufficient for supporting farm resilience regarding all criteria. The results can serve as a reference matrix that helps identifying research directions towards supporting the resilience of agricultural systems. Multi-agent systems (MAS) modeling has appeared as a promising approach for model farming system resilience. Using the above-mentioned criteria we also analyzed the current limitations of this model family and elaborate possible future developments as subjects of follow-up studies.

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