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An open platform to build, evaluate and simulate integrated models of farming and agro-ecosystems☆

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ABSTRACT

Due to significant changes in agro-ecological contexts, farmers need new solutions to produce goods. Modelling complements field experiments in the design of new farming systems. French researchers involved in such design issues developed a specific modelling platform to help model, simulate and evaluate cropping systems. After testing several existing environments, the RECORD platform was developed under the VLE environment, allowing the design of atomic and coupled models. It integrates different time steps and spatial scales and proposes some standard formalisms used to model agro-ecosystems (e.g. difference equations, differential equations, state charts…). A graphic user interface was designed to simplify coding tasks. A variety of research projects already use this platform. Examples are given showing the ability to recode simple models, encapsulate more complex models, link with GIS and databases, and use the R statistical package to run models and analyse simulation outputs. The option to use web interfaces enables application by non-scientist end-users. As the models follow a given standard, they can be placed in a repository and used by other researchers. Linking RECORD to other international platforms is now a compelling issue.

1. Introduction

Agriculture is currently driven by continuously evolving challenges (e.g. climate change, environmental concerns, market globalisation, food safety and quality) and requires the development of innovative sustainable production systems. In this context, agronomic research should have an active role in assisting extension agents, consultants and farmers by providing tools for investigating, evaluating and designing alternative cropping systems. Field-based approaches such as regional agronomic diagnosis (Doré et al., 1997, 2008) and prototyping (Vereijken, 1997; Rapidel et al., 2006; Lançon et al., 2007) have been tested and used successfully. These approaches are too slow however to provide timely responses to rapid contextual changes and are unable to explore a large number of systems (Rossing et al., 1997). Moreover, they are field-level tools, while cropping system assessment must take place at the farm, catchment or territory level. Integration in space, time and across disciplines is one of the major challenges in agronomic research. In-silico approaches, based on the study of a wide range of possible systems through modelling and simulation could more quickly identify those systems that respond to current social, economic, political and environmental concerns (Malézieux et al., 2001; Loyce and Wéry, 2006; Bergez et al., 2010). However, building, testing, evaluating and using models (i.e. simulating different combinations of management, soil and climate conditions and policy and environmental constraints) is far from being a straightforward task. Numerous models that can address questions about agro-ecosystem functioning already exist. The major issue now is how to combine or couple these models and use them at different spatial and temporal scales rather than develop new models (Rotmans, 2009).

☆ Thematic Issue on the Future of Integrated Modeling Science and Technology.

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In the past decade, several generic crop models have been developed (e.g., STICS (Brisson et al., 1998, 2003), APSIM (Wang et al., 2002; Keating et al., 2003), CERES (Ritchie, 1998), CropSyst (Stockle et al., 2003), DSSAT (Jones et al., 2001)) and conceptual generic frameworks have been proposed for cropping systems modelling. They may be based on some underlying theory such as complex systems theory (Zeigler et al., 2000). As with generic crop models, several conceptual frameworks exist (e.g. Aubry et al. (1998), Derry (1998), Thornton et al. (1991), Hillyer et al. (2003), Martin-Clouaire and Rellier (2009), Le Gal et al. (2010), Adam et al., 2010). To overcome the problems which arise when building, simulating and reusing models (Reynolds and Acock, 1997; Acock and Reddy, 1997), generic computing platforms have been created: e.g., GPSF (Gauthier et al., 1999), GUICS (Acock et al., 1999), SIMILE (Muetzelfeldt and Massheder, 2003) or ModCom (Hillyer et al., 2003). Most of these platforms capitalise on advances in computer science (e.g. object-oriented, modular and generic programming) and propose model repositories to facilitate their use and re-use (e.g. CropSyst (van Evert and Campbell, 1994) or ICASA (Bouma and Jones, 2001)).

To take advantage of these developments the French cropping-system research community developed an integrated modelling platform, RECORD ("*REnovation and COORDination of agro-ecosystems modelling*"), to gather, link and provide models and companion tools to answer new agricultural questions. The software-engineering community routinely uses a number of tools, techniques, and protocols which simplify the development, implementation, and maintenance of software applications. Many of these techniques have the potential to improve the way in which environmental and other agricultural models are developed (Papajorgji et al., 2004). Using these techniques, the community of agronomic modellers can build well-documented models that are constructed in such a way as to facilitate code modification and reuse.

This paper describes how the RECORD platform was developed and demonstrates several uses in scientific projects. Section 2 describes RECORD's functional requirements. Section 3 explains the technical choices made during the development and highlights main features. Section 4 presents examples of models developed using RECORD, which illustrates its usefulness in a wide variety of situations. Section 5 discusses the future development of RECORD and ways it helps with integrated environmental modelling and assessment.

2. Functional requirements of the platform

The RECORD project aims to create a computer platform for modelling and simulation of innovative cropping systems that will provide tools for analysis, evaluation and optimisation of agronomic, environmental and economic criteria. The platform follows a multidisciplinary approach (e.g. agronomy, soil science, bioclimatology, epidemiology, management science, statistics, applied mathematics and computer science). The following functional requirements were defined following a survey targeting modellers from the Environment and Agronomy department of INRA and a 2-day seminar (Bergez et al., 2007). Approximately 50 French researchers who use models to understand, analyse and develop cropping systems participated in this meeting. The main requirements raised during the workshop were:

- *Scope*. The platform must be able to simulate cropping systems and interactions with the surrounding territory (Fig. 1).
- *Users*. Four types of users were identified: i) researchers working on and designing cropping systems and crop-management models, ii) researchers using cropping system models to simulate some outputs iii) extension service personnel who want to test new cropping-systems proposals and iv) graduate students being trained in modelling. For years, INRA researchers have developed their own models with programming languages such as Fortran, C++ or VBA. The aim of the platform should not be to hide code from researchers by following a complete declarative approach, but to help them build models with a graphical interface allowing module-by-module development and generation of some standard bits of code (API functions). Because the two latter types of users are usually less familiar with models and programming languages the aim of the platform should be to provide specific services which facilitate the use of models implemented on the platform.
- *Functioning and outputs*. The platform should facilitate i) implementation of optimisation methods by simulation, ii) implementation of methods of multicriteria choice, iii) comparison of cropping-systems models and iv) use of data-mining techniques to exploit simulation results. Links with already existing packages, such as the R-statistical package should be facilitated.
- *Accepting various time steps*. Different time steps must be permitted: from hourly simulation (e.g. to simulate a fungal infestation) up to several decades for sustainability studies.
- *Accepting various spatial aggregations*. Spatial aggregations include a plot or a set of plots representing one or more farms, including, if necessary, interstitial areas and larger areas such as a territory when dealing with natural resources (e.g. a catchment). Transfers between different spatial units must also be modelled (e.g. water exchange, pests, genes, spores).
- *Accepting various formalisms*. Most current models are dynamic with discrete time steps. However, the platform also should able to incorporate static and stochastic models and different formalisms (e.g. difference equations, differential equations, Markov chains, state charts, cellular automata).
- *Focussing on management*. It is particularly important that the platform be able to handle management models for cropping systems. Modelling factors such as technical operations sequences, competition among agricultural tasks, spatial distribution of agricultural practices and choice of crop rotations in a field must be possible.
- *Using existing models*. Existing crop models cover a wide variety of crops, crop-management options and spatial and temporal scales. The architecture of the platform should enable integration of these different types of models, either by recoding (i.e. completely rewriting new code) or by encapsulating existing code (i.e. dealing only with interface code).

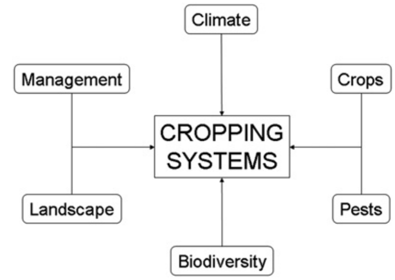

Fig. 1. RECORD aims to simulate cropping systems (soil–plant interactions, managed by a farmer and subject to weather and pests). RECORD also considers interaction of cropping systems within a landscape and their effect on biodiversity.