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# Modelling Adaptive Decision-Making of Farmer: an Integrated Economic and Management Model, with an Application to Smallholders in India

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## 1 Introduction

Farmers plan their cropping systems and farm operations depending on their expectations on economic, social and environmental contexts, and they make tactical adjustments to face uncertain rainfall, variable market prices, and changing resource availability. We use modeling to represent a farming system and we define its adaptation opportunities to drought events, delay in monsoon onset, limited irrigation water and market prices fluctuation in the Berambadi watershed, Karnataka, India. It is represented as three interacting sub-systems: the agent system, the operating system and the biophysical system (Martin-Clouaire & Rellier 2009; Le Gal et al. 2010). We focus on the agent system representation. Once the objectives and farm representation of the farmer have been identified, we use a double loop process to combine a proactive economic model with a reactive farm management model to simulate the planning and adapting process of the farmer under water constraint.

## 2 Materials and Methods

A case-based survey provided specific information on 27 farmers. Farmers were asked to detail their farm practices and management decisions. Changes and adaptation of their practices when facing downside climatic and price conditions were discussed to bring out adaptation decision-rules.

Individual farm representation were first formalized with a Belief-Desire-Intention architecture (Bratman 1987) and conceptualized with UML object diagrams. Theory building from cases provided generic graphs by introducing expert knowledge (Eisenhardt 1989). An ontology was built with UML class diagrams.

Decisions on irrigation equipment and infrastructure investments were optimized using a stochastic dynamic programming approach. Our economic model described the strategic decision of the farmer to upgrade his irrigation capital stock (e.g., borewells, pumps) in order to optimize access to irrigation water.

Cropping system decisions and management practices were represented with UML sequence diagrams. Our farm management model used decision-rules to allow tactical adaptations in the crop choice and operational flexibility in the daily crop management tasks.

The agent system and its interactions with the biophysical system of crop growth and ground water level were implemented within the RECORD modeling platform (Bergez et al. 2013).

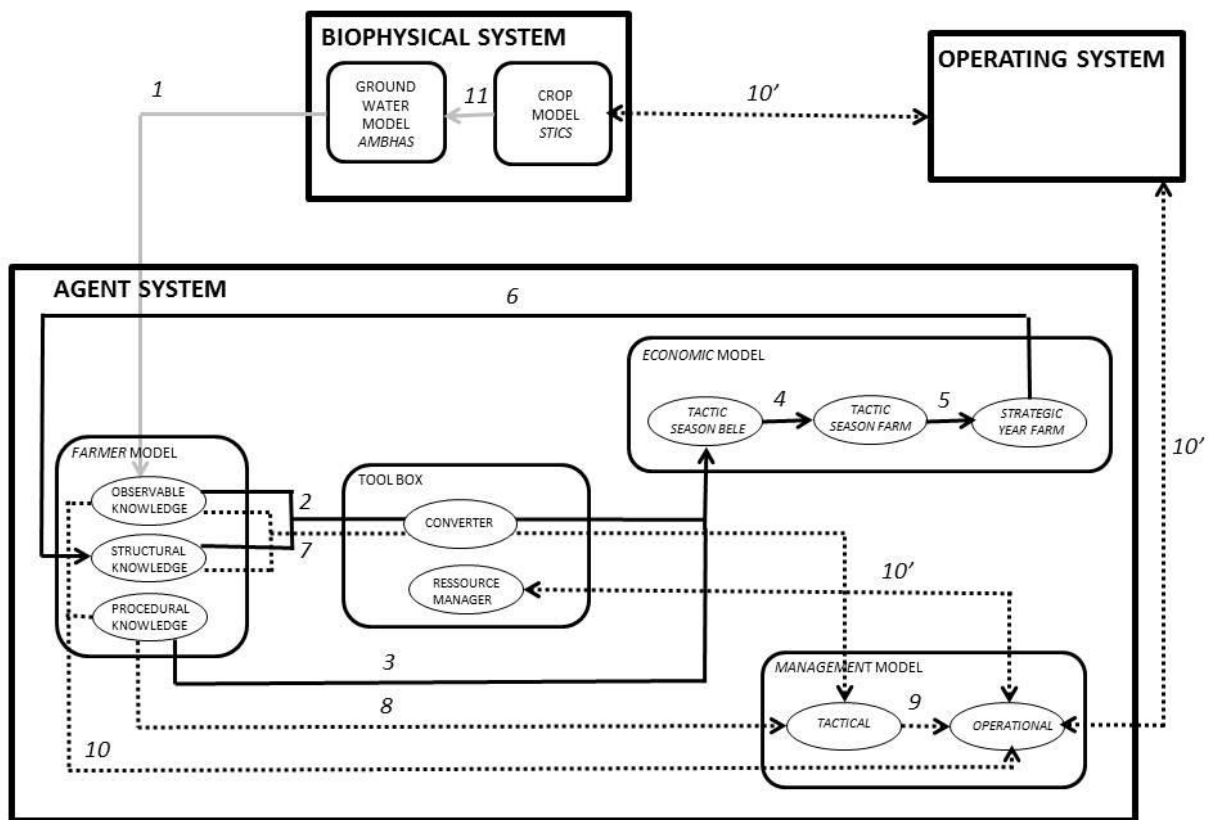
## 3 Results - Discussion

The conceptual approach is presented in Fig. 1. *AMBHAS* model (<http://ambhas.com>) provides information on the ground water (GW) volume available to the farmer for irrigation (1). Considering possible investments in irrigation equipment at the beginning of the year (e.g. dig a new borewell, buy a new pump, rebore a borewell), a converter combines the GW with other water resources (tank, canal, river), and irrigation equipment, and predicts the total available water for irrigation on the farm per irrigation investments (2).

Based on rainfall and crop price expectations, farm resources (equipment, labor, manure, and production techniques) (3), water available (2), the *tactical season bele* model provides to the *tactical season farm* model a matrix of crop yields per bele (i.e. per plot) and irrigation investment levels (4). Crops considered include any suitable crops that respect a crop rotation constraint, a preceding effect constraint, and a crop return time constraint. The *tactical season farm* model then selects the optimal cropping system that maximizes farmer's income for each irrigation investment level (5). The *strategical year farm* model selects the irrigation investment at the beginning of the year associated with the highest income. The *economic* model (*tactical season bele* + *tactical season farm* + *strategical year farm*) returns this value to the *farmer* model (6) and updates the available water volume on the farm at the beginning of the *Kharif* season that is sent to the second loop within the management model (7).

In the *tactical* part of the management model, decision rules (8) allow the farmer to adapt his cropping system to actual rainfalls and prices at the beginning of the season (9). Once crop choice is made, the *operational* management model applies production techniques (10) to trigger the daily farm operations. This model strongly interacts with a resource manager module (10') and crop model *STICS* (Brisson et al. 2003) (10') as a loop where rainfall, soil moisture, weed

and pest pressures, and crop stage are checked before each operation (10). After each irrigation or rainfall event, *STICS* sends the water abstracted and drainage to *AMBHAS* (11).



**Fig. 1.** Conceptual representation of the farm system, information flux between sub-systems and double loop in the agent model (loop 1 as continuous dark line in economic model, loop 2 as dotted line in management model).

#### 4 Conclusions

The double-loop process used in our approach models the sequential and continuous aspect of the farmer’s decision-making process. As time passes and more information become available, the farmer is able to adjust his strategic choices (economic model and optimization) and adapt his farming practices (management model and tactical and operational decision-rules) to his changing environment.

This farm system design helps in modelling farm practices in a context of water scarcity and climate change and their impacts on the ground water level evolution.

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