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A simulation tool to support the design of crop management strategies in fruit tree farms. Application to the reduction of pesticide use

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ABSTRACT

Strategic decisions condition the orientation and associated agricultural practices of farms for many years, especially in fruit production where trees are planted for ten to fifteen years. However, this type of decision is rarely addressed in decision support approaches. An approach was developed to support strategic thinking in fruit tree farms through the use of a simulation tool called CoHort and built in Excel®. CoHort evaluates the impacts of a given set of practices on the economic performances (gross and net margins), labour organization and phytosanitary performances (Treatment Frequency Index) of fruit tree farms. It has been built with cooperatives technicians and used with apple farmers in a participatory process to integrate the needs and objectives of the farmers and technicians. The approach alternates between simulations with the tool and discussions with the farmer. It is illustrated for two apple farmers in France aiming to reduce their pesticide use. The first farmer wanted to convert five hectares out of eight to organic production. Simulations showed that the raw margin was increased by 259%, the Treatment Frequency Index was reduced of 26%, but the labour demand was 9% higher. The second farmer wanted to replace 1.5 hectares out of 15 ha with a new scab-resistant cultivar. Results showed that the average TFI at the farm scale was decreased by 17%, the labour demand was similar, and the raw margin increased by 5%. Based on simulation outputs apple farmers could estimate the possible impacts of their projects to their farm. The tool flexibility allows using it with different farm structures and projects.

1. Introduction

Crop management can be thought of at different levels of a farm (Le Gal et al., 2010): (i) at a strategic level, regarding multi-annual orientations, investments and sizing of farm enterprises, (ii) at a tactical level, regarding the annual or seasonal planning of activities to be conducted, and (iii) at an operational level on a daily basis, leading to the agricultural practices performed by the farmer at the plot scale. The levels are interrelated to ensure the consistent functioning of the farm. In permanent crops such as fruit trees, results of decisions can take several years to manifest, so they need to be considered carefully. The first set of strategic decisions is made at planting, when the farmer chooses the cultivars. At the beginning of each year, farmers plan their specific tactical intervention, which enables them to manage their input stocks and to size their work force and equipment based on the resources available on the farm (Penvern et al., 2010). Farmers then make their operational daily decisions according to their plan and the daily events they might face, such as pest/disease development, rainfall or wind.

Changing practices may imply strategic decisions, which can affect farm performance for several years and therefore must be thought out and evaluated before implementation. For example, investing in a scab-resistant cultivar or pest-exclusion nets have consequences on farm performances and work organization that are difficult to assess. Such evaluation requires new approaches to support farmers in considering these different options at different farm management levels. Simulation tools are known to provide such *ex ante* evaluations based on exploratory scenarios at the farm level (Le Gal et al., 2011; Sempore et al., 2015). These tools have several advantages: (i) providing quantitative information on the potential impacts of innovative practices on farm performances by simplifying the systems modelled, (ii) saving time compared to field experiments as the planting and growing phases over several

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years can be skipped, (iii) and avoiding costly trials and error processes (Martin et al., 2012).

Some production models have been developed in the fresh fruit industry (Soto-Silva et al., 2016). They usually address one main issue, such as the optimization of harvest dates to reach optimal quality (González-Araya et al., 2015) or the characterization of the best management of resources (equipment and labour) and tasks (practices) to reach the highest fruit quality and quantity (Bohle et al., 2010). Since these research models often imply complex programming, mainly through optimization, they are not easily transferred and used by technicians who advise farmers. In the French fruit sector, a large range of decision support tools exists to assist farmers in managing orchard (list available at https://iris.angers.inra.fr/BDDOADFruitsnCo/). But they rarely address strategic decisions at the farm level. To fill this gap, we have designed a support approach based on a simulation tool called CoHort for aiding farmers in their strategic reflections by evaluating the effects of different sets of crop management strategies on work organization, phytosanitary and economic performance at the farm scale.

CoHort was developed and tested in the French apple sector, where 60% of the farmers are organized into cooperatives (Agreste, 2011). These cooperatives are in charge of the marketing and selling of the fruits and employ technicians who support farmers in managing technical aspects according to the specifications of their buyers (exporters, supermarkets, retailers). They provide information and advices to farmers who combine this knowledge with their own experience. Technicians play then a big part in the daily decisions of farmers, but rarely in strategic support.

The apple sector is an interesting case to develop a strategic support approach. Apple farmers are limited in their solutions to change their practices, particularly regarding crop protection, since they are challenged with growing perfect-looking fruits with no disease symptoms or insects (Pissonnier et al., 2016). Moreover, apple prices are very low, approximately 0.3€/kg, and the production costs are usually close to the selling prices, as the crop is labour consuming. Since alternative practices to pesticides have uncertain effects on crop yield and quality, farmers need to evaluate *ex ante* the possible consequences of implementing alternative practices on their farm performance and management.

This paper presents the approach developed first by explaining the design process of CoHort and then by describing the software structure and operation. Two applications are then presented for two different apple farms which aim at reducing their pesticide use. The values and limits of the approach and the tool are then discussed.

2. Design process

2.1. Main objectives of the support approach

The support approach using CoHort aims to enhance farmers' reflections regarding their strategic projects by quantifying the potential consequences on farm performance of systemic changes in their production systems, such as the introduction of new equipment or a reorientation of activities. To do so, a technician or researcher works with individual farmers in a face-to-face process to design scenarios. The initial configuration of the farm is represented first, then alternative configurations are developed (Le Gal et al., 2013). Each scenario is then simulated with CoHort, its outputs are compared with the initial and other alternative scenarios, and the set of results feeds the discussions with the farmer regarding the feasibility and value of each scenario to fulfil his/her intentions of change. The objective is not to help the farmer to make a day-to-day decision, such as the choice of a pesticide to fight a disease, but to provide him/her a set of information that will help in preparing a mid-term strategic decision that often involves factors other than the ones included in the simulation tool (Le Gal et al., 2011).

In this support framework, CoHort aims to explore how a given farm may evolve rather than precisely predict the consequences of strategic changes, an objective which would be difficult to achieve for decisions involving numerous and uncertain elements. In this respect, trends between scenarios are more important than absolute values of simulation outputs. The nature of the input data depends on the type of knowledge being integrated into the scenarios and does not need to be very accurate. The calculations are based on basic arithmetical operations rather than complex equations representing mechanistic processes.

2.2. A co-designed simulation tool

CoHort was built with a co-design process, including the participation of technicians of two apple farmer cooperatives, one near Montpellier (South-East France) and one near Limoges (Centre-West France), and two researchers. Participatory research has several advantages, such as the following: (i) integrating from the very beginning the objectives and knowledge of all the stakeholders, i.e.: researchers, technicians and growers in this case (Vall et al., 2016); (ii) taking into account different kinds of knowledge, scientific from researchers and know-how from growers and technicians (Meynard et al., 2012); (iii) improving communication between stakeholders (Berthet et al., 2015); (iv) taking into account the diversity of objectives and existing situations (Dogliotti et al., 2014); (v) and facilitating the transfer of the co-designed tool afterwards (Faure et al., 2014). For the CoHort tool, technicians and researchers co-intervened at different steps: definition of the general objective of the tool, definition of the tool specifications, choice and definition of the concepts mobilized.

2.3. Specific objectives and requirements

One meeting per cooperative was first organized with its technician to agree on the general objective of the tool: simulating the impact of a given set of crop management practices on the work organization, economic performance (gross and net margin) and phytosanitary performance estimated with the treatment frequency index (TFI; see equation in Suppl.Mat.1) of the farm (Brunet, 2007).

Then two to three meetings at different stages of the tool design were organized separately with each technician to adapt the structure of the tool to their expectations and needs for its ultimate use by the technicians. The design process was framed to achieve ten objectives defined with technicians and based on both the technicians' needs to integrate the farm level in their advice with a flexible and quick to use tool, and the need to cover the diversity of farms, strategies and practices highlighted in a previous study conducted with the same cooperatives (Pissonnier et al., 2016):

(i) to take into account the farm characteristics, resources and constraints regarding equipment, labour, areas and activities;
(ii) to be generic enough to be used across diverse farms and diverse objectives of farmers;
(iii) to represent a diversity of strategies, for instance regarding crop protection from a pesticide shift to a complete different system, including new cultivars or heavy equipment;
(iv) to model a whole farm or only a part of it;
(v) to be adaptable to the level of information and data available on the farm, e.g., if the user wants to indicate each pesticide used or only the pesticide categories;