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Relevancy and role of whole-farm models in supporting smallholder farmers in planning their agricultural season

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ABSTRACT

The way a model is designed to assist farmers in their decision-making may influence how it is understood and perceived by farmers and shape interactions between farmers and model users (researcher, advisor). This study compared the strengths and weaknesses of three types of whole farm models used by researchers to assist 18 crop-livestock farmers in Burkina Faso in planning the next agricultural season. Due to its simplicity, the static simulation tool of annual farm stocks and flows led to superior changes in the farmers' knowledge and practices. The rule-based dynamic simulation tool helped the researchers grasp farmers' decision-making processes but was difficult for farmers to understand due to the discrepancy between its multi-annual time step and the farmers' short-term planning horizon. The optimisation tool stimulated more strategic discussions regarding paths to improve farm income despite a design that was distant from the farmers' reality.

1. Introduction

Faced with an increasingly complex and uncertain environment, fluctuating input and agricultural product prices, climate change impacts, and societal concern for the environmental impacts of agriculture (Thompson and Scoones, 2009), farmers worldwide are being forced to innovate. They do so by introducing technical changes or reorganizing how activities are combined on their farms. This innovation process can involve three decision levels: daily farm operations of field/animal components, seasonal planning, and long-term strategic choices (Cros et al., 2004; Martin et al., 2013). As proceeding by trial and error is a time-consuming and risky process, modelling can be useful in assisting farmers to design, assess and implement innovative and sustainable production systems (Attonaty et al., 1999; Le Gal et al., 2011). Numerous modelling methods such as crop models (Chatelin et al., 2005; Benjamin et al., 2010; Thorp et al., 2008), expert systems (Vandendriessche and van Ittersum, 1995; Snow and Lovatt, 2008) and information management tools (Jensen et al., 2000; Cornou and Kristensen, 2013) have been developed for daily farm operations. Seasonal planning and long term strategic choices require the support of holistic tools such as whole-farm models. Such tools render it possible to evaluate resource allocation decisions that farmers must make when designing and implementing change on their farms. While some of these models are mainly used by researchers to assess the merits of technical options (van Wijk et al., 2009; Whitbread et al., 2010), others are used with farmers to help them make their decisions or consider potential changes on their farms (Vayssières et al., 2009b; Dogliotti et al., 2014).

With the tremendous progress made in hardware and software development over the past 20 years, the use of modelling in research studies is now widespread. However, the use of modelling to assist farmers in their decision-making has been problematic (McCown, 2002; Jakku and Thorburn, 2010; Matthews et al., 2008). Rather than providing ready-made solutions, farm management models, used in interaction with a researcher or advisor, aim to help a farmer consider his or her

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options by comparing and discussing alternative production strategies (Le Gal et al., 2011; Rodriguez et al., 2014). To render the use of these models more effective, improved understanding of the interaction between model design, farmer needs, and the role of the model user (usually a researcher or an advisor) in management change is required. Several issues need to be addressed. The way a farmer understands and perceives a model helps shape the interaction between the farmer and the model user. The question which must be addressed is how does the design of a model influence this perception? To avoid a "black box" effect, the model should be transparent and produce outputs that make sense to the farmer (Rivington et al., 2007; Barnaud et al., 2008). An understanding of the kind of learning derived through the use of the model, both for farmers and the researcher or advisor working with them, also is critical (Matthews et al., 2011). The learning process that results from a model's iterative simulations includes (i) a better understanding of the farmer's current management practices, especially regarding interactions between the various components of the farming system, (ii) reflections regarding the potential alternatives to be simulated and (iii) evaluation of the consequences of each alternative on farm performance (McCown, 2012).

A wide range of whole-farm models currently are available, which render difficult their selection in a decision support perspective. Three main types emerge from a review of the literature (Le Gal et al., 2011): (i) static simulation models, describing farm operations on the basis of stocks and flows over a single year (Martin et al., 2011; Andrieu et al., 2012; Rodriguez et al., 2014); (ii) rule-based dynamic simulation models with decision rules representing farmers' management modes in the form of "IF Conditions THEN Action" rules, simulating changes in the farm state over one or several years (Andrieu and Nogueira, 2010; Bergez et al., 2012; Moreau et al., 2013); and (iii) static linear programming models maximizing a utility function (income, for example) under constraints, representing the farm as a combination of linear activities, either over a single year (Groot et al., 2012; Rodríguez-Sánchez et al., 2012) or over several years (Naudin et al., in press). The specific objectives of a decision support process should determine the type of whole-farm model used. To date, however, scant attention has been paid to whether the different features of the various model types impact the interaction between the farmer and the model user. Ideally, model developers should consider whether their tool actually helps farmers in managing their production systems (Keating and McCown, 2001), yet few do so (Le Gal et al., 2011; Dogliotti et al., 2014). Moreover, in the decision support case studies reported, multiple decision support tools have rarely been used since researchers usually focus their studies on one model type, for instance optimization (Dogliotti et al., 2014) or a stock and flow simulation tool (Le Gal et al., 2013).

Conducted in the frame of a two-year interaction between researchers and eighteen farmers in Burkina Faso, this study aims to investigate how farmers perceive models and what both farmers and researchers learn from the use of three modelling methods implemented in a decision support process at the farm level. The support process focussed on seasonal planning issues, which are critical for farmers due to a context characterized by deep uncertainty regarding the climate and economic environment. First, we present the study area, the three different tools used, the farm sample, and the approach followed. We then compare the use of the three tools using three criteria: assessment by farmers, facilitation of farmers' learning, and facilitation of researchers' learning. Lastly, we discuss the relevance of these types of tools in helping to design innovative production systems.

2. Materials and methods

2.1. The study area

The study was conducted in the village of Koumbia in western Burkina Faso (latitude 12° 42′ 207″; longitude 4° 24′ 010″). Increasing demographic growth, with a current population density of 66 inhabitants/km^2, and rising demand for plant and animal products is putting strong pressure on agro-pastoral resources (Vall and Diallo, 2009). The area also is characterized by a spatial-temporal rainfall variability, with an average of 900 mm/year, and three main cropping seasons: the rainy season, when biomass is produced (May to October); the cold dry season, (October to February), when crops are harvested, fodder stocks are replenished and animals are allowed to graze on fields after the harvest; and the hot dry season (March–April), when herds consume the fodder stocks. During that period, herds can leave for transhumance, i.e. go to other village areas to access water and pasture. Farmers are operating in an economic environment marked by the rising cost of agricultural inputs and fluctuating global cotton fibre and local livestock prices. There are three main types of farmers in Koumbia: crop farmers (CF) cultivating cotton and cereals using animal traction; crop-livestock farmers (CLF) cultivating large areas and owning large herds; and semi-settled Peulh livestock farmers (LF) practicing cattle breeding and subsistence farming (Vall et al., 2006).

2.2. The three models

The three tools used, *Cikεda*, *Simflex* and *Optimcikεda*, each belong to one of the three types of models noted in the introduction. All three represent a mixed crop-livestock farm and are *ad hoc* tools (Affholder et al., 2012), meaning tools developed specifically for the study area. Each tool, along with the main characteristics of its model type, is briefly described below (see Table 1 for the main inputs and outputs of each model).

Cikεda is an static simulation model. This kind of tool represents decision outputs, such as cropping plans, crop management or herd diets, rather than decisions rules. This simple modelling structure is meant to be easier to understand, but it requires the use of some approximations (Le Gal et al., 2013). For instance, crop yields are not calculated based on mechanistic biophysical equations as in a crop model, but are directly entered by the model user. *Cikεda* aims to support a farmer's assessment of the consequences of strategic (type and size of agricultural activities) and tactical (management of plant and animal production) choices on a farm's technical and economic performance (see Andrieu et al., 2012 for a detailed description). The balance between supply and demand for nutrients (nitrogen N, phosphorus P, potassium K), fodder, and cereals, as well as economic results, are calculated at the farm level for each configuration of the production system defined by the model user. Deficits in fodder result in the purchase of cotton meal which impact economic results. The biophysical processes considered are represented by static mean data obtained through surveys (average crop yield according to type of climate year), review of the literature (biomass mineral element content), and simplified calculations (exports of mineral elements). The simulation takes place over the course of one year.

Simflex is a rule-based dynamic simulation model which explicitly represents farmers' decision rules. This kind of model is assumed to be a powerful tool for evaluating the consequences of management decision rules on farm performance since it mimics farmer behaviour (Cros et al., 2004; Chatelin et al., 2005 Andrieu et al., 2007). Decision rules can be either pre-established in the model based on on-farm surveys (Vayssières et al., 2009a) or entered by the model user based on a meta-language (Romera et al., 2004). This modelling structure is supposed to be easily understood by farmers since their own rules are represented, but some simplifications are made to reduce the actual complexity of farmer decision rules (Romera et al., 2004). *Simflex* originally was developed for use in research exploring the impact of farmers' strategies to adapt to multiannual variability in economic and climatic conditions on their farms' technical and economic performance (Andrieu and Chia, 2012). Its direct use with farmers was tested in this study. Farmers' decision rules in response to changes in price and rainfall were represented using Python programming language. They were pre-established based on surveys conducted with another sample of farmers representing the three main farm types in the study area. These rules include (i) cropping plan choices based on the gross margin per hectare of cotton, (ii) mineral fertilisation of maize based on the purchase price of mineral fertilisers, (iii) the purchase of cotton meal or the start of transhumance based on the fodder stocks available and the purchase price of cotton meal, and (iv) the sale of animals when there is a negative economic balance. *Simflex* performs multi-annual simulations involving different climate and economic variables. Each year is independent of the year preceding it with the exception of the evolution of cattle herds and fodder stocks.

Optimcikεda is a linear programming model developed using GAMS software applications (Barbier, 1998; Dabire et al., 2011). This kind of optimization tool is based on a vision of a decision-maker being able to choose the solution maximizing his utility function from a large range of possibilities thanks to the completeness of the information available to him and his capacity to compare all of the solutions possible (Duke et al., 2012; Salassi et al., 2013). The tool is appreciated for its capacity to integrate biotechnical and economic variables, for instance to evaluate effects of policy decisions on farm incomes (Veysset et al., 2005) or potential value of