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# BANAD: A farm model for *ex ante* assessment of agro-ecological innovations and its application to banana farms in Guadeloupe

Jean-Marc Blazy [a,*], Philippe Tixier [b], Alban Thomas [c], Harry Ozier-Lafontaine [a], Frédéric Salmon [d], Jacques Wery [e]

[a] INRA, UR 1321 Agrosystèmes Tropicaux, Domaine Duclos, Petit-Bourg F-97170, France
[b] CIRAD, UPR 26, PRAM – BP 214, F-97285 Lamentin Cedex 2, Martinique, France
[c] INRA/Université de Toulouse I, UMR 1081, Économie des ressources naturelles LERNA, Université des Sciences Sociales de Toulouse, 21 Allée de Brienne, F-31000 Toulouse, France
[d] CIRAD, UPR 75, PRAM, BP 214, 97285 Lamentin Cedex 2, Martinique, France
[e] Sup Agro, UMR 1230, SYSTEM, CIRAD-INRA-SupAgro, F-34060 Montpellier, France

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ABSTRACT

The *ex ante* assessment of innovative agro-ecological innovations is a key step in the development of more sustainable crop management systems. To this end, models are useful tools because they make it possible to rapidly assess numerous innovations in different contexts. Whereas many farm optimisation models focusing on the farmer's strategic decision to adopt new crop management systems have been published, little attention has been given to the *ex ante* modelling of the dynamic operational impacts of innovation adoption at the farm level. BANAD, a mechanistic model for such applications, is proposed. It allows the *ex ante* assessment of innovative management systems including new agro-ecological techniques, while taking into account different farming contexts and policy and market conditions. It includes three components: (i) a crop management system model, (ii) a crop model (SIMBA) and (iii) a farming system model. Our results applied to the *ex ante* assessment of six innovative banana management systems for three contrasted farm types in Guadeloupe showed that the impacts of agro-ecological innovations, which include rotations, improved fallow, intercropping, pest-resistant cultivar, and an integrated organic system, can vary considerably according to (i) the farm type in which the innovation is integrated, (ii) the nature of the agro-ecological innovations, and (iii) the criteria considered and the temporal horizon of the assessment. Innovative intercropping systems that were effective at the field level in terms of the yield improvement and decreased pesticide use could be problematic at the farm level because they increased the workload and decreased income. The adoption of rotations or improved fallow seemed to be relevant for smallholders but could induce a critical period of 1.5–2.5 years during which income decreased drastically. Under certain conditions of markets and subsidies, very environmentally friendly innovations that are less productive can however be economically effective.



## 1. Introduction

Climate change, increasing societal demand for cleaner production and market and policy fluctuations act on agricultural systems as driving forces because they create new production conditions that make conventional agricultural systems irrelevant or unfit for these new conditions (Hatfield et al., 2007). In this changing context, adopting agro-ecological innovations is a key point for farmers to maintain the economic sustainability of their farm while conforming to environmental regulations. Agronomists, ecologists and economic scientists can help farmers to innovate by developing technological innovations adapted to their problems and personal conditions. A key step in the development of alternative management systems is the *ex ante* assessment of innovations (van Ittersum et al., 2008). At a early stage of the design of alternative management systems, an *ex ante* assessment allows the identification of the critical points that have to be improved and to determine the conditions in which innovations will or will not be suitable.

Participatory on farm research is a promising approach to jointly assess the economic, biophysical and environmental impacts of innovative techniques (Vereijken, 1997; Franzel et al., 2001). Nevertheless, on-farm trials are generally considered costly

* Corresponding author. Tel.: +590 (0)5 90 25 59 10; fax: +590 (0)5 90 94 16 63.
*E-mail address:* jean-marc.blazy@antilles.inra.fr (J.-M. Blazy).

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and time-consuming to implement. For this reason, computer bio-economic models are increasingly used to design and evaluate innovative agricultural systems because they enable the *ex ante* assessment of innovations in a limited time and with few resources. Models indeed provide the opportunity to assess a considerable number of innovative options across a large range of situations (e.g., Dogliotti et al., 2004).

According to the review of bio-economic models made by Brown (2000), we can distinguish basically two main categories of models. On the one hand, the cropping system models represent in a mechanistic way the biological processes under different technical and environmental conditions to simulate agro-ecological processes. These models run at the field level and mainly focus on the biophysical impacts of innovative technologies (Tixier et al., 2008a; Keating et al., 2003; Stöckle et al., 2003; Loyce et al., 2002). Even if these models often include an economic module, they are not appropriate to assess the operational economic and technical impacts of innovations at the farm level, which is however crucial information for farmers to decide whether to adopt an innovation.

On the other hand are the economic optimisation farm models. These models are increasingly used and have been critically reviewed by Brown (2000) and Janssen and van Ittersum (2007) on their strengths and weaknesses in assessing technological innovation and policy changes. In these models, the decision-making process is seen as an optimisation problem in which the farmer has to choose the intensity of use of current and alternative production possibilities to optimise one or multiple objectives given several constraints. As mentioned by Brown (2000), the key limitation of economic optimisation models is " *in their ability to model the agro-ecological processes involved in such a way as to simulate the actual biological processes rather than simply using a fixed set of parameters for a finite set of activities derived from empirical observations*". In other reviews of bio-economic farm models, Janssen and van Ittersum (2007) noted that many studies focus principally on current alternatives and not on innovative management systems such as those involving agro-ecological techniques. Moreover, among the few studies conducted on innovative systems, the definition and description of alternative agricultural activities that form the inputs of the model are generally not explicitly described. Too many model studies do not mention the sources of their data on technical coefficients used to describe the alternative options, while many others do not explicitly discuss the assumptions in formulating their current and alternative activities. Technical coefficients are generally derived from production functions that are linear-segmented approximations of non-linear functions. These functions are difficult to establish empirically for very innovative management systems that are currently not present on real farms. At an early stage of a prototyping research program, it is indeed common to have minimal knowledge about the possible interactions among the innovative techniques and farm-specific economic and environmental contexts that may vary greatly at the regional level. Accounting for spatial heterogeneity of farms is thus necessary to assess the variability of economic and biophysical performances of innovations. This makes the estimation of technical coefficients of innovative alternatives difficult to establish and can limit the cross-pollination between the prototyping and farm modelling approaches (Sterk et al., 2007).

The objectives of this paper is to propose a simple mechanistic model named BANAD to assess *ex ante* the technical, economic and environmental consequences at the farm level of adopting innovative agro-ecological management systems for different production contexts. The BANAD model has been parameterised and evaluated for assessing several innovative prototypes of environmentally friendly banana management systems in Guadeloupe, in the French West Indies (F.W.I., 16°15′N, 61°32′W). In this tropical island, pesticide use has to be decreased because of serious environmental problems resulting from decades of intensive practices (Cabidoche et al., 2009; de Barros et al., 2009).

## 2. Material and methods

### 2.1. Overview

BANAD is a bio-economic farm model that jointly simulates the biophysical and technico-economic processes of resource management at the farm level under different scenarios of farm context and innovation adoption. It is a mechanistic model based on the available theory and knowledge of field biophysical functioning and farm management processes. BANAD is a dynamic model that runs at a weekly time-step and at the farm level, the farm being represented as a system of production processes under the control of farmer's tactical and strategic technical decisions. In this model, the strategic decision of adopting an innovation is forced by the model's user. Tactical decisions related to weekly actions are modelled with a set of decision rules. BANAD is a normative model in which the norm is the implementation of this set of decision rules. These rules result from the systemic integration of one or several innovations into the current observed practices that are adapted according to the nature of these innovations and the farm type.

Fig. 1 gives an overview of the general structure of the model. The outputs of the model are dynamic at a weekly time-step and relative to the banana production, cash flows, workload, and environmental impacts indicated with the total amount of pesticide active ingredient used. These four dimensions are key components of sustainability and of farmers' decision making for deciding whether to adopt an innovation (Gafsi et al., 2006). These outputs can be summarised at different time scales (month, year, crop rotation, transition from one crop management system to another) and spatial levels (field, groups of fields of one kind, entire farm). The inputs of the model are sets of parameters that define: (i) the farm's economic, technical and environmental characteristics; (ii) the innovative crop management system parameters; and (iii) the policy and market conditions. The model takes into account the spatial heterogeneity of farms at the regional level through different farm types. These sets of parameters are computed in a parameterisation module that allows the definition of consistent sets of parameters for each scenario of the simulation from the inputs database. Integrating an agro-ecological innovation into a crop management system indeed requires some adaptations of decision rules to make the innovative situation still consistent after adoption (e.g., adopting intercropping requires the cessation of herbicide treatments). The farm model is made of two components, a cropping system model that represents the biophysical and technical processes at the field level, and a farming system model. Following the representation of Rapidel et al. (2006), the cropping system model is represented as a biophysical crop model in interaction with a crop management system model (CMS). The crop model (called SIMBA, Tixier et al., 2008a) simulates the biophysical processes such as the crop growth, pest development and environmental impacts, and all the techniques that have an impact on these processes. The CMS model simulates all the cultural practices on the field during each week. The farming system model manages the farm level allocation of resources and combines and integrates the results from the different kind of fields present on the farm.