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SIMBA, a model for designing sustainable banana-based cropping systems

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Abstract

Banana monocultures (*Musa* spp., AAA, Cavendish sub-group cv. Grande Naine) can have a detrimental impact on the environment. In these agro-systems, pesticide treatments can lead to surface and groundwater pollution, as is the case in the tropical insular conditions of the French West Indies. Using models to design alternative cropping systems is of growing interest but most of the research work has been concentrated on annual crops and most often in temperate climate. A specific model called SIMBA was built to assess environmental risks under a large range of cropping techniques and to help design more sustainable cropping systems. SIMBA simulates banana-cropping systems at field level over several cropping cycles. It includes sub-models that simulate soil structure, water balance, root nematode populations, yield, and economic outputs with a sound balance between representing the major phenomena well and keeping the model simple to reduce the parameterization costs in a large range of conditions. Agro-environmental indicators generated by the model make it possible to assess the major potential environmental impacts. The model has been developed and calibrated in Guadeloupe and Martinique and is used to draw up practical recommendations for farmers and for virtual experiments of agro-technological innovations or field management strategies. The structure of SIMBA is presented and a methodology is proposed for designing sustainable banana-based cropping systems using the model. SIMBA has been evaluated in a broad range of cropping systems in Guadeloupe by comparing model estimates to data collected in field experiments and surveys. Simulations lead to trends in rotation-based cropping systems characterized by systems that can be considered as intensive for profit evaluation, and combinations of frequent replanting, low nematicide application, no ploughing, and low fertilization level, for environmental evaluation. Simulations performed to optimize the replanting decision rule showed that relatively frequent replanting is good for profit while low frequency replantations (over four banana cycles) give a better environmental evaluation.

Keywords: Crop model; Agro-environmental indicators; Multicriteria evaluation; Guadeloupe; *Musa* spp.

1. Introduction

Intensive agriculture has led to major environmental issues that affect global sustainability (Tilman et al., 2002). It is now essential to design new cropping systems to address both the needs of farmers, the authorities, and the society, while preserving the environment simultaneously. Several strategies are being explored to solve these problems, including new field practices or new spatio-temporal arrangements of practices. New concepts

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and innovative predictive tools are needed to design more sustainable cropping systems (Boiffin et al., 2001). Agronomists must work in multidisciplinary research groups that include modelers, social scientists, and plant pathologists in collaboration with farmers′ groups (Boiffin et al., 2001; Meynard et al., 2002; Dogliotti et al., 2004). Vereijken (1997) proposed a methodology for designing farming systems involving four steps, respectively: (i) analysis and diagnosis, (ii) design, (iii) testing and improving, and (iv) dissemination of a prototype (Sterk et al., 2007). Designing a prototype always begins with a thorough survey of the situation and an assessment of potential developments. This analysis facilitates the choice of the most appropriate model outputs or the additional complementary analyses and experiments that are required. Dogliotti et al. (2004) proposed that this approach can be improved by models, which allow fast exploration of crops and techniques and can be used to optimize their combinations and evaluate their production and externalities. Another type of model-based approach has been used to design prototypes of wheat-based cropping systems (Loyce et al., 2002a,b). This model simulates and compares specified cropping systems on the basis of their yield, cost, gross margin, nitrogen use, pesticide use, seed quality, and energy balance. When targeting sustainability in the evaluation of cropping systems, one needs to consider both an environmental objective defined by society or the authorities and an economic objective defined by the farmer. In this context, scientists or stakeholders have to set objectives, which are often a trade-off between environmental and economic constraints. However, most crop models perform evaluations simply on the basis of a few criteria, such as yield, and may not take into account the effects of all innovative techniques, which limits their utilization to design prototypes (Lançon et al., 2007).

In the case of banana-based cropping systems, evaluations have to focus on agronomic performances as well as environmental impacts, i.e. mostly risks linked with pesticide dissemination in the environment. Throughout the world, banana production (*Musa* spp., AAA, Cavendish sub-group cv. Grande Naine) for export is mainly based on intensive monocrop systems, which are generally not environmentally friendly. The agronomic and ecological sustainability of these systems is often hampered by a high level of root parasitism, including nematodes. Air, soil, and water quality may be adversely affected by the frequent applications of chemical pesticides that are required to control this parasitism and by soil and plant management practices that may lead to severe erosion. These risks are magnified in fragile, tropical, insular conditions such as those found in Guadeloupe, in the French West Indies (F.W.I., 16°15′N, 61°32′W) where inhabited areas, coral reefs, and rainforests are close to agro-systems (Bonan and Prime, 2001; Bocquené and Franco, 2005). This issue also concerns all areas of intensive production of banana (Matthews et al., 2003; Castillo et al., 2006; Chaves et al., 2007). At the same time, managing manpower, adapting to a fluctuating and highly competitive market, or limiting pesticide use are major economic problems that threaten the whole banana production sector in F.W.I. (Bonin et al., 2004).

To design new banana-based cropping systems, a model called SIMBA was built to simulate this system and to assess its performances and impacts. The model takes into account the specificities of this semi-perennial tropical system and seeks to simulate the set of outputs needed to assess its performances on a multicriteria basis. To fulfill these objectives, biophysical modules were developed and a set of economic and environmental indicators were defined. SIMBA can be used to optimize suitable practices that take into account the dynamics of the state variables of the system (pests, plant population, soils, etc.) in order to reach a target objective. The design of the model was therefore mainly driven by a pull approach guided by the cropping techniques (generated as much as possible by decision rules) and by the assessment criteria. Knowledge on the key biophysical mechanisms was available from experiments and experts' knowledge, which served to build a modular soil-crop-nematodes model linking techniques and indicators. SIMBA was developed to simulate and assess the main environmental risks in banana-cropping systems (pollution of water and soil erosion) over several cropping cycles.

In this article, we present how a model like SIMBA could be used to evaluate existing or innovative cropping systems in a variety of soil and climate situations and thus helps select the best cropping system prototypes for on-farm experiments. We first present the structure of the SIMBA model, and then we present a two-step method to generate and assess cropping systems with the model. The example of banana-fallow rotations is explored and optimized regarding economic and environmental goals.

2. The SIMBA model

2.1. Model structure

Instead of starting from an existing crop model, adapting it to the banana-nematodes system, and deriving some indicators from the output variables, we created a new model to produce the assessment indicators based on existing knowledge. This modelling approach allows accounting for the specificities of the system and to use expert knowledge more easily. The evaluation criteria of the simulated systems were profit margin and environmental risks associated to pesticides and erosion. Consequently, the yield and the state variables of the system, and their dynamics, have to be taken into account. Two types of formalisms were developed to compute these variables. For processes that can be simulated biophysically, process-based modules were developed. These included plant growth, plant population structure, soil cover, physical soil properties, water balance, and plant-parasitic nematode population densities. For processes that cannot be easily simulated at field