SIMBA: a comprehensive model for agro-ecological assessment and prototyping of banana-based cropping systems. An application in the French West Indies.

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Abstract

Monospecific banana (*Musa* spp., AAA group, cv. Cavendish Grande Naine) based cropping systems may present important threats to the environment. In these agro-systems, pesticides cause significant risks of pollution for surface and ground water, enhanced in the tropical insular conditions of French West Indies. In order to assess these risks and to help the design of more sustainable cropping systems a specific model called SIMBA was built. SIMBA simulates banana cropping systems through several cropping cycles. SIMBA includes sub-models that simulate soil structure, water balance, root nematode populations, yield, economic outputs, etc. Agri-environmental indicators linked to the model allow environmental assessment. The model is used in Guadeloupe and allows practical recommendations to farmers, virtual test of agro-technological innovations or field management strategies.

Introduction

Worldwide, banana production for export is often based on intensive monocropping systems that are generally not environmentally friendly. The agronomical sustainability of these systems is often endangered by an important root parasitism including nematodes. Air, soil and water quality may deteriorate due to the frequent application of chemicals used to control these pests, and by soil and plant management practices that may lead to severe erosion. These risks are magnified in fragile tropical insular conditions as in Guadeloupe (F.W.I. , 16?15'N, 61?32'W) where inhabited areas, coral reefs and rainforests are located close to agro-systems.

In this context of intensive agriculture, specific scientific tools are required for the evaluation of existing systems and the design of more sustainable systems (Boiffin *et al*., 2001). SIMBA is a new model aimed at simulating and assessing the main environmental risks in banana cropping systems through several cropping cycles. It simulates and allows the agronomic and environmental assessment of existing or innovative cropping systems in various pedo-climatic situations. As a result, SIMBA constitutes a powerful tool to select the best candidates for farm experiments.

Structure of the model

SIMBA includes sub-models that simulate plant growth, plant population structure, physical soil properties, water balance, nematode population densities. These variables interact with climate and farmers' practices via decision-rule processes. Outputs include agronomic and economic performances of the system and environmental assessment. Environmental risks (pesticides water pollution, erosion and nitrogen efficiency) are assessed with integrated agro-environmental indicators.

SIMBA was developed on STELLA? software environment from High Performance Systems ? (Lebanon, NH, USA). It runs on a weekly step at the field scale. Climate (rainfall, temperature, solar radiation) and soil properties are necessary input data to run the model. Systematic decision rules are described with a calendar of practices and conditional decision rules are described with control variables and thresholds.

The long-term simulation is a key point to assess banana cropping systems. In banana crops, plants develop at their own rhythm and do not follow a synchronous cycle. A homogenous plant population after planting becomes heterogeneous after few cropping cycles with plants at different phenological stages at the same time in the field. This process has a strong influence on harvest, water, nitrogen, soil cover and pest dynamics. The module SIMBA-POP based on the cohort population concept (Tixier *et al*. 2004) simulates plant population structure and its evolution including the management of the plant population by farmer (choice of sucker, plant falling and replacing, etc.).

In the Growth module, plant growth is calculated separately for each phenological stage (cohort). Potential leaf area and biomass production are calculated using heat units accumulated in each cohort. Biotic and abiotic stresses are simulated and reduce the potential growth due to a lack of nitrogen, drought or parasitism effect. Water and nitrogen balance were designed in accordance with the specific pedo-climatic environment of Guadeloupe (andisols, important rainfall). These modules allow the computing of water and nitrogen efficiency and growth stresses.

The module SIMBA-NEM simulates nematode populations in banana roots. It links root growth, soil water content, soil pesticide stocks and nematode populations. It includes inter-species competition.

SIMBA outputs include profit margin calculated from the simulated yield, the selling price (that varies over the year), inputs and labour cost. The **figure 1** shows the global structure of SIMBA and the various links between modules.

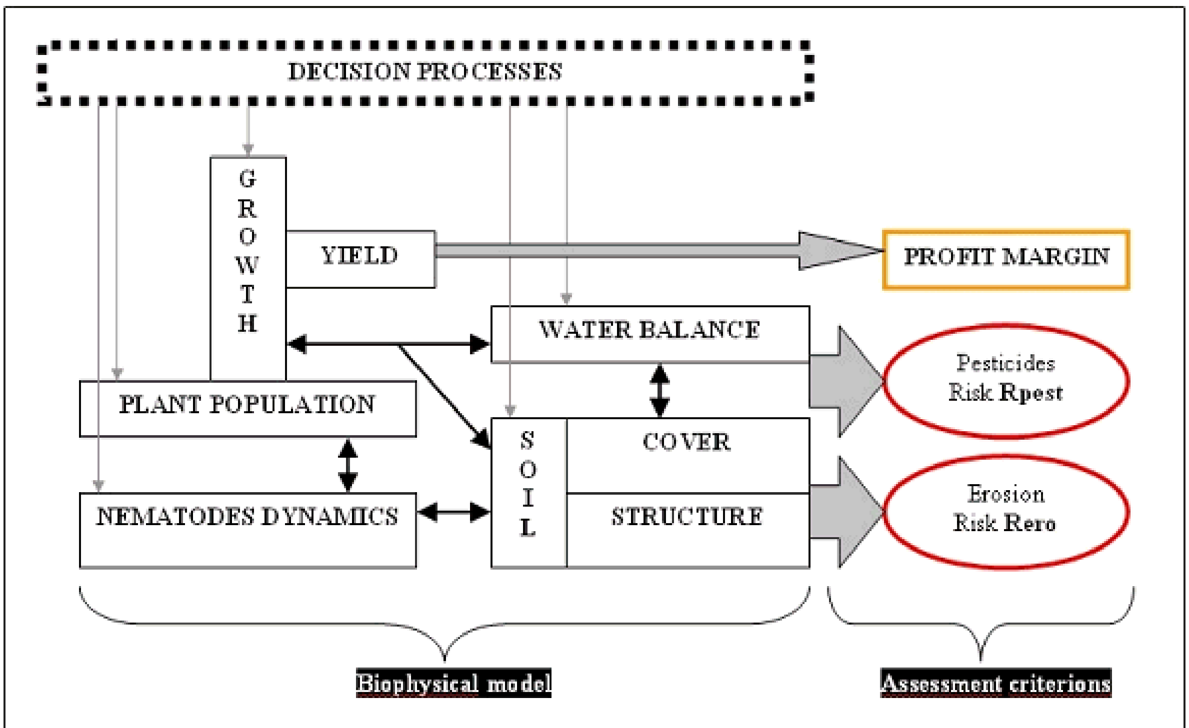

Fig 1. Global structure of SIMBA model

Risk assessment

Specific integrated indicators were built to assess complex environmental risks such as pesticides water pollution risk and erosion risk over time. These indicators are based on the aggregation of variables using expert system and fuzzy logic (Girardin *et al.* 1999) and linked to the biophysical variables in SIMBA. This structure allows a weekly assessment where existing indicators allow only annual assesment. The erosion risk indicator Rero and the pesticides water pollution risk indicator Rpest are dynamic, and hence allow the detection of the higher risk periods. The note of risk they supply every week can be integrated over the complete period of the cropping system with a mean note or a distribution of notes by classes that is a powerful tool to compare different cropping systems.

Each module of SIMBA was calibrated and validated separately using data from Guadeloupe. The outputs of the model are used as criteria for assessment. The **figure 2** shows the SIMBA outputs for 2 typical banana systems (intensive monoculture and banana after sugarcane). Outputs are presented in a control panel board that help comparison between systems using all dynamical data or more integrated value such as distribution of risk notes by classes for pesticides and erosion risk indicators.

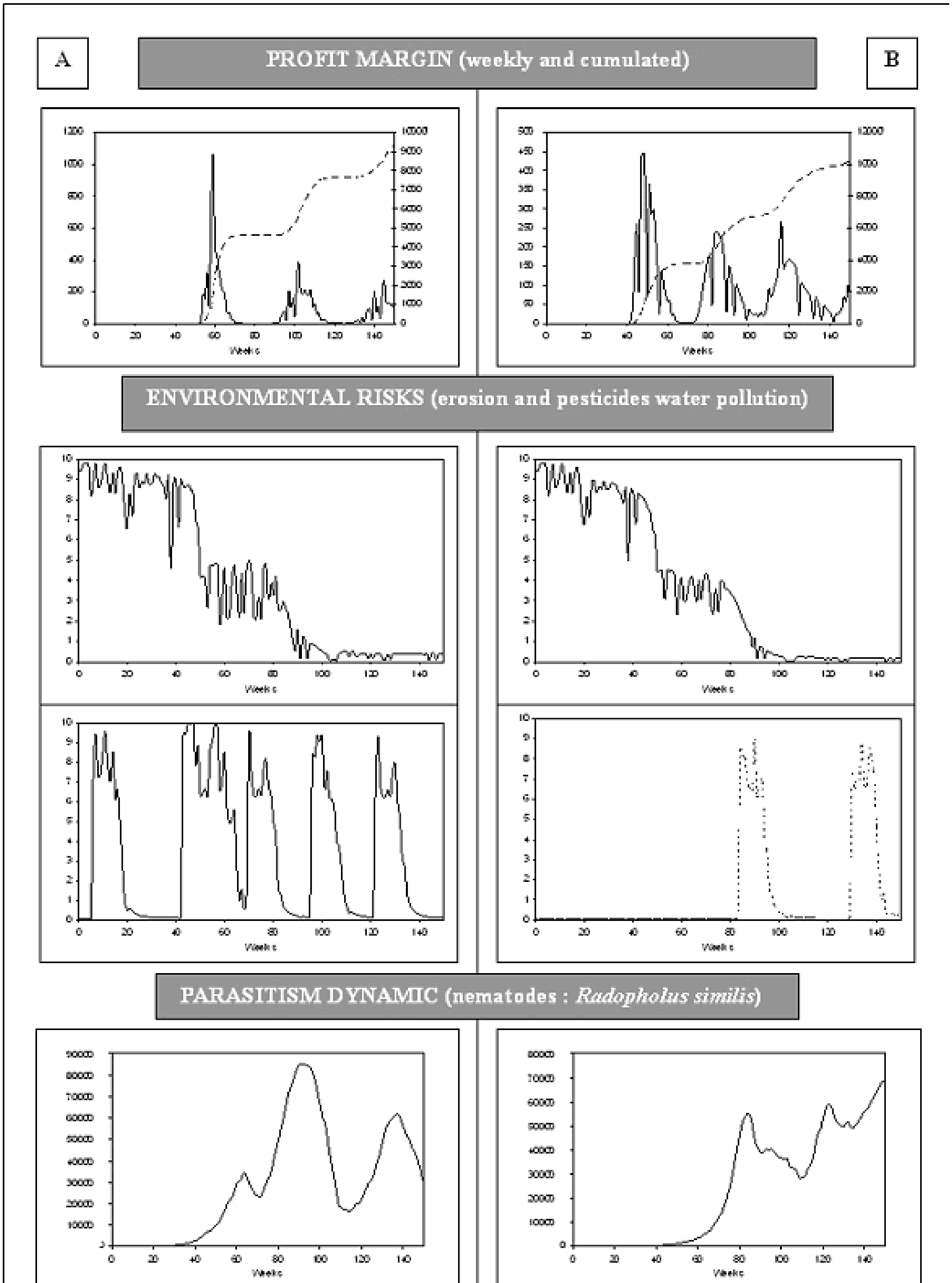

Fig 2. SIMBA control panel for 2 cropping systems (A: an intensive monoculture in medium altitude ; B: a banana after sugarcane in low altitude). Weekly and cumulated profit margine (in euros) vs. time (weeks), Weekly erosion and pesticides water pollution risk indicators note, weekly nematodes (Radopholus similis) stock per square meter.

Uses of the model

SIMBA is a tool that allows various uses. It can be used as an aid to prototype new cropping systems, by testing new sets of decision rules, or by an exhaustive exploration of decision rules. Iterative processes that optimise step by step the decision rules to reach an objective can also be used. An assessment requires an objective for the system such as minimizing environmental risks or maximizingthe economic margin with minimum environmental risk.

SIMBA allows a multi-criterion assessment of different farming strategies in order to establish practical recommendations to assist farmers, regarding the efficiency of new agro-technological innovations and field management strategies. It is a powerful tool to test new practices one by one or set by set. The global and long term approach allows realistic solution to agronomic or environmental problems that are not possible with usual crop models. Another way of prototyping cropping systems is to assess exhaustively all the possible decision rules combining and choosing the ones that are closest to the fixed goal (Dogliotti et al. 2003 ; Loyce 1998). More complex approach is by optimisation of the decision rules step by step to reach objectives in a particular pedo-climatic environment (Tchamitchian et al. 1998). The **figure 3** shows the different strategies to use the model to help prototyping more sustainable cropping systems.

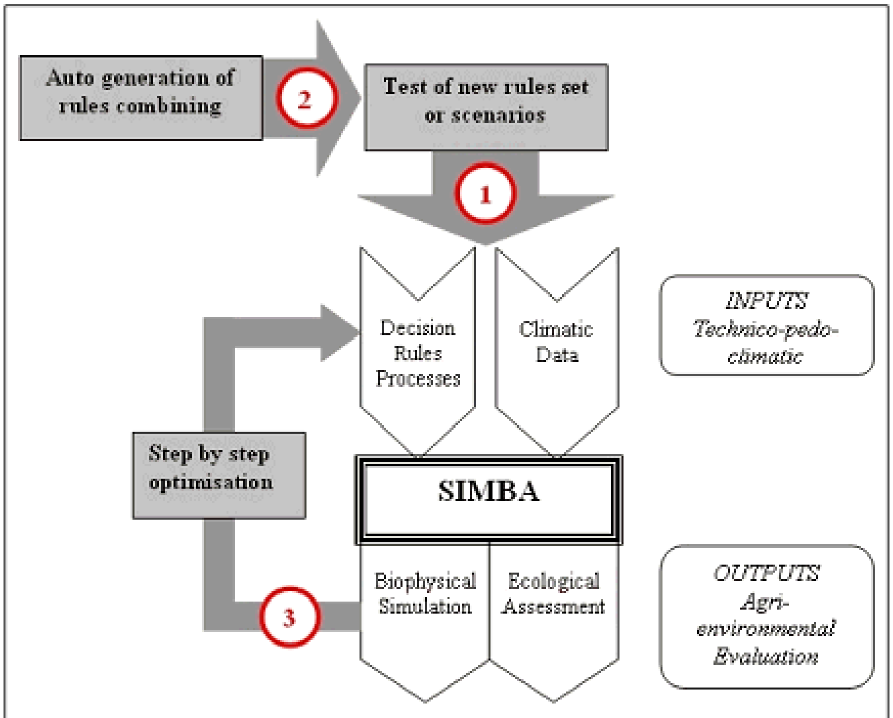

Fig 3. Uses of SIMBA for prototyping cropping system

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