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

P. Tixier[1], E. Malezieux[2], M. Dorel[1]and **J. Wery[3]**

[1] CIRAD-Flhor, UMR SYSTEM, 97130 Capesterre, Guadeloupe, French West Indies, France. Email tixier@cirad.fr
[2] CIRAD, UMR SYSTEM, TA179/01, 34398 Montpellier Cedex 5, France. Email malezieux@cirad.fr
[3] Agro-Montpellier, UMR SYSTEM, TA179/01, 34398 Montpellier Cedex 5, France. Email wery@cirad.fr

Abstract

Monospecific banana (*Musa* spp., AAA group, cv. Cavendish Grande Naine) based cropping systems may be very detrimental to the environment. In these agrosystems, there is a high risk of pesticide pollution of surface and ground water, especially in the insular tropical conditions of the French West Indies. A specific model called SIMBA was built to assess these risks and help design more sustainable cropping systems. SIMBA simulates banana cropping systems through several crop cycles. It includes sub-models that simulate soil structure, water balance, root nematode populations, yield and economic outputs. Agri-environmental indicators linked to the model enable environmental impact assessment. The model has been implemented in Guadeloupe and will be useful for drawing up practical guidelines for farmers, and virtual testing of agro-technological innovations or field management strategies.

Media summary

SIMBA is a new model to prototype banana cropping systems that simulates crop growth, soil properties, water and nitrogen balance, nematode parasitism and assesses environmental risks using integrated indicators.

Key words

Banana, cropping systems, crop model, agri-environmental indicators, prototyping

Introduction

Worldwide, banana production for export is often based on intensive monocropping systems that are generally not environment-friendly. High root parasitism, including nematodes, often reduces the agronomic sustainability of these systems. Air, soil and water quality may be degraded by the frequent application of chemicals used to control these pests, and by poor soil and plant management practices that may lead to severe erosion. These risks are magnified in fragile insular tropical conditions like those that prevail in Guadeloupe (F.W.I. , 16?15'N, 61?32'W) where inhabited areas, coral reefs and rainforests are located close to agrosystems.

In this intensive agriculture context, specific tools are required to assess existing systems and design more sustainable systems (Boiffin et al., 2001). The SIMBA model was developed to simulate and assess the main environmental risks in banana cropping systems through several cropping cycles. It can be used for agronomic, economic and environmental assessment of existing or innovative cropping systems under various pedo-climatic situations. It is therefore a powerful tool for selecting the best prototypes of cropping systems for on-farm experiments.

Structure of the model

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

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

Long-term simulation is essential for assessing banana cropping systems. In a banana field, each plant develops differently , so the growth cycle of the plant population is not synchronous. After planting, an homogenous plant population becomes heterogeneous after a few cropping cycles with plants at different phenological stages at the same time in the field. This process has a marked influence on harvest, water, nitrogen, soil cover and pest dynamics. The SIMBA-POP module, based on the cohort population concept (Tixier *et al*. 2004), simulates plant population structure and its changes, including those induced by the farmer's crop management strategies (choice of sucker, plant falling and replacement).

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 by each cohort. Biotic and abiotic stresses are simulated and reduce the growth potential due to a lack of nitrogen, or to the effects of drought or parasitism. Water and nitrogen balance modules were designed to take into account the specific pedoclimatic environment of Guadeloupe (andisols, high rainfall). These modules are used to compute water and nitrogen efficiency and growth stresses. The SIMBA-NEM module simulates nematode populations in banana roots. It links root growth, soil water content, soil pesticide stocks and nematode populations. It includes trophic competition between nematode species.

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

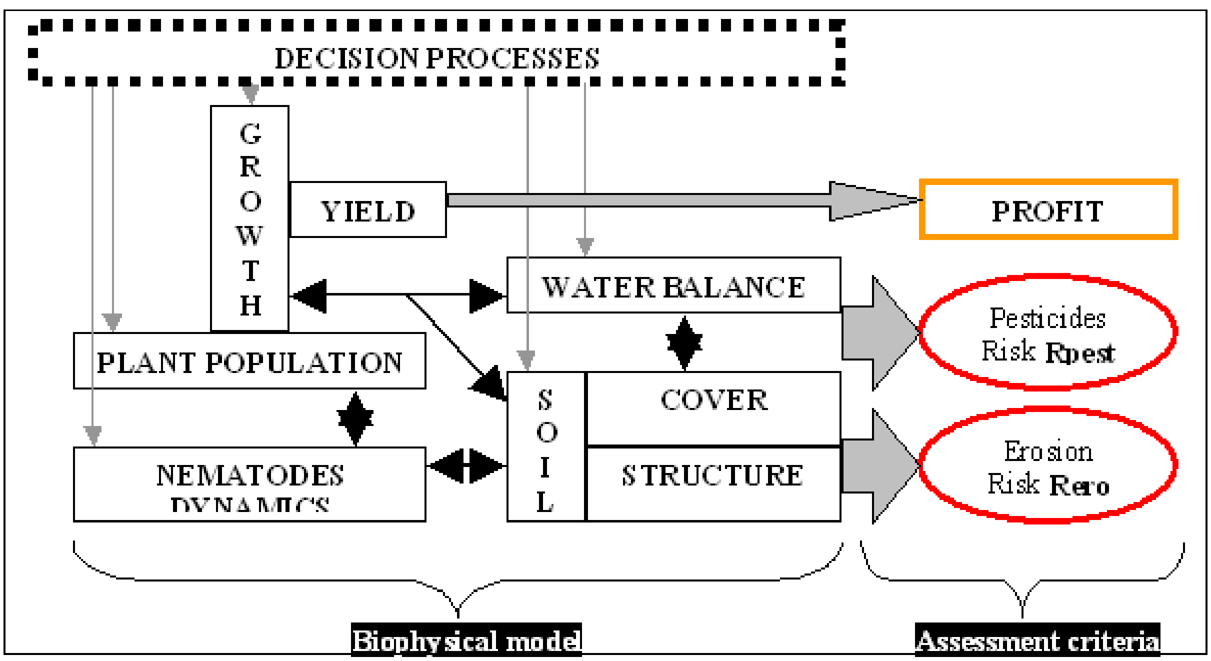


Figure 1. Global structure of the SIMBA model.

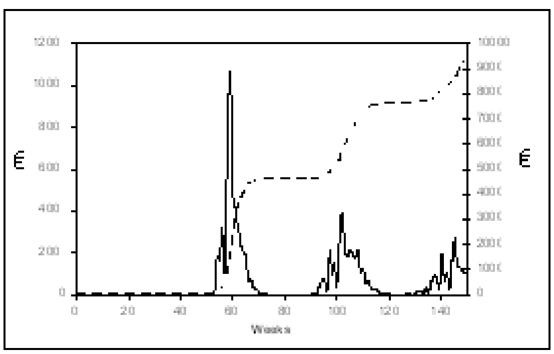
Risk assessment

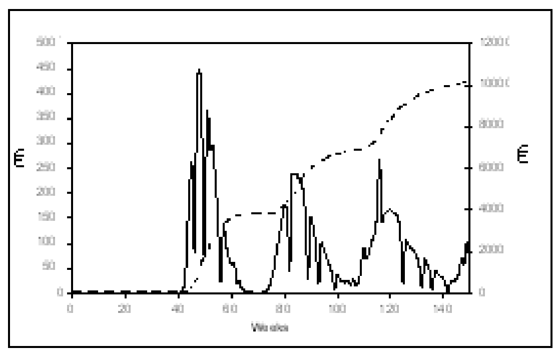
Specific integrated indicators were built to assess complex environmental risks such as exposure of water to pesticides and erosion risks over time. These indicators are based on the aggregation of variables using expert system and fuzzy logic (Girardin *et al.* 1999) and linked to the biophysical variables in SIMBA. This structure enables weekly assessments of the system whereas existing indicators only enable annual assessment. The indicators of erosion risk (Rero) and risk of water pollution by pesticides (Rpest) are dynamic, and hence allow the detection of maximal risk periods. The weekly risk score generated can be integrated over the complete cropping period for each system, with a mean score or a class-based score distribution, which is a powerful tool for comparing different cropping systems.

Each SIMBA module was calibrated and validated separately using data from Guadeloupe. The outputs of the model are used as assessment criteria for the cropping system. Figure 2 shows the SIMBA outputs for two typical banana systems (intensive monoculture and banana after sugarcane). The outputs are presented in a control panel board to facilitate comparison between systems using all dynamic data. It is possible to calculate more integrated values such as class-based score distributions.

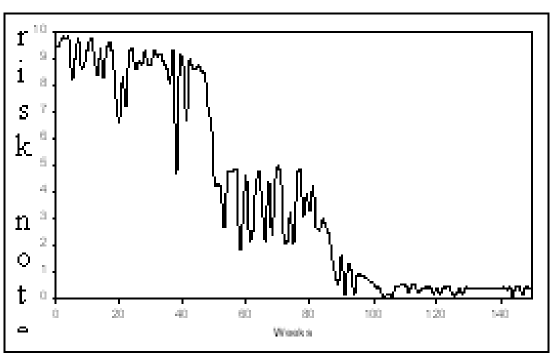
A **B**

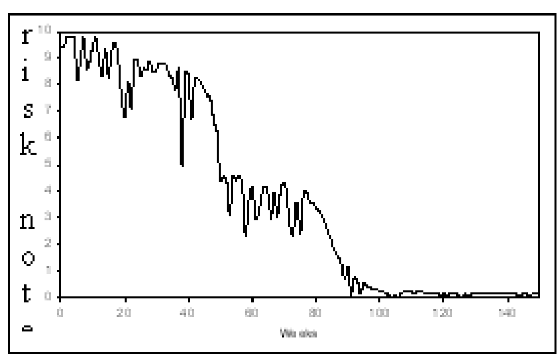
a. Profit margin (weekly and cumulated)

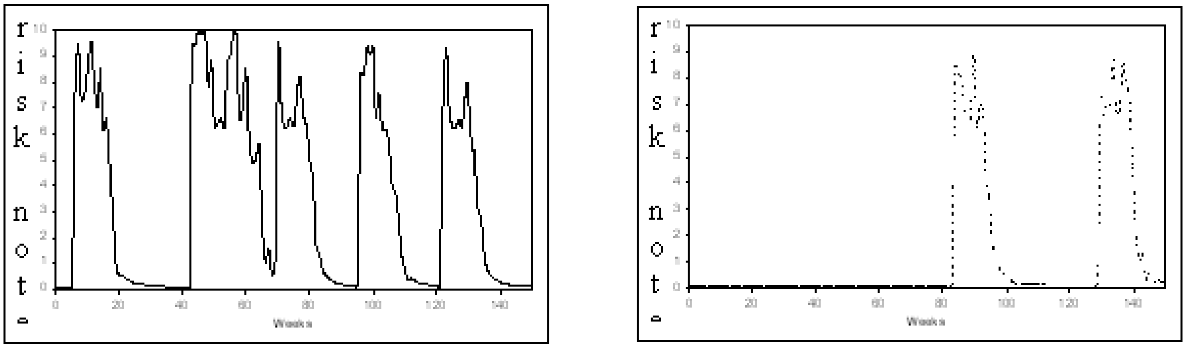




b. Environmental risks (erosion and pollution of water by pesticides)







c. Parasitism dynamics (nematodes: *radopholus similis*)

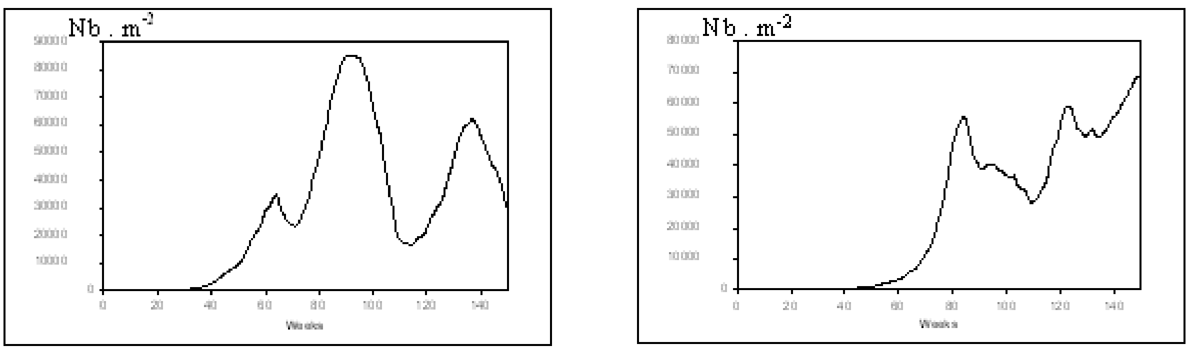


Figure 2. SIMBA control panel for two cropping systems (A: an intensive monoculture at medium elevation; B: a banana after sugarcane in lowlands). (a) Weekly and cumulated profit margin (in euros), (b) weekly erosion and water exposure to pesticide pollution (indicator note) and (c) weekly nematode (*Radopholus similis*) stock (per m^2).

Uses of the model

SIMBA allows a multicriterion assessment of different farming strategies to enable the user to draw up practical guidelines to assist farmers regarding the efficiency of new agro-technological innovations and field management strategies. It is a powerful tool for the test of new practices one by one or in combination. The global and long-term approach provides realistic solutions to agronomic or environmental problems that are not possible with standard crop models.

As shown in Figure 3, SIMBA can also be used as an aid to prototype new cropping systems (Vereijken, 1997), via multicriteria assessment of one by one decision rules (1) or of all possible combinations of decision-rules using an autogeneration module (2) and selection of those that are close to the preset goal (Dogliotti *et al*. 2003; Loyce *et al.* 2002). A more complex approach is to optimise the decision rules step by step (3) to reach objectives for a particular pedoclimatic environment (Tchamitchian *et al*. 1998). Assessments are performed to ultimately reach a target objective concerning the system, such as minimizing environmental risks or maximizing the economic margin with minimum environmental risk.

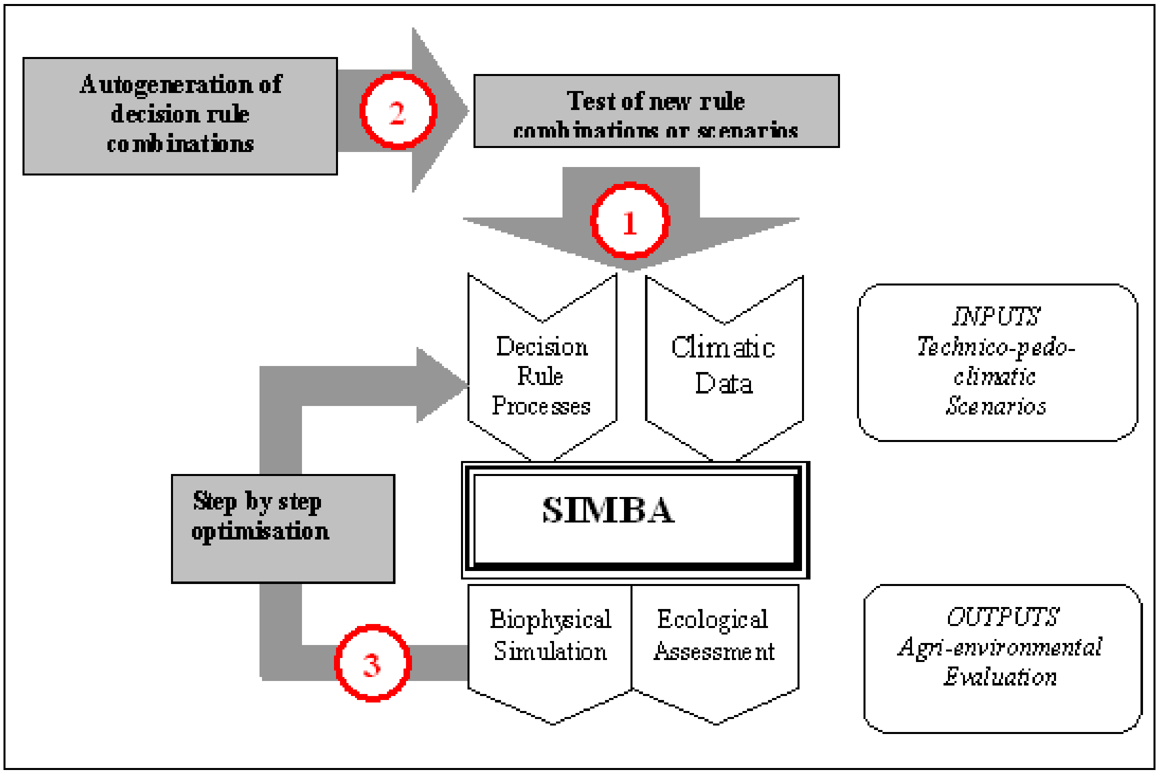


Figure 3. Uses of SIMBA for prototyping cropping systems.

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