2003 BELTWIDE COTTON CONFERENCES, NASHVILLE, TN – JANUARY 6-10

COTONSIMBAD SYSTEM : MODELING FEEDING BEHAVIOR OF COTTON BOLLWORMS FOR EVALUATION OF CROP PEST INTERACTIONS

S. Nibouche, P. Martin, M. Cretenet, and E. Jallas,
CIRAD
Montpellier, France
S. Turner
USDA-ARS
Mississippi State, MS

Abstract

The indeterminate growth habit of the cotton crop allows yield compensation in specific conditions of fruit shedding. This peculiarity complicates the determination of economic damage thresholds. A single pest population may cause variable damage levels depending on the ability of the crop for compensation. The multiple interactions between the environment, the agronomic practices, the plant growth and the pest population dynamics limit study of thresholds with a classic field experimental approach. Recent progress in the modeling of cotton crop offer new tools for economic threshold studies. SIMBAD model (SIMulation of Bollworm Attacks and Damages) simulates the demography of four species of cotton bollworms (*Helicoverpa armigera*, *Diparopsis watersi*, *Earias biplaga* and *Spodoptera littoralis*) and their damages according to their specific feeding behavior. The linkage of SIMBAD to the crop model COTONS allows an assessment of yield loss due to a bollworm attack, depending on the agronomic practices and the environment characteristics. SIMBAD includes three sub-models, modeling respectively the populations dynamics of bollworms, their feeding preferences and their voracity. The COTONSIMBAD system may be used as a farmer decision-aid tool or as a research tool for study of economic thresholds.

Introduction

Defining economic damage thresholds for cotton pests is a complex undertaking, since cotton growth is indeterminate and the plant can compensate for the loss of fruiting organs. A given population of insects can cause varying yield losses, depending on whether or not the crop is able to compensate for damage. The multiple interactions between the environment, the crop management sequence, plant growth and pest population dynamics make it difficult to establish damage thresholds using a conventional experimental approach in the field. The recent progress made on the COTONS model of cotton development (Jallas *et al.*, 1999) has paved the way for a clearer understanding of the interactions between the plant and pests.

The SIMBAD (SIMulation of Bollworm Attacks and Damage) model was developed with a view to modeling the demography and feeding behavior of four species of cotton bollworms (*Helicoverpa armigera*, *Diparopsis watersi*, *Earias biplaga* and *Spodoptera littoralis*). Coupling the COTONS and SIMBAD models allows an assessment of yield losses due to bollworm attacks, depending on parameters such as the size and species composition of the pest population, date of the attack, potential yield of the crop, etc.

The COTONSIMBAD System

SIMBAD is structured around three sub-models:

- a demographic model, which simulates the changes in bollworm numbers depending on temperature and natural mortality;
- a feeding preference model, which determines the type and position of organs likely to be attacked by bollworms;
- a voracity model, which determines the number of organs attacked.

Demographic Sub-Model

The demographic sub-model is a rather basic model, since the aim of this model is not to forecast bollworm infestations on a long time period, as the rate of decision making in a threshold protection program should be twice a week or every week. The demographic sub-model is based on two parts:

- relationships between growth rate of larvae and temperature,
- survival rates of the successive larval instars.

Growth rate of bollworm larvae are driven from Twine (1978) for *H. armigera*, from Galichet (1964) for *D. watersi*, from Sidibé and Laugé (1977) for *S. littoralis* and from our laboratory studies for *Earias biplaga*. Relationships with temperatures are modeled by polynomial equations.

Survival rates of *H. armigera* larvae have been studied in the field in Cameroon and compared to published data (Wilson *et al.*, 1980; Hogg and Nordheim, 1983; Ma Shijun and Din Yanquin, 1989; Kyi *et al.*, 1991; Room *et al.*, 1991). All these results reveal a great variability of survival rates in the field, depending on the year and on the part of the season. For that reason, we have implemented three options in the sub-model: high, medium or low survival rates. These rates are derived from the above cited results.

Feeding Preference Sub-Model

The feeding preference sub-model allows a qualitative simulation of bollworm damages: type of organs attacked and location of attacks. These models have been developed from four years field studies in Cameroon with IRMA 1243 variety.
Two models may be chosen by the user:

- the odds-ratio feeding preference sub-model,
- the 3-D feeding preference sub-model.

The odds-ratio model is inspired by Wilson and Guttierez (1980). It uses feeding preference coefficients *C* as follows:

attacked bolls / attacked squares = *C* x available bolls / available squares.

C coefficients were estimated from field data with a log-linear model (McCullagh and Nelder, 1983). Feeding preference coefficients are different among bollworm species and, for some species, different among larval instars. Feeding preferences coefficients change from the beginning to the end of the crop cycle. Fruiting organs are distributed in two classes only (bolls and squares) as the effect of the age of the organs on feeding preferences appear to be weak (although statistically significant).

The 3-D feeding preference sub-model locates bollworm attacks in the 3-D plant architecture simulated by the COTONS model. The nature of the fruiting organ attacked is inferred from the location of the attack on the plant. The limit ages below which squares are not attacked and above which bolls are no longer attacked have been determined and included in both sub-models.

Voracity Sub-Model

Laboratory studies have been carried out to quantify the number of fruiting organs damaged by each larval instar of every four bollworm species. Studies were more detailed for *H. armigera* than for the other species.

Firstly, the total amount of fresh matter consumed during the whole larval life has been quantified. No strong effect of the substrate (i.e. nature and age of the organ consumed) on the total weight consumed by a larva was noticed.

Secondly, the quantity of fresh matter consumed by a larva for each attacked organ was quantified. Relationships between initial weight of organs (before attack) and final weight (after damage) depend on the larval instar and on the age of the attacked organ (square and young bolls vs. medium and old bolls).

Thirdly, the effect of damages on the future of fruiting organs was assessed. The sensitivity to abscission of pierced bolls appeared different from those of healthy bolls. Attacked bolls are still able to shed when healthy bolls are no longer able to. For example, a 28 days old healthy boll has a 0.0035 probability to abscise, whereas a pierced boll abscises with a 0.30 probability at the same age. For non abscised damaged bolls, we studied the relationship between the quantity of fresh weight destroyed in the boll and the number of boll locules damaged. These results allowed modeling of the quantity of rotten cotton at boll opening.

Use of the COTONSIMBAD System

The COTONSIMBAD model may be used in two modes: the “what-if” mode and the automated mode.

In the “what-if” mode, COTONSIMBAD is a tool for decision making and operates closely to the COTONS model. The user defines his entry data (crop management, weather and bollworm population observed) and observes the effect of the bollworm damages on the yield (total yield and quantity of rotten cotton). Graphic interfaces allow the visualization of pest population dynamics, of damages and of effect on the plant morphology (figures 1 and 2). Simulations are possible in the “average plant” mode or in the “plant population” mode, where several sowing rows are modeled simultaneously (Jallas *et al.*, 1999).

In the automated mode, several simulations are run and results are saved in output files. These outputs allow further processing with an appropriate software. Figures 3 and 4 give examples of estimation of economic thresholds corresponding to given agronomic, soil and weather conditions, estimated with SAS G3GRID procedure (SAS Institute, 1990).

Acknowledgements

The field and laboratory data used for development of the SIMBAD model were collected in collaboration between IRAD (Institut de Recherche Agricole pour le Développement, Cameroon) and CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement, France). R. Babin, J. Beyo, T. Brevault, R. de Chazeaux, E. Gozé, A.A. Moussa and F. Pedron are recognized for their contribution to this project. Work was partly funded by PRASAC (Pôle Régional de Recherche Appliquée au Développement des Savanes d'Afrique Centrale).

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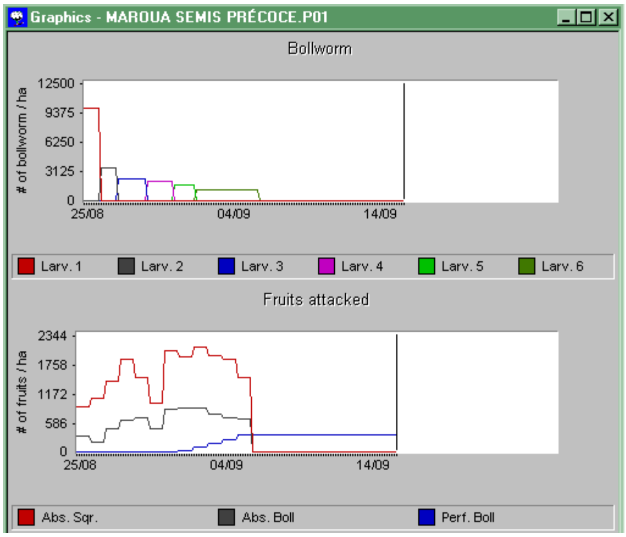

Figure 1. Graphic outputs of CotonSimbad: bollworm population dynamics (top), evolution of damages (below).

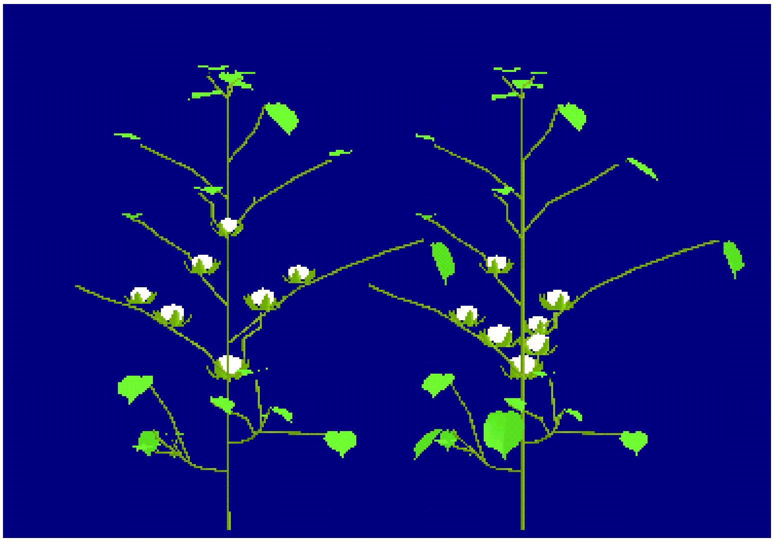

Figure 2. Example of graphic output of plant morphology: unattacked average plant (right), plant attacked at the beginning of flowering (left).

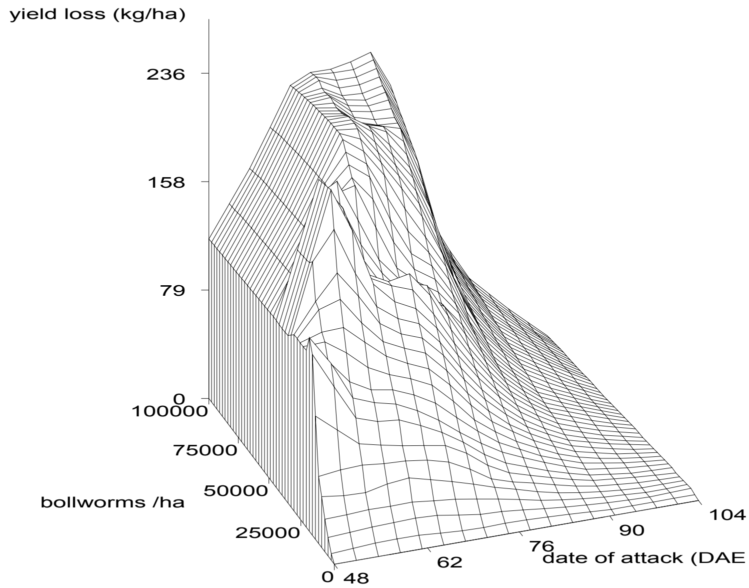

Figure 3. Example of simulated yield loss with different intensities of bollworm infestation (# larvae per ha) at different age of the crop (DAE = days after emergence).

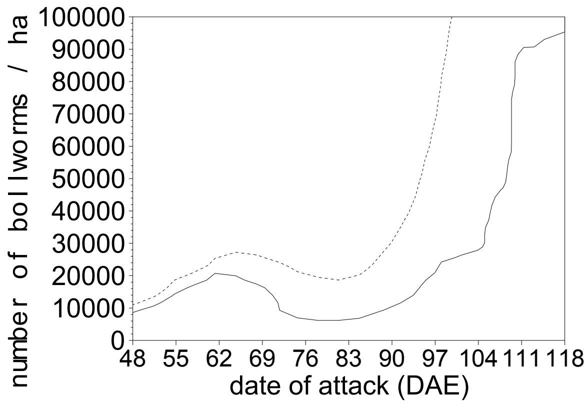

Figure 4. Example of simulated yield loss, represented with a contour plot. Solid line: yield loss is 13 kg/ha. Dotted line: yield loss is 40 kg/ha.