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TYPES AND PURPOSES OF MODELS IN ECOLOGY AND CROP PROTECTION: AN OVERVIEW

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Abstract Models are mathematical tools in which knowledge about agricultural systems is integrated. Both the process of model building and the application of models increases knowledge. Based on their mathematical nature, three important categories of models comprise analytical models, simulation models, and descriptive models. Different purposes require different models. This contribution reviews major differences between models in mathematical nature and in application purpose, with illustrations from the field of crop protection. Reasons for the lack of application of models in IPM are discussed.

Introduction

A model is a simplified representation of a system and a system is a limited part of reality. Mathematical models represent numerical relationships between elements of a system. Building models is a way to draw together knowledge and to make it available for various purposes. Both process and product are important because they help to define and categorize the state of knowledge on a subject, and they help to set priorities for research by locating gaps in knowledge. At the same time models provide a means of disseminating knowledge, and a tool to make integrated knowledge operational for policy making and resource management.

There are many different types of mathematical models and many criteria to classify them, e.g. process-based *versus* statistical, dynamic *versus* static, deterministic *versus* stochastic, and spatially explicit *versus* temporal (De Wit, 1993). The character of a model depends foremost on its purpose. In this introduction to the papers on "IPM and modelling", aspects of models will be discussed from two points of view: their mathematical nature and their purpose, drawing heavily upon especially Penning de Vries & Rabbinge (1995) and Van der Werf *et al.* (1995).

Models of different mathematical nature

In crop protection ecology, three categories of models are prevalent: analytical models, simulation models, and descriptive models. These models differ in many aspects, including the level of aggregation and simplification, structure, purpose, methodology and data requirements. These three approaches could be characterized as speculative, mechanistic and correlative.

Analytical models Analytical models summarize the main components of dynamic biological systems in a few equations that characterize the rates of change of the state variables. Aim of analytical models is to study general principles underlying systems dynamics. Predictions by analytical models are usually formulated as general insights. Such predictions may be difficult to operationalize in a specific system. An example of an analytical model of interacting pest and enemy populations is the system of differential equations

$$\begin{cases} \frac{\mathrm{d}x}{\mathrm{d}t} = \alpha x - \beta y \\ \frac{\mathrm{d}y}{\mathrm{d}t} = \gamma y \end{cases}$$

where x is the state variable prey density and dx/dt is its rate of change; y is predator density; α is the relative growth rate of the prey population (assuming unlimited resources); β is the prey consumption rate per predator (assumed to be independent of prey density); γ is the relative growth rate of the predator population (assuming unlimited food). This simple set of equations characterizes some fundamental aspects of the interaction between spider mites and predatory mites in local patches (Janssen & Sabelis, 1992). For example, it can be shown that the prey will finally be eradicated if the initial predator/prey ratio is greater than $(\alpha-\gamma)/\beta$. This result shows how the critical initial predator/prey ratio is affected by the relative growth rates of the prey and predator populations and by the feeding rate of the predator.

Analytical models are criticized by biologists for being oversimplified, which makes their results less credible. Moreover, the mathematics involved in many papers on analytical models deters interest by biologists, especially if the results of mathematical analysis are not confronted with biologically interesting questions. Nevertheless, analytical models are a powerful tool for analysing and demonstrating general principles in biological systems.

Simulation models Simulation models are much less aggregated than analytical models. Details such as stage structure in life cycles and spatial processes, are often explicitly represented in computer code. The model integrates the processes into a 'grand picture' of the whole system. Such dynamic explanatory models enable the study of the relationship between individual traits, environmental factors and the behaviour of the system. Simulation models are system specific, and predictions are therefore not of general validity. Examples of simulation models have been presented in earlier IOBC Bulletins (e.g. de Moed *et al.*, 1990) as well as in the current issue (Van der Werf *et al.*, Van Roermund & Van Lenteren).

Three phases and a total of ten steps may be distinguished in the process of development of explanatory simulation models (Figure 1). During the phase of problem identification the problem is defined and key components and processes are identified. A useful distinction is between the ecological and technical components of a system versus the management aspects. Problem identification results in a conceptual model of the system. When the results of this first phase lead to the conclusion that all relevant information is available, the next phase is improving systems design and management. Often, more information on production ecological relations is needed, necessitating a phase of increasing ecological insight before embarking upon systems design and management (Figure 1). During the phase of increasing ecological insight, production ecological theory and experiments are used to quantify key processes, and a comprehensive simulation model is constructed. In the course of the phase of systems design and management various options for solving the problem are identified and confronted with objectives. Usually simplification of the information obtained in the previous phases in needed ('summary models').

In population-based simulation models state variables pertain to categories of individuals (e.g. eggs, leaves, fruits). An alternative approach in population models is to represent the individuals themselves and build an individual-based model (Van der Werf *et al.*, 1989). This approach is especially appropriate for systems with small numbers of moving individuals in which spatial interactions and chance processes (encounters) are of prime importance. The result of an individual-based model can be summarized in a functional response formula (Mols, 1993; Van Roermund & Van Lenteren, this issue), which, in its turn, can be implemented in a population-based model.

An important limitation to simulation models, based on state variables, is the often lengthy and poorly documented code. Strict programming discipline is important, but seldom practiced. In the process of building a simulation model it often becomes obvious that essential data are unavailable. While useful for prioritization of experimental work, knowledge caveats may frustrate the timely development and fruitful use of simulation models.

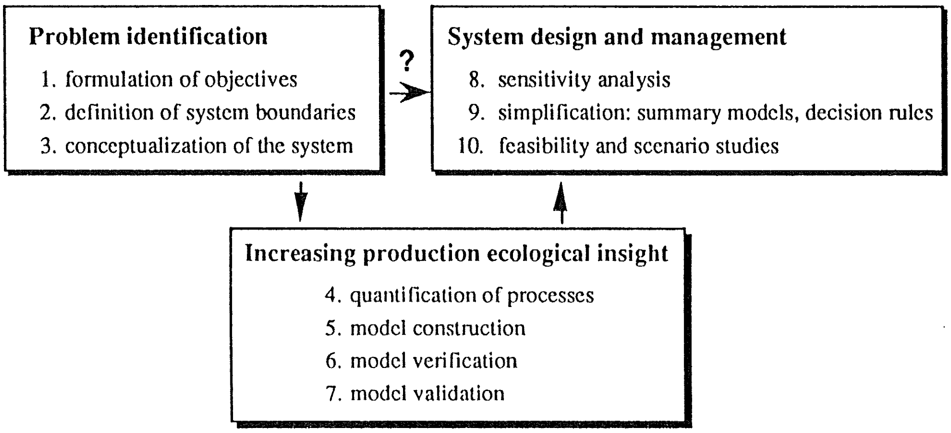

Figure 1. Developmental phases and steps in system research (after Rabbinge & De Wit, 1989).

Descriptive models Descriptive models are based on statistical analysis of data, without an attempt to unravel mechanisms underlying observed phenomena. They are complementary to analytical and simulation models. Their purpose is to predict an 'output' variable on the basis of knowledge of one or more 'input' variables. Most descriptive models are static. Examples of this are regression equations that predict disease intensity on a regional scale, based on prior weather. Daamen *et al.* (1992) predict mildew severity in winter wheat in the Netherlands as

$$y = -132 + 12\,x_1 + 10\,x_2$$

Here, y is predicted percentage of mildew-infested fields, x_1 is the average temperature in the preceding month of October (°C) and x_2 is the average temperature over the period december-March. This static regression model is based on biological and empirical insight in what are key factors in the system and on thorough statistical analysis of the data set.

Models of different purpose

Models can be useful for the development of science, for prediction and for instruction, but not all at the same time. Scientifically interesting models are often too detailed for application, while models for predictive or management purposes are often too crude or too trivial to challenge scientific interest. The categories of models described above can be compared with respect to their predictive, scientific and instructive values and their level of simplicity (Table 1).

The scientific value of a model represents the degree to which it helps us to understand the real world, to evaluate alternative hypotheses, and to suggest experiments to falsify them. The predictive value of a model represents the extent to which it simulates accurately the behaviour of a system. It measures the usefulness of the model as an instrument for application of knowledge in practice and planning, and for explorative feasibility studies. The instructive value of a model, finally, emphasizes its use in disseminating knowledge to students, extension services, farmers and policy makers. For this purpose the model should represent critical behaviour of aspects of the system in a transparent manner.

Table 1. Usefulness of different model types for different purposes. More + signs indicate greater usefulness.

Model type	Predictive value	Scientific value	Instructive value	Simplicity
Analytical	+	+++	++	++
Simulation				
• conceptual	+	+++	++	++
• comprehensive	++	+++	+	+
• summary	+++	+	+++	++
Descriptive	+++	+	+	+++

Despite its potential for prediction and instruction, the contribution of summary models to practical IPM has been limited. Most IPM systems are based solely on expertise and empirical information, and few IPM systems have been formalized into computer-based decision support systems. As a consequence IPM in new crops or upgrades of existing systems must also be based on trial and error, which is inefficient in terms of financial and natural resources. In addition, training of newcomers to IPM practice will benefit from well-structured and easily accessible information. The situation calls for closer interaction between 'producers' and 'consumers' of model-based knowledge, to exchange opportunities and constraints with the joint goal of consolidating the increasing application of IPM.

References

Daamen, R.A., Stubbs, R.W. & Stol, W., 1992. Survey of cereal diseases and pests in the Netherlands. 4. Occurrence of powdery mildew and rusts in winter wheat. Netherlands J. of Plant Pathology 98, 301-312.

de Moed, G.H., van der Werf, W. & Smits, P.H., 1990. Modelling the epizootiology of Spodoptera exigua nuclear polyhedrosis virus in a spatially distributed population of *Spodoptera exigua* in greenhouse chrysanthemums. SROP/WPRS Bull. XIII/5 (1990), 135-141.

de Wit, C.T., 1993. Philosophy and terminology. In: On systems analysis and simulation of ecological processes, with examples in CSMP and FORTRAN. Ed. P.A. Leffelaar. Kluwer, the Netherlands, pp. 3-9.

Janssen, A. & Sabelis, M.W., 1992. Phytoseiid life-histories, local predator-prey dynamics, and strategies for control of tetranychid mites. Experimental and Applied Acarology 14, 233-250.

Mols, P.J.M., 1993. Walking to survive; searching, feeding and egg production of the carabid beetle *Pterostichus coerulescens* L. (=*Poecilus versicolor* Sturm). PhD Thesis, Wageningen, 201 pp.

Penning de Vries, F.W.T. and Rabbinge, R., 1995. Models in research and education, planning and practice. In: A.J. Haverkort & D.K.L. MacKerron (eds.) Potato ecology and modelling of crops under conditions limiting growth, Kluwer, the Netherlands,. p. 1-18.

Rabbinge, R. & de Wit, C.T., 1989. Systems, models and simulation. In: R. Rabbinge, S.A. Ward & H.H. van Laar (Eds): Simulation and systems management in crop protection. Pudoc, Wageningen, p. 3-15.

Van der Werf, W., Smits, P.H., Downes, M.J. & Griffin, C.T., 1995. Concepts and prespects for modelling the efficacy and ecology of entomopathogenic nematodes. In: Ecology and transmission strategies of entomopathogenic nematodes. Eds C.T. Griffoin, R.L. Gwynn & J.P. Masson, COST Action 819, Biotechnology, EUR 16269 EN, European Commission, Luxembourg, pp. 42-51.

Van der Werf, W., W.A.H. Rossing, R. Rabbinge, M.D. de Jong & P.J.M. Mols, 1989. Approaches to modelling the spatial dynamics of pests and diseases. In: R. Cavalloro and V. Deluchi (Eds): PARASITIS 88, Proceedings of a scientific congress, Barcelona, 25-28 October 1988, p. 89-119.