Simulation of plant growth and crop production

F.W.T. Penning de Vries and H.H. van Laar (Eds

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PREFACE

This book is an introduction to dynamic simulation of plant growth and crop production. It summarizes a good deal of the experience in modelling an programming of this subject that has been accumulated in Wageningen, the Netherlands, in the last decade. It concerns in particular the disciplines of crop physiology, crop micrometeorology, soil physics and soil microbiology. The experience results from research done at the Department of Theoretical Production Ecology of the Agricultural University and its teaching programmes, from research at the Centre for Agrobiological Research and at other departments and institutes, and from the work of visiting scientists. Much of this technical experiences and know-how is presented in the Chapters 2 to 6 in this book. We have tried to make it accessible to readers by means of many exercises and examples.

The systems approach applied to a wide range of subjects has led to a particular view of simulation and modelling of plant growth and of crop production. This view has been translated into a practical approach. Both view and approach are the subject of the introductory contributions in Chapter 1 of this Monograph.

The motive to publish this Simulation Monograph was an advanced international course on the same topic, held in Wageningen in the spring of 1981. It was organized by Dr van der Kloes of the Foundation of Post Graduate courses of the Agricultural University in Wageningen. The 15 lectures of this course have been moulded into this book with the full cooperation of the authors.

During the editing of this Monograph, Ir Drees has been particularly helpful in developing exercises and formulating their answers. For the skillful typing of the manuscript and drawing of the figures Mr van Amersfoort and Mr Beekhof are kindly acknowledged.

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1.1 Simulation of living systems

C.T. de Wit

1.1.1 Systems, models and simulation

System analysis and simulation has been used by engineers for more than 30 years. Their successes inspired biologists and agronomists to apply similar techniques in their disciplines. The approach is characterized by the terms: systems, models and simulation. A system is a limited part of reality that contains interrelated elements, a model is a simplified representation of a system and simulation may be defined as the art of building mathematical models and the study of their properties in reference to those of the systems.

Although any model should have definite goals, be lucid and achieve its objective, in practice it seems that goals are too often described in such broad terms that sufficient lucidity is reached only for the initiated, and that the models achieve less than expected by the biologist. For these reasons the word 'art' rather than 'science' is used in the definition of simulation.

It follows from the definition that a model is a system, but the reverse may also be true. A work of art is a simplified representation or a model of the vision of the artist. A machine is a model of the conception of the engineer and it certainly performs worse than anticipated. And when an engineer applies simulation, he develops simulation models that lie in between his conception and reality. The ultimate machine is in fact a model of his simulation model, which in its turn is a simplified representation of his mental conception.

Although some wish it otherwise, biological systems are not simplified representations of the conception of the biologist, and the interchange of the terms models and systems does not make any sense. Therefore, it may be that the approach that has been so successful in engineering is not as useful in biology. Fools rush in where wise men fear to tread. Much of this rushing in simulation in biology is done by agronomists, perhaps because they are fools, but maybe because they deal with systems in which the technical aspects overrule more and more the biological aspects.

As has been said, a system is a limited part of reality, so that a border has to be chosen. It is wise to make this choice so that the system is isolated from its environment. This is almost always impossible, but then it should be attempted to choose a border so that the environment may influence the system, but the system affects the environment as little as possible. To achieve this, it may be necessary to choose a system that is larger than necessary for the original purpose.

In agricultural systems, for instance, the microclimate is often part of the system, but everybody happily neglects the influence of the agricultural system on the macroclimate, even though this is not correct. However, the assumption that everything is related to everything is sure to kill all research.

1.1.2 Explanatory models

A file with data on an ecosystem may be called a model, but it is a model without purpose and lucidity. Potential uses of the data may be formulated and then lucidity may be introduced by a treatment of the data. This may result in maps that represent aspects of the ecosystem, or in statistical analyses, which summarize some of the interrelations. Dynamic models are obtained if the time dimension is introduced during the collection and treatment of the data. But those models remain descriptive, showing the existence of relations between elements without any explanation, but, of course, this was not their purpose to begin with.

However, models that have the purpose of explaining systems are possible in biology because various levels of organization are distinguished in this science, as many other natural sciences. These different levels of organization may be classified, according to the size of the system, as those of molecules, cell structures, cells, tissues, organs, individuals, populations and ecosystems. Models that are made with the objective of explaining are bridges between levels of organization; they allow the understanding of larger systems on the basis of the knowledge gained by experimentation on smaller systems. In this way the properties of membranes may be understood better by studying molecules and the properties of ecosystems by studying species.

If the knowledge on the level which is used for explanation is sufficiently detailed and complete, and on the basis of this a model of the system which behaviour has to be explained is designed, it may not be necessary to evaluate the model by comparing its results with those of the real system. For example, models for space travel are so good that the 'proof of the pudding' – the journey itself – is unnecessary. But explanatory models in biology are so rudimentary that proof of their usefulness is necessary. And even when there is good agreement, there is room for doubt. However, good agreement is still more the exception than the rule.

If there are discrepancies between model and real system, the model may be adjusted to obtain better agreement. Then, something that started as an explanatory model degenerates progressively into a descriptive model. The term 'degeneration' in this context does not mean that descriptive models are inferior to explanatory models. It is used here to emphasize that in this way inscrutable models are obtained with an unjustified pretention to explain something. It is for this reason that many models are still doing more harm than good.

The proper way of working is heuristic, by the road of gradual improvement. If unacceptable discrepancies between model and system are observed it may be possible to judge which aspects of the model should be treated with suspicion, by experimenting with both. These aspects are then studied on the level that is used for explanation. On basis of this renewed study, elements of the model may be replaced by others and then a renewed confrontation between the results of the model and the real system may be again useful.

Explanatory models may be of the static or dynamic kind. An example of a static model is a model that contains all the necessary calculations to achieve the relation between respiration and growth on basis of the knowledge of the underlying biochemical processes. Another example is a model that is used to calculate the light distribution over leaves based on canopy architecture, leaf properties, solar position and so on. Such static models form often a part of dynamic models.

It is characteristic for all systems discussed in this book that major elements (like plant biomass) change only gradually in amount with time or in space in response to changing external factors such as weather or fertilization. Such systems are called 'continuous', in contrast to 'discrete' systems (cf. Brockington, 1979), which deal with numbers and discontinuities in time.

1.1.3 The state-variable approach

For dynamic models that claim to be of the explanatory type, the state-variable approach is gaining wide acceptance. These models are based on the assumption that the state of each system at any moment can be quantified, and that changes in the state can be described by mathematical equations. This leads to models in which state, rate, and driving variables are distinguished.

State variables are quantities like biomass, number for a species, the amount of nitrogen in soil, plant or animal, the water content of the soil. Roughly, those variables that can still be measured when time stands still as in the fairy world of the Sleeping Beauty, are state variables.

Driving variables, or forcing functions, characterize the effect of the environment on the system at its boundaries, and their value must be monitored continuously. Examples are macrometeorological variables like rain, wind, temperature and irradiation, but also the food supply or migration of animals over the boundaries of the system. It depends on the position of these boundaries whether the same variables are driving, state or rate variables. For instance, the heat stored within a vegetation canopy is a state variable when the system includes micrometeorological aspects, but a driving variable that has to be measured when the micrometeorological aspects are excluded from the system.

Each state variable is associated with rate variables that characterize their rate of change at a certain instant as a result of specific processes. These variables represent flows of material or energy between state variables, for example, between vegetative biomass and grazing animals. Their values depend on the state and driving variables according to rules that are based on knowledge of the physical, chemical and biological processes that take place, and not on a statistical analysis of the behaviour of the system that is being studied. This is the most important distinction between models that describe and models that attempt to explain.