6.1 Prospects for simulation and computerized decision making

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6.1.1 Introduction

Simulation is one thing but decision making is quite another. Simulation is a wonderful research tool that provides enlightening insight and helps to define research priorities, while encouraging a certain humility with regard to one's own performance in research. Decision making is very different from simulation; it is usually done without the help of simulation and, certainly in crop protection, simulation is not even a prerequisite. Even so, we claim that simulation is a good tool with which to support management and decision making.

In Chapter 5, preliminary results of a combination of simulation and managerial models were given. Our claim, therefore, will be considered in the light of agro-automation. Before going into detail, some aspects of decision making in agriculture, and more specifically in crop protection, will be discussed.

6.1.2 Agricultural knowledge and decision making

The art of decision making is studied by the managerial sciences. We still call it an art, but art without knowledge is vulnerable when the stakes are high. Experience, skill and insight, combined with intuition and know-how are also essential. The book 'Industrial dynamics' by Forrester (1961), which inspired simulation research more than any other publication, was intended to improve decision making. When the 'system' is relatively limited, as in the manufacturing industry, when the data-base is broad and accurate, and when the decision maker is relatively independent of his environment, simulation can certainly support decision making. The decision models actually used are, however, of another type. Agriculture is different from the manufacturing industry in two respects: the knowledge to be applied and the decisions to be made.

6.1.3 Levels of decision making

Decision making in agriculture, as in other economic sections, occurs at various levels of aggregation. In Chapter 1, these levels were distinguished and it was shown that at each level objectives should be formulated and instruments or tools for decision making should be developed. At the regional/country level the objectives and the way they are reached are mainly subject to political decisions. At farmer, crop and pathogen levels, decision making is based on well-defined technical and economic objectives, which may vary from field to field, and from farm to farm. The following paragraphs mainly concern decision making at the crop level. Discussions and statements on higher aggregation levels are given elsewhere (de Wit et al., 1987; Zadoks, 1989).

6.1.4 Knowledge in agriculture

Some people have 'green fingers'. Whatever they touch will grow and flourish. 'Green fingers' are an implicit mixture of intuition, experience, attentiveness and foresight. Plant growing can be taught and learned, 'green fingers' cannot. In analogy, we believe in 'green brains', when insight into cause-effect relations and the ability to select the important questions to be addressed are added to the mixture. These psychological qualifications should be seen against the background of phytopathological knowledge which is inherently hazy, as recent studies have indicated. This haziness is partly due to the nature of agricultural processes, which run their genetically programmed courses in manifold interactions among themselves, and within a capricious environment. The haziness is also due to the nature of the decision making process in crop protection, where implicit reasoning, based on the senses seeing, hearing, smelling and feeling, often preceeds explicit logic.

6.1.5 Decisions in agriculture

Decisions can be strategic or tactical (Zadoks & Schein, 1980). Strategic decisions are those taken before the start of the growing season. They refer to choices of crop, cultivar, level of inputs required, and so on. Tactical decisions are the day-to-day decisions taken during the growing season, such as 'to treat' or 'not to treat'. Both tactical and strategic decisions are made at two levels, roughly indicated as 'collective' and 'entrepreneurial' (Zadoks & Schein, 1980), here simplified as 'government' and 'grower'. Government has facilities similar to those of an industrial leader; it has access to data, it can outline objectives, and it can apply simulation techniques. Government decisions are usually of the strategic type. The world in which government operates is so complex, that even large simulation models can only provide partial answers to partial questions.

The grower's situation is different. He is always one of many, who consider themselves colleagues rather than competitors. Simulation models are not tools that he can handle, but he welcomes models for decision support. In principle, the grower's situation can be modelled, but we are not aware of any attempts to model his frame of mind or the way he makes decisions, although interesting papers on decision making in crop protection, in theory (Norton, 1976, 1982; Norton & Mumford, 1983) and in practice (Mumford, 1982a, b; Tait, 1978, 1981, 1982), have been published.

When social scientists and agronomists shake hands, the results may be interesting. One result seems to be that decision making is not as logical as a natural scientist might assume it to be. More modestly phrased, his logic does not always result in him obtaining a true picture of the grower's logic. Personal characteristics play a role, one grower being clearly risk-avoiding, the other accepting risk with an open mind. The two attitudes may dwell together in a single mind. One wheat grower in the Netherlands took a great risk with respect to winter killing, choosing a highly productive but not so winter hardy variety, but started spraying when he saw the first aphid. Where is the logic? Rice farming peasants in the tropics quote insects as the major risk, but by far the most money and effort is spent on weed control. Where is the logic?

Many farmer decisions are based on implicit knowledge, tradition, intuition and social convention. Present efforts aim at rationalizing available knowledge and explaining explicitly the consequences of various options. The contribution of agricultural scientists towards improving agricultural production, may lay in explicitly formulating the consequences of various decisions and thus iteratively improving decision making. Farmers are applying more and more scientific knowledge and, as a result, agricultural production has increased considerably.

One wonders about future developments and about the contribution of systems analysis and simulation to these developments. To address this question, recent developments in the computerization of agriculture will be considered, using the Netherlands as the example.

6.1.6 Agro-computerization in the Netherlands – facts

Computerization in agriculture is the official policy in the Netherlands. A concerted effort by representatives from grower organizations and the Ministry of Agriculture should lead to the formal definition of various farming systems and the decisions taken therein. These studies must ultimately lead to software for decision support in pathosystem management, crop management and farm management. No simulation is foreseen, the aims being packaging the message rather than improving its content. Policy makers seem to be more optimistic about the possibilities of computerization than the scientists.

The actual situation is complex. We distinguish two types of computers, the local computer and the distant computer. The local computer is a process computer or a personal computer on the holding, directly accessible to the grower. The distant computer can be any size, from micro to large mainframe, centralized somewhere in the country, and at the service of the growers. Access is rarely direct, as in the pay-television system VIDITEL (the Dutch version of PRESTEL), but indirect or mediated. An operator is contacted by telephone or letter, and a recommendation is returned by telephone and/or letter.

A sample survey provides a fair picture of computerization in Dutch agriculture (Table 39). Emphasis is clearly on process computers, which either take the decisions, as in the control of glasshouses, or provide rather stringent recommendations, as in dairy cattle feeding. The scientific basis of the process computers in glasshouse climate regulation is still weak and needs further improvement. The technical possibilities developed by the engineers, are now so good that even more physiological insight into crop performance is needed to use these possibili-

Table 39. Computers in Dutch agriculture, 1985, according to a sample survey. (Source: Amro Bank, 1985, 1986).

Branch	Type of application	Number of business units	Computers in use	
			number	%
Horticulture		9500		
	process		5200	55
	administration		730	8
Dairy farming		43200		
	process		5300	12
	administration		–	0
Arable farming		11000		
	process		–	0
	administration		550	5
Total		63700	11780	18

Table 40. Matching the general and the specific.

System	Subject	Number
SAP	cows (living)	4500000
	bulls	100000
COMZOG	sows	55000
EPIPRE	fields	1000

SAP = Sire Advice Program of the Royal Netherlands Cattle Syndicate, Arnhem.
COMZOG = Cooperative Program for the Management of Production Sows, originally designed by a farmer, managed on a distant computer by LARC Ltd (a subsidiary of the organization of cooperatives), Deventer, providing veterinary and zootechnical recommendations to circa 300 holdings.
EPIPRE = Decision support system for crop protection in wheat, managed by the Research Institute for Arable Crops (PAGV, Lelystad), serving about 400 farmers with some 800 fields (1986 data).

ties so that growth and production can be optimized. Decision making in cattle feeding is still largely based on empirical knowledge instead of detailed insight into feeding physiology.

The link between process computer and personal computer for administrative purposes is not yet very strong, although this link is desirable for managerial purposes. A rapid increase in the use of personal computers is to be expected. The use of distant computers for managerial purposes is rather intensive. Table 40 shows only a few examples. The national registration system for dairy cattle and the selection of sires is probably the most extensive system in Dutch agriculture; the ensuing decisions are strategic. In comparison, the crop protection system EPIPRE (Section 5.1) supports tactical decisions.

The pay-television system VIDITEL is being used to transmit commercial information, but its contribution to crop protection is meagre, anno 1986. For fruit growers in the river districts, there is one page available on crop protection. This page was estimated to have been consulted 5000 times in 1986, compared to 29000 consultations for the telephone answering services providing the same message (Zadoks, 1986).

6.1.7 Agro-computerization in the Netherlands – opinions

Decision support systems should satisfy the following criteria:
- simplicity
- time efficiency
- reliability
- solidity
- updating facility
- upgrading facility.

The first set of three criteria speak for themselves. They are partly a matter of packaging the message, that is of programming and screen editing. Several pathosystem management schemes do not comply with these three criteria. Monitoring and sampling may also be too complicated. Their results may be unreliable so that decisions become risky. For this reason, considerable attention in computer-supported decision systems is spent on developing simple, accurate, reliable and time-saving monitoring and sampling techniques (Rabbinge, 1981).

The second set of three criteria refers to more basic characteristics of research, and the resulting software. Solidity refers to the soundness of the recommendations. No combination of data may lead to nonsense recommendations; and they should be in accordance with good agronomic practice. The updating facility is needed for tactical (in-season) adaptations, e.g. to a change in the spectrum of physiological races or in the sensitivity of fungi to fungicides. The upgrading facility is needed for gradual, iterative improvement of the software between growing seasons, as was (and still is) the case with EPIPRE. In this way, the best of our knowledge finds its way directly to the farmer's field. At the same time, scientists can adjust their research efforts. This is a comparative advantage of computerized decision support systems.

Most of the computerized services require a fee of some kind, some services being strictly commercial, others (e.g. EPIPRE) requiring at least partial coverage of costs. The grower will be prepared to pay a fee if he thinks he can profit from the message obtained. He will not accept a computer-generated message as being imperative (process computers excepted). We expect more and more growers to make a habit of considering computer-generated messages before making a decision. Two points must be made here. (1) A grower will consider both profit and risk, two essentially different concepts. Both are stochastic variables, but present computer-generated messages are deterministic. EPIPRE considers profit but not risk. In another upgrade, variations in profit and risk could be made explicit, even if they could not be calculated accurately. (2) The computer-generated message must be inherently better than messages generated in other ways, especially those generated in print. Speed of delivery is seldom an argument, because the difference in arrival time between a computer-generated and a printed message is only a matter of hours. Any printed message is of a general nature, containing, say, 80% accuracy for 80% of the growers, but this message is possibly wrong for some of them. In this respect, the present VIDITEL messages are little more than modernized press issues, old wine in new bottles.

The comparative advantage of a computer-generated message must be such that a grower is ready to pay for it and, under the present imperfect conditions, to accept some extra inconvenience. The message has additional value if the general knowledge, as provided by the scientist, is matched to the specific situation of the grower. Growers have been trained to do the matching themselves. Scientists, without farm experience, do not know much about specifics. Scientists were never trained to do this matching of the general with the specific. On the contrary, their training was to disregard the specific and to find the general by the process of abstraction. Today's challenge is different (Zadoks, 1986). Successful computerization depends on the scientist's capability to provide messages that do match general knowledge to specific situations. The matching process demands considerable intellectual effort on the part of the scientist. The program selecting the best bull for any specific cow, whose production and inheritance data are available, obeys our matching criterium. The EPIPRE system also does this in the crop protection area. To give just one example: if for some reason yellow rust (*Puccinia striiformis*) on wheat went out of control because of a cultivar's loss of resistance, or because the fungus became resistant to the fungicide normally used (an improbable event), EPIPRE would recommend omitting the last top-dressing of nitrogen. This top-dressing is usually applied just before flowering and by omitting it, the development of the epidemic, which is stimulated by nitrogen-rich leaf material, is no longer stimulated.

6.1.8 Simulation applied

Simulation is a tool used by the scientist to model a segment of the real world and to see how that real world might react under a variety of conditions. By either simplification, as in EPIPRE (Zadoks, 1988), or by completely different approaches, the resulting messages can be listed as recommendations to the growers. These lists will usually be written in the IF ... THEN ... mode, arranged in a time sequence in the form of a computerized decision support system with a clear comparative advantage. Dynamic simulation provides a good start, but it does not provide the end point. This is true for the grower and, *a fortiori*, is true for a government faced with situations of far greater complexity than those of individual growers.

6.1.9 Comprehensiveness

If one wants to develop marketable agro-software, which is really going to gain impetus, there will be a conflict of interest between local computer services and distant computer services. Maybe there will be room for both and, in the long run, possibly a coupling between the two systems. An interim solution is partial decentralization, as foreseen by the cooperative organization in the Netherlands, whose farm advisers will use microcomputers and software provided by one distribution centre. Growers, though willing to use computers if they increase profits, are not computer hobbyists. They will require (1) foolproof systems and (2) systems that have obvious advantages over a few books. Here, we touch on the subject of comprehensiveness.

In the past, simulation models developed like trees trying to incorporate as many variables as could reasonably be useful. As indicated in Chapter 1, an optimum should be found for the number of state variables that harmonizes the conflicting trends towards completeness of the model; i.e. accuracy and practicability. This is not, however, the comprehensiveness intended here. A compromise is needed. The early, simulation-based EPIPRE system almost failed to be accepted, not because of its inaccurate predictions, but because it was only concerned with yellow rust (*Puccinia striiformis*). Wheat farmers had more problems than yellow rust alone. Since the fungicide triadimefon, available at that pioneer time, was as good against mildew (*Erysiphe graminis*) as against yellow rust, farmers wanted, as a minimum requirement, recommendations concerning both diseases. In the future, farmers will not readily accept one piece of software with disease warnings, another for nitrogen fertilization, a third for weed control, and still another for bookkeeping and stock administration. Single-issue software is not marketable. Good agro-software should have all these items in one, with easy switching between modules. When a farmer makes and carries out a decision, he only wants to have to enter it once and then expects it to be entered into all relevant registers; simultaneously, all relevant modules should be updated and ready for consultation.

The comprehensiveness outlined here is very demanding on space and speed of hardware and software. The grower-orientated software will, therefore not pay much attention to simulation models for immediate application, but will give preference to simple decision structures such as decision trees or networks (Norton, 1982), or simple projections with a limited time horizon (Zadoks, 1988) for threshold-based (Zadoks, 1985) decisions. Of course, these may have their roots in explanatory simulation models, summary models, or models which emulate simulation techniques. Typical examples are the decision systems for weed control (Aarts & de Visser, 1985; de Visser et al., 1986) advocated by the Research Institute for Arable Crops (PAGV, Lelystad), which were incorporated in a VIDITEL-transmitted advisory system in a 1987 trial run. The best example of a comprehensive package is COMAK(R), which contains administrative modules, a disease identification module, and an EPIPRE-like decision support module. If computerization in agriculture by way of local computers is going to be successful, it will be because of the comprehensiveness of the software available for everyday access.

For services provided through distant computers, with direct or mediated access, there will be plenty of scope. Direct access is good for the fast transmission of general messages, but there are some doubts about the interactive use of distant computers. Matching of general and specific knowledge is needed for managerial purposes. Special purpose services using distant computers, to be consulted at more widely spaced intervals, as in cattle breeding, will remain extremely useful. In view of the expectations outlined here, there seems to be little scope for the use of simulation models in advisory work through distant computers.

6.1.10 Conclusions

Simulation models, be they explanatory or summary, may be a good basis on which to develop decision support systems, but they are not (yet) suitable for immediate on-the-farm application. Decision support systems could be constructed without simulation models. Simulation models should, however, be used to condense, formulate, test and validate that particular mix of intuition, experience and knowledge, which we endearingly call 'green brains'. For the crop-protection scientist, dynamic simulation is a scientific tool of great value, but it is certainly not an end in itself.