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Preface

Probing the enigma of the decision support system for farmers: Learning from experience and from theory

1. Background

For much of the past 25 years it has seemed only a matter of time until computerised decision support systems (DSSs) became standard tools in the management of family farms. It would, of course, take some time for computers to become commonplace in such enterprises. Today, most farmers in industrialised countries own and use computers; Hayman and Easdown (2002) cite a recent figure of 75% for Australian grain growers. Hundreds of agricultural decision support packages are readily available and affordable. Yet, contrary to expectations, use of the DSS in management of the contemporary family farm has not grown with computer ownership, as was expected (e.g. Parker, 1999; Ascough et al., 1999).

Although there are cases of local success, as a field of agricultural research, DSS work is in a state of crisis. DSS research has largely disappeared from the agendas of most organisations that fund research and this is reflected in fewer journal and conference papers on DSS. Since agricultural research is a dynamic enterprise, and agendas are continually changing, a sceptic might reasonably ask whether this 'crisis' warrants special attention. As laudable as the idea of computerised scientific tools to aid farmers' decision making may be to some researchers, persistent lack of demand by farmers for DSS cannot be ignored. A reasonable response might be that special concern about changes in funding priorities away from the DSS is justified only if they might be changing for the wrong reasons or on the basis of inadequate information. This Special Issue is a response to apprehension that the DSS enterprise is in danger of being relegated to history without an adequate *understanding* of reasons for its market failure. *With* such understanding, it is possible that changes in approach could make a critical difference. *Without* it, researchers may be already naively repeating earlier mistakes.

What would need to happen for farmers to value these tools in their decision making? Is the DSS idea fatally flawed and best written off as a learning experience

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for researchers? The guest editors of this Special Issue believe that we, as a profession, are not well placed to answer either of these questions. Ideally, any effort by DSS workers to intervene in farming practice would have been accompanied by critical documentation and focused evaluation activities. But since such activity has not been a part of our research tradition, it would be unfair to be overly critical of the fact that such information is rare. This Special Issue is an attempt at what may be the next best thing—the collation and interpretation of a sample of in-depth experiences of scientists who built and implemented significant DSSs. The result is a combination of revelations about difficulties, and, significantly, about successes that stand out as exceptions to a general state of affairs that we are casting as 'critical'.

This 'case story' approach is not without its problems. Getting papers from otherwise busy authors has proved challenging, even when they were sympathetic to the idea of extracting learnings from experiences more easily left in the past. After the first deadline passed without receipt of any of the eight papers from committed authors, we sent a message setting out three alternative options, one of which was to abandon the project. In replying that he must, reluctantly, withdraw from the project, a prominent DSS developer commented that

> In retrospect I think the problem for all of us is that we are not used to retrospection. We have all spent our careers looking ahead, and when push came to shove anything new that came along trumped a revisitation of old material.

Two others also withdrew, but broadening the scope to include grazing systems brought in two new papers. Especially against this background, the six case papers which follow can be appreciated as important and rare opportunities for readers to better understand the DSS phenomenon 'on the ground' in agriculture and to extract learning that may be valuable for future efforts.

Although the case story approach offers potential for insight, it should not be expected to 'double' as a *survey* of the field. We never considered it feasible to obtain a representative sample of DSS efforts, let alone capture the set of 'major' ones and risk offending those whose efforts, by implication, were not major. Those whom we invited had, in our judgement, significant experiences—significant financial investment over a significant period and who seemed to offer significant learning possibilities to others. As it happens, in exhausting the space available in a special issue, what follows does capture, in our judgement, much of the contribution to learning that a greater number of case stories might provide.

The paper preceding the DSS cases (McCown, 2002a) attempts to enhance this learning by connecting it to its roots in the experience with information systems for managers that preceded and preshaped the era of the agricultural DSS. A simple theoretical framework is constructed from this history of Operations Research/Management Science and the decision support system movement that followed. This framework helps highlight the social/practical dimension of the task of supporting decisions, a dimension with a history of being handled badly by developers preoccupied with scientific/technical content.

Further opportunities for learning from the case histories lies in the patterns of similarities and differences among them and in the evolution over time in individual decision support programs of what proved successful in providing value to farmers' management. The final paper of the issue (McCown, 2002b) attempts abstraction of these. Building on the framework from the introductory paper, it then draws on relevant theory to probe the human nature of management practice, the nature of the 'gap' between farmers' practice and the DSS, and changes in scientific practice that promise greater effectiveness.

An inescapable aspect of a project in which understanding is sought in *experience*, is the possibility, if not the inevitability, that an account is less independent of personal characteristics of the one relating it than is the case in normal science reporting. As guest co-editors of this special issue, we are rather self-conscious of being closely associated with the FARMSCAPE case. It has been this experience that has motivated us to convene this special issue and to venture into new 'social' territories, discussion of which comprises much of the final paper. But while we have tried to be even-handed and unbiased, we know that our efforts will not always be seen as meeting expectations of neutrality and/or objectivity. We entreat the readers of these stories and essays to make adjustments rather than dismiss as 'non-rigorous' this attempt at gaining new insights to the persistent enigma of decision support systems for farming.

2. Introducing the case histories

The six experiences in building and implementing decision support systems reported here provide insights to the design strategies, implementation strategies, problems, and achievements of fourteen DSS products. These six cases are augmented by information about three other significant DSS cases. Two of these are from earlier reflective and comprehensive accounts: EPIPRE (Zadoks, 1989) and CALEX-Cotton (Plant, 1997; Goodell et al., 1993). Characteristics of the third, GOSSYM/COMAX, are amply provided by Hodges et al. (1998), but evaluation of its use and usefulness is from a highly relevant but less comprehensive report by Boone and Porter (1997). The aim in what follows is to sketch the main features of the products and the stories to provide cues for reading the cases with one eye on the objective in the final paper of this Special Issue (McCown, 2002b), i.e. interpreting this rich set of experiences, in ways that are meaningful for future action (or inaction). The fact that the focus of the Issue is on DSS *implementation*, aspects of stories that provide insights to entry (or not) of a DSS into farming practice, or to its frequency or duration of use are of particular importance.

2.1. SIRATAC, EPIPRE, and CottonLOGIC

SIRATAC (Hearn and Bange, 2002, this issue) is one of four DSSs dealing with cotton production decisions among the 14 products considered here. However, as an information system, SIRATAC had more in common with the European wheat DSS, EPIPRE (Zadoks, 1989) than with the other three cotton DSSs.

- Both begun in 1976, they were among the very first agricultural DSS initiatives.
- Development of both had a normative intent in that they were motivated by strategic ecological concern about pesticide use. Nevertheless, they relied for farmer adoption primarily on the appeal to farmers of operational cost savings.
- The primary logic of both was that of integrated pest (and in the case of EPIPRE, also disease) management featuring maximum thresholds for triggering spray actions.
- They both featured a service that utilised a network around a central computer. During the subsequent DSS era, which featured software on a farmer's microcomputer, this earlier centralised architecture seemed archaic. Yet, with the development of the Internet, the centralised architectures of SIRATAC and EPIPRE can be viewed as a source of learning relevant to a new generation service. Welch et al. (2002, this issue) describe the case of PCYield as part of such a service using the Internet.
- Although SIRATAC and EPIPRE predated the 'shell' that facilitated expert system structure, both had expert system *functionality* with regard to transforming inputs to outputs. They were forced to use qualitative rules by a combination of commitment to using *existing* scientific data and these proving to be inadequate for mathematical models. Both provided 'optimal' decision recommendations.
- Both served intensive industries where the 'problem' was that farmers were willing to bear the costs of high chemical inputs to attain high control certainty.
- A significant learning in both cases was that chemical inputs could be reduced substantially without economic loss.
- A prominent phenomenon was farmers learning from the DSS and then no longer needing it.

An interesting feature of the SIRATAC story is that in addition to grappling with social dimensions common to all other cases (relevance of technology and construction of relevance through interaction between farmers and DSS professionals) SIRATAC had to contend with conflict between stakeholder groups. This aspect of the SIRATAC experience may be of special 'early warning' value with regard to use of information systems as tools in negotiations among stakeholders in farming in conflict regarding effects on natural resources, public health, etc.

CottonLOGIC is a combination of much of SIRATAC logic with new generation software design. The premium value in early development was simplicity, but comprehensiveness and complexity has increased over time. CottonLOGIC ownership and reported use by farmers and consultants in the Australian cotton industry is exceptional. But it is not entirely clear to what extent the product is valued for its guidance of decisions on irrigation, fertilisation, and insecticide application vis a vis its role in justifying and documenting actions with regard to 'best practice' in a program of industry 'self-regulation' regarding pesticide use.

2.2. CALEX-Cotton and CottonPro

Plant (1997) and Goodell et al. (1993) reported on lessons learned in implementing CALEX-Cotton. This DSS was a large, comprehensive expert system developed and implemented according to the principles set out by Plant and Stone (1991).

> As finally implemented, CALEX/Cotton was a rule-based expert system running...on a personal computer and providing information for agronomic management as well as integrated pest management. [ ] The objective was to develop an integrated program that would provide comprehensive support for crop management decisions. ...it became clear that the issues addressed by the software needed to meet certain criteria for inclusion into the program: (1) the issue must be sufficiently important that a grower would be motivated to seek advice about it; (2) it must be sufficiently complex that the involvement of a computer was justified; and (3) there must be a sufficient knowledge-base about the issue that reasonable guidelines could be constructed. (Plant, 1997, p. 34)

Of particular significance in the CALEX-Cotton story is the high level of investment in involving farmers in the development phase and supporting them following release of the software.

> During the development of CALEX-Cotton, industry committees were established to provide direction, set priorities, and review progress. Members were cotton industry leaders who were willing to spend their time, share their expertise, and express their opinions. They participated in the early design, examined the early versions, and gave feedback to the developers. In the process they became stakeholders in the project, people who were part of the process rather than passive recipients of the technology.[ ]
>
> During the early releases, meetings were organized to provide the initial training and explanation of the program. In 1988, 24 operators were selected to receive on-site visits. The visits occurred twice monthly during which the program's current uses were reviewed and data collection techniques were demonstrated.
>
> [In 1989] ...groups met monthly in three locations throughout the San Joaquin Valley with the primary purpose of providing close user support. At the meetings, questions could be answered, problems solved, and program components that would be used in the next four weeks introduced. In addition, users were asked to respond to a survey concerning their CALEX-Cotton use patterns and their opinions about the value of the program.
>
> In addition to the monthly meetings, a monthly newsletter was sent to all cooperators outlining the possible applications of CALEX-Cotton in the next four weeks. The newsletter also addressed problems that might have come to light in recent weeks and provided solutions to these problems. Since cotton growers tended to use the program during the evening hours, a telephone answering machine was installed to record questions during periods when the main Cooperative Extension switchboard was closed. [ ] Users support was continued in 1991 through monthly production meetings... (Goodell et al., 1993, p. 16, 17).

In a survey conducted in 1992, of 145 registered CALEX-Cotton users, 75 responded. Of these, only 15 were still using the program (Plant, 1997, p. 34). Of the latter, the most valued uses of the DSS capitalised on 'plant mapping'. This learning by developers prompted separation of these simple functions from the complex CALEX-Cotton, forming the basis of CottonPro.

CottonPro is a decision calculus rather than an expert system (McCown, 2002a, this issue). CottonPro represents a shift from CALEX-Cotton's tactical planning role to a management control mode in which users want to run the program without leaving the field (Plant, 1997).

2.3. GOSSYM/COMAX

GOSSYM was one of the first comprehensive crop growth models. In contrast to the other cotton DSSs, SIRATAC, CottonLOGIC and CALYX-Cotton, GOSSYM is an elaborate model of the cotton crop that simulates responses to weather and cultural practices in both the soil and the crop. The GOSSYM strategy is grounded in two premises: (1) relevance to a farm situation requires comprehensive site-specific inputs, and (2) flexibility of a model to be able to accommodate diverse circumstances requires that it be mechanistic in nature (Hodges et al., 1998). These premises, however, contribute to making its specification and use among the most demanding of the DSS cases. The designed solution for this problem was the expert system, COMAX, which can be considered an artificial expert assistant to a user of GOSSYM. The knowledge domain of COMAX is 'how to use GOSSYM as a DSS for crop management'. It facilitates estimating model parameters for a situation and the interpretation of GOSSYM outputs as recommended actions to non-professional users.

After a period of great optimism, in which GOSSYM–COMAX was used by a number of farmers across much of the cotton-belt, there has been a serious decline in farmer interest (Boone and Porter, 1997).

2.4. WHEATMAN

The core approach of WHEATMAN (Woodruff, 1992; Hayman and Easdown, 2002, this issue) is simulation using a relatively complex model, but the approach taken to simplify management of the model in a DSS is different to that taken by the GOSSYM team. In WHEATMAN, the strategy was to substitute for the model a large set of outputs from simulations conducted for a network of key sites and a matrix of cultural practices. Behind the interface of the DSS, outputs of simulation runs are accessed via look-up tables. In addition, although soil water and N measurement can be input, an alternative for initialisation of soil N status can be made using empirical relativities drawn from histories of crop sequences, grain yields, and protein contents (Woodruff, 1992).

The WHEATMAN story is distinguished by an extraordinary joint effort by research and extension staff to produce a useful tool for farmers and by the degree to which farmers were involved prior to release. However, in spite of modest ongoing support and substantial changes to software design, use as a proportion of farmers who own computers has declined. There is evidence that this was due in part to discontinuation of use by farmers after they had *learned* as a result of using the DSS.

The focus of the original WHEATMAN was the selection of a wheat cultivar with the best phenological characteristics for a specific planting opportunity. This task is non-intuitive and the decision calculus 'selects' the cultivar that is the best stochastic compromise between early maturity to avoid risk of early terminal water stress and late flowering to avoid frost damage during sensitive reproductive stages. As with CottonLOGIC and GrazFeed, and in contrast to CALEX-Cotton and GLA, the development history of WHEATMAN features an original narrow scope and progressive additions of functional features and notional problems.

2.5. PCYield

PCYield was designed to enable the ready use as a DSS of the complex simulation model, CROPGRO-soybean by non-expert model users. The paper by Welch et al. (2002, this issue) describes the techniques used to achieve this, involving clever interface design, minimisation of run time and interpretation of variability by standardised output of the current year relative to a 'normal' year, and minimisation of local measurements by providing ready access to spatial soil and weather data for the user's region. The aspect of PCYield that makes it an especially important and interesting experiment concerns its use of the Internet in the interface with the user. PCYield has been fully privatised and is marketed as part of a commercial online weather information service and is linked to a network of advisers and input suppliers.

2.6. GLA and NUTBAL

GLA (Stuth et al., 2002, this issue) is a DSS for resource planning that grew out of computer techniques for training university students in grazing ecosystem function and ranch resource management. While inclusive of enterprise production and economics, it places much greater attention to natural resource information than livestock producers would normally allocate. GLA is a case of a normative DSS marketed by the university as a formal tool for management intervention by a government agency with responsibility for resource conservation. This case portrays some of the challenges within commercial relationships in the entrepreneurial climate of contemporary university research.

While GLA is built to influence producers' decisions, it is used to achieve a public agency's objectives. However, a second DSS discussed by Stuth et al. (2002, this issue) is a derivative of GLA that became a stand-alone product based on the demand by producers for achieving *their* objectives. NUTBAL is an information system to interpret analyses of cattle faeces in a service to producers on the nutritional status of their animals on pasture. Its success is due to the timeliness and affordability of advice from analyses made possible by near-infrared spectroscopy. NUTBAL is a decision calculus used in conjunction with specific information on system status not previously available and is providing increased profits from livestock feeding. The authors note the value of NUTBAL to conservation agency staff as a means of establishing relationships with producers that provide opportunities to engage on conservation issues.

2.7. GrazFeed and GrassGro

The fundamental rationale of Donnelly et al. (2002, this issue) for investment in a capability for simulating grazing animal production systems is that meaningful experiments on grazing animal production are inherently expensive and difficult to conduct without serious anomalies. This paper sketches the evolution of such a simulation capability. GRAZPLAN is presented as a suite of "decision support tools". The predominance of simulation and optimisation in software used by trained intermediaries and not by farmers puts this effort more in the tradition of Operations Research/Management Science (discussed in McCown, 2002a, this issue) than that of the DSS.

The core model system for animal production in GRAZPLAN is GrazFeed. In one mode it is the animal production module in GrassGro, which provides 'upstream' models of pasture performance, diet quality, and intake of grazing animals and 'downstream' enterprise analysis routines. In conjunction with MetAccess weather databases, this constitutes a versatile 'simulator' (Banks et al., 1991) of grazing systems. An enhancement of the simulator aimed at reducing the information costs and requirements for operator expertise in specifying such a complex model system is the development of 'templates' for typical situations. An operator can choose the template that best approximates the situation at hand.

In another mode GrazFeed serves as a tactical, stand-alone simulator of short-term animal performance in response to given input data on nutrient intake. It plays a similar role to that of NUTBAL (Stuth et al., 2002, this issue), except that nutritional status is calculated from pasture on offer rather than faecal analysis. The analogue of NUTBAL's novel analytic technology is new skill of GrazFeed users in estimating pasture inputs, and these have been developed through training workshops conducted by extension collaborators.

2.8. FARMSCAPE

The FARMSCAPE approach to decision support as described by Carberry et al. (2002, this issue) is a way of using a simulator of cropping systems (APSIM) to aid discussions with farmers to aid their planning and learning. It has emerged from a program of Implementation Research (McCown, 2002a, this issue). The original problem was that the group was expected to produce new DSSs for dryland cropping, but there seemed to be a surprisingly weak market among farmers for *existing* DSSs. The research entailed studying the effect of removing obvious barriers to farmers' experience of how simulation might help them think about their management, especially in relation to highly variable rainfall. Construction of farmers' *felt* relevance of the simulation was initiated by working with farmers on what they found problematic in managing scarce supplies of water and nitrogen and, in the process, collecting data that enabled simulation of specific fields and crops. After credibility of the simulator was established by simulating the shared field experiments, originally sceptical farmers became very keen to use it to 'extend' the experiments in time and to conduct other virtual experiments quickly and cheaply. 'What if?' analysis and subsequent discussion, often in farmer groups, became valued by farmers and their advisers and is the basis of a program of training and accreditation for agribusiness consultants to deliver a service to farmers. In its use of a versatile simulator (Keating et al., in press), FARMSCAPE, like GrassGro, is more in the tradition of certain styles of operational research than of decision support systems.

3. Concluding comments

In probing, in this special issue, the puzzling phenomenon of the low use of DSSs developed for farmers, the focus is on the human side of the technology from a user standpoint. But in the following six stories we often also see the human side of the technology's *creation*—the dreams, achievements and disappointments, camaraderie and conflict. We are admiring of the authors' critical reflection and candour as much as of their considerable achievements.

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Book review

Agricultural system models in field research and technology transfer
Edited by L.R. Ahuja, L. Ma, T.A. Howell

This volume is a collection of 16 expository review chapters, each on some aspect of crop modeling. Although not necessarily evident from the title, the book is almost exclusively devoted to crop simulation models: there is one chapter on forage models and virtually no mention outside of this chapter of animal physiological or behavior models. To quote from the first sentence of the Preface, the purpose of the book is "to present the state-of-science of applications of agricultural system models, and tremendous benefits to be derived from the use of these computer models in agriculture research and technology transfer in the 21st century." The editors are all USDA-ARS scientists, and the Foreword, written by an ARS administrator, implies that the project of developing the book was conceived within that organization.

The editors have clearly made some effort to include a perspective from outside the USDA. Of the 16 chapters, five have no authors from either ARS or the ARS-associated IBSNAT modeling program. Two of these, however, represent the experience of users of models developed by USDA-ARS scientists, so that there are only three papers that have little or no ARS influence. Two are from the CSIRO modeling group in Australia, and one is from the group at the Center for Agricultural Landscape Research in Muencheberg, Germany. In part, this reflects the dominant role that ARS scientists have played over the last three decades in the development of successful crop models, that is, crop models that are useful and survive to be used by people outside the lab where the model was developed. There are, however, some notable absences. The scope of the book would have been much enhanced by the inclusion of chapters from the Wageningen school, as well as from the group associated with James Thornley, to name two examples. The primary focus of the volume is on models developed under the auspices of ARS (primarily EPIC, the CERES and CROPGRO models, and GOSSYM and GLYCIM). A good source of further information for those unfamiliar with crop model acronyms is the Register of Ecological Models, http://eco.wiz.uni-kassel.de/ecobas.html

After the introductory overview chapter written by the editors the remaining chapters are organized into a sequence of four thematic groups. The first group, Chapters 2 through 5, represent what may be loosely described as the developers' perspective. These chapters describe the history and philosophy of the programs that produced FARMSCAPE, GOSSYM/COMAX, GLYSIM, and the DSSAT collection, which incorporates the CERES and CROPGO models. In each of these chapters the focus is not so much on the internal workings of the models as on the history of their development, the goals of the modelers, and how the model achieved

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these goals. None of the chapters contain a detailed description of how the model works; there are few flowcharts and virtually no equations. In each chapter there are a number of fairly detailed descriptions of successful applications of the model, both in research and in support of farm management or policy decisions.

Chapters 6 through 9 represent what might be considered the user perspective of these models. Chapter 6, written by scientists from the International Fertilizer Development Center, describes their experiences with models in various applications, both at the farm and the policy level, in Asia and Africa. Most of the discussion involves the DSSAT models but there is also some discussion of other models such as QUEFTS and COTONS. Chapter 7 provides a systematic and thorough comparison of the RZWQM, CROPGRO, and CERES-Maize models under a variety of applications. Chapter 8 describes the experiences of the authors in implementing models for decision support in Australia. Both this chapter and Chapter 6 detail some of the problems experienced in using models as on-farm decision support tools. This is a sufficiently important topic that I will devote a more lengthy discussion to it later in the review. Chapter 9 reviews a variety of models to a variety of applications in semi-arid regions.

Chapters 10 through 13 are devoted to the currently most active area of crop modeling research: the incorporation of spatial variability into simulation models through linkage with a geographic information system. Hartkamp et al. (1999) provides a review of this topic that contains a very useful structure for organizing and classifying the various ways to link a model with a GIS, and this paper is a good introduction to the subject before reading these chapters. As with single-plant crop simulation models such as those described in Chapters 2 through 5, some of the most prominent and successful farm and landscape scale models, such as ALMANAC and SWAT, have been developed under the auspices of USDA-ARS. Chapter 10 provides a description of these models and a demonstration of their use to various problems at different spatial scales. Chapter 11, which is one of two European contributions to the volume, describes the application of the HERMES simulation model to two questions involving spatially variable fertilizer application. Chapters 12 and 13 contain two relatively short discussions of linking a simulation model to a GIS to simulate spatial variability at the field level, and of the incorporation of topographic variability into a simulation, respectively.

Chapters 14 through 16 discuss various topics in crop simulation model research. Chapter 14 provides a systematic and useful review of the problem of parameter estimation and how to do it in a statistically consistent manner. Chapter 15 provides a description of the Object Modeling System (OMS) project currently under way at USDA-ARS. This is a laudable attempt to develop a common standard for object-oriented model development that, if implemented on a wide scale, would permit more efficient interchange of components of crop simulation models. Anyone who has ever waded through pages of FORTRAN code sprinkled with GO TO statements can only applaud this effort. Finally, Chapter 16 forecasts some future directions of research in crop simulation modeling.

The subtitle of the volume explicitly addresses the twin applications that have motivated the development of crop simulation models over the years, field research and technology transfer (which prominently includes decision support). Not surprisingly, the conclusions of most individual chapters are largely upbeat. The two principal exceptions are in Chapters 6 and 8, which mention some of the difficulties associated with the use of crop models in on-farm decision support. On a personal level, my own experiences probably reflect those of many who have been involved with crop modeling. On the one hand, crop simulation models can provide a useful tool for developing precisely stated hypotheses that are subject to test in field experimentation. On the other hand, the international effort to develop farm-level decision support systems (DSS's) based on crop models and expert systems (a form of model), which began in the late 1980's with such high expectations, had by the end of the century been largely abandoned as a failure. The authors of Chapter 8 have themselves sponsored a collection of papers published in the journal *Agricultural Systems* that addresses the roots of this failure. In the introductory paper to this collection, McCown and Carberry (2002) develop a subtle and well-thought out analysis. At the risk of oversimplifying their work, I want to focus on one aspect of it.

McCown and Carberry (2002) note that the failure of DSS in agriculture reflects a more widespread failure of such systems observed throughout the discipline of operations research. One of their ascribed causes of this failure is the "Delphic" approach to DSS in which the flow of information is strictly in one direction: from the system to the user. Technology transfer workers in Australia have responded by developing a new paradigm, described in Chapter 8of the reviewed volume, in which farmers and scientists participate in group exchanges of information, with the simulation model serving as a vehicle for enhancing discussion and understanding. This experience reflects my own and that of other researchers and I think may be generalized to other applications of simulation modeling.

In their insightful history of crop simulation Sinclair and Seligman (1996) make the case that those who benefit most from the development of a simulation model are the modelers themselves, through the use of the development effort as a vehicle for organizing one's thoughts and synthesizing linkages between knowledge segments. (This paper is part of another special series of papers, entitled "Use and Abuse of Crop Simulation Models," that should also be on the reading list of anyone interested in this subject.) Sinclair and Seligman present an unpublished argument of Imanuel Noy-Meyer that states that it is not necessary even to complete the development of an actual model to achieve the benefit. While this takes the argument perhaps to an extreme point, the combined experiences presented here indicate that successful use of a crop simulation model as a technology transfer tool requires a collaborative effort between farmers and scientists in which the model is used as a device to assist in organizing knowledge of the participants, rather than as a source of knowledge in itself. Similarly, a model can be best used as a research tool if individuals who understand its assumptions and limitations use it to propose experiments whose outcome can be interpreted within these limitations to test a well-formed hypothesis.

So where does that leave the subject of this book review? Obviously, all of us who have worked with models and decision support systems over the last 20 years or so have emerged with a few lessons learned, sometimes the hard way. With the exceptions already noted, the volume does not really offer much in the way of lessons learned through failure, and thus perhaps presents an overly optimistic view of the potential of crop models as research and decision support tools. There have been many successes, however, and crop models clearly have a significant place in the scientific toolbox, both in research and in technology transfer. Those who want to learn about crop modeling and are seeking an objective comparison of a wide variety of crop models developed around the world will likely be disappointed by this volume. Those who are seeking information on the many prominent crop simulation models developed under the auspices of, or in collaboration with, the USDA-ARS, and examples of highly successful applications of these models, are likely to find exactly what they are looking for. It is a tribute to the prominent role of the ARS in crop simulation modeling that there are sure to be a very large number of scientists who fall into this second category.

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