Understanding and applying decision support systems in Australian farming systems research

by

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DECLARATION OF ORIGINALITY

I declare that the work presented in this thesis is, to the best of my knowledge and belief, original and my own work, except as acknowledged in the text. The thesis has not been submitted, either in whole, or in part, for a degree at this or any other university.

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Jeffrey Brett Robinson
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ABSTRACT

Decision support systems (DSS) are usually based on computerised models of biophysical and economic systems. Despite early expectations (e.g. Dillon 1965) that such models would inform and improve management, adoption rates have been low, and implementation of DSS is now “critical” (McCown et al. 2002). The reasons for this are unclear (McCown et al. 2002) and the aim of this study is to learn to better design, develop and apply DSS in farming systems research (FSR).

Previous studies have explored the merits of quantitative tools including DSS, and suggested changes leading to greater impact. In Australia, the changes advocated have been:

- Simple, flexible, low cost economic tools (Dillon 1979 and Malcolm 1990),
- Emphasis on farmer learning through soft systems approaches (Hamilton 1995),
- Understanding the socio-cultural contexts of using and developing DSS (Cox et al. 1996),
- Farmer and researcher co-learning from simulation modelling (McCown 2001a), and
- Increasing user participation in DSS design and implementation (Lynch et al. 2000, Lynch 2003).

Twenty-four simple criteria were distilled from these studies, and their usefulness in guiding the development and application of DSS were assessed in six FSR case studies. The case studies were also used to better understand farmer learning through models of decision-making (Janis and Mann 1977) and learning (Vygotsky 1962, King 2000).

It was found that decision-making is not the logical, information-starved process depicted in the agricultural decision support literature. It is a complex process based on experience and emotional conflict. Better understanding of decision-making will improve FSR practice, which relies on effective decision-making, and FSR theory, which must understand decision-making.

Contemporary DSS in FSR were found to be:

- Able to be improved by application of the criteria from the studies listed above. However, most of the criteria are subjective and abstract, and may be of limited use in specific cases. There is no “one size fits all” solution to effective design, development and application of DSS,
- Insufficient as catalysts of change without pre-requisite conditions and farmer engagement. In most cases, change requires prior motivation from within farmer’s existing decision-making frameworks. However, DSS and their associated processes can provide additional experiences (both virtual and real), and quantitative
frameworks for assessing their existing knowledge and beliefs. Learning is the yardstick of successful DSS application,

- More efficient and likely to be more effective when based on simple task-oriented models than complex models. Researchers find simple models problematic and easy to criticise. Tools of appropriate complexity require few resources to develop, few resources to apply, are trustworthy, and have simple interfaces,
- Best applied in environments conducive to learning. There is a need to move beyond the failed concept of DSS as decision-making systems. If they are not part of a learning system, they are not relevant or effective.

Use of the models of decision-making and learning was useful in the interpretation of actions by participants in case studies, leading to enhanced understanding of the decision and learning processes and the places of the participants within them.

The “enigma” of non-adoptions of DSS is explained by models of decision-making (e.g. Janis and Mann 1977), which show that if people are content with their decision-making abilities, there is no market for a DSS. Even where discontent occurs, the DSS must be an acceptable solution, fitting in with existing management constraints (e.g. high demands for physical work).

A variation on the action learning cycle (Kolb 1984) is presented that emphasises the strengths and benefits of research and farmer cultures, and seeks to minimise the negative impacts of each culture on the other. Early DSS implementation sought replacement of farmer decision culture by researcher decision culture. DSS implementation has involved researchers’ models, tools, methods, language and symbols. Hence there is considerable scope for DSS developers to recognise and learn from farmers’ models and decision-making processes. Most importantly, DSS development should proceed from a position that recognises farmers are effective decision-makers without DSS (Hayman and Easdown 2002). Hence, improvements in decision-making will be evolutionary rather than revolutionary, additive rather than competitive. To make DSS useful complements to farmers’ existing decision-making repertoires, they should be based on: (i) a decision-oriented development process, (ii) identifying a motivated and committed audience, (iii) a thorough understanding of the decision-makers context, (iv) using learning as the yardstick of success, and (v) understanding the contrasts, contradictions and conflicts between researcher and farmer decision cultures.
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Glossary

APSIM – The Agricultural Production systems SIMulator. A detailed model of soil, crops and management.
APSRU – Agricultural production systems research unit.
Clay – Primary soil particles smaller than 0.002 mm in diameter. Clay soils (>50% clay) are important in Queensland for cropping.
Constructivism – A philosophy that truth is personal and separated from falsehood by adding and synthesizing new experiences with prior knowledge.
Conventional tillage – The use of machinery (ploughs in particular) to manage weeds and modify soil conditions.
CQFSP – The central Queensland farming systems project.
Dialogue – Communication that exchanges ideas or opinions between two or more people.
Drainage – Soil moisture that moves below the root zone.
Duplex soil – Any soil with a substantial change in texture between the surface and subsoil. In the study area, many red loam soils have such a texture contrast in the range of 10 to 30 cm depth.
Empiricism – A philosophy that experience and measurement are the bases of human knowledge.
Epistemology – Systems for understanding knowledge.
Extension – The facilitation of positive change in agricultural systems (usually through learning and experience).
Fallow – A period in which no crop is grown.
FE - Fallow efficiency – the proportion (often expressed as a percent) of fallow rainfall accumulated as soil moisture. FE may range from 10 to 50 %, but figures around 20 to 25 % are most common.
FSR - Farming systems research – research that recognises the importance of links between different farm enterprises and commodities, and takes a more holistic, multidisciplinary, or whole-farm approach than traditional research.
GRDC – The Grains Research and Development Corporation
Hard systems – Systems that include biophysical and rational economic components, but not personal and social components. Founded in logical positivism.
Intuition – Unconscious judgement. Decision-making via pre-attentive or inattentive processes.
Ley pastures – Pastures grown in a crop rotation, usually to improve soil fertility or structure or suppress weeds or diseases.
Logical positivism – A philosophy espousing that empiricism separates truth from falsehood.
Ontology – A systematic account or study of existence.
PAR – Participatory action research. Action learning by people acting as a collective or cooperative. Often has a goal of acquiring objective knowledge.
PAW – Plant-available water (the amount soil moisture available to plants, mm)
PAWC – The plant-available water capacity of a soil. Usually more is better.
Pluralism – A philosophy that reality has many forms besides universal laws and dualities such as true/false and self/object.
Reductionism – A philosophy that reducing a problem to a few components and relations between them improves knowledge of them.
Runoff – Rainfall that is unable to infiltrate the soil.
Sodicity – A common soil condition that limits rainfall infiltration and air entry. Primarily due to an excessive proportion of sodium on the cation exchange complex.
Soft systems – Systems that include personal, organisational and social components. Concerned with sociocultural views of reality.
Soil organic matter – The remains of plant, animal and other living material in soil.
USDA – United States Department of Agriculture
Water use efficiency (WUE) – Marginal grain yield (kg/ha) per unit rainfall (mm).
WFSP – the western farming systems project.
Zero till – farming with the use of herbicides in place of mechanical cultivation.
Introduction

This is a period of great change for Australian agricultural research and extension. Funding for traditional agricultural research is declining. Traditional extension services are in strong decline (Marsh and Pannell 1999). Much hope (and funding) is being placed in farming systems projects as the future developers and communicators of relevant solutions to problems in agriculture. But do the stakeholders and funding organisations understand farming systems research (FSR)? Who knows whether FSR works, how it works and why it works? What are the opportunities for identifying better theory and practice?

My motivation for this thesis was to understand decision-making and the impact of decision support systems (DSS) in FSR. Put simply, DSS are struggling for acceptance while contemporary FSR is popular with funding organisations because FSR is perceived to achieve holistic, sustainable outcomes for farmers. How can the outcomes for DSS and FSR be so different, given their similar intentions?

At a deeper level, my enthusiasm for further technological and sociological progress in FSR stems from a view that FSR is a means of achieving holistic goals for rural and urban societies. The roles of sustainable consumption and sustainable primary production as a foundation for society and civilisation are easily overlooked (Flannery 1994).

Traditional R&D and FSR

Conventional Australian agricultural research and extension have a long history of successfully developing solutions to problems faced by farmers. Much progress has been made concerning technical constraints to the efficient use of resources, such as water, sunlight, nutrients and genetics. However, many of the simple deficiencies have now been overcome, and “systems” research has evolved which aims to improve farming by understanding the more complex features of farms.

Systems research aims to overcome some of the limitations of “component” research by understanding relations between components of the system, and its structure, in addition to the components. Systems research may be effective if several components need to be managed in concert or if new ideas and processes are required. However, systems research is “easier said than done” (Anderson and White 1991).

“Hard” FSR is research at a systemic level that focuses on biophysical and organizational elements of a situation. It is different from “soft” systems research in that personal and social elements are not considered or given low priority.
From the 1960s, economists and agricultural researchers in hard FSR promoted the development and application of many software systems for solving “problems” or “problem” situations. These software “tools” included computer-based models of biophysical and economic systems, many of which became known as DSS. The DSS concept ranges from: (i) any computer-based system supporting decision making (Finlay 1994), to (ii) “an interactive, flexible, and adaptable computer-based information system, especially developed for supporting the solution of a non-structured management problem for improved decision making. It utilizes data, provides an easy-to-use interface, and allows for the decision maker's own insights” (Turban 1995). The concept used in this thesis is Finlay's (1994) broad definition. In particular, examples of non-interactive software and well-structured problems are included.

Power’s (2002) typology of DSS separates communications DSS, data DSS, document DSS, knowledge DSS, and model DSS. The most relevant types to this thesis are the: (i) model DSS which emphasizes application of a statistical, financial, optimisation, or simulation model, using data and parameters provided by the DSS user, (ii) knowledge DSS which provides specific problem-solving expertise stored as facts, rules and procedures, and (iii) communication DSS which supports cooperative efforts in decision-making. In practice, the boundaries between the DSS types, and between computer-based and human-based decision support become considerably blurred.

Edwards-Jones (1992), Lynch et al. (2000) and McCown (2001b) present evidence of continued lack of success in implementing DSS in agricultural decision-making. In an attempt to promote better practice, several authors have proposed guidelines for developing and applying DSS.

The relevant literature was reviewed and criteria and guidelines proposed by previous authors were summarized. Six Australian researchers from farming systems and related areas had provided 24 criteria. Briefly:

- Dillon’s work (1979) was concerned with the failure of economic tools, as was Malcolm’s (1990).
- Hamilton (1995) was concerned with hard and soft systems approaches to farmer learning.
- McCown (2001a) was concerned with co-learning from simulation modelling.
- Cox et al. (1996) was concerned with the socio-cultural context of using and developing DSS, and
- Lynch et al. (2000) evaluated the adoption and impact of a range of DSS.
Examining the usefulness of the criteria was explored as one means of improving DSS development and application.

Because DSS should be supporting decision-making, and because improved decision-making is a process of learning, the other needs of this study were models of decision-making (Janis and Mann 1977) and of learning (Vygotsky 1962 and King 2000). The models were used to assess whether DSS are well suited to the task of decision support. This was the second means by which improvement to DSS development and application was explored.

Action research (Kolb 1984, Zuber-Skerritt 1993) was used to develop most of the learnings of the thesis. Action research involves planning, action, observation and reflection. The action was in the form of six studies of the development and use of DSS in the grainbelt of southern Queensland. These case studies provided evidence concerning the merits of the (i) different types of DSS and systems for implementing DSS, (ii) the 24 criteria, (iii) the Janis and Mann model, and (iv) the action research cycle and traditional research diffusion.

The details of these selections, further explanation of the methods of inquiry, results and discussion unfold throughout the remainder of this thesis.
Goals

My goal in this thesis is to identify ways of improving the effectiveness of the development and application of DSS in FSR.

This included identifying:

1. Effective and efficient instances of DSS use,
2. Effective and efficient types of DSS,
3. Effective and efficient processes for applying DSS, and
4. Deficient theory or practice concerning DSS and their use.

These ultimate goals were reached via simpler, proximal propositions for examination and discussion. Arriving at the propositions, involved:

- Reviewing the history and intent of FSR (Chapters 1 and 2). Differences between “hard” and “soft” FSR are discussed,
- Reviewing the history of development and application of DSS and other hard systems tools in Australian agricultural RD and E (Chapter 3). Some of the successes and failures of these tools are discussed, and common patterns and determinants for success are sought,
- Collecting existing criteria for developing and applying DSS from the literature (Chapter 4), and
- Examining the process of decision-making (Chapter 5).

The resulting propositions and methods of inquiry used in this thesis are presented in Chapters 7 and 8.
I. LITERATURE REVIEW

Chapter 1. What is FSR?

The origins of contemporary FSR

This section is a synopsis of the origins of contemporary Australian FSR. Collinson (2000) describes a wide range of theory and practice in international FSR, which is outside the scope of this thesis.

The origins of contemporary Australian FSR are from at least six areas, some of which overlap or are related:

1. Systems research; studies of hierarchies, information and energy flows,
2. Farm management research and farm management economics (FMR/FME),
3. On-farm research (OFR) in low-income countries (LICs),
4. Systematic agronomy; experimental identification of constraints to crop production,
5. Adult learning, and
6. Participatory action and participatory research.

Systems theories underwent rapid expansion in the late 1950s and early 1960s when physical scientists were taking an interest in systems as subjects of study (e.g. hierarchies, information and energy flows). By the late 1960s, computer scientists had developed frameworks for describing and analysing systems (e.g. computer-generated flowcharts, etc). By the late 1980s systems approaches had multiplied into confusion, and systems practice has taken a long time to dispense with unmanageable theory. “Authors would better keep their models and methodologies to themselves until they can demonstrate a problem solved by the use of them…” (Checkland 1981). However, systems theory still underpins soft systems research, and is increasingly accepted as a valid part of contemporary FSR, even if its utility is poorly understood and it is not simple to apply in FSR (Anderson and White 1991).

Farm management research and farm management economics (FMR & FME) have central places in the history of contemporary FSR. The origins of FME were from the late 1800s, particularly in the USA, when there was an active interest in farm economics by agronomists, farm advisors and other non-economic specialists. By the late 1950s, “proper” theories of farm economics were devised. In the 1960s and 1970s, these had become highly theoretical and complex. Australian economists were at the forefront in these developments. By about 1990, computers and software overcame most of the computational difficulties of linear programming (LP), simulation, etc. However, despite the improvements in technology, FME per se was in decline, and limited to a few teams and individuals (e.g. the MUDAS and
MIDAS teams, Pannell 1996). However, the principles of FME are being applied in contemporary FSR through many economists assembled into multi-disciplinary FSR teams. They mainly use simple budgeting tools, especially spreadsheets (Malcolm 1990). The use of tools such as LP and simulation has recently been directed at whole systems rather just the economic components of farming systems.

On-farm research in low-income countries has contributed to the contemporary emphasis on farmer-participative research in Australia and elsewhere. From the late 1950s and early 1960s, agronomists from western countries working in low-income countries increasingly found success by employing indigenous knowledge and methods (Collinson 2000). By the late 1970s farming systems theories were being developed concerning appropriate technology and extension methods; this was boosted by the parallel development of systems theories in the biological and computing sciences.

Collinson (2000) presents a history of FSR that focuses on work in the low-income countries (LICs). He concludes that the discipline-oriented methods of research that had grown up in the industrialised countries were inadequate for improving farm practices in the LICs. The reasons for this included:

- A lack of local understanding by foreign researchers,
- A lack of influence by local farmers on research and technological options,
- A lack of on-farm research,
- Research that mainly benefited rich farmers, and
- Research that benefited educated farmers.

Comprehensive agronomic research has a long history in Australia and makes a major contribution to FSR through detailed trial work to understand the complex interactions of biophysical factors in farming systems. By the late 1950s, agronomists and others were conducting highly systematic experiments that were crossing discipline boundaries. **Systematic** as used here refers to a high degree of completeness in the biophysical factors being considered in an experiment. In the 1960s and 70s farming systems research included multi-factorial small-plot research targeting biophysical constraints in farming systems. Although fewer large field experiments might be conducted than in its heyday, systematic research is well integrated into Australian FSR (French 1995).

Adult learning concepts have been incorporated into FSR through recognition of farmer learning as an important outcome of FSR. Use of these concepts came relatively late to FSR. By the 1970s it was well known that learning was a key element of social and technological change. In the 1990s, concepts of learning and behaviour were being rapidly adopted in agricultural extension and FSR (King 2000).
Concepts of farmer participation and involvement are essential elements of FSR, both in Australia and internationally (Martin and Sherington 1997). Their development in FSR expanded rapidly in the 1980s, when they were used to overcome limitations of conventional research in producing productive and sustainable outcomes for resource-poor farmers. Recently, however, there has been a recognition that participation is not without its problems, and that the quality as well as the quantity of participation needs to be considered (Christoudoulou 2000).

Farm management research (FMR) has been a type of research that is closely related to FSR. But according to Collinson (2000), in the 1980s FSR distinguished itself from FMR through:

- Eliciting farmers attitudes, opinions, and contributions in an inexpensive and systematic manner,
- Designing, implementing and evaluating on-farm trials involving farmers themselves, and
- Addressing sustainability issues.

In their review of Australian FSR, Petheram and Clark (1998) conclude that:

- FSR is an approach to improving farming that involves farmers and specialists in holistic approaches,
- The goal of holistic FSR is to improve the well-being of farmers, and
- FSR therefore includes many social goals as well as biophysical goals.

Hence, contemporary FSR avoids some of the limitations of traditional research, including the Cartesian, reductionist view held by scientists. Contemporary FSR extends basic empirical realism to allow for personal and social constructions of reality (e.g. Hamilton 1995). These ontological and epistemological differences are further discussed below.

A key element of the FSR approach is identifying systemic problems, constraints and opportunities. From beginnings as a research method in low-income countries (LICs), it has grown and diversified into a wide range of approaches to research, development and extension (R, D and E) (Petheram and Clark 1998). Some related methods have been annexed or subsumed by FSR, including systemic or holistic extension methods and practices. FME and FMR are two such areas subsumed by contemporary FSR.

The rise and fall of farm management research

Brennan and McCown (2001) reviewed many aspects of FME/FMR. They come to some significant conclusions, but as a farm management economist and a reductionist researcher (respectively), their perspectives on the issues were probably different to those of many
contemporary farming systems researchers. Therefore, the next section presents a synopsis of
the rise and fall of FMR, from my perspective as a farm management researcher turned
farming systems researcher (i.e. increasingly soft systems oriented) employed on the second
wave of optimism in FMR that came with the surge of microcomputer availability in the
1980s (e.g. Hardaker and Anderson 1982). By the late 1980s I had become a farming systems
researcher, interested and involved in soft systems approaches because I perceived that hard
systems tools including DSS were not matching the requirements of advisors and farmers,
who effortlessly crossed back and forward between “hard” and “soft” perspectives of their
systems.

The first great wave of optimism in FMR began in the 1960s and 1970s when the powerful
economic theories of the time were combined with new mathematical techniques and digital
computers (D. Freebairn, P Hayman, pers. comm.).

Dillon (1965) was typical of those expecting unbounded expansion of academic FME/FMR:

“This expansionary tendency will be abetted by the feed-back pressure from
the fast developing profession of farm management consultancy, in turn
reflecting the increasing and never-ending managerial pressures faced by
farmers arising from their vulnerability to the vagaries of climate, the
inelastic demand for food, advances in farm technology, the pressures of
integration and the development of an ever-widening array of synthetics. As a
result there seems little risk in predicting the continued expansion of farm
management as an academic and professional discipline. Like the gentle sex,
farm management, with its charms and its challenges, has an assured future.”

The tools of the FME/FMR revolution provided for the first time the possibility of detailed,
quantitative analysis of farming systems. The purpose of these tools and this effort was to
solve the classic economic “problem” – allocation of the available resources to maximise
profit. In mathematical terms, this is also known as optimisation of the production functions.

There was certainly no shortage of tools.

- Linear programming
- Simulation modelling
- Mathematical programming
- Dynamic programming
- Decision theory
- Utility analysis
- Probability analysis
- Decision trees
However, the early optimism was not matched with empirical success in the 1970s. Hardaker and Anderson (1981) wrote of “gloom not doom” in the application of computer technology on Australian farms. Then, in the early to mid 1980s, a second wave of enthusiasm arose coinciding with the wider availability of microcomputers. In the late 1980s, models of production systems were devised by many groups of scientists and economists, and some became extraordinarily complex. Yet, despite the increasing availability of mathematical analysis of farming systems, and great technical precision, the vision of a modern, optimised agriculture was never achieved. This was despite scientists and economists pushing for the adoption of intensive analysis for many years.

In the end, it appears to have been all too complex and too fallible. The models were too narrow in scope, unfamiliar to consultants and farmers, and too time-consuming to be much use to real management (Hardaker and Anderson 1981, Malcolm 1990). Even in the 1990s, when better personal computers and a familiarity with software made many of these tools easier and faster to use, they have not been widely adopted by agricultural R D and E practitioners (Cox 1996, Lynch et al. 2000). One particularly influential FME group, from the University of New England (Armidale), was already disbanding in the 1980s because of the failure of the group to overcome their lack of practical relevance to Australian agriculture (Dillon pers. comm.).

Of course, there are still a few faithful adherents to both the vision and the methods, but the evidence indicates that stand-alone hard systems economic analysis has passed into history.

Collinson (2000) has a similar view of DSS and model use in contemporary FSR, regarding systems simulation as an abstract art that fails to sufficiently engage the farmer enough to be an effective tool in farm management. McCown (2001a) has similar views of past FME and FSR, and Malcolm (1990, 2000) certainly regards the complex, theory-laden systems as too complex, and unlikely to succeed. What then, is the source of motivation for DSS development and application, both in resource-poor and industrialised countries?

The rise and re-thinking of operations research (OR)

McCown et al. (2002) reviewed the place of operations research relative to FME and FSR. They note that as far back as the 1930s, there was a modernisation/optimisation style in some agricultural research. In a nutshell, operations research may be said to have had massive technical potential, which was well explored conceptually and practically, but ultimately failed in implementation. While Checkland (1978, 1983) and others considered the OR approach impotent because of its purely logical and technical focus (i.e. ignoring the people), others regarded the overall failure of implementation in OR enigmatic. For McCown et al.
(2002), there seems to be a hope that Checkland’s assertions were strictly relevant to OR, and that FSR can learn from, and avoid such failure:

“The point that is crucial to the objective of this paper is that not only does the model-based agricultural DSS have its roots in early OR/MS but our present problem of non-adoption by farmers of available model-based DSSs has an historical precedent in this earlier field as well. Knowledge of the diagnosis and response to the earlier problem in OR/MS of non-use of scientific models in management practice may be important to our response to our current crisis”

A key question* arises from this proposition; Can a purely technical DSS be successful?

*At several places in the literature review I will pose key questions, that serve two purposes: (i) focussing on the material presented in the previous few paragraphs or pages via a simple but challenging rhetorical question, and (ii) indicating the formulation of inquiries that will lead to the propositions examined later in this thesis.

**Hard and soft FSR**

Since the 1970s, and perhaps earlier, FSR has had sub-categories of soft systems research, dealing primarily with people and social systems, and their mental constructions of the world (Checkland 1981), and hard systems research, dealing primarily with the biophysical systems, with people as unbiased observers (Checkland 1978, Anderson and White 1991, Ison et al 1997). The differences between the two approaches go deep, to different ontologies and epistemologies. Soft systems approaches have a liberal view of reality (ontology) and means of acquiring and interacting with knowledge (epistemology), whereas the hard systems approach adheres to the view that there is only one true reality, and that logic and experimentation are the means of determining the truth about that reality (logical positivism). See Jackson (1991) for a discussion of systems thinking in terms of ontologies, epistemologies, modernism and post-modernism.

Hard and soft FSR have different views of farming systems and different system boundaries. A hard systems approach will usually focus on a physical system as if it is simply a problem-laden biological network (Figure 1). In this view, the system has a latent capacity for improvement through understanding and action. Improvement is synonymous with greater utility (often profit) from the system. A soft systems approach would focus on the system as if it consists of the dynamics of the people and their social networks in motion (Figure 2). In terms of soft systems, improvement would be measured degrees of satisfaction of the people involved with what is happening in the system.
There have been periods of hostility and competition between people in the two camps concerning the theory of systems. According to McCown (2001b) and others, a soft - hard division in FSR practice persists. However, my experience is that by the late 1990s many FS workers, particularly those trained in extension, saw no conflict between the logical positivist approach of hard FSR and other approaches of soft FSR. However, this may be through uncritical acceptance of different epistemologies. FSR practice is often not well informed by theory.

Alternatives to subject-object dualism have also been proposed, such as the language world of Wittgenstein (1968, 1974), the action world of Heidegger (Schurmann 1987) and the dualism plus conceptual world of Popper (1972). As discussed in the methods section, pluralism is taken as a useful starting point for this inquiry, given that there is no prima facie evidence for either monism or dualism. Similarly, language, action, concepts, etc. may be simply compatible elements of the world, and none of them is its primary characteristic. Jackson (1991) and others regard worldviews as having important consequences. Just as importantly, Rorty (1991) shows that arguing the merits of different worldviews is a philosophical and practical dead-end.

Figure 1. Part of the hard systems view of a farming system; a farm as a biological network suitable for mathematical solution (Source: McCown 2001b with modifications by Robinson, unpublished).

To summarise, hard FSR deals with the “true world” of objects in the Cartesian subject-object view of reality (Wittgenstein 1953, 1968). These objects can be studied to minimise
uncertainty and maximize predictability and manipulated to bring about improvements in the system (Wittgenstein 1979). Hard systems tools include a range of computerised systems that emphasise quantitative analysis. Where the focus of the tool is decision support, those systems are usually called DSS, although they have also been called intelligent support systems (Lynch et al. 2000) and discussion support systems (Nelson et al. 2002). The term DSS is also misapplied by agriculturalists to almost any database or quantitative analysis system, whether it has potential for supporting decisions or not.

Soft systems research focuses on the subject (usually the farmer) more so than the object (usually the farm or catchment). In particular, “constructivist” soft FSR deals with knowledge and learnings of the subject in terms of personal and sociocultural “constructions” or perspectives. Considerations of others’ views are central to the theory and practice of soft systems research.

Hence, soft systems FSR can, for the purposes here, be considered a set of research that has focuses on people, their mental constructions and their relationships with the biophysical farming system that is the focus of hard systems FSR.

![Diagram of Soft Systems View of a Farming System](image)

Figure 2. Part of the soft systems view of a farming system; the farm as an arena for gaining experience and increased understanding. Superimposed on the biophysical plan is a modified action learning cycle (Source: Zuber-Skerritt 1993 and McCown 2001b, modified by Robinson, unpublished).

Appendix 1 contains a more detailed discussion of associations between ontologies, epistemologies and knowledge domains. Many associations are summarised in Table 1,
though this is by no means intended to be a comprehensive treatment of the subject. There is a clear differentiation between the place of a scientific view (concrete reality – logical inquiry – knowable universe) and the parallel views that are important in soft systems FSR. The differences in the “nature” of farming, and the means by which one may learn about farming are informative. Behaviourism, for example, implies a dominant role of conditioning and the subconscious mind in life. The extent to which this or any of the other worldviews can be said to be true is likely to be difficult to assess in practical FSR. However, there is value in understanding that different people, in different positions, at different times, are acting in ways that can be better understood by considering a wide range of different worldviews.

Table 1 Some differences between the hard systems position (logical positivism) and some soft systems positions (Source: unknown, modified by Robinson, unpublished).

<table>
<thead>
<tr>
<th>Worldview/position</th>
<th>Logical positivism (hard)</th>
<th>Constructivism</th>
<th>Cognitivism</th>
<th>Behaviourism</th>
<th>Critical theory</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Farming is</strong></td>
<td>Physical</td>
<td>Individual</td>
<td>Managerial</td>
<td>Habitual</td>
<td>Cultural</td>
</tr>
<tr>
<td>Decision support</td>
<td>Objective</td>
<td>Personal</td>
<td>Instructive</td>
<td>Supportive/</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Affirmative</td>
<td></td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td>Authoritative</td>
<td>Dialogue</td>
<td>Deductive</td>
<td>Training</td>
<td>Political</td>
</tr>
<tr>
<td><strong>Reality</strong> (Ontology)</td>
<td>Concrete, knowable</td>
<td>Personal, plural</td>
<td>Experience</td>
<td>Conditioning</td>
<td>Socio-cultural</td>
</tr>
<tr>
<td><strong>Meaning of learning</strong></td>
<td>Prediction</td>
<td>Progress</td>
<td>Rule-making</td>
<td>New behaviour</td>
<td>Changing society</td>
</tr>
<tr>
<td><strong>Methods of learning</strong></td>
<td>Experimentation</td>
<td>Interaction</td>
<td>Memory</td>
<td>Practice and feedback</td>
<td>Debate and dialogue</td>
</tr>
<tr>
<td><strong>Ideal learner</strong></td>
<td>Investigator</td>
<td>Motivator</td>
<td>Elaborator</td>
<td>Habituator</td>
<td>Emancipator</td>
</tr>
<tr>
<td><strong>Role of bias</strong></td>
<td>The enemy</td>
<td>Personal / Natural</td>
<td>Individualism</td>
<td>Bend the environment</td>
<td>Shaper of the future</td>
</tr>
</tbody>
</table>

**Personal experiences of hard and soft systems approaches**

My experience is summarised below, both as a guide to my biases, and an insight into how and why I found it necessary to understand and apply both hard and soft systems approaches.

In 1984 I moved from working as a programmer in hard FSR (coding crop simulation models), to a mixture of hard and soft FSR in developing and extending simple computer programs to farmers. Generating interest in models of farming with advisers, farmers and agribusiness involved more time interacting with potential users of the system than dealing with the hard system components. The biophysical, technical side could be covered in a few minutes, by showing the merits of the system, but to explore the potential use of the DSS in
the working lives of the users would take much longer, and was a much more complex task. The world in which I was moving was one of opinions, emotions, traditions, etc. – mostly social constructions (Berger and Luckman 1966, Searle 1995). To me, fostering interest in DSS was an almost purely social activity. In spite of a background in science, and a disposition towards the technical, from 1984 I began slowly learning about extension and related soft systems approaches. By 1990, I was observing the power of simple DSS in the hands of extension workers and the failure of more sophisticated systems. From 1990 to 1995, I was often engaged with economists, who taught me much about pragmatism. I could see that they were discerning and discriminating about the value of agronomic details for the farmer. In 1996 I moved to work with a group using detailed simulation models, and found that they were also discovering the limitations of a hard systems approach to the deployment of a DSS (McCown 2001b, McCown et al. 2002).

Thus, the foundations were laid for my theoretical and empirical exploration of hard and soft FSR.
Chapter 2. The multiple goals of FSR

The problem of successful farm management

Pannell (1996) summarised some of the difficulties of farm management:

“Managing a farm can be blindingly complex. In deciding on the best mix of farm enterprises and management practices, the diversity and extent of relevant information is enormous. The choice of farm strategy may be influenced by the farmer’s knowledge of: scientific issues (biological and/or physical), machinery, economic/commercial factors, political events, legal constraints, historical trends, climate/weather, environmental issues, personal circumstances and any number of practical considerations. Even if a farmer had a complete grasp of all relevant information, the problem of combining it and appropriately evaluating its significance for decision making would be very substantial indeed. A thorough and detailed analysis would certainly be beyond the capability of any single human mind.”

Nevertheless, it is individual farmers, with cooperation from their peers and advisors, who are managing most farms in the Australian grainbelt. How do they do it?

Science, management and FSR

The goal of management is utility and profit (i.e. economic gain from the world), while the goal of science is knowledge (i.e. predictive accuracy about the world, Forster 2002). Passioura (1996) gives clear examples of the differences between managerial and scientific approaches to problem solving. Engineering examples are given for what is called the managerial approach in this thesis – solving problems without concern as to whether a fundamental understanding has been reached.

Sometimes, understanding supports management goals, or vice versa. However, the goals of science and management are often different enough to leave a “gap” in orientation and understanding, in FSR and elsewhere (Ridge and Cox 1996, Lynch et al. 2000, McCown 2001b). FSR aims to improve management via scientific methods, but it is also clear that the methods and goals of science are too few and too narrow to enable FSR practitioners to reach their goals. FSR has more practical and broader goals than science. Put simply by Ridge and Cox (1996):
“Farmers are managing the same biophysical system [as scientists are researching], but their need for understanding is different to that of the scientist. Farmers are managing this system within the context of a whole farm in order to generate an income.”

A characteristic of effective FSR is that it identifies relevant scientific information and tools that assist management.

The differences between managerial and scientific problem solving are important because decision-makers in agriculture are mainly managers, whereas scientists mainly develop formal DSS. This may result in a mismatch between the reasons for developing the system and the needs of users, as observed by Ridge and Cox (1996), Lynch et al. (2000), McCown (2001b) and others.

Employing scientific and related styles of research in improving management is much more difficult than at first appearance, at least partly because science treats knowledge in different ways to practical management. According to McCown (2001a), FSR practice has not recognised the importance of the differences:

“Researchers know that practical farming is profoundly different from ‘scientific’ farming. But there has been little incentive for them to be good students of the differences.”

Learning and knowledge

Learning has become a central feature of FSR in the last couple of decades. Also, there has been a revolution in understanding of learning and cognition, especially in everyday activities and low-status occupations. Learning is a significant driver of behaviour, and a shaper of human experiences. Researchers such as Lave and Wenger (1991) have raised the profile of non-intensive, non-academic learning, used in everyday activities like farming. According to Rölling (1990, 1991) and others, the purpose of agricultural development and extension is learning.

Learning and FSR?

Learning is an integral part of FSR. In the 1990s, participatory FSR became a very popular and effective co-learning process (e.g. Allen et al. 1998). In participatory FSR, facilitated workshops provide a learning environment where a shared understanding of others’ perspectives and actions is central. The learning includes not only the “facts” (hard systems content), but also the reasons and context leading to the “facts” (the soft-systems, socio-
cultural context to the “facts”). These contextual learnings are said to be more meaningful to farmers, especially in complex systems with multiple goals (Allen et al. 1998).

According to Hamilton (1995), education and learning are useful extension paradigms that enable individuals to better understand a situation, make choices and take action to improve their situation. It deals with more complex situations than transferring technology and requires a higher level of human resources (Hamilton 1995). Similarly, King (2000, p10-13) explores the changing nature of agricultural extension through time, and concludes that in the late 1990s the cutting edge of extension was concerned with facilitating social learning. The agenda was “merging social justice and ecological sustainability” and the theoretical foci were “systems thinking and cognitive processes”. However, effectiveness in facilitating social learning is considered by King (2000) to be difficult:

“The facilitation of participatory and social learning is much more complex than realised by extension practitioners, and as such, the tools they use are often inadequate. The reality is also much more complex than extension theorists realise too, and the methodologies and methods they provide in theory (often as ‘recipes’) rarely allow for contingencies and uncertainties inherent in participatory learning.”

Types of extension

Extension and development fall into a range of types. Bloome (1991) considered four types:

1. Technology transfer
2. Problem solving
3. Education
4. Human development

According to Blacket (1996a,b), there is considerable potential for education and human development to succeed in complex situations where the simpler methods of technology transfer and problem solving often fail.

_How can we learn effectively?_

John Dewey (1859-1952) was the leader of the progressive movement in education in the late 19th and early 20th centuries. During this time, the reliance on techniques such as rote learning and formality was reduced. Education was further evolved by Vygotsky (1962), who provided simple and effective models and principles to educationalists:

1. Assume the learner is competent
2. Know the learner
3. Share an interest with the learner
4. Follow the learner’s lead
5. Capitalise on uncertainty

These remain some of the most important principles in learning. More recent theories of learning relevant to DSS and FSR include situated learning theory (SLT), which rejects cultural elitism and intellectualism (King 2000). A summary of SLT is contained in Appendix 2.

Adult education and learning may be seen as fitting within a spectrum of complementary types of extension (see Types of extension above, and Hamilton 1995, p. 10). Furthermore, within learning, there is a range of styles, or modalities of learning based on preferences in perceptions (James and Galbraith 1985, Hamilton 1995 p. 150). For example, some people are more effective listeners than observers, and vice versa. The most effective farmer learning for Hamilton (1995) occurred through haptic (touch) and interactive (discussion) tools and processes.

Reeve and Black (1998) and Fulton et al. (2003) have conducted detailed evaluations of extension, learning and change in Australian agriculture. Key findings of relevance to this thesis include recommendations that computer skills are important in farm management, and that farmer groups have benefits over other means of engagement (Reeve and Black 1998), and that barriers to participation in learning or change opportunities are poorly understood (Fulton et al. 2003).

Impact from learning programs is founded on effective design of the program (Fulton et al. 2003). Ingredients of an effective learning design include:

- Being specific, well thought out, realistic, integrated with experience,
- Working with all members of the agricultural community,
- Learning from other sectors about bringing on change (e.g. SunSmart, Tidy Towns),
- Focussing on meaningful benefits,
- Having clear goals,
- Using specialists where necessary,
- Choosing a delivery method that suits the participants,
- Creating discomfort in a safe environment (being challenging),
- Focussing on leverage and impacts,
- Being flexible in delivery,
- Using action learning,
- Addressing social issues,
• Understanding the people and the system, and
• Finding ways to motivate people.
(Fulton et al. 2003)

Action learning

Kolb (1984) and Zuber-Skerritt (1993) describe a model of learning known as action learning (or action research). It separates and emphasises four steps in a type of experiential learning: planning, action, observation and reflection. When reflection leads to renewed action, the process becomes a learning cycle, which is a much-used concept. However, in practice, many variants arise besides simple cycles (King 2000). Advocates of action research claim that it:

“not only advances knowledge, but also improves practice...”

Zuber-Skerritt (1993)

Argyris and Schön (1974) coined the terms “single loop” and “double loop” learning. Single loop learning refers to a single iteration of the planning, action, observation and reflection cycle. With respect to the use of a DSS, this might encompass a single application of the system. Double loop learning refers to an iteration of the cycle with respect to learning about the single, “inner cycle”. With respect to DSS, this might be planning, action, observation and reflection about better using the DSS. The difference between the two levels of learning is of great practical importance. As shown by Barr and Sharda (1997), there is evidence that single loop learning with DSSs can lead to dependence on the system and decrease the efficiency of decision-making. On the other hand, DSSs and implementation systems that are effective at providing double loop learning will, to some extent, reduce reliance on the DSS, making the learner confident, experienced and independent. There are many examples of successful DSS being rapidly adopted and later discarded. These examples include SIRATAC (Hearn and Bange 2002) and WheatMan (Woodruff 1992). Hayman and Easdown (2002) reported a representative individual’s experience with Wheatman:

“An extension agronomist commented that 90% of his use of Wheatman was in his first two years when newly appointed to a region in southwestern Qld in the late 1980s. He used the DSS to examine the trade-offs between early sowing and frost risk and describes the experience as ‘sort of like learning to drive a car, I drew up the relationships on graph paper for my own confidence and discussion with growers. I guess I learned from Wheatman and then abandoned it.’”
King (2000, p.43-44, p.53-59) has also made detailed investigations into the roles and meanings of single and double loop learning in FSR, and highlighted the practical importance of these systems for social learning.

**Behaviour change as an aim of FSR**

If learning and understanding are the immediate or proximal goals of much of FSR, the ultimate goals are behavioural, social and cultural change. DSS often aim at behaviour change through providing relevant information. The positive behavioural changes implied in much of the DSS literature are enactments of improved decision-making as a way of adapting to and benefiting from, the physical farming system.

However, connections between DSS, learning and behaviour change are not simple or direct. Most DSS merely provide new information to the decision-making process. In ideal circumstances, DSS are implemented in such ways that maximise learnings from the information. In some cases, the learning system may be more elaborate and well resourced as the DSS (e.g. Stewart et al. 2000). These mechanisms provide influences on decision-making and behaviour that are woven into an extraordinarily complex pattern (Janis and Mann 1977, Plous 1993). Figure 3 shows some of these influences and their interactions.

![Figure 3. An overview of factors affecting behaviour. A complex, interacting, non-hierarchical system is at play. (Source: Robinson, unpublished)](image)

Such a figure makes a modest change in knowledge appear an unlikely source of new or changed behaviours. Therefore, it important for strong and effective learning systems to accompany information from DSS. An example of such a system is the farming simulation game “Risky Business” (Stewart et al. 2000).
However, while the psychology of decision-making is complex, there are also simple and strong neurological pathways from stimuli to behaviour. For example, it is well established that there are strong neurological links between emotions and decision-making (Tranel 2002), and that physical and emotional consequences can lead to rapid learning and new behaviours.

Figure 4 shows a simple diagram of the three neurological pathways that prompt behaviour. The most simple is the reflex system, while the most complex is the attentive system. Gladwin and Murtaugh (1980) highlight the importance of the simpler, pre-attentive systems, and quote Alfred North Whitehead (1861 – 1947, a mentor to the young Bertrand Russell):

“It is a profoundly erroneous truism, repeated by all copy books and by eminent people when they are making speeches, that we should cultivate the habit of thinking of what we are doing. Civilisation advances by extending the number of important operations we can perform without thinking about them.”

Following the erroneous truism of cultivating thinking, the neurological system that receives the greatest emphasis in hard FSR is the attentive system. While technical specialists and experts use intuitive, pre-attentive means to arrive quickly at solutions, quantitative tools like DSS used as decision making tools provide low efficiency, attentive approaches (Table 2). The attentive system is also the least efficient and least suited to multiple concurrent decisions. Fortunately, farmers are over-represented among people who prefer cognitive, attentive problem solving (data from unpublished survey of farmers in the study region- data not shown), which will work in favour of the use of DSS in FSR.

Alternatively, effective implementation of a DSS as a decision learning tool may lead to insights (double loop learnings) leading to more expert-like decision-making (confident, independent, etc.) by the user of the system.

Table 2. Associations between decision-making (and decision-makers) and the three neurological pathways to action. (Source: Gladwin and Murtaugh 1980, modified by Robinson, unpublished)

<table>
<thead>
<tr>
<th>Neurological system</th>
<th>Attentive</th>
<th>Pre-attentive</th>
<th>Reflex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience</td>
<td>Beginner</td>
<td>Master</td>
<td></td>
</tr>
<tr>
<td>Temperament</td>
<td>Sensing</td>
<td>Intuitive</td>
<td></td>
</tr>
<tr>
<td>Awareness</td>
<td>High</td>
<td>Low</td>
<td>Nil</td>
</tr>
<tr>
<td>Multi-tasking</td>
<td>Very low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>
The nature of the task is an important factor in determining the merits of different pathways to change. For very simple problems, everyone has reflex and rule-of-thumb learnings and responses. Furthermore, reflexes are continually learned (Pavlov 1925). Hence, cognitive behaviour and subconscious conditioning are equally important aspects of adult behaviour (Lindsay and Powell 1997).

The crux of the matter is whether issues in FSR are beyond the scope of farmer’s cognitive and intuitive decision-making abilities. If they are, then solutions will be found by:

(i) Training, encouraging or teaching additional reflexes or intuition,
(ii) Providing information for existing cognitive skills,
(iii) Improving cognitive problem-solving, or
(iv) Various combinations of (i), (ii) and (iii)

Key questions: Are DSS advocated as decision-making systems or systems for increasing decision-making skills? Are the learning environments of DSS maximising the high-level learnings available?
Chapter 3. DSS and similar hard systems tools

This chapter is a review of some of the types of DSS and hard systems tools that have been developed and used in Australia. The literature is examined for support, and challenges to, the development and use of these tools. These opinions are examined in terms of contemporary knowledge of the origins and goals of hard and soft FSR.

What are DSS?

DSS and the related decision- or management-orientated systems are a diverse collection of computerised tools that are chiefly connected via their purpose – supporting decisions. Finlay (1994) defines a DSS broadly as "a computer-based system that aids the process of decision making." In a much more precise way, Turban (1995) defines it as "an interactive, flexible, and adaptable computer-based information system, especially developed for supporting the solution of a non-structured management problem for improved decision making. It utilizes data, provides an easy-to-use interface, and allows for the decision maker's own insights."

Lynch et al. (2000) and Lynch (2003) called these systems “Intelligent support systems”, which includes computerized models of two types: expert systems and numerical models. I am primarily concerned with DSS based on numerical models. They have a long history of development and use and outnumber other types of DSS used in Australian agriculture.

Numerical models on which DSS are based

Numerical models used in DSS fall into four distinct categories:

- Dynamic, deterministic biophysical models. These range from models of a single crop, such as the Cornish and Murray wheat model (Cornish and Murray 1989), through detailed single crop models such as the O’Leary wheat model (O’Leary et al. 1985), to multi-crop models such as PERFECT (Littleboy et al. 1989) and APSIM (McCown et al. 1996). Examples of Australian FSR involving simulation models are Hammer et al. (1987), Woodruff (1992), McCown (1991), McCown et al. (1998), and Robinson et al. (1999).

- Dynamic and stochastic bioeconomic models, such as Riskfarm and Riskherd (Milham et al. 1993, Milham et al. 1995). This type of model is complex in nature and has been more popular with economists than biophysical scientists in Australian FSR.
• Static, deterministic models or databases of biophysical and economic relationships. These include many simple through to complex spreadsheet models. An example is Greencalc (Lisson et al. 2001), which is used for calculating greenhouse gas emissions for the sugar industry. Many simple economic calculators, partial budgets and whole-farm models fall into this category, which are widely used in Australia (Malcolm 1990).

• Mathematical linear programming models of farm management and economics, including static models such as MIDAS (Morrison et al. 1986) and MUDAS, which represent dynamic and stochastic elements (Kingwell et al. 1993). Other examples of Australian FSR using LP have been reported in Kingwell and Pannell (1987), Robinson et al. (1995), and Robinson et al. (1996a).

Deterministic simulation modelling has been a strong segment of hard systems research since the 1960s (Bowden 1992). While Kingwell et al. (1993) and Huda (1994) highlighted the opportunities of responding to variability in climate or prices, Pannell et al. (1995) noted that explicitly probabilistic models are rarely more useful than averaging, deterministic models at evaluating farm management strategies. This debate continues.

Another debate is concerned with an appropriate level of complexity in models. To avoid some of the disadvantages of complex simulation models, some DSS either consist of databases of results from limited sets of pre-run simulations (e.g. WhopperCropper, Nelson et al. 2002) or combine inputs and options into sets (e.g. a limited number of soil types in HowWet?, Freebairn et al. 2001). These DSS are simpler than detailed models (e.g. APSIM, WheatMan), though spreadsheets and the like may be used to develop even simpler DSS. Most of these have a low profile, appearing at conferences and workshops rather than in the FSR literature. Although few of these are considered explicitly in this thesis, their impact may be substantial. There is certainly evidence that WhopperCropper and HowWet? are being well received (H. Cox, pers. comm., D. Freebairn, pers. comm.).

Support for using models in FSR and decision-making

Bowden (1992) has seen a long and established history of promoting models for use by agronomists and farmers. So much has been done that:

“After 25 years of exposure to modeller’s propaganda it should not be necessary to re-state why agronomists should be using models routinely.”

The advantages of modelling should be self-evident, according to Bowden (1992):
“Before the advent of mechanistic simulation modelling in the mid sixties, agronomists had only empirical or regression modelling as a tool to predict crop production across a range of biophysical environments and management systems. This was far too restrictive in terms of its ability to integrate across discipline and knowledge boundaries, and too demanding of the resources used to obtain the empirical data that are necessary for building comprehensive regression surfaces.”

Other reasons cited by Bowden (1992) for using agricultural models included:

- Quantifying outputs,
- Transferring research findings,
- Integrating multi-disciplinary research,
- Investigating the experimentally impossible,
- Education, and
- Knowledge gaps and research priorities.

Some examples in the northern grains belt of model experiments aiding applied research include assessing the:

- Negative consequences of management, such as soil structural decline on crop yields (e.g. Connolly and Freebairn 1996),
- Use of seasonal climate forecasts in cropping systems (e.g. Robinson and Butler 2001),
- Long-term profitability of N fertilisers (e.g. Robinson et al. 1999),
- Value of improved management due to additional or improved information (e.g. Turpin et al. 1998)
- Productivity of spring-grown mungbeans (Robertson et al. 2000)
- Productivity of skip-row sorghum (Hochman et al. 1998)

Therefore, in context of research, the advocates of models can show that they can replace expensive research programs, and quantify responses to environmental and managerial effects.

In extension, many DSS developers and users (e.g. Hochman et al. 2000) have proposed the use of models and DSS as means of discovering and transferring information for positive change. These tools variously inform, prompt and inspire changes in decision-making. Hochman et al. (2000) found two means by which learning was achieved: (i) as a result of a virtual experience, and (ii) as a discovery of principles. For a theoretical review of the relations between DSS-based intervention and other types of extension, see McCown (2001b). This review argues strongly that DSS can contribute to extension.
Game playing using DSS has long history in Australian agriculture (at least since the 1960s - Longworth 1969) but the business community and others have recently rediscovered it as a useful means of learning about and experiencing management systems (Lane 1995). The farm management game “Risky Business” has been used by Stewart et al. (2000) to increase understanding about decision-making, especially concerning risk management and innovations. This management game particularly gave context and substance to risk and the value of research for those who are rarely, if ever, faced with the large financial risks of farming, such as researchers, educators and administrators.

The following list of features of games is an extension of Longworth’s concepts of the value of management games for players (Longworth 1969, 1979). Players get to:

- Formulate clear goals and strategies,
- Learn to recognise opportunities and hazards,
- Isolate the sensitive parts of the system,
- Make many decisions, with varying degrees of information and certainty, and
- See and feel the consequences of their actions.

**Criticism concerning using models in decision-making**

Passioura (1973, 1996) has presented cases showing that the costs of using models often exceed their benefits. His studies also cast considerable doubt on their scientific integrity and validity. For example, testing the accuracy of outputs is usually restricted to a tiny proportion of the potential combinations of inputs. Model use is therefore accompanied by the use of numerous functions whose extrapolation and interpolation have varying degrees of validity.

There are also major practical limitations to the validity of model use. Hayman and Collett (1996) demonstrated that management and models have mis-matched scale or precision, and that research tools may not inform management. For a researcher, precision, prediction and accuracy are required, whereas for a farmer managing the same issue is often simple. In a case concerning opportunity cropping on the Liverpool Plains, Hayman and Collett (1996) found that despite the models demonstrating changes in outcomes, the growers’ planting rules provided insufficient flexibility for management to change. In their words:

“When models are used as tactical tools there may be mismatch between the finer resolution in risk assessment offered by the models and the limited decisions options that are available to manage the risk. In short, a case of measuring with a micrometer, marking with a piece of chalk, and cutting with an axe.”
Evidence of failure of DSS and models in FSR

Passioura (1973) warned that models were unscientific and would be no panacea, either in science or in management. This seemed to have little effect on the proponents of models and DSS. However, by 1993 one of Australia’s most informed and enthusiastic DSS developers, Dr. Maarten Stapper, was seriously questioning the effectiveness of these tools. Stapper (1993) was deeply involved in, and was obviously anguished over poor historical performance of the tools. Stapper’s title reflects the ambivalent sentiment of the paper: “The application and use of information technology on farms: Applications in search of users or users in search of applications?”

Almost a decade later, a number of reviews of DSS were revealing a lack of relevance and impact even more clearly. Lynch et al. (2000) found that:

“most systems are still developed because the information is there…”

and

“Few systems appear to be developed to satisfy a need articulated by farmers.”

Lynch’s (2003) evidence indicates that few systems make substantial impact in terms of units sold or distributed, or the usage they receive. Those data and conclusions match my experience closely. My experience includes that of several systems whose goals were poorly known or not revealed. In some cases development was poorly planned, implementation was uncoordinated, and/or evaluation was biased. The results have been what could reasonably be expected from such a process.

Ridge and Cox (2000) conducted market research for decision support for dryland cropping. One of their key findings was that although farmer decision-making is based on simple, stable models that have many faults, scientists’ models are “partial, opaque, unstable and non-adaptive”. Ridge and Cox (2000) also refer to the deficiencies of enabling change through the assertion of model results. Their conclusions are that models may be more useful if used to facilitate common mental models of the world, through processes such as participatory technology development (Jiggins 1993).

McCown (2001b) examined the impact of hard systems FSR on farm management in detail, and concluded that:

“It is problematic to refer to a phenomenon of failure of DSSs because it is difficult to point to unequivocal evidence…”
“But there is increased overt recognition of the reality of failure of DSSs to influence farm management. The commercial successes forecast over a decade ago by Jones (1989) are still not in sight, and public funding for R&D has dried up. No longer can low usage of such software by farmers be excused by low computer ownership.”

By 2002 realism concerning the past was setting in, but confidence about the future of DSS was being maintained (McCown 2002):

“Within the decade of the 1990s, decision support system (DSS) research has fallen from its zenith as a research priority to be talked about, increasingly, in the past tense. Yet, the fundamental rationale for the DSS venture still seems remarkably appealing: information technology making science more accessible and useful for guiding management of production systems. It still seems tenable that a scientifically sound DSS should be useful to a farmer, and both models and computer software have improved immensely in their capabilities and ease of use. There has been no diminution of farmers’ need[s] for good planning and decision-making”

In 2002, Agricultural Systems published a special issue - “Probing the Enigma of the Decision Support Systems for Farmers: Learning from Experience and from Theory”. The “enigma” (McCown et al. 2002) was that:

“As laudable as the idea of computerised scientific tools to aid farmers’ decision making may be to some researchers, [the] persistent lack of demand by farmers for DSS cannot be ignored”.

The state of non-adoption of DSSs in agriculture was said to be “critical” (McCown et al. 2002).

In summary, agricultural DSS have disappointed researcher-developers with their low level of acceptance by farmers. Some researchers see the concept of DSSs as laudable, while others see DSS as failing to meet the needs of farmers.

Key question; Which types of DSS are practical failures supported by laudable concepts?

Factors that may be limiting the adoption of modelling in FSR

Bowden (1992) considered the lack of uptake of DSS by consultants and the professional agronomists in State departments of agriculture. He concluded that models were useful tools that had a bad name because:
• Agronomists are ignorant of their benefits,
• New ideas are easily ignored or rejected,
• Agronomists have an anti-maths bias,
• Models were initially over-sold,
• Models are annoyingly simple when compared with reality,
• Models are easily criticised if they are transparent,
• There are many examples of models failing,
• More than one model appears redundant because they are expected to be universally applicable,
• Experts and others have been highly critical of models.

This list was based on considerable experience, and contains worthwhile insights, especially concerning the choice of decision-making methods by farmers and consultants.

In a special issue of *Agricultural Systems*, the developers of some better-known DSSs contributed reviews of factors that resulted in the perceived lack of adoption of their systems. These included SIRATA (Hearn and Bange 2002), WHEATMAN (Hayman and Easdown 2002) and FARMSCAPE (Hochman et al. 2000, Carberry et al. 2002). The developers of the SIRATA model were concerned with science delivery, and while it was successful in that mode (Hearn and Bange 2002), it failed to recognise non-scientific goals and values (Cox 1996). Limitations to the success of SIRATA and associated DSSs were (Hearn and Bange 2002):

• The high cost of software/programming,
• The very high cost of delivering software tools to farmers,
• Biologists disagreeing with engineers over priorities,
• There was a “moving target” of issues and decisions,
• Confusion about the desired technology – e.g. database or expert system, and
• Confusion regarding representing one knowledge domain or several.

For WHEATMAN, Hayman and Easdown (2002) described a range of “limiting factors”:

• Few farmers use computers for farm management,
• Early versions may be subject to great criticism,
• Positive early responses may create unrealistic expectations,
• Ownership is limited to the development team,
• WHEATMAN now perceived as outdated compared to contemporary approaches,
• Gains are at paddock level, not whole industry,
• Several years of drought affected (reduced/eliminated) management options,
• Competition from other forms of simpler DSSs, and
“Many decisions addressed by WHEATMAN have a relatively large solution space”,

Lynch et al. (2000) and Lynch (2003) examine DSS development, and find that low uptake of DSS is often associated with low user participation in system design. These results are consistent with the wider findings of Jiggins (1993) who considered regular participation an important element of participatory technology development (PTD). PTD is a more devolved, soft systems approach than transfer of technology and traditional FSR (Jiggins 1993).

The approach, results and contemporary position of FARMSCAPE are informative. FARMSCAPE (Farmers, Advisers, Researchers, Monitoring, Simulation, Communication And Performance Evaluation) represents a group of projects that have invested a large amount of resources in participatory FSR in the grains industry (Hochman et al. 2000, Carberry et al. 2002).

FARMSCAPE began in 1991, when some of the staff of CSIRO in APSRU began working on independent projects that led to the core FARMSCAPE projects. The concept of these projects was to have farmers and researchers using a simulation model to solve problems of crop and soil management. At this stage, the model was applied as problem-solver, and the DSS developers sought increasing realism as a means of achieving acceptance and impact. A lack of acceptance and impact surprised the developers (Cox et al. 1996), who escalated the technical development of the model. Later, on-farm experiments were included to further enhance and reinforce the predictive capacity of the model. The projects were still failing to deliver in terms of farm management (McCown 2001b) until the emphasis shifted from teaching and problem-solving to co-learning (Coutts et al. 1998, McCown 2001b) and participatory action research (Hochman et al. 2001).

According to McCown et al. (1998) and McCown (2001b) the path to success would be a “marriage” between hard and soft systems approaches. Whether the FARMSCAPE projects would achieve that was equivocal (McCown et al. 1998):

“Time will tell if FARMSCAPE represents a sustainable paradigm shift in the way researchers of farming systems and farm advisory services interface with real farming, marrying hard and soft systems thinking and methods in a form of systems agriculture”

Little has changed since this comment was made in 1998 with respect to knowledge of the sustainability of the FARMSCAPE paradigms. That, in itself, is an interesting result, showing that this large team of researchers has achieved little in the short-term and has had to grapple long-term with successfully integrating soft and hard systems approaches, making them useful to farmers and applying them in an efficient manner.
A common feature of DSS is that they find consistent support from farmers in evaluations. Given their patchy acceptance in the farming community, there is clearly a difference between farmer’s responses concerning DSS in evaluations and their responses to DSS in practice. It may be that farmers regard DSS as better in theory than practice. However, the answer may be far simpler than that. DSS developers have asked users to rate the usefulness of the DSS, based on the truism that evaluation is good. However, this approach may be almost useless. Why? Firstly, because it demands an answer, when the user may not know an answer and may not wish to share their opinion. Secondly, even when the question is asked by an independent, third party, the user is well aware that the answer will be returned to the developers, who have resourced the development of the DSS with their funds, minds and hearts. The result is a trade-off between honesty and reality that ensures healthy relationships, but prevents measurement of perceptions.

Some observations

Many times in the early 1980s my peers told me that I was employed “ahead of my time”. They said there would be a massive rise in the use of hard systems technologies “when a computer-comfortable generation is farming”. Some people went further, to say that farmers were anti-technology or fearful of computers.

The reverse is now arguably the case – farmers are seeking out useful software. The notion that the adoption of the DSS was limited by unavailability, fear or dislike of computers should logically be dismissed by now.

Furthermore, the story concerning farmers not wanting to use computers was always untrue, even if it was popular. Taking early transportable computers to farms in the 1980s showed me that the farmers were usually interested in, and had positive views of the technology. Few of them had seen a computer until the late 1980s, and they were keen to see what it was and how it worked. The populist “fact” that farmers and agronomists didn’t like computers may have been a convenient means by which researchers absolved themselves of blame for a lack of uptake of DSS. Reflection and reporting on a role for DSS began slowly, and was initially cautious about questioning their potential (e.g. Stapper 1993).

Key questions; Is there user-resistance to DSS technology? If so, is it associated with subjective or objective reasoning? Is it a common thing to like the DSS approach and to seek out DSS?
Chapter 4. Some criteria for assessing DSS

FSR has been described and its goals examined in Chapter 1 and Chapter 2. The uptake and impact of DSS and related tools was described in Chapter 3 and some plausible reasons for low uptake were discussed.

This chapter looks at guidelines, or criteria, suggested and implied by Australian authors who have also noted deficiencies in the development and application of DSS. I have used the Australian literature because it is: (i) most relevant to contemporary FSR issues, (ii) comprehensive enough to raise many of the themes of the international literature, and (iii) a numerical compromise based on diminishing returns for new information with more authors and publications. Except for the most recent examples, the context for these suggestions was not contemporary FSR, but they are nevertheless relevant to the application of DSS in FSR. They are listed in chronological order, which emphasises changes in emphasis and direction through time.

It was the 1960s when computer models and computerised DSS first impacted on agriculture. It is surprising that few texts on building effective systems, for either secondary industries or agriculture, appeared for at least a decade (e.g. Sprague and Carlson 1982). In Australian agriculture, hard systems work involved only a few isolated individuals doing theoretical work until the FME/FMR developments, from which John Dillon, Jock Anderson and others learned the science and art of practical applications of systems theory and methods.

Dillon’s criteria

Concerning the difficulties of implementing quantitative analysis, Dillon (1965) issued an interesting, and perhaps fateful forecast:

“…the main challenge to mathematics these days is in the social sciences”

Later, however, Dillon offered both technical and social reasons for a lack of success with FME. Dillon (1979) is quoted by Brennan and McCown (2001):

“First, data are not available to be able to specify the relevant production processes (both physical and non-physical) to any significantly relevant degree - particularly if we recognize the uniqueness of individual farms.”
“Second, the farm system is dynamic, not static, both in the broad as a purposive organization in a changing environment and also through the pervasive role of biological time-dependent growth processes in its technical subsystem.”

“Third, even if data were available to specify the required production processes adequately, the task of analysis even under perfect information would be both too complex and too costly for either farmers or computer-aided professionals. ‘Non-optimizing’ mode of behaviour has to be used.”

“Fourth, the problem of uncertainty has to be handled. Again this is pervasive in agriculture due to the stochastic vagaries of climate and markets especially, but also because of uncertainty about technology, policy and people. While techniques have been suggested to handle such uncertainty, their cost on a thing approaching an individual farm basis makes them impractical.”

“Fifth, even if all farmers faced the same production functions and the same judgements about the probabilities, they would still have different preferences and so need different prescriptions for utility maximisation across their individual multiple goals”

Simplifying Dillon’s five rules to a dot point each, they are:
- Data must be available for specifying processes [HS]
- The biophysical representations must be dynamic not static [HS]
- Complexity and cost should be avoided [HS+SS]
- Uncertainty must be represented [HS]
- Farmer preferences and goals must be represented [SS]

where HS is a hard systems issue, and SS is a soft systems issue.

Malcolm’s criteria

Malcolm (1990) has described the shortcomings of FME:

“In the days when production economics was king, little emphasis was placed on the human, technical, financial and management aspects of farm production, or on the operation of individual businesses.”

Malcolm (1990) has highlighted the important role of budgeting in FME and recorded not only the survival, but also an increase in the use of budgets as management tools, while FME theory and practice fell from use:
"Throughout this time [the decline of FME] management professionals, and the managers of farms, battled on with the simple budgeting techniques whose chief virtue was that they were general enough to allow a comprehensive picture of all the important aspects of the problem and the full ramifications of the solutions(s) to be weighed in the decision. Indeed the validity of the budgeting techniques have not only stood the test of time but their usefulness and analytical power have been enhanced enormously in modern times by the computer spreadsheet. In particular, the spreadsheet enables the risks, time and dynamic aspects of a problem to be analysed more practically and fully than ever before”

According to Malcolm (1990) and Makeham and Malcolm (1993) the great success of the spreadsheet/budget tools relative to other FSR tools boils down to three main features:

- A broader coverage of the elements of a problem relevant to a decision maker [HS+SS]
- It enables more active participation by the decision maker [SS], and
- It allows customisation of the problem representation [HS+SS].

Malcolm (2000) re-visited the arena of FME, and came to an even simpler conclusion in the last sentence of his paper – “Sophisticated thinking and simple figuring is the rule.” This paper, presented to the annual conference of the Australian Agricultural and resource Economics Society, contains insights into many aspects of FME and FSR and asks significant questions about theory and practice, and the differences between them.

No objective measures were described by Malcolm (1990) for these criteria. In the case studies that follow, they are subjectively assessed.

**Hamilton’s criteria**

Hamilton (1995, p. 157) provides some insights into successful FSR tools, and the preferred methods for applying those systems, in the northern grain belt. While Hamilton focused on physical tools, he also assessed one DSS/software tool. This was the “Fallow Management Game”, which was both realistic in terms of management, but unrepresentative of any particular farm. The system involved “stepping through” the decisions made during simulated fallows. Effective management of the fallow is critical to successful cropping in the northern grainbelt of Australia (Waring et al. 1958, Freebairn and Wockner 1986). For the farmer participants, using this DSS was fun, empowering and effective in learning about farm management (Hamilton 1995, p. 148).
In very simple terms, Hamilton’s six guidelines for effective tools are that they:

- Are used by participants, not researchers [SS]
- Have capacity for comparative analysis [HS+SS]
- Have high relative accuracy, not necessarily absolute accuracy [SS]
- Emphasise tangible variables [SS]
- Provide intangibles with graphic representation [SS]
- Must be open to validation and interrogation to establish trust [SS]

**Cox’s criteria**

The work of Cox (1996) took a high-level perspective and emphasised the roles of learning and culture in the application of complex DSS.

In a related paper, Cox et al. (1996) proposed four sets of question, leading to knowledge that allows successful (re)engineering of DSS:

- Knowledge of purpose (“What are we in the business for?”) [SS]
- Knowledge of culture (“How do we generate a better organisational environment?”) [SS]
- Knowledge of process and performance (“What is the most effective means of getting the results we want?”) [HS]
- Knowledge of people (“Who do we want or have to work with”) [SS]

These questions reflect Cox’s interest in estimating the market for DSS, and supplying DSS, that best meet market needs. No objective measures were described by Cox (1996) or Cox et al. (1996) for these criteria. In the case studies that follow, they are subjectively assessed.

**McCown’s criteria**

McCown et al. (1994) suggests limitations to confidence in the use of models stem from a lack of biophysical data and understanding, and the complex, shifting nature of people and their problems. Hence, McCown (2001b) considered it important for models of farms, or more usually the subcomponents of farms, to be realistic and “situated”, in that they are a mathematical representation of a real situation. McCown (2002) argues that an ability to explore virtual management options is the key to learning, and a detailed, realistic model can provide that management simulator. If the learnings are transferable to realistic situations, they should enable better management in the real world (McCown 2002).

In summary, McCown sees three essential ingredients in effective development and application of DSS:
• Degree of realism must be high (i.e. faithful representation of the scientists’ view of the system) [HS]
• Easily parameterised to a specific site and situation [HS]
• Ability to research management options with farmers must be high [HS+SS]

Lynch et al.’s criteria

Lynch et al. (2000) reported the results of a survey concerning the design and uptake of DSS. They found:

“Few ‘successful’ systems could be identified and thus there is limited data on which to make judgements concerning the relative success of different development methods”

Despite this difficulty, the importance of an ability to customise the DSS was emphasised (Lynch et al. 2000, Lynch 2003), as well as:

• Depth to the user participation [SS]
• Particular styles of participation [SS] and
• A high degree of user influence on the system design [SS+HS]

Lynch (2003) described the coding used for analyses concerning these criteria. Lynch’s 3-way coding was replaced with a 5-step hierarchical coding that represents “not meeting” the criterion, through to “fully meeting” the criterion. For example, “Fully meeting” a criterion is equivalent to high achievement in the “best” of Lynch’s three categories. The 3-steps failed to represent significant differences in practice for many of the criteria. Five steps was a good compromise between losing information through too few steps and creating a façade of precision assessment.

Author/criteria biases and trends

Clearly, many different criteria and processes have been proposed as solutions to the problem of lack of DSS adoption and impact. It is worth summarising the obvious specialisations of the above authors and biases in the criteria. These are:

• Better technical representation of the problem (Dillon 1979)
• Less zealous theoretical and technical analysis (Malcolm 1990)
• Bridging the “learning gap” by having researchers understand farmers (Hamilton 1995)
• Reducing reductionism and over-confidence (Cox et al. 1996)
• Researching the “gap” between management and science (McCown 2001b, 2002)
• Greater participation by farmers in the development and use of DSS (Lynch et al. 2000)

There is a clear trend through time from biophysical and technological factors towards socio-cultural and learning factors. Historically, most of the criteria can be simplified to:

• Lack of computer hardware (1960s to 1980s),
• Lack of technical information and software (1970s on),
• Lack of user-friendly software (1980s on), and
• Lack of participation (and knowledge of participation) (1990s on).

While this list does not capture some specific issues (e.g. cultural understanding by Cox), it is nevertheless an informative model of the chronology, and will be discussed later.

Key questions; Are the more recent propositions (i.e. insufficient participation may be responsible for ineffective DSS application) more valid than the earlier propositions? If participation is a limitation, is the weakness in understanding or practice? What are the weaknesses of current practice in participation? Who in DSS implementation understands and practices quality participation?
Chapter 5. Decision-making

Having explored FSR and the DSS that are intended to support decision-making, this chapter reports:

- Learning about the foundations of decision-making,
- Choosing a model of decision-making for analysing the case studies,
- Relating DSS use to decision-making, and
- Considering impediments to effective decision-making.

The where and why of decision-making

The essence of decision-making is to determine, if possible “What should I do?” This deceptively simple activity is not unique to farmers, or even to humans. It is an age-old problem, and so it not surprising that it is the subject of a large volume of literature.

Anatomically, human decision-making is centred in the frontal brain, and is separate from many other functions that reside there, such as memory (Bechara et al. 1998). It is strongly associated with emotions and feelings (Bechara et al. 2000). That decision-making is emotive as well as experience-based has not rated mention in the agricultural decision-support literature. Of course, good and bad experiences give rise to feelings, so there is plenty of opportunity for knowledge and experience to cross over to affect decision-making, but it is via emotion, not memory that this occurs.

An important factor determining farmer decision-making and behaviour is their concept of self – how they think of themselves and how they think that others think of them (Seabrook and Higgins 1988). Therefore, strong psychological and emotional factors are at play in decision-making, and these may have been underestimated in studies of DSS.

Both Hamilton (1995) and Stewart et al. (2000) have emphasised the importance and impact of turning systems information or knowledge into physical and emotional experiences in order for decision-making and management to be highly impacted.

Decision-making theories

Understanding of decision-making is often described in terms of two well-established theories. Normative theory presents guidelines and techniques for accomplishing predetermined goals. It is a theory of “I want to make the right decision and can be told how to do this via a series of prescriptions”. Positive theory explores “This is how things are, and
this is how it works, but let’s not make judgements about what’s good and what isn’t good”. Normative theory assumes that decisions rely on facts (or at least things that are probably true) and the deductions of a rational actor in the system (Allison and Zelikow 1999). This is why hard FS researchers have been attracted to this model of decision-making - it emphasises the ability of people to change the system to meet their technical goals, such as profit maximisation, via the application of tools to derive new understanding.

However, normative theory has serious limitations, especially when poor judgement and irrational decision-making occurs (which is very often, Plous 1993). Complex FS decision-making that might involve multiple or special objectives or groups of people may not be well suited to normative theories.

The use of hard FSR tools, implemented in a hard systems situation including normative decision theory, has not been very successful. The situation has been summarised by McCown (2001b)

“If after more than 5 decades of theoretically normative policy research and interventions, the outcomes of [scientific] principles and recommendations for optimal action have been disappointing. The experience of the Farm Management Research movement epitomises this failure”

However, it would be a mistake to assume that normative approaches have caused these failures. There is considerable scope for both the system and the “pilot” of the system to cause it to crash, and only subtle and substantial investigation will reveal what goes wrong when hard FSR is used for positivist, normative interventions.

Key question; *Is the hard-systems, normative approach a causal or coincidental factor in this lack of success?*

**Choosing a model of decision-making**

Models of decision-making used to be split into two types: “rational” and “irrational”, but there is considerable overlap, and the labels are misleading in that the processes are only rational or irrational in a superficial way. The deeper differences relate to the *degree* to which logic is important in the process. Simon (1955, 1956) introduced the concept of bounded rationality, which proposed that limited cognitive effort is applied to problems (though the name misleadingly suggests that within a limited scope, a model of a problem may be considered rational). This reduced cognitive effort is associated with what is called *satisficing*, or reaching a level for a criterion where no further effort is required.
Two examples of decision-making models of the “irrational” type are the “muddling through” model of Janis and Mann (1977, p. 33) and the “garbage can” model (Cohen et al. 1972, Kefford 1994). Examination of these models shows that they have limited relevance to the intent of the use of hard FSR tools. If farmer-users of hard FSR tools are free to make choices, based on their wishes and logical deductions about the system that they manage, the decision-making framework is expected to be more consistent with the “rational” than “irrational” models of decision-making.

Janis and Mann (1977, pp. 45-80) proposed a well-regarded “rational” model of decision-making. Many of the more recent rational models, such as those of Amundson et al. (1996) and McEwan (1997), are largely refinements or re-organisations of the Janis and Mann (1977) model. Therefore, the Janis and Mann model is the main framework used for further exploration of decision-making in this thesis.

**The Janis and Mann five step model**

It is obvious from their diversity that the criteria for applying or evaluating models and DSS in FSR listed in Chapter 4 do not apply to all aspects of farmer decision-making. Different hard systems tools and the criteria used to evaluate them apply to particular contexts, even though the authors may have not defined the context or may have presented the tools or criteria as universally applicable.

As explained above, the model of Janis and Mann (1977) is oriented to cognitive, rational decision-making and is based on relatively few and simple stages. The five stages are:

1. Appraising the challenge
2. Surveying alternatives
3. Weighing of alternatives
4. Deliberating about commitment
5. Ending (adherence, implementation, etc)

The stages are not progressive – for example, when no suitable alternative exists, a decision-maker may go “back” from weighing alternatives to surveying alternatives. Figure 5 shows the details of the five stages. For this thesis, the key information is; what is the purpose of each stage? This helps identify which decision-makers are at the stage and what their purposes are. Response to a DSS is dependent on matching the DSS to appropriate stages. For example, it is no use rushing to weigh alternatives if the decision-makers are just appraising a challenge (probably a common mistake). In addition, among a group of decision-makers there is almost certainly heterogeneity in their positions, and the criteria used to assess alternatives. The model assists analysis of the later case studies by making these differences better defined, and more understandable and explicit.
Challenging negative feedback or opportunity

STAGE 1
Appraising the challenge

Are the risks serious if I don’t change?

NO

MAYBE or YES

STAGE 2
Surveying alternatives

Search for another alternative

Is this alternative acceptable?

Have I sufficiently surveyed the alternatives?

YES

NO

STAGE 3
Weighing of alternatives

Further search for and evaluation of consequences

Which alternative is best?

Could the best alternative meet the essential requirements?

YES

NO

STAGE 4
Deliberating about commitment

Shall I adopt the best alternative and allow others to know?

YES

NO

Discard unacceptable alternative

YES

NO

Janis and Mann (1977) give numerous examples of using the model to disaggregate a problem and the positions of people making decisions about problems. In some circumstances, there isn’t an acceptable exit from the process, and waiting is the only option.
(e.g. for a change in situation such as rain or selling the farm). Hence, farmers often fret about their management in situations such as droughts. A quick analysis in the framework shows that farmers are mostly concerned with outcomes due to the drought, not discontent with their current management. Drought is a state where no management options produce satisfactory outcomes, and there is little value in the repeated scrutinising of management options.

In detailed study of factors affecting adoption of technology in the American corn belt, Abd-Ella et al. (1981) found that aspirations were a far more important factor for predicting the adoption of technologies than any other biological, physical, educational or financial factor. This shows the importance and validity of the first stage of the model (Janis and Mann 1977), where continuance is dependent on aspirations to new conditions, or personal feelings of conflict or dissatisfaction with the contemporary conditions.

**Cognition, illusions and heuristics**

An added degree of richness and complexity is added to human decision-making by our skill in weighing alternatives. The complexity of problems often exceeds the ability of people to produce an accurate assessment of the costs and benefits of various potential solutions. This is not simply a matter of lack of information concerning the problem; the human mind is very well equipped at making decisions quickly and intuitively, but not accurately. Inaccuracy often comes from simple biases. For example, studies show a lower uptake (by doctors, who are obviously well-educated) of a medical procedure said to have a 7% mortality rate than a 93% survival rate (Nicholls 1999).

Many other examples of cognitive biases in apparently simple problems have been reported in the psychological literature, in both laboratory and field studies (Plous 1993).

An account of the many biases and illusions that undermine decision-making in businesses and for individuals is contained in Russo and Schoemaker (1989). Nicholls (1999) explains the difficulties in presenting weather forecasts, and especially long-range forecasts, in the community, when altered perceptions and misconceptions are so important.

An important and consistent feature of decision-making is that people over-estimate their ability to make decisions (Plous 1993, p. 217-225). Additionally, there is rarely any relationship between the accuracy of decision-making and the confidence of the decision-maker. A large number of studies show no correlation between accuracy and confidence, for both expert and non-expert judges (Plous 1993, p. 225-229).
To have decision-makers who are cognitively biased and under illusions, as well as overconfident in their decision-making ability would appear to be very fertile ground into which to introduce hard FSR tools. Indeed, McCown et al. (2002) refer to the potential attraction of DSSs for poor decision-makers. They also found the lack of success of DSSs in such an environment “enigmatic”. However, decision-makers’ overconfidence in themselves would likely result in underestimation of the value of DSSs unless persuasive evidence or comparisons were available. Such a persuasive comparison or demonstration would presumably be clear and revealing – or “transparent” to use a term used by Hamilton (1995) and others. Frequent use of this term in discussions concerning models and DSS may indicate a general concern about the veracity of information and comparisons in this field of study.

Key question; What are the implications for DSS use if both DSS developers in FSR and farmers are overconfident concerning their decision-making systems?

Socio-cultural impediments to change

Lacefield et al. (1988) have discussed the importance of social factors in technological change in agriculture:

“Fear of change, whether fear of lost income or loss of respect by one’s peers, is a very real phenomenon. Adoption of new technologies is very often found to occur in clusters where support groups occur. No-till farming, agroforestry, pasture-based dairy production, and management-intensive grazing are all examples of alternative production systems that have benefited from local support groups”

They go on:

“Overcoming social impediments to adoption of new technology is often the most difficult challenge. Whereas economic and biophysical obstacles can be easily analysed and logically addressed, many social constraints may not have rational bases or may be very nearly intangible.”

If these general principles apply in cases of applying DSS, cultural factors will play an important role in the perceptions of farmers adopting new technologies. The technology of a computer-based system for supporting farm management would appear to have considerable potential conflict with the priorities or cultural values of many farmers, and so might be a challenge to apply. Lynch et al. (2000) commented that there is a large difference between leaning on a fence talking to a neighbour and implementing a formal, computerised system.
Appendix 2 contains a discussion of psychological factors other than cognition that affect decision-making.

**DSS and support for decision-makers**

There have been a small number of studies of the relationships between DSS and similar tools and the needs of decision-makers in Australian FSR. These include Lynch et al. (2000), Lynch (2003), Hayman and Collett (1996), Hayman and Alston (1999), Hayman (2001), Hayman and Easdown (2002), Hearn and Bange (2002) and Carberry et al. (2002). Because DSS development and application in Australia involves only a small social network, it is difficult to be impartial, because there are strong emotional attachments to systems. For example, the common syndrome of finding self-worth in employment and creation of a system may lead to strong defence of that DSS (see Hayman and Easdown 2002 for discussion of this phenomenon, which David Freebairn also calls the “Precious baby syndrome”).

Because reviews have mainly been written by the developers of the DSS systems, it is therefore surprising that except for Hearn and Bange (2002) and Carberry et al. (2002), DSS have been found to be ill matched to the needs of decision-makers. Detailed assessments of the relationships between the needs of users and the purpose of developers are contained in Lynch et al. (2000) and Lynch (2003). According to Lynch et al. (2000), the main reason for DSS being developed in Australia is that researchers want something (perhaps anything) to do with their data.

Both Hearn and Bange (2002) and Carberry et al. (2002) review DSS projects that are currently operational. In the case of Hearn and Bange (2002), the various DSS have passed through periods of high and low impact. Currently their activities and impacts are at levels well below the historical highs, but they have managed to maintain continued support from researchers and funding organizations. For Carberry et al. (2002), the DSS developments have run parallel to the development of models for research, resulting in higher efficiencies and cross-subsidization. It is therefore difficult to gauge the relevance and impact of the DSS activities alone. However, in an independent assessment of their DSS activities, Lynch (2003) found a low impact, due to a lack of demand.
Chapter 6. The study region

The region of interest is shown in Figure 6. The area of land cropped is considerable, and increasing; from 494,000 ha in 1996 to 552,000 ha in 2000 (WFSP 2000). Cropping is primarily concerned with wheat production, though grain legumes and ley pastures are of increasing importance. Grain legumes increased from approximately five-fold between 1996 and 2000 (WFSP 2000).

Historically, prices have greatly affected land use. Cropping increased around 1975, when beef prices fell, and again in the 1980s, when wool prices also fell while wheat prices remained strong. Hence cropping histories in many areas are less than 40 years, and often less than 20 years. Each farm is typically between 2,000 and 6,000 ha in area, has a value of more than AUD$1M, and carries a small debt (12% of value, K. Smith, unpublished report). Income is derived mainly from livestock (about 40% of total) and winter crops (about 50% of total). Median shire yields of wheat crops range from 1.3 to 1.5 t/ha/year in the east, to 0.8 to 1.0 t/ha in the west, with standard deviations of 0.5 to 0.65 t/ha/year. Unlike most of the Australian wheat belt, yields are not increasing (Cornish et al. 1998).
A substantial quantity of technical information has been published on the deleterious effects of continuous wheat cropping on yields, and also on improved alternate methods of production (Littler 1984, Dalal and Mayer 1986a-e, Dalal and Mayer 1987a,b, Dalal and Mayer 1990, Dalal et al. 1996, Probert et al. 1996, Strong et al. 1995, Weston et al. 1996, Marcellos et al. 1996). However, low levels of adoption of the alternatives to continuous cropping in the 1980s suggested that either the RD and E were not oriented to farm management or it was ineffective (WFSP 2000). Evaluation of the impact of the first five years of the WFSP (1995 to 2000) indicated a major increase in the application of alternative cropping technologies, including reduced tillage, pulse crops and ley pastures (WFSP 2000).

**Population and social issues**

A census of socio-economic indicators in non-metropolitan Australia (BRS 1998) reveals the following conditions in statistical regions of the western farming systems project (WFSP) region:

- Population is declining; 5 to 20 % decreases between 1991 and 1996,
- Declines in the rural workforce range from 0 to 20 % (1991 to 1996),
- Recent average taxable income ranges from equal to, to well below, the non-metropolitan national average,
- Indigenous people are present in approximately the same proportion as in the general non-metropolitan national population (4 %), and
- Secondary school attendance ranges from equal to the average for non-metropolitan Australia (76%), to more than 20% below the average in some local government areas.

Clearly, there are important social issues in the region. These reflect both an historical lack of services and opportunities in outback Australia, and a locally depressed rural economy following poor seasons and low commodity prices in the early 1990s.

**Geology, vegetation and soils**

The subsurface and outcrop rocks of the area are mostly of the Mesozoic era (230 to 65 million years before present (BP)) and of a variety of sedimentary types, including sandstone, siltstone and mudstone. The sedimentary basin in which these rocks formed is known as the Surat Basin (see Figure 7 for the location of Surat), which overlays older rocks of Permian to Triassic age rocks (Slater, 1991).

Since the early Cainozoic (65 million years BP to present), the land surface has remained tilted to the south or southwest, and the overall pattern of drainage (northeast to south-west)
was developed (Slater 1991). Of the Cainozoic materials, the older soils (mostly Tertiary sands, silts and gravels, Slater 1991) are generally coarser textured and often red in colour. It is suspected (Slater 1991) that deep weathering of rock and soils occurred during the Tertiary period. Quaternary materials (2 million years BP to present) are generally finer textured clays on the floodplains of the major rivers. These clay soils are the most productive for cropping and are extensively utilised.

The native vegetation consists mainly of perennial trees, shrubs and grasses. A few areas have annual or ephemeral groundcover species, but these are of minor significance. Forests and woodlands are common, but grasslands are a feature of some of the cracking clay soils. Many landforms and soils are associated with particular suites of species. The main ones described by Cooper (1991) of interest in cropping are:

- Areas of clay soils adjacent to the jumpups, probably consisting of alluvial deposits from them. These are associated with forests dominated by brigalow (*Acacia harpophylla*). Belah (*Casuarina cristata*) and poplar box (*Eucalyptus populnea*) are often present to some degree. Ground cover is often sparse. These soils are suitable for cropping, though their limited extent means that they are of low importance.

- Sheets of heavy clay soils associated with brigalow (*Acacia harpophylla*), its companions, as described above. Most of this vegetation has been cleared for farming. These soils are potentially highly productive, are extensive in the region and are therefore important for cropping.

- Shallow heavy clay soils, mainly in the north of the region, with grassland and open forest of poplar box (*Eucalyptus populnea*) and associated species. The soils are mainly developed from fine-grained sedimentary rock, and may be colluvial. These “open downs” soils range from low to high potential productivity, and are important for cropping in the northern part of the region.

- Floodplains, mainly in the southern parts, associated with coolibah (*Eucalyptus microtheca*), myall (*Acacia pendula*) and belah (*Casuarina cristata*). Mitchell grasses, flinders grasses and a range of other species form widespread grasslands. A significant proportion of this vegetation has been cleared for farming. It is potentially highly productive, and is extensive, so has a high level of importance for cropping.

- Rolling hills of red loams and red sandy loams, associated with poplar box (*Eucalyptus populnea*), some belah (*Casuarina cristata*) or narrow-leaved ironbark (*Eucalyptus crebra*) and understorey shrubs such as wilga (*Geijera parviflora*) and false sandalwood (*Eremophila mitchelli*). Some of this vegetation has been cleared for farming, though it is generally less productive than the brigalow and coolibah land systems with their heavy clay soils.
Figure 7. Simplified land systems of the Balonne and Maranoa. (Source: Natural Resources and Mines, compiled by Robinson).
Figure 7 shows the land systems of the region. The dominant features of this figure include the alluvial soils deposited by the Condamine, Maranoa, Balonne and other rivers. Many soil types are present, but they may be thought of as a few groups of many sub-types. The most favourable soils for farming are the Quaternary deep cracking clays. These soils contain clays consisting of three layers of aluminium and silicon oxides (smectite and related clays), which can absorb large amounts of moisture into their structure. Much of this moisture is available to plant roots, and the soils are said to have a high plant-available water capacity (PAWC). These high PAWC soils are known as “cracking” clays because of this swell-shrink characteristic. In Figure 7, these soils occupy a broad alluvial fan adjacent to the Balonne River. Intermediate soils include the late Cainozoic clays, and weathered labile and basaltic materials.

Soils that are farmed vary widely in their fertility and capacity to hold moisture. The alluvial clay soils associated with coolibah (*Eucalyptus microtheca*) have PAWC exceeding 200 mm, while some red earth soils associated with mulga (*Acacia aneura*) and poplar box (*Eucalyptus populnea*) have PAWC as low as 50 mm (N. Christodoulou, pers. comm.). Given the dependence of cropping on the storage of fallow rainfall, soils with low PAWC are likely to have their yields severely limited by the supply of water in a large proportion of years. With respect to wheat production, many soils are deficient in nitrogen and phosphorus, and some are deficient in zinc via their alkalinity.

**Climate and weather**

Average annual rainfall varies from about 520 mm in the west of the region to about 650 mm in the east. St George has averaged about 540 mm since 1960, and Roma about 600 mm. Average annual evaporation may be as high as 2000 mm in the west (1800 mm at St George, 1750 at Roma), declining to about 1500 mm in the east. Average monthly evaporation exceeds rainfall by considerable amounts (Figure 8) in all months, with the greatest differences occurring in the summer period.
Drought is a major feature of the climate. Droughts occur approximately 1 year in 5 in the region (Hamilton 1995, p. 20). The region suffers severe water deficits for much of most years, and the mean potential evaporation rate is about double the mean rainfall in every month (Figure 8). Summer fallows are used to store rainfall for use during the growing season by the crop as the rooting depth increases (Waring et al. 1958). Temperatures can also limit the growing of some crops due to seedling mortality and heat-induced sterility. Maximum air temperatures regularly exceed 40°C, and soil temperatures may reach 60 to 70°C.

Summer rainfall is produced in local storms that are the result of convection and instability. The intensity of storm rainfall is sometimes very high; in the order of 100 mm/hour, which can result in severe soil erosion unless measures are in place to ameliorate the problem. In those parts of the region with significant slopes, such as much of the eastern and northern parts, it is common practice to build contour banks to slow the downhill progress of water and soil (Figure 9). In areas with lower slopes (less than 1%), such as flood plains, strip cropping can be employed to reduce runoff velocity. In a wide range of situations it is also common to use minimum tillage practices that retain crop stubble, and thereby reduce runoff and soil loss (Freebairn and Wockner 1986).

Although the low, variable rainfall, and high, relatively consistent potential evaporation result in a very high proportion of seasons in which crop yields are limited by water supply, both summer and winter crops can be successfully and economically grown in this environment if sufficient moisture is stored in the soil before sowing, to provide a buffer against dehydration.
Farming systems research in the region

The effects of continuous wheat cropping, alternate methods of production or remedial treatments for land degradation are the dominant themes of scientific investigations in the region.

Thomas et al. (1996) examined the factors that limited wheat yields with zero till at Billa Billa, in the southeast of the study region. They found that as well as the expected limitations due to low rainfall, plant diseases had important deleterious effects. In particular, crown rot (*Fusarium graminearum*) and root-lesion nematodes (*Pratylenchus neglectus*) caused reductions in yields that were removed when the soil was fumigated. A ley pasture of lucerne had a similar effect on yields as fumigation, indicating it effectively reduced the incidence of the main soil-borne diseases. There were no significant responses to N fertilisers in yield or grain protein, indicating that N supply was not a limiting factor.

Dalal and Mayer (1986a-e), Dalal and Mayer (1987a,b), and Dalal et al. (1995) reported the rundown of soil organic carbon content and nitrogen content, as well as responses to ameliorative management such as grain legume rotations, fertiliser application and pasture leys.

A long-term experiment at Warra, which is at the north-easternmost extremity of the study region, was a prominent point of reference for researchers and farmers when the WFSP began. Strong et al. (1996a,b) reported wheat crop responses to N fertilisers and changes in organic carbon and nitrogen in different cropping systems. Weston et al. (1996) reported on the differences in water balance for three different types of pasture leys in the Warra trials.

Consistent with Jiggins’ (1993) summary of the weaknesses of the transfer of technology and simplistic FSR approaches to technological innovation, this research appeared to do little to encourage the development and use of more sustainable or profitable farming systems. Particularly in the west, the Warra results were considered irrelevant or untrustworthy for...
many reasons, some of which seemed to be related to soil types, weather, crop yields and fertiliser sales.

Probably the best-known sets of research results in the region were 1) Ram Dalal’s graphs of rundown in soil organic matter over time (see Dalal citations above), and 2) David Freebairn’s graphs of ground cover versus runoff (Freebairn and Wockner 1986). The former was well known as an indicator that something needed to be done about soil fertility, and reinforced the experiences of farmers that protein levels were declining in some areas due to reduced mineralisation of organic N. However, from a farmer perspective, neither the indicator, nor the results from Warra apparently indicated what could be done about the situation. The research results of David Freebairn were also well known and respected and similarly provided warning of a “risky situation”, in this case, a lack of cover leading to soil erosion. Unlike the situation with organic matter decline, many farmers felt that they had done, or would be doing something positive about the erosion situation by increasing soil cover through conservation tillage and reduced tillage systems.

Hamilton (1991) regarded ley pastures as the main area where information was needed by farmers to improve management. The economics and sustainability ley pasture systems in the west are difficult for farmers to assess because farmers’ and advisors’ have limited experience of the alternative farming systems. Even the dominant system of continuous cropping with spring wheat has been operating for only 20 to 40 years, and that system has changed in the last few years with the introduction of minimum tillage and N application.

An emerging technology that may increase yields in these farming systems is through reducing the dependence of sowing on rainfall by “moisture-seeking”, or deep sowing. Substantial increases in yield and cropping frequency appear likely with this relatively simple technology (data not shown).

**Uses of models and DSS in the region**

In the late 1970s and early 1980s, the suitability of cropping in areas around St George and Roma was questioned. In particular, there was concern that an expansion in the area cropped was due to “a few good years”. Average wheat yields and annual variability of yield at a variety of locations were assessed via simulation modelling by Hammer *et al.* (1987). Modelling used long-term rainfall records to estimate crop yields since the 1890s. The results indicated that crop yields were sufficiently high and consistent to support a permanent grains industry.

Probert *et al.* (1996) simulated soil conditions and crop yields in several treatments in the Warra trial. The APSIM model (Agricultural production systems simulator) gave satisfactory
reproduction of the accumulation of total soil water and total soil nitrate during the summer fallow periods. However, in the simulations of Probert et al. (1996) soil water and nitrate were reset to measured values annually (at harvest), so there is doubt whether these APSIM results for long-term simulations are valid. Testing modelled data against field measurements, Robinson et al (2001) concluded that wheat yield and protein estimates from APSIM carry large errors in low-yielding sites in southwestern Queensland. Low relative precision in the study region reflects (i) development of the models from data collected in higher-yielding regions, and (ii) consistent absolute error (~1 t/ha RMSE) across the yield range resulting in maximum relative error in the study region, where yields are at their lowest (1 to 3 t/ha). Appendix 3 is a detailed study of the predictive accuracy of APSIM for wheat crops in the study region. Appendix 4 is an analysis of the sensitivity of APSIM results to management parameters and historical variations in climate.

Other simulation experiments have defined some benefits of new farming practices, such as reduced tillage and ley farming (Berndt and White 1976, Littleboy et al. 1992, Connolly and Freebairn 1996, Scott et al. 1992, Connolly et al. 1998).

Connolly and Freebairn (1996) showed that in some circumstances the economic imperative and resource stewardship are complementary, providing opportunities for farm managers to maximise both the short and long-term performance of the farm. In other circumstances, the management systems maximising profit and long-term yields were different, and a compromise may be required between profit and environmental sustainability. A feature of the results of Connolly and Freebairn (1996) was that the economic responses were counter-intuitive. The degraded site with low potential productivity responded weakly to the introduction of a pasture ley, and the cumulative discounted gross margin (GM, $/ha) of further continuous wheat cropping exceeded that of the ley system. The more productive site gave a greater cash return from the pasture ley due to the higher grain yield and grain yield × protein responses. The key message, then, was that only sites with high yield potential could be economically salvaged from degradation.

The WFS project

The WFSP commenced in 1994, and so was one of the first of the “new generation” of FSR projects in the grains industry in Australia (Martin et al. 1996). Although historical research undoubtedly provided a scientific basis for progress with respect to the issues for farmers in the region, there remained perceptions that the relevance of research could be greater, and that farmer uptake of knowledge could be greater and that a more integrated approach was required. The project was to have four “modules”: (i) core trial sites, for basic research, (ii) on-farm research sites, (iii) action learning workshops and activities, and (iv) simulation and DSS development (Martin et al. 1996).
Organisationally, the WFS project originally involved the Grains Research and Development Corporation, NSW Agriculture, Qld Dept of Natural Resources, Mines and Energy, Qld Dept of Primary Industries and the University of Western Sydney – Hawkesbury. In 2000, the project split into components in WFSP-NSW (WFSn) and WFSP-Queensland (WFSP), and the WFSP integrated its four modules into a more holistic organisational structure.

Improved decision-making has a prominent place in the vision of the WFSP, being:

“An enthusiastic vibrant partnership between the farming community and the WFS team that is helping all parties learn from each other and improve their decision making and understanding, which will enhance their progress towards a more sustainable farming system (environmentally, economically and socially).

It will use a combination of rigorous participatory RD+E methods in addressing these issues. The project team will find personal reward and recognition for their collective and individual work.”

The project has been evaluated (WFSP 2000) in terms of impact on the knowledge, aspirations and practices of farmers. In economic terms, the changes in farming systems practice between 1995 and 2000 were estimated to have an on-going benefit of AUD$4.8M/year in regional economy. The largest contributions to this were from an increase in the area cropped and increased use of N fertiliser.

From the respondents in the survey (53% of those mailed out), there were some very favourable ratings of the project, including:

- 97% stating that it had a positive effect upon “helping people improve their farming”, with 74% stating it had a large or very large effect,
- 90% stating that it had a positive effect upon “reducing land degradation”, with 44% stating it had a large or very large effect, and
- 91% stating that it had a positive effect upon “increasing the profitability of farming” with 52% stating it had a large or very large effect.

In general, farmers were impressed with the R D and E processes of the WFSP (Table 3). Although farmers are generous, the results indicate an endorsement of the R D and E processes. That nearly three quarters felt that the improvement was large to very large emphasised to all concerned that the farming systems approach was distinct from the previous, traditional agronomic R D and E.
Table 3. Farmer ratings of the WFSP RD and E processes relative to previous RD and E. (Source: WFSP 2000)

<table>
<thead>
<tr>
<th>Region</th>
<th>No improvement</th>
<th>Improvement</th>
<th>Large or very large improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>1 %</td>
<td>99 %</td>
<td>73 %</td>
</tr>
</tbody>
</table>

Farmers were using much more nitrogen fertiliser, in both the rate used and the area applied, and a higher percentage of farmers were using grain legumes (Table 4). Staff in the WFSP felt that the increasing use of grain legumes (48 % currently growing some, up from 28 % growing some in 1996) was an indicator of improved system sustainability.

On reflection, it appears that although previous experimentation had shown favourable responses to N fertilisers, ley pastures and grain legumes, a lack of engagement of farmers in the process had resulted in relatively few farmers choosing to use these practices. A series of N budgeting workshops appear to have been crucial in gaining the interest and cooperation of farmers and researchers to explore the N fertiliser requirements of cropping systems in the region (Lawrence et al. 2000).

Table 4. Median fertilised area (% of wheat area) and rate (kg N/ha/year) and grain legume use (% of wheat area) in 1996 and 2000, and expectations for 2005. (Source: WFSP 2000)

<table>
<thead>
<tr>
<th></th>
<th>1996</th>
<th>2000</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen fertiliser area</td>
<td>0 % (73 %)</td>
<td>29 %</td>
<td>42 %</td>
</tr>
<tr>
<td>N fertiliser rate</td>
<td>0 (72 %)</td>
<td>37</td>
<td>36</td>
</tr>
<tr>
<td>Grain legumes</td>
<td>0 % (72 %)</td>
<td>0 % (52 %)</td>
<td>16 %</td>
</tr>
</tbody>
</table>

Where the median equals zero, the percentage of responses equal to zero is shown in brackets.

Farmers also made many other major changes to their farming systems during the period 1996 to 2000. Some of the most significant that appear related to the operation of the WFSP include:

- Increased soil testing,
- More trials of new crops and rotations, and
- Better understanding of soils.

Summary

Important characteristics of the region and the challenges faced in farming systems include:
- Rainfall that is unreliable and low on average (450-600 mm/year),
- Summer-dominant rainfall and high summer temperatures,
- Soils that range from shallow, infertile sandy loams with low water-holding capacity (less than 80mm) to deep fertile clays with high water-holding capacity (greater than 200mm),
- Declining soil organic matter levels due to continuous cropping with winter cereals,
- A lack of reliable and productive ley legumes

Responses to these challenges have included significant use of urea fertilisers, much greater use of reduced tillage systems, and the introduction of controlled traffic systems.
II. PROPOSITIONS AND METHODS

Chapter 7. Propositions

The purpose of this chapter is to set out some contentious, testable propositions for assessment through the experience of case studies.

The propositions, and a brief explanation of their relevance, are:

1. Criteria exist, or can be developed, that encourage effective development and application of DSS in FSR

Many authors have suggested that DSS and hard systems tools have not been effective, or at least not as effective as originally hoped for (Bowden 1992, Lynch 2003, McCown 2001b) There are many reasons why these systems might be “under-achieving”. Dillon (1979), Brennan and McCown (2001), Malcolm (1990, 2000), Makeham and Malcolm (1993), Hamilton (1995), Cox (1996), Cox et al. (1996), McCown (2001b), Lynch et al. (2000) and Lynch (2003) all offer guidelines or criteria to guide the development and application of DSS and related tools. The proposals by the various authors are, in total, diverse and complex, and have superficial appeal, but have not been used in DSS development and application. There is a need for evaluation and integration of the criteria, and for greater sense to be made of the current place of DSS in FSR, both in Australia and internationally.

A further question arises concerning the evaluation of various DSS by the authors listed above. What were the circumstances in which they evaluated the DSS? Were they more concerned with development or implementation of the DSS?

2. That DSS are effective catalysts of change and action

The literature was inconclusive concerning the “goodness of fit” of DSS, for decision support in participatory FSR. While DSS are based on rational decision models (Chapter 5) and aim to alter cognitive decision-making and promote learning (Chapter 3), DSS are not proven or established catalysts of change and action. Testing DSS in the case studies might identify strengths and weaknesses of DSS in this domain.

3. Detailed models are more effective sources for DSS than simple models
It is not clear from the literature which types of DSS are the most effective in participatory FSR. While Malcolm (1990, 2000) and Lynch (2003) found that simple tools, and tools co-developed by farmers and researchers, were more successful than others, the foci of those authors (i.e. economic tools and DSS) are somewhat different to those of typical practitioners in FSR. Stewart et al. (2000) and McCown (2001b) have used DSS as simulators of farming systems for learning, and such uses require realistic complexity.

The issue of complexity is also closely tied to efficiency of DSS development, because the complex tools require more resources. Would the resources invested in one complex DSS be better invested in five simple DSS?

4. That sufficient knowledge of farmer decision-making processes exists to make DSS efficient and effective

Decision-making features in the business and financial literature, but not very prominently in the FSR or even the agricultural literature. Can hard and soft FSR benefit from the use of the extra decision-making knowledge available from other disciplines, such as the model of Janis and Mann (1977)? The case studies will examine the use of this knowledge in practice.

5. That the interactions between DSS and learning processes are well understood

From the literature, it is clear that DSS are unlikely to have impact unless their application is oriented to learning by the decision-maker. What types of DSS suit what learning processes? Given that DSS are founded in hard systems approaches and learning systems are not, this proposition raises questions about crossing boundaries from hard systems to soft systems and beyond.

Also, can good process compensate for a poor DSS? Does a good DSS need good process?
Chapter 8. Methods of inquiry

This chapter sets out the means used to acquire and manage knowledge about the propositions and related questions. A more detailed discussion of reasoning and epistemologies is presented in Appendix 1. This thesis approaches inquiry via experience and empiricism within an action-learning framework (Zuber-Skerritt 1993), employing both deductive and inductive reasoning for the understanding of a plural world. In colloquial terms, things were learned through cycles of planning, acting, observing and reflecting, and specific and general conclusions were made of physical and mental things, actions and concepts, of which I was part.

**Deductive reasoning**

As mentioned previously, hard FSR is associated with logical positivism. Logical positivism uses deductive reasoning to reach conclusions. Deductive reasoning is the process of reasoning from the **general to the specific**. For example, because the sum of the angles in all triangles is 180 degrees, you can conclude that the sum of the angles in any individual triangle is 180 degrees. This may not seem very powerful, but deductive reasoning provides a high degree of certainty.

First, one must prove or at least test the general rule, or “law”. In FSR one may set up a rule that farmers will adopt technology X, not Y. The next step is to seek to disprove the theory by finding an example where a farmer adopted Y. Much of modern science combines experimentation or measurement (empiricism) with deductive reasoning. The technical content of this thesis employs some deductive reasoning. However, because of the complexity and probabilistic nature of social and biophysical responses in farming systems, simple rules are usually not challengeable. Hence there is considerable reliance on reasoning from the **specific to the general**; inductive reasoning.

**Inductive reasoning**

If all the sorghum crops you’ve ever seen were grown in summer, you might conclude that sorghum crops are grown in summer. However, this “fact” is susceptible to finding an exception to the rule, and indeed, inductive reasoning can never form a final proof.

Much of the reasoning in this thesis involves examining others’ understanding, as reported in the literature, and making observations from practice, and deriving new information, which are not absolute facts, but which may nevertheless have a degree of utility and reliability.
Therefore, inductive reasoning is useful because it is often suited to analysing complex systems, and the results can be useful and meaningful, if never factual in the sense of facts that are deduced.

**Action research**

Action research (Ross *et al.* 1994) is an effective learning method for adults that was widely employed in the cooperative farmer-researcher activities describes in this thesis. The method is consistent with those epistemologies that emphasise a role for “doing” as well as “thinking” in knowledge acquisition and processing.

There are four stages or phases in action research - Plan, Act, Observe and Reflect (Kolb 1984, Zuber-Skerritt 1993, Figure 10). Together they are known as the action research cycle.

![Figure 10. The experiential (or action) action learning cycle (Source: Kolb 1984, Ross *et al.* 1994).](image)

The stages are:

- **Act/Experience**
  Acting is doing something that makes use of prior learning. Acting is an important step for adults to take towards doing something better. In simple terms, you attempt something, and collect evidence to indicate levels of success. That information enables you (the ‘doer’) to improve next time, especially if the observations and reflections are un-biased.

- **Observe/Measure**
  What happened because of the action? What physical or systematic changes occurred? Measurements need to be relevant and unbiased.

- **Reflecting/Concluding/Evaluating**
  Concluding happens when you develop a conceptual model describing what is happening. They may be your own original thoughts, other people's original thoughts,
or some ideas gathered from reference material. This phase builds understanding. It is also, perhaps, the most easily overlooked step in the cycle, and for some people may be the least “natural”.

- **Planning**

Planning precedes the next set of actions and experiences. It may be based on conscious or unconscious thoughts and re-actions. Planning often focuses on a particular aspect of the 'doing'. Plans themselves will often be implicit and subconscious.

Like many other activities, the more practised people are at following the steps in the action research cycle, the more effective they become at using it. So, potentially, it would seem that you could learn more each time you go through the action research cycle. However, where the learning is finite or limited (which is usual) the potential improvement may get smaller after each cycle. So there will be a trade-off between increased technical efficiency in learning and diminished subject matter or diminished relevance of the subject matter. What usually happens is that learners become interested in fresh, new areas of learning where they can express their abilities and get substantial returns for their efforts.

Action learning theories are not without their critics. Rogers (1996, p. 10) points out that "learning includes goals, purposes, intentions, choice and decision-making, and it is not at all clear where these elements fit into the learning cycle." Habermas has also proposed that there are at least three kinds of learning and that we have different learning processes and styles for each (Rogers 1996, p. 110).

In this thesis, I have used action research methods to describe and evaluate learnings from the use of DSS. This type of learning is sometimes referred to as meta-learning or double-loop learning (Argyris and Schön 1974). This concept is shown in Figure 11.

![Diagram of the action learning cycle and meta-learning](Source: Kolb 1984, Robinson, unpublished)
Second-loop, outer-loop or meta-learning is learning about the status and progress of learning. An example experienced in the WFS project that shows some elements of the two levels in farming is the workshops where farmers and researchers learned about better N fertiliser use. Farmers went away with learnings about the science and technology of N fertiliser – single loop learnings, and some changed views about fertiliser and workshops – second loop learnings. The WFS team went away with single loop learnings about how to run such workshops, and double loop learnings about the role and effectiveness of such workshops.

Superficially, the action research method is similar to the scientific method (empirico-deductive). However, it is easily distinguished through its emphasis on:

- Social planning and pre-experimental deduction, whereby relevance to farmers’ specific problems of management is maximized (perhaps at the cost of more general understanding), and
- Action, in the sense of Heidegger’s view of people as actors in the world, not researchers of the world (Schurmann 1987).

Oquist (1978) regards the social and subjective elements of action research strong enough to make it inconsistent with empiricism, logical positivism and structuralism. It is, according to Oquist, a viable process for pragmatism and dialectical materialism.

**Case studies**

The evidence of six case studies is examined to explore the merits of a variety of DSS in different learning situations. The evidence is used to test propositions and theory from the literature review. (Background to the case studies was given in Chapter 6 and the studies are given in Chapter 9).

The premise of each case study was that FSR could improve farmers’ situations. In some cases, the research was participatory action research, while in other cases it had some separation between the research and extension activities that are more characteristic of the transfer-of-technology or diffusion model (Jiggins 1993, Hamilton 1995). In one case a DSS was co-developed with farmers and consultants, in a process similar to what Jiggins (1993) calls participatory development of technology (though in Jiggins’ context the technology was simple and aimed to assist the resource-poor rather than computer technology for Australian farmers).

The technical details of the case study are presented first. In most case studies, this includes the traditional Introduction, Methods, Results, Discussion and Conclusions. As well as a
technical summary, there is a summary of learnings about the interactions between myself, other project staff, farmers and other participants. Then, a table is developed showing the degree to which the criteria from Chapter 4 were met in the case study and whether the criteria were meaningful. Scoring in this table was my subjective evaluation. Except for Lynch (2003), the authors of the criteria did not give measures for use with their criteria. Given that the scores presented here were subjective, one may ask whether they are valuable. While the scores for a single case might be biased, a reliable and meaningful pattern is likely to emerge in connection with all six cases. Also, a principle of the second loop of action research is that improvements in methods can be made through action. Evaluating 24 criteria over six case studies is a substantial evaluation of the DSS and their associated processes.

The ratings are examined in the discussion for: (i) causal factors and associations, and (ii) any bias in the ratings. Following scoring and judging of all of the criteria, the usefulness of particular criteria is further described. In most cases, this involved one or two of the criteria suggested by each author, selected because they were either strongly consistent or inconsistent with evidence from the case. In other words, they provided the clearest evidence for accepting or rejecting the various proposals.

In each case study, a table was developed showing the scores for the criteria, indicating on a five point scale whether they were not met (one point), through to fully met (five points). The criteria were scored for both: (i) the DSS or systems tool, and (ii) the process used to apply the DSS. Some criteria were not applicable in some categories, and were not scored. Based on whether the case study met the criteria and was successful, or whether the case study did not meet the criteria, but could have been more successful if it had, the criteria were judged to have been meaningful (or not) in each case study.

Each case study was also interpreted in terms of Janis and Mann’s model of decision-making. The stages that were most relevant in the case are described, and learning about these stages is highlighted.

Learnings from the case study, especially those relevant to the propositions, are then drawn together from the analysis. These learnings will go on to form the basis for the final discussion and conclusions.
III. INQUIRY

Chapter 9  The case studies

How were they developed?

As a systems agronomist in the WFS project, I was involved in about 20 activities between 1996 and 2004 that were concerned with decision-support. Selection of case studies from these was based on avoiding redundancy (some activities were similar to others), and selecting a subset that made significant use of DSS and related tools, covered diverse issues (e.g. water, nutrients, profit) and involved different styles and amounts of participation with farmers.

Six cases were chosen on this basis. They are:

1. Modelling wheat crop responses to N fertiliser on grey clay soils, where annual N fertiliser use is historically very low (Robinson et al. 1999)
2. Comparisons of fallow length on red earth soils, which have limited moisture storage capacity
3. Using the FARM whole-farm budget to compare rotations and farming systems in terms of economics and environmental sustainability (Robinson et al. 1998)
4. Assessing the value of the Southern Oscillation Index (SOI) for winter crop management, including selecting N fertiliser rates and wheat varieties (Robinson and Butler 2002)
5. Summer cropping opportunities in western farming systems, where winter crops presently dominate the system
6. Modelling historical rainfall and potential wheat yields at St George to put recent yields in the context of long-term climate
Case 1: Modelling wheat crop responses to N fertiliser on grey clay soils

There are large areas of grey vertosol (grey clay) soils in the southwest of the study area, including areas around the townships of St George, Nindigully, Thallon and Dirranbandi. This case study reports project activities in 1996 and 1997 dealing with farmer and researcher concerns about the need for N fertiliser in the farming systems. Traditionally, these soils had high organic matter levels and crops were supplied with sufficient mineralised N, but this was being exhausted in some areas. Therefore, some studies were considered necessary to evaluate the costs and benefits of N fertiliser application on wheat crops in the area.

Also, an experiment had been established to measure responses to N fertiliser. The simulation study was designed to provide information about N responses in a long-term context while the field experiment was still at a preliminary stage (1 year of data from 1996).

Introduction

In contrast to much of the grains belt of Australia, wheat yields in the study area not increasing, or increasing very slowly (Hamblin and Kyneur 1993, Cornish et al. 1998). It was suspected that high variability in yields and prices might be leading to reduced adoption of technological improvements, or reduced benefits of new technologies. One such technology is the use of fertilisers, particularly N fertilisers. Figure 12 shows variability in wheat yields, and the variable response to N fertilisers in an experiment at Warra, located between Dalby and Roma in the northeast of the study area (data from Strong et al. 1996b).

![Figure 12. Wheat yields with and without fertiliser at Warra Wheat yields (t/ha) from an experiment at Warra, in the east of the study area (Source: Strong et al. 1996b)]
As already mentioned, soil fertility, particularly available soil nitrogen, is declining in much of the study area, limiting or reducing yields in many areas (Dalal et al. 1995). Although N fertilisers can overcome the associated yield decline, investment in fertiliser is risky due to the variability in yields and prices described above.

Climatic factors that prevent crop responses to N fertiliser include infrequent winter rainfall and low average rainfall. N fertiliser is usually applied before or during the sowing of the crop in the northern grainbelt to overcome the problem of infrequent rainfall events. However, this fertiliser will only increase the yield if subsequent rainfall, and therefore soil moisture, is in good supply during the growing of the crop. As shown in Figure 12, 50 kg N/ha at Warra can result in as much as a 50% increase in yield or, in many years, no increase in yield (data from Strong et al. 1996b).

This study reports the influence of seasonal variability on profitable N fertiliser use in the study area. Information about N responses from a field experiment that was still at a preliminary stage (1 year of data) is placed in context with long-term climate variability.

**Methods**

APSIM (the Agricultural Production systems SIMulator, McCown et al., 1996) was used to simulate wheat production in the trial. APSIM is software that allows several partial models to be run together to simulate a limited agricultural system. Partial models include crops, pastures, soil water, soil nutrients, soil erosion and crop residues. Together they can represent an area with nominally homogenous biophysical attributes and management, such as a farmer’s paddock.

An experiment was established in the WFSP area at Nindigully to trial new farming systems. Nindigully is 44 km south of St George and approximately 500 km west southwest of Brisbane. This experiment, established in 1996, provided information on the yield of wheat and responses of wheat to N fertiliser, as well as other information about farming systems.

The N response experiment at Nindigully grew crops with 0, 30, 60 or 90 kg N/ha of N fertiliser applied at sowing. Variety Hartog was sown at 38 kg seed/ha on 25 May 1996. Available N in the soil before sowing (0 to 120 cm depth) was 69 kg N/ha. Yield and grain N were measured at harvest. Grain N concentration is important because it indicates the grain protein concentration (protein = 5.7 × N), which may affect the grain price. Grain N may be increased by N fertiliser applications, even if yield is not.

Yield and grain N concentrations were simulated at the same four levels of N fertiliser that were applied in the trial. Other data used in the simulations were weather data and
measurements of plant-available soil moisture (PAW) and available soil N before sowing. Simulated data for 1996 were subjectively compared with the measured values. The model was then applied to long-term weather data (1960-1993) for St George. Available soil moisture and soil nutrient levels were set at the time of sowing (which was also fixed each year) to isolate the effects of seasonal conditions during the growth of the crop from preceding conditions. These modelling experiments, where soil moisture, available soil N, N fertiliser rates and sowing date are preset, are useful for answering questions such as; “How much yield and protein can I expect from these rates of fertiliser, GIVEN that the crop is sown on date X, with Y amount of PAW, and Z amount of available soil N?”

Effects of sowing date on responses to N fertilisers were similarly examined by simulating 0 and 60 kg N/ha at three sowing dates (25 April, 25 May and 25 June). In 1996, the sowing date was 25 May, which was typical. For these simulations, PAW and available soil N at sowing were set at 108 mm and 69 kg N/ha, respectively.

Annual gross margins (GM, $/ha/year) were calculated from the simulated yields and grain N concentrations. Prices at the nearest delivery depot of the Australian Wheat Board (Thallon) were used to calculate income. These were $137/t for more than 10% protein, $150/t for more than 11.5%, and $164/t for more than 13.5%. N fertiliser was assumed to cost $1/kg N including application. All other variable costs were assumed to total $80/ha.

Results and Discussion

Wheat yields at Nindigully in 1996 were higher than average. There was very high PAW at sowing (204 mm), equal to 95% of the PAWC of the soil profile. Also, rainfall received between sowing and harvest was above average (201 mm), with a fair distribution between early crop growth (131 mm before anthesis) and during grain fill (70 mm after anthesis).

Comparison of the measured and modelled yields (Figure 13) shows that APSIM was useful for estimating the yields and yield responses to fertiliser N applications in 1996. Comparisons of the measured and modelled grain protein concentrations (Figure 14) were also favourable. Figure 13 and Figure 14 together indicate that the model was able to estimate the yield and protein concentration (and hence price) of wheat for a range of fertiliser rates at Nindigully in 1996.
The historical climate sequence

Figure 15 shows that the measured yields and the yield responses were similar in 1996 to the simulated long-term means (1960-1993). Therefore, although yields in 1996 were reputedly well above average, this was not due to conditions during the growing season. *Given the excellent conditions at sowing*, the measured and simulated yields in 1996 were close to the simulated long-term average.
Figure 15. The measured wheat yields (kg/ha) in 1996 and the means of the simulated yields for 1960 to 1993 (Source: Robinson et al. 1999).

Figure 16 shows the simulated annual yields (1960 to 1993, + 1996) for the four N fertiliser treatments (0 to 90 kg N/ha). Note that any differences between years are caused by different conditions during the period of crop growth, because conditions at sowing were set to those for 1996. Figure 16 provides further evidence that the yield responses to N fertiliser in 1996 were normal given the sowing date and measured PAW and available soil N.

Figure 16. Simulated yields (kg/ha) for 1960 to 1993, and 1996, given 204 mm (95% PAWC) of available soil moisture and 69 kg N/ha of available soil N at sowing (Source: Robinson et al. 1999).
Fertiliser responses in each year were highly variable (Figure 16), ranging from negative or no yield response in 1982 and 1991, to doubling of the yield with 90 kg N/ha in 1966. This annual variability in the fertiliser response suggests that caution is required if interpreting 1 or 2 years’ results from field experiments, as responses could be under- or over-estimated. The simulated yield sequence indicates that a substantial yield response to fertiliser occurred in a high proportion of years given the conditions at sowing. Table 5 shows the high percentage of years with positive yield, price and profit responses to 60 kg N/ha given the high PAW (204 mm) measured in 1996.

Table 5. Frequency (% of years) of positive responses in wheat yield, price and profit to applying 60 kg N/ha fertiliser with the profile 25%, 50% or 95% full.
(Source: Robinson et al. 1999)

<table>
<thead>
<tr>
<th></th>
<th>54 mm (25% PAWC)</th>
<th>108 mm (50% PAWC)</th>
<th>204 mm (95% PAWC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield response</td>
<td>34</td>
<td>43</td>
<td>86</td>
</tr>
<tr>
<td>Price response</td>
<td>11</td>
<td>26</td>
<td>94</td>
</tr>
<tr>
<td>Profit (GM) response</td>
<td>29</td>
<td>40</td>
<td>97</td>
</tr>
</tbody>
</table>

*Effects of PAW at sowing and sowing date*

Because the abundant soil moisture at sowing measured in 1996 is not a common occurrence in the study area, further simulations were conducted with conditions of 108 mm PAW (50% full, a typical condition) and 54 mm PAW (25% full, poor conditions) at sowing. Figure 17 shows that the simulated yields for 108 mm PAW were lower and more variable than for 204 mm (Figure 16). Yields for 54 mm PAW were very low (data not shown). Table 5 shows the frequency of obtaining positive responses in yield (kg/ha), price ($/t) and profit (GM, $/ha) to 60 kg N/ha at 3 levels of PAW at sowing. With higher PAW there is a much larger percentage of years with positive responses.

Unexpectedly, price responses (Table 5) were more strongly dependent on PAW than yield responses. This is apparently because the available soil N without fertiliser N was often sufficient to maximise the grain price ($164/t) by achieving 13 % protein. At low PAW the combined yield and price responses are very frequently less than the N fertiliser cost of $60/ha for 60 kg N/ha. Conversely, at high PAW there is a high probability of obtaining a profit response because available soil N is insufficient to maximise grain yield and price under these conditions (Table 5).
Table 1. Simulated yields (kg/ha) for 1960 to 1993, and 1996, given 108 mm (50% PAWC) of available soil moisture and 69 kg N/ha of available soil N at sowing (Source: Robinson et al. 1999).

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield (kg/ha)</th>
</tr>
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<tbody>
<tr>
<td>1960</td>
<td>N0 N30 N60 N90</td>
</tr>
<tr>
<td>1965</td>
<td>N0 N30 N60 N90</td>
</tr>
<tr>
<td>1970</td>
<td>N0 N30 N60 N90</td>
</tr>
<tr>
<td>1975</td>
<td>N0 N30 N60 N90</td>
</tr>
<tr>
<td>1980</td>
<td>N0 N30 N60 N90</td>
</tr>
<tr>
<td>1985</td>
<td>N0 N30 N60 N90</td>
</tr>
<tr>
<td>1990</td>
<td>N0 N30 N60 N90</td>
</tr>
<tr>
<td>1995</td>
<td>N0 N30 N60 N90</td>
</tr>
</tbody>
</table>

The means of the simulated grain yields for the period are shown in Figure 18. The flatness of the yield response at 54 and 108 mm PAW is apparent. Also, PAW at sowing had a sizeable effect on the mean yields at each level of N fertiliser. This effect is despite the crop usually receiving appreciable rain during the 4 months that it is growing (mean ≈150 mm).

Figure 18. Mean simulated grain yields (kg/ha/year) with 0, 30, 60 or 90 kg N/ha applied at sowing. Available soil moisture at sowing was 54, 108, or 204 mm. (Source: Robinson et al. 1999)
At high PAW yield increased with up to 60 kg N/ha, at intermediate PAW with up to 30 kg N/ha, and no significant yield increase occurred at low PAW. This agrees with observations that responses to N fertiliser are reduced when available soil moisture is in short supply. Crops with abundant N relative to their water supply can be too leafy early in the season, use too much soil moisture, and suffer stress during critical periods for grain production around anthesis and grain fill.

![Figure 19. Gross margins ($/ha/year) from the simulated wheat crops grown with 4 rates of N fertiliser and 3 levels of available soil moisture at sowing. (Source: Robinson et al. 1999)](image)

Like grain yields, simulated gross margins and responses of simulated gross margins to rates of N fertiliser were very sensitive to PAW at sowing (Figure 19). The sensitivity is partly due to increased protein and price responses with higher PAW at sowing. The mean price responses to 60 kg N/ha were $0/t, $2/t and $21/t at the low, medium and high levels of PAW at sowing, respectively.

Later sowing date reduced mean yields at both 0 and 60 kg N/ha of fertiliser (Figure 20). Late sowing leads to a shorter growing season, allowing less biomass to accumulate, and the crop maturing later in the year, when temperatures and evaporative demand are usually higher. The response of wheat yields to 60 kg N/ha of fertiliser were also least at the latest sowing date (Figure 20). Loss of yield benefits from N fertiliser at the late sowing is probably due to increased moisture stress around anthesis and during grain filling becoming more strongly limiting with later sowing. Because N fertilisers make the crop leafier, the
chances of severe moisture stress increase, so the yield benefits of N for late-sown crops are less. In severe seasons, yields may be reduced due to excess leaf area and soil moisture use by the immature crop.

Effects of sowing dates on the mean gross margins (Figure 21) reflect the greater yield response at early sowing. Nevertheless, at each of the three sowing dates nil fertiliser is more profitable than 60 kg N/ha under these conditions (108 mm PAW, 69 kg N/ha available soil N at sowing).

Figure 20. Simulated wheat yields (kg/ha/year) for three sowing dates, with 108 mm of available soil moisture present at sowing (50% of the available soil moisture capacity). (Source: Robinson et al. 1999)

Figure 21. Simulated gross margins ($/ha/year) for three sowing dates, with 108 mm of soil moisture at sowing (50% of the available soil moisture capacity). (Source: Robinson et al. 1999)
General Discussion and Conclusions

The Nindigully experiment provided new information concerning wheat production, measuring yields under near-ideal conditions at sowing and good conditions during crop growth. The simulation model was able to add to this information by placing the results from 1996 in a broader context of seasonal conditions and conditions at sowing. This showed that the profitable response to N fertiliser found in 1996 depended on the abundant PAW at sowing. The modelling experiments with APSIM clearly showed that unless soil moisture conditions at sowing are favourable, as in 1996, the yield, grain N and price responses of wheat to N fertiliser are greatly diminished. When PAW at sowing is more usual, N fertiliser is uneconomic.

Technical summary

Wheat yields are highly variable in northern Australia because rainfall is variable. Economic benefits from applying nitrogen fertilisers are uncertain because yield responses depend on a good supply of soil moisture during the growing of the crop that provides a high potential yield. While an experiment in 1996 indicated that up to 90 kg N/ha of N fertiliser is profitable, it was not known whether this response is reliable or typical. A crop model and historical climate records (1960-1993) are used in this study to produce a long-term record of yield and grain protein responses to N fertilisers. Responses in 1996 are shown to be atypical due to the favourable conditions in that year. Under typical growing conditions it is not economic to use N fertiliser. The simulations quantified the relationship between responses to fertiliser and the amount of soil moisture available at sowing. It is concluded that applications of N fertilisers will be most profitable if used when measurements indicate that the plant-available soil moisture content before sowing is above average.

FSR learnings

The field trials received a variable reception from farmers. In 1996, and in subsequent years, farmers argued for increased relevance through trials of lower rates of fertiliser. Whether the farmers really were financially incapable of outlaying the cost of high rates of fertiliser was not the issue; the farmers were making decisions as a resource-poor group, and in a situation where transfer of technology was ineffective. Additionally, many researchers believed, and probably continue to believe, that farmers in this region are reluctant to apply appropriately high rates of N fertiliser. A reluctance to invest in fertilisers or improve crop yields has been interpreted as conservatism and poor management.

This study, however, shows that farmers’ decisions not to apply N fertiliser may be quite rational. There is little or no yield, price or profit gained in the majority of years when the
soil profile at sowing is only partly full of moisture. However, the results of the simulations also support the experimental results from 1996 that show a high rate of N fertiliser is profitable when PAW at sowing is high (204mm). An annually flexible strategy that adjusts the fertiliser rate to PAW appears the most economic strategy. Further studies may also clarify the effects of available soil N on the frequency and magnitude of responses to applied fertiliser. In general, less available N is expected to increase both the yield and price, and hence profit, response to N fertilisers.

This information was discussed at some grower meetings in the summer of 1996/97 and received considerable interest. One of the main themes discussed was the probability of receiving rainfall and yields like 1996 in the future. Many farmers said that if they were going to achieve these high yields on a regular basis, they would consider increasing their N fertiliser rates, perhaps to the high levels shown to be economic in the trial (i.e. 60 to 90 kg N/ha). Conversely, if 1996 was a comparatively rare event, many farmers implied that they would leave their fertiliser rates alone. Some simple analyses were done, and graphs developed to show that the combination of a very favourable fallow in 1995/96 and a good season in 1996 was not a common occurrence.

The field day at the Nindigully field trial in 1997 provided insights into the indigenous knowledge of farmers and their needs and expectations. The field day was organised so that small groups of farmers and WFSP staff circulated between focal points in the paddock. Each focal point was assigned one or more issues to be discussed. At the stop where the modelled results were shown I spent some time discussing the theory and practice of N responses, as well as the model results. I was surprised by the strength of conviction and depth of knowledge that farmers had concerning N fertiliser responses. Several of the farmers expressed opinions about the design, methods and conclusions of WFSP research. This included the following statement from a farmer to the discussion group, contrasting the results from the model and the discussion that we were having, with the views of researchers at the “other” stops where high rates of N fertiliser (60 and 90 kg N/ha/year) were being advocated:

“Thank heavens. *If I do what that lot [the other researchers] are suggesting, I’ll go broke*”

I conclude that although the field measurement, transfer of technology approach produced accurate information for a particular set of conditions (1996), the modelling-DSS combined with an inclusive, discussion-based process was very much more effective and efficient in increasing the understanding of farmers.
Which of the criteria were useful in this case?

Table 6 shows scores for the criteria, and Table 7 contains extra discussion of criteria that are the most relevant in this case study.

Table 6. Scores and judgment for the DSS and processes used in the case study of N fertiliser response on grey clay soils (+ = not met, ++++= fully met, NA=not applicable). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria for DSS success</th>
<th>DSS</th>
<th>Process</th>
<th>Meaningful for this case study?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Data must be available for specifying processes</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Biophysical representations must be dynamic not static</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Complexity and cost should be avoided</td>
<td>++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Uncertainty must be represented</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Farmer preferences and goals must be represented</td>
<td>+</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage of the elements relevant to a decision maker</td>
<td>+</td>
<td>++</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Involvement of the decision maker</td>
<td>+</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Customisation of the problem representation</td>
<td>+</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Used by participants, not researchers</td>
<td>+</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Capacity for comparative analysis</td>
<td>++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>High relative accuracy, not necessarily absolute accuracy</td>
<td>++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Tangible variables should be emphasised</td>
<td>+</td>
<td>++</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Intangibles require graphic representation</td>
<td>+</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Tools must be open to validation and interrogation to establish trust</td>
<td>+</td>
<td>++</td>
<td>No</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the purpose</td>
<td>NA</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the culture</td>
<td>NA</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the process and performance</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the people</td>
<td>NA</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td>McCown</td>
<td>Degree of realism must be high</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Must be easily parameterised to a specific site and situation</td>
<td>++</td>
<td>NA</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Ability to research management options with farmers must be high</td>
<td>++++</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Depth to the user participation</td>
<td>NA</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Participation oriented to the user’s perspective</td>
<td>NA</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>A high degree of user influence on the system design</td>
<td>+</td>
<td>NA</td>
<td>No</td>
</tr>
</tbody>
</table>
Table 7. Selected criteria and interpretations from the case study concerning N fertiliser rates. (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Farmer preferences and goals must be represented</td>
<td>Although the DSS was created for research and researchers, the process was familiar and encouraging for farmers. The criterion was met via the process, not the DSS, and farmers were enthusiastic about the process.</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage of the elements relevant to a decision maker</td>
<td>In this study, the model was a detailed type, used in a narrow sense, but the DSS and process made an impact because they concerned a key question for the farmers. Decisionmakers were not engaged for most of the process, and then were highly involved in the last stages. This was successful under these circumstances.</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Used by participants, not researchers</td>
<td>Farmers were looking to the researchers for information, not to learn to use the DSS or how to decide from the results</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Tools must be open to validation and interrogation to establish trust</td>
<td>Farmers were enthusiastic about the results and had no issues concerning the trustworthiness of the model. Any lack of trust appeared to be with the unpredictable climate and maybe the interpretation of the field trial.</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the culture</td>
<td>I had not expected to receive such robust feedback from growers. At the time I had seen this work as fairly objective and suited to hard systems analysis, but the experiences of the field day showed me how important personalities, perceptions and emotions can be.</td>
</tr>
<tr>
<td>McCown</td>
<td>Must be easily parameterised to a specific site and situation</td>
<td>Modelling the Nindigully site appeared to provide all the information required concerning N fertilisation for these farmers. Farmers indicated that they could meaningfully “transfer” the learnings to their own paddocks and situations.</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Participation oriented to the user’s perspective</td>
<td>This seemed very important, especially when comparing the results from the model with those from the field trial. The model provided a context for 1996 and gave a long-term perspective that was unavailable from the field trial.</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>A high degree of user influence on the system design</td>
<td>Farmers in this example were unconcerned that researchers devised the DSS used. They trusted the model. However, because the results corroborated farmers’ indigenous knowledge and gut feel, I was concerned that the farmers may have uncritically rushed to establish this relationship.</td>
</tr>
</tbody>
</table>

Table 8 breaks the process into decision-making stages, from the farmers’ perspective. It is clear that the focus was on Weighing of alternatives. In hindsight, it was not surprising that
the results from the model needed so much explanation of context in order for them to be useful to farmers. A considerable exchange was required before the farmers and researchers had similar mental pictures of the challenges, alternatives, attitudes and other facets of the system. It was also clear from favourable comments about the results from the model that if the dialogue was effective and mutual respect was developed, there was no barrier to appreciation by the farmers of the contribution that could be made by the researchers and their model.

Table 8. Support given to participants in the N fertiliser case study at the various decision-making stages described by Janis and Mann (1977). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Decision-making stage</th>
<th>Level of support for decision stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appraising the challenge</td>
<td>None.</td>
</tr>
<tr>
<td>Surveying alternatives</td>
<td>Little. Mention of ley pasture and grain legumes as sources of N, but a focus on artificial fertiliser N. Discussion of the other options would have significantly improved the process.</td>
</tr>
<tr>
<td>Weighing of alternatives</td>
<td>Lots of support for one set of alternatives – different N fertiliser rates. The modelling exercise was very much an attempt to optimise the N fertiliser rate for a hypothetical situation.</td>
</tr>
<tr>
<td>Deliberating about commitment</td>
<td>None. It was assumed that deciding on a fertiliser rate at a field day or in a workshop would have been sufficient motivation to carry through to using that rate. This was very naïve. A better process would have included follow-up sessions, perhaps over a period of years, in which farmers could have discussed their decisions and experiences.</td>
</tr>
</tbody>
</table>

Findings and propositions:

1. A quality extension process contributed to more effective learning, despite the farmer-model interactions being limited in scope and depth. In terms of single and double loop learnings: (i) the single loop learnings were derived with traditional research methods (my crop simulations), and (ii) farmers then participated in dialogue at the field day to develop the second loop learnings. Fortunately, a clear understanding of the decisions and likely areas of dialogue allowed me to prepare sufficient single loop learnings to provide the “fodder” for excellent second loop learnings. This raises questions about the roles of decisionmakers in single loop and double loop learning that will be discussed in other case studies and in the discussion. The model was unsuited to farmer use because it was complex and difficult to parameterise. Nevertheless, the results were “engaging” and “understandable”. A sound understanding of the decisionmakers’ goals and careful management of the extension messages made this process appropriate for the farmers.
2. The criterion “broad coverage of elements relevant to the decision-maker” was one of the most difficult to rate. Boundaries to this and other FS problems are diffuse, not categorical. There are two ways that this could be interpreted, (i) Are different decisions requiring a different range of elements or analyses, supported with the DSS? or (ii) Are many elements represented, making for more holistic representation of a single decision, in a single DSS? Without defining whether “relevant to a decision-maker” indicates fine-scale or broad-scale, it is difficult to rate this criterion. In practical terms, different decisions will result in the decisionmakers sometimes clustering closely around similar elements, and at other times diverging to different elements due to their individual areas of interest.

3. Farmers were satisfied with analysis of a “district level” or “average” representation. It is unclear whether modelling farmers’ individual paddocks would have altered their decision-making, but the farmers indicated that it would have had little effect. This result contrasts with the views of McCown (2002b), who regards simulation of individual farmer’s management and biophysical system an important ingredient for successful application of DSS. A relevant difference is that between the farmers in this study, who were considering introducing an N fertiliser program to their management, and the farmers in McCown’s work, who have been users of N fertiliser for some time, and are concerned with optimising their N inputs. With hindsight, it becomes clear that precision is needed to surpass the decision-making of experienced farmers and calculate optimised management, while an approximate result is well suited to an appraisal of the situation by farmers who are relative novices with respect to N fertiliser management.

4. In this case, trust was established quickly, partly because of doubts and concerns about alternative methods. Entering into apparently simple group discussions quickly established trust and familiarity with the model and the DSS process. As suggested by Malcolm and Lynch et al., it proved to be a very important factor in the success of this study. Trust and familiarity made the extension process effective despite being limited. Partly, the trust was established due to a mistrust of other researchers and their more traditional approaches. This highlighted that trust is not always well-intentioned. In this case, farmers chose dialogue with me not because of attraction to the content and process, but because the alternative content and process were unpalatable. It also concerned me that perceptions are so easily swayed. Some of the factors that cost trust concerning the traditional approaches to scientific experiments and extension included (i) over-confidence by researchers in the applicability of the results, (ii) low status given to farmers and farmer knowledge, and (iii) less dialogue with growers.

These propositions and learning are followed up in the discussion.
Case 2: Comparisons of fallow length on Red Earth soils at St George

This case was developed following a request for information on fallow length for red soils that came from a farmer discussion group in the Boolba area west of St George. The Red Earth soils are widespread in the central and southwestern portions of the study area, particularly near St George. They are challenging to management and profitable farming because they are less fertile and have lower plant-available water capacity than other soils. This case study reports some team and farmer activities from 1997 concerning these soils.

Initially, a WFSP researcher spent some time with the group working out a testable hypothesis. The hypothesis is that beginning fallow operations in January, long after harvest has no water storage disadvantage compared with November fallowing. This question arises because red Earth soils have a small water-holding capacity, which can often be filled by a relatively short fallow before the winter crop is sown (in May to July). The alternative is to let the weeds grow (maybe grazed) until January, which was assumed to be costly in terms of water use by weeds, and to lowered crop yields, but valuable for livestock enterprises.

Introduction

To help answer this question, I used APSIM to simulate moisture accumulation during fallows on a typical red Earth soil. Although moisture storage is a key objective of fallowing, there are others that farmers might wish to take into account when considering these results. For example, weeds might leave residues that reduce yields or set seed to create recurrent problems.

Methods

The red Earth soil was assumed to be 100cm deep, with a PAWC of 76mm. This is a low PAWC by the standard of clay soils, but realistic for many of the lighter red soils. The USDA runoff curve number was set to 85. Cover was set to 500kg/ha of wheat stubble at the start of the simulated fallow, representing typical post-harvest, post-chisel plough conditions.

Four sets of conditions were simulated: fallowing from either 1 November or 1 January, and starting with either dry soil or soil wet from 10 cm to 40cm depth (equal to 30mm of plant-available water in this soil). Plant-available soil moisture was calculated on 1 May to indicate the performance of each fallow. Simulations were run for the period 1960 to 1998, using St George (1960 to 1995) and Nindigully data (1996 to 1998).

Results
There is little or no disadvantage in shorter fallows in most years. For the initially dry soil, the average store of available soil moisture on 1 May was 51mm from a 1 November fallow, and 44mm from 1 January. Figure 22 shows the annual amounts. One reason for the small differences was that runoff decreased with the shorter fallow, from an average 53mm to 38mm. For the initially wet soil, the respective stores of soil moisture were 61 and 56mm.

These differences are so small (7 mm and 5 mm) that the effects of the shorter fallow appear negligible. However, in several years the shorter fallows had some substantial effects. In the driest half of the November fallows (20 of the 39 years), average storage in the initially dry soil was 32 mm, but only 23 mm was stored from January. This is still only a difference of 9 mm, but large in relative terms (28% less), and probably equal to between 90 and 180 kg/ha less yield. Therefore, while the average losses from fallowing in January are small, they may be relatively large or important in some years, especially drier years.

Figure 22. Available soil moisture on 1 May, for the simulation assuming a dry soil at the start of the fallow on either 1 November or 1 January. (Source: Robinson, this thesis)

Figure 23 shows the relationship between moisture storage in the two types of fallow.
Technical summary

In most years at St George (22 of 39 studied) there was no extra soil moisture available at the end of a fallow begun dry on 1 November, compared with a fallow begun dry on 1 January. The difference in average moisture storage was only 7mm less for the January fallow. However, although the average decrease in available soil moisture at the end of the fallow was small, the decreases may be large (>40mm) or important (>90%) in some years.

FSR learnings

This work was part of on-going group discussions about manipulating the water balance for increased productivity. The research question - concerning the time of starting the fallow - was developed in the group. Some of the researchers then decided that APSIM was an appropriate tool for working on the problem. So APSIM was never introduced to the group – it was used to produce the results, which were handed back to the farmers in the group.

The results included a variety of farmer-relevant information - about the frequency of “filling” the profile, fallow efficiency, rainfall effectiveness and reliability, and other aspects of soil moisture supply. However, the farmer discussion group pursued none of these topics.

Which of the criteria were useful in this case?
Table 9. Scores and judgment for the DSS and processes used in the case study of fallow on red Earth soils (+ = not met, +++++ = fully met, NA=not applicable). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria for hard systems DSS success</th>
<th>DSS</th>
<th>Process</th>
<th>Meaningful for this case study?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Data must be available for specifying processes</td>
<td>+++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Biophysical representations must be dynamic not static</td>
<td>+++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Complexity and cost should be avoided</td>
<td>+</td>
<td>NA</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Uncertainty must be represented</td>
<td>+++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Farmer preferences and goals must be represented</td>
<td>+</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage of the elements relevant to a decision maker</td>
<td>+</td>
<td>++</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Involvement of the decision maker</td>
<td>+</td>
<td>+++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Customisation of the problem representation</td>
<td>+</td>
<td>+++</td>
<td>Maybe</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Used by participants, not researchers</td>
<td>+</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Capacity for comparative analysis</td>
<td>+</td>
<td>+++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>High relative accuracy, not necessarily absolute accuracy</td>
<td>+</td>
<td>+++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Tangible variables should be emphasised</td>
<td>+</td>
<td>++</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Intangibles require graphic representation</td>
<td>+</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Tools must be open to validation and interrogation to establish trust</td>
<td>+</td>
<td>+++</td>
<td>Maybe</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the purpose</td>
<td>NA</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the culture</td>
<td>NA</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the process and performance</td>
<td>+++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the people</td>
<td>NA</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td>McCown</td>
<td>Degree of realism must be high</td>
<td>+++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Must be easily parameterised to a specific site and situation</td>
<td>++</td>
<td>NA</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Ability to research management options with farmers must be high</td>
<td>+++++</td>
<td>++</td>
<td>Yes</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Depth to the user participation</td>
<td>NA</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Participation oriented to the user’s perspective</td>
<td>NA</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>A high degree of user influence on the system design</td>
<td>+</td>
<td>NA</td>
<td>No</td>
</tr>
</tbody>
</table>
Table 9 shows the scores for the 24 criteria, and Table 10 contains extra discussion of several criteria that were the most relevant in the case study.

Table 10. Selected criteria and interpretations from the case study concerning fallow length on red Earth soils. (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Biophysical representations must be dynamic not static</td>
<td>The biophysical representations in this study are well understood, and are dynamic and complex. Most models of similar complexity to APSIM can provide accurate estimates of fallow moisture accumulation. However, this accuracy comes with complexity and cost, so a trade-off exists between these criteria in some situations.</td>
</tr>
<tr>
<td></td>
<td>Complexity and cost should be avoided</td>
<td></td>
</tr>
<tr>
<td>Malcolm</td>
<td>Involvement of the decision maker</td>
<td>The decisionmakers were involved in that the “problem” was “theirs”. They defined the context and engaged me as the technician/user of the model. These were important elements of the process.</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Capacity for comparative analysis</td>
<td>This was highly desired by the farmers, and was specified in their hypothesis. The model was well-suited to this task, and the results appealed to farmers.</td>
</tr>
<tr>
<td></td>
<td>High relative accuracy, not necessarily absolute accuracy</td>
<td>The farmers expressed a need for relative accuracy. There were already farmers using the two systems being compared, but they wanted to know approximately “how often” and “how much” the benefits would be.</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the culture</td>
<td>This study involved farmers who were mostly “early fallowers”, interested in quantifying the benefits of “their” system. These results challenged the culture of early fallowing. The farmers probably expected much more frequent and sizable benefits from their farming system.</td>
</tr>
<tr>
<td>McCown</td>
<td>Degree of realism must be high</td>
<td>The farmers accepted the results as real. The degree of realism exceeded requirements.</td>
</tr>
<tr>
<td></td>
<td>Ability to research management options with farmers must be high</td>
<td>The ability to represent and explore farmers’ management systems was a key element of success.</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Participation oriented to the user’s perspective</td>
<td>I was concerned that farmers’ participation in this work involved thinking and acting from a researcher’s perspective (e.g. hypothesis testing). However, the hypothesis was very much “owned” by the farmer group, and the farmers effectively steered the process towards their desired conclusions.</td>
</tr>
<tr>
<td></td>
<td>Depth to the user participation</td>
<td>Feedback from the farmer group was that they enjoyed developing a research question with members of the WFSP team and discussing the model results.</td>
</tr>
</tbody>
</table>
Table 11 breaks the process into decision-making stages of Janis and Mann (1977), from the farmers’ perspective. This case is somewhat complex in terms of the decision stage. It was only in hindsight that I realised the farmers were NOT weighing two alternatives. Most, perhaps all of the farmers were “early fallowers”, and although they espoused an interest in weighing their current system against the alternative, for the purpose of deciding which system to operate, I recognised that in fact they were valuing their commitment to their current system. This makes sense in terms of the lack of interest in follow-up research. The farmers wanted to do a check that they were better off, even if only marginally, with their current system.

Table 11. Support given to participants in the fallowing case study at the various decision-making stages described by Janis and Mann (1977). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Decision-making stage</th>
<th>Level of support for decision stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appraising the challenge</td>
<td>None</td>
</tr>
<tr>
<td>Surveying alternatives</td>
<td>Done by project staff and farmers in a group meeting. They developed two scenarios that they wanted tested with the model.</td>
</tr>
<tr>
<td>Weighing alternatives</td>
<td>The farmers and project team recognised the difficulties of assessing the two options in the field. Using the model was very important for them achieving the comparison they were after.</td>
</tr>
<tr>
<td>Deliberating about commitment</td>
<td>The results were taken back to the farmers by project staff. My understanding is that the results were considered realistic, but no farmers would be changing their management. Most of them were already “early fallowers”. It seems that they were valuing a component of their current systems with the purpose of maintaining commitment, rather than surveying alternatives or weighing alternatives. It was not surprising that the farmers were happy with the results, which showed some benefits from early fallowing.</td>
</tr>
</tbody>
</table>

Findings and propositions:

1. The decision-making framework provided useful insight into the workings of this study. In particular, using the framework to understand that some, if not most, of the participants were NOT at the stage of Weighing alternatives. This highlighted the depth and complexity of the messages and signals between the decisionmakers and the project staff. As a project eager to foster co-operative decision-making, it was perhaps inevitable that some evaluation or assessment tasks might be painted as decision-support, either for the project’s, the staff’s or farmer’s benefits. To avoid confusion and collusion it is important that everyone’s motivations behind the work are revealed.
2. As in the previous case, the farmers in this study were involved as double loop learners, while I carried out the semantics of the single loop iterations (the detailed simulations). This arrangement suited the farmers who were interested in maintaining the independence of their assessment of the costs and benefits of early fallowing. It was also clear with hindsight that farmers were unconcerned about the processes and assumptions that I used for the “internal”, single loop. Perhaps they assumed that I would be a fair judge, or assumed that their skills were inferior to mine, but in any case their focus was on the consistency of the second loop messages with their own models – their previous assessments - of the costs and benefits of early fallowing.

3. It was important to know the culture of the farmers in this case study. I initially misunderstood the perspective of the farmers, and set about weighing alternatives, when the primary goal of many of them was later found to be a desire to reinforce and inform their commitment to the practice of early fallowing. Understanding the status quo would have provided greater insight to the real purpose of the study, and made the processes more effective. The second loop learnings from this study concerned costs and benefits of the decisionmakers’ own cultural-managerial norms.

4. Although the direct effort required to achieve the technical results in this case study was very small, it was wasted from the perspective of facilitating positive change in the farming system. Endorsing or reinforcing current behaviour is arguably inefficient and ineffective. It may be a challenge to the developers and implementers of DSS to engage users in scenarios that deconstruct and challenge rather than reinforce and corroborate their view of the system.

5. There were, however, learnings that were made that were important. The farmers did use the scenarios to test a system that was not current practice and was outside their “zone of comfort”. Their learnings at least had the potential to challenge the status quo and facilitate positive change. They also may have met the farmers’ needs in other ways, such as re-assurance that they run efficient systems.

These propositions and learning are followed up in the discussion.
Case 3: The FARM whole-farm budget

This case was developed in 1996 from a project by local consultants who were developing spreadsheet-based software for evaluating farm management options (Robinson et al. 1998). The aim of the software was to allow farmers, consultants and researchers anywhere in the grainbelt of Australia to assess both the profitability and sustainability of farms. Farmers, consultants and researchers came together in a number of workshops in 1996 and 1997 to specify the systems for quantifying profitability and sustainability. My principal role was to develop and modify the software to ensure that the farming system representations were consistent with the perceptions of the participants, easy to specify, and the logic and calculations in the spreadsheets were easy to understand.

Background

Farmers operate complex businesses. The complexity of the choices of enterprises and products and the farming systems required to successfully produce a range of products can make mixed farms difficult to manage. In southern Australia a “wheat-sheep” farm may produce canola, lupins, oats, barley or triticale as well as wheat, lambs, hoggets, ewes and wool. Wheat and the other grains are segregated into quality classes that have substantial price differentials and may require special farming methods. Even the simplest farming systems in the northern grain belt that have wheat as the sole crop produce wheat of different quantity and quality at different times, and the results often depend strongly on management.

Farmers also deal with land degradation, and this affects their business decision-making. Land and water are easily degraded or ruined by poor stewardship.

Despite the importance of both profit and stewardship in farm decision-making, farm business economics has not usually linked profits with the economics of land and water stewardship. Some recent studies have gone as far as relating soil management and consequent changes in soil erosion to wheat gross margin. However, a more comprehensive approach linking profit and sustainability at a farm level would be a useful advance.

Major objectives of many farmers, are to earn an adequate living and protect their resources. But how? Having a good mix of suitable enterprises is an essential ingredient of productive, sustainable farming. Suitable enterprises are usually those with a good balance of profit and sustainability, and a good mix enhances the performance of the individual enterprises. For example, pasture leys often have positive effects on the profitability and sustainability of wheat cropping systems.
So how do farmers choose suitable enterprises and a good mix of enterprises? In some locations, there are benchmarks for production or quality from enterprises or rotations. For example, maintaining 10% protein in wheat achieves Australian Standard White (ASW) prices and requires maintenance of available soil nitrogen. This usually involves legume leys in the south and fertiliser applications in the north. Other ways of selecting a farming system are to use trial and error (at least to fine-tune a system), or to mimic or make minor adaptations to systems that perform well.

While benchmarks, rules-of-thumb and mimicry may be useful, good management of individual farms is very specific (Malcolm 1990). Analysis of the circumstances of individual farms may be a way of improving management. Budgeting has been useful, and activity budgets, whole-farm budgets, partial budgets, cash-flow budgets and sensitivity budgets have been developed and applied in farming (Malcolm 1990). These are all relatively simple and powerful. More complex analyses of inputs, outputs and enterprise mixes are also possible. These include mathematical programming (MP) methods used in the MIDAS (Morrison et al. 1986) and PRISM (Robinson et al. 1995) models, and other tools such as dynamic programming. Simplicity is a major advantage of budgets over complex tools like MP.

Activity budgets that calculate gross margins (GMs) are very popular. However, they are not helpful for deciding enterprise mix or choice because they do not allow for inter-activity benefits and costs, and these are often important in determining the best enterprise mix or rotations (Morrison et al. 1986, Robinson et al. 1995). For example, GMs will allocate the benefits of legumes in rotations to later cereal crops because that is where the benefit is expressed in increased yield or price (for quality). Also, we usually calculate GMs on a per crop basis, and do not usually account for effects of crop frequency. For example, growing 2 crops with GMs of $100/ha each would be preferable to growing 1 crop in the same period with a GM of $150/ha. Whole-farm analysis also allows for the use of reduced/different machinery, labour, etc. when looking at substantial changes, such as introducing ley pastures, irrigation, intensive crops, share-farming, etc. Malcolm (1990) considers a crude analysis at a whole-farm level to be preferable to a detailed analysis of a small part of the farming system.

A whole-farm budget that easily allowed the user to compare enterprise mixes and rotations (including the sustainability costs) would be a very useful management tool. What was sought was generalised budgeting system to work for the major farming systems of the Australian cropping zone, allowing users to tailor the DSS to their particular needs. This case study describes the development and application of the DSS and evaluates the approach taken.
Development of FARM

The whole-farm budget was initially specified and developed as an Excel workbook. Consultation with other team members led to the development of a workbook with 6 spreadsheets, specifying land and machinery values and overhead costs, crop and pasture sequences, livestock production, crop gross margins (2 sheets - winter and summer crops), and results. Figure 24 shows the key parts of the crop and pasture sequences sheet and Figure 25 shows the main table of results. Users enter coded crop, pasture and fallow names in a sequence to specify cropping systems. A sequence is represented by entering codes from left to right (for up to 9 years, 5 shown). In this example, summer and winter crops and pasture (lucerne) are grown, with 1 sequence on soil type A and 2 sequences on soil type B. Note that although a linear, chronological sequence is represented in the input sheet, the calculated results are for an equal mix of all annual rotation components in all years. The annual yield and gross margin results for the example shown for soil type A in Figure 24 are static at two fourths of the annual results from sorghum-fallow, plus one fourth from sorghum-wheat and one fourth from mungbeans-fallow.

Codes are used to access yield and economic information from the crop and pasture GM sheets. All of the codes and the GM information are user-definable (e.g. wheat could be coded ‘w’ or ‘Hartog’, GMs for durum wheat or tomatoes could be added). Appropriate GMs are linked from separate spreadsheets.

Following the development of this part (Version 1), a workshop was convened (in Adelaide) to display and evaluate the budget and brainstorm the development of budgets for sustainability issues. Team members developed sections on issues that were important in their farming regions. Several sustainability issues were identified and methods of estimating their costs were devised. In each case, the cost was estimated as either the on-farm cost of the factor (soil erosion, acidification and structural decline) or the on-farm cost of ameliorating a
problem that usually occurs off-farm (salinisation). Some important issues were considered too difficult to cost, such as pesticide hazards. As well as continuous review and consultation with the workshop participants, improvements leading to Version 2 were based on a workshop in Toowoomba with consultants and scientists in late 1996.

### GM and profit (annual mean of rotation/sequence)

<table>
<thead>
<tr>
<th>GM from</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropping on soil A</td>
<td>$88,000</td>
</tr>
<tr>
<td>Cropping on soil B</td>
<td>$21,360</td>
</tr>
<tr>
<td>Permanent pastures</td>
<td>$19,080</td>
</tr>
<tr>
<td>Pastures on soil A and B</td>
<td>$2,480</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Overheads</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>$25,000</td>
</tr>
<tr>
<td>Machinery replacement</td>
<td>$34,420</td>
</tr>
<tr>
<td>Other overheads</td>
<td>$</td>
</tr>
<tr>
<td>Cost of working capital</td>
<td>$10,521</td>
</tr>
</tbody>
</table>

**Operating profit**  
$60,979

| Capital value ($ thousands)            | $1,460 |
| Return on capital (% per annum)        | 4.2%   |

Figure 25. Layout of part of the FARM results sheet, indicating GMs, overheads, operating profit and return on capital (at full equity). Machinery replacement is equal to depreciation. Data for a large farm on the Darling Downs. (Source: Robinson et al. 1998)

### Sustainability Costs

<table>
<thead>
<tr>
<th>Sustainability Costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Erosion - Soil Loss</td>
<td></td>
</tr>
<tr>
<td>Salinity - Loss of GM to Redress</td>
<td>$2,839</td>
</tr>
<tr>
<td>Acidity - Cost to Redress with Lime</td>
<td>$3,571</td>
</tr>
<tr>
<td>Wind Erosion Damage- Loss of GM</td>
<td>$108</td>
</tr>
<tr>
<td>Structural Decline - Loss of GM</td>
<td>$435</td>
</tr>
</tbody>
</table>

**Total Sustainability Cost**  
$6,953

**Op. Profit after Sustainability**  
$(2,936)

**Return on Capital after Sustainability Costs (% pa)**  
-0.3%

Figure 26. Layout of the sustainability costs as shown on the results sheet. These data are from a small mixed farm in southern NSW. (Source: Robinson et al. 1998)

Version 3 was developed from responses given by the farmer, advisor and researcher participants in workshops in Dalby, Muresq, Horsham, Bendigo, Wagga Wagga and Adelaide. At Dalby and Adelaide, the attendees filled out questionnaires concerning the concepts and usefulness of the system. Responses to the questionnaires generally indicated
A topical issue in the northern grain belt is whether sorghum growers would be better off growing dryland cotton. The GMs for cotton crops are higher than for sorghum, but cotton requires long fallows and the yields and costs are variable (see Table 12). Cotton is more intensively managed, needing extra labour, machinery and expertise. The example presented here is a synthesis of several analyses conducted in workshops in the region that grows both summer and winter dryland crops. The GMs and results are approximations only, and for brevity, only the economic results are discussed.

Table 12. Yield and price assumptions used in a FARM analysis of sorghum, wheat and cotton cropping options. Gross margins are shown for 2 sorghum and cotton farming sequences. (Source: Robinson et al. 1998)

<table>
<thead>
<tr>
<th>System</th>
<th>Sequence</th>
<th>Summer crop yield</th>
<th>Wheat yield</th>
<th>Crop gross margins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum</td>
<td>sorghum-winter fallow-</td>
<td>4.5 t/ha</td>
<td>3 t/ha</td>
<td>S=$323/ha*</td>
</tr>
<tr>
<td></td>
<td>sorghum-winter fallow-</td>
<td></td>
<td></td>
<td>W=$382/ha*</td>
</tr>
<tr>
<td></td>
<td>summer fallow-wheat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>cotton-wheat-</td>
<td>4.0 bales/ha</td>
<td>1 t/ha</td>
<td>C=$780/ha*</td>
</tr>
<tr>
<td></td>
<td>summer fallow-winter fallow</td>
<td></td>
<td></td>
<td>W=$62/ha*</td>
</tr>
</tbody>
</table>

* sorghum price = $130/t, cotton price = $440/bale, wheat price = $170/t, fallow costs = $35/ha.
Assumptions

Sorghum is grown in a sequence of sorghum, winter fallow, sorghum, winter fallow, summer fallow, wheat. Sorghum yield = 4.5 t/ha, net $130/t, giving a GM of $323/ha. Wheat yield = 3 t/ha, net $170/t giving a GM of $382/ha. Fallow costs are $35/ha summer or winter.

Cotton grown in a sequence of cotton, wheat, summer fallow, winter fallow. Cotton yield = 4 bales/ha, net $440/bale giving a GM of $780/ha. Wheat yield = 1 t/ha, net $170/t giving a GM of $62/ha. Fallow costs are $35/ha summer or winter.

The average GM for the sorghum sequence is $308/ha/year, and $386/ha/year for the cotton sequence. The high crop GM for the cotton sequence is attractive, however FARM also highlights some less obvious overhead costs, such as the opportunity cost of the working capital that is invested in crops. Because the costs of cotton are high, the opportunity cost of its capital is $25/ha/year, while sorghum’s is only $14/ha/year (@ 10% p.a. (with an investment period of 4 months for the variable costs).

FARM can calculate the effects of changes in other overhead costs. Taking the example above, a medium-sized farm (500 ha) may require extra casual labour ($5,000) and extra machinery ($50,000 for planter and spray rig upgrades and a stubble buster, replaced at 10% p.a.), so overhead costs could increase by $10,000. After including these costs the operating profits of the cotton and sorghum sequences are $105,000 and $82,000 p.a. respectively. This is a smaller difference than one might think, given the cotton and sorghum crop GMs of $780/ha and $323/ha. This clearly shows the deficiency of comparing the GMs of dissimilar crops and enterprises.

FARM can be used to examine the effects of changing the assumptions, and can help work out the conditions where 2 systems are equal in profit or sustainability. Take the example above, where the sorghum and cotton sequences have operating profits of $82,000 and $105,000 p.a. By changing the sorghum yield and observing the changes in profit the user is able to find the yield necessary to match cotton. The results are: 4.5 t/ha = $82,000, 4.75 t/ha = $92,000, and 5 t/ha = $102,000 p.a. Therefore, the sorghum system is effectively as profitable as cotton if an average yield of 5 t/ha is achieved. This may be important information for a farmer comparing the 2 systems. A farmer might well be able to achieve the higher yields and profit within their sorghum system with fewer management changes than if they changed to cotton. A similar analysis shows that a price change for sorghum from net $130/t to $145/t has the same effect on profit, highlighting the strong influence of price on the relative profitability of the 2 systems.
Technical summary

Farming is a technically complex business where profit and sustainability affect management. Ideally, farm management tools would consider both profit and sustainability. FARM addresses both farm profitability and sustainability, and helps managers to evaluate and compare farming systems.

FARM integrates enterprise budgets into a whole-farm budget. The costs of soil erosion, acidification, salinisation and soil structural decline are estimated. The user can specify the enterprise budgets and all of the cost, price and yield data, so FARM is very flexible.

Much of the input data is specific to individual farms and farmers and is subjective but relevant. Although the use of estimated, somewhat subjective input data might have biased the results, this is generally considered preferable to the alternative of imposing external estimates of input data that might have been more technically accurate for another situation.

FSR interactions and learnings

FARM was developed iteratively with users from its inception. The result was a system that could be applied by those users (and others) to analyse many scenarios from a farmers’ or consultants’ perspective. This is no small achievement.

To develop this DSS, I simply observed and collected farmers’ and consultants’ concepts and analyses. FARM was a novel collection of concepts and analyses, but nothing in FARM was novel. Indeed, the familiarity of its concepts was a major strength.

The sensitivity analyses available with FARM have been popular with farmers and consultants. Conducting the analyses in close consultation with farmers has had 2 important advantages: realistic scenarios are developed, and managers are able to rapidly evaluate results. Although FARM and similar management tools can be applied in isolation from data concerning particular farms and farmers, it is naive to believe that the results could then be applied on farms or be relevant and interesting to farmers. Farmers and their consultants have very different interests to scientists and operate under different environmental and economic conditions. Farmers can conduct highly relevant analyses with FARM because they use their own data. Although the input data may then be biased (i.e. wrong) and the biases may have complex origins, they are clearly and simply expressed in FARM in the yields, costs, prices and a few other factors. This is quite different to complex MP and simulation models that conceal biases in complex arithmetical and logical expressions. This transparency of the assumptions and biases in FARM gives it a substantial advantage over more complex “black box” farm management tools.
The various applications of FARM discussed above are all management games of one sort or another, and the playing is obvious when FARM is used in workshops. FARM often provided a high-energy environment for discussion and testing various theories, as well as many of the other advantages of a simulation game for management learnings. The players:

- Formulated goals and strategies,
- Isolated and worked on the sensitive parts of the system, and
- Tested both the virtual agricultural system and their own ideas in a financially (but not psychologically or socially) risk-free environment.

By late 1997, the project had appointed a new, specialist economist who already had spreadsheet tools for whole-farm analysis. Although FARM was available to him, I saw little evidence that he used it. This is consistent with suggestions that DSS require “champions” to promote them (Lynch et al. 2000).

*Which of the criteria were useful in this case?*

Table 13 shows scores for the 24 criteria, and Table 14 contains extra discussion of several criteria that were the most relevant in this case study.

Table 15 breaks the process into decision-making stages, from the farmers’ perspective. It shows that the spreadsheet DSS and associated processes offered broad support for decisionmakers, relative to the previous examples.
Table 13. Scores and judgment for the DSS and processes used in the case study of developing and using the FARM whole-farm budget (+ = not met, ++++= fully met, NA=not applicable). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria for DSS success</th>
<th>DSS</th>
<th>Process</th>
<th>Meaningful for this case study?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Data must be available for specifying processes</td>
<td>+</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Biophysical representations must be dynamic not static</td>
<td>+</td>
<td>NA</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Complexity and cost should be avoided</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Uncertainty must be represented</td>
<td>++</td>
<td>NA</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Farmer preferences and goals must be represented</td>
<td>+</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage of the elements relevant to a decision maker</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Involvement of the decision maker</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Customisation of the problem representation</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Used by participants, not researchers</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Capacity for comparative analysis</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>High relative accuracy, not necessarily absolute accuracy</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Tangible variables should be emphasised</td>
<td>+</td>
<td>++</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Intangibles require graphic representation</td>
<td>+</td>
<td>++</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Tools must be open to validation and interrogation to establish trust</td>
<td>+++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the purpose</td>
<td>+++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the culture</td>
<td>NA</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the process and performance</td>
<td>+++</td>
<td>NA</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Know the people</td>
<td>+++</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td>McKown</td>
<td>Degree of realism must be high</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Must be easily parameterised to a specific site and situation</td>
<td>++</td>
<td>NA</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Ability to research management options with farmers must be high</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Depth to the user participation</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Participation oriented to the user’s perspective</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>A high degree of user influence on the system design</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Table 14. Selected criteria and interpretations from the case study concerning whole-farm profitability and sustainability. (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Biophysical representations must be dynamic not static</td>
<td>There was a conflict between these two criteria in this case. Farmers indicated that they deal with discrete paddocks and years of production. This static model of the farm matched their perceptions, and was effective because it enables farmers to interact “naturally” with the DSS. Therefore, preferences were more important than dynamic representations.</td>
</tr>
<tr>
<td></td>
<td>Farmer preferences and goals must be represented</td>
<td></td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage of the elements relevant to a decision maker</td>
<td>Coverage of the elements was achieved by using traditional methods, such as gross margins for the enterprises, which have evolved to successfully deal with many situations. This was very useful.</td>
</tr>
<tr>
<td></td>
<td>Involvement of the decision maker</td>
<td>Many of the inputs were familiar to, and chosen by farmers. This depth of involvement improved the outcomes.</td>
</tr>
<tr>
<td></td>
<td>Customisation of the problem representation</td>
<td>Throughout the development process the spreadsheets were customised to meet the needs of the users. Farmers, researchers and consultants were enthusiastic about the co-development process.</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Capacity for comparative analysis</td>
<td>Enthusiasm for the comparative analysis</td>
</tr>
<tr>
<td></td>
<td>Tools must be open to validation and interrogation to establish trust</td>
<td>Validity and trust were quickly established. Farmers often regarded the DSS as a handy “calculator” for their ideas. Emphasis usually shifted from the validity of the outputs to the validity of the inputs.</td>
</tr>
<tr>
<td>McCown</td>
<td>Must be easily parameterised to a specific site and situation</td>
<td>The ease with which this DSS is tailored to a specific farm and its ability to explore management are important factors in its success. This farmer-oriented DSS met these criteria and was effective for doing so – a major advantage over simplistic and complex DSS.</td>
</tr>
<tr>
<td></td>
<td>Ability to research management options with farmers must be high</td>
<td></td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Depth to the user participation</td>
<td>First explaining the system and thereafter having the farmers make the choices and “run” the analyses was empowering for the farmers and effective in problem solving. Problems explored with the DSS were different to those perceived as important by the researchers.</td>
</tr>
<tr>
<td></td>
<td>Participation oriented to the user’s perspective</td>
<td></td>
</tr>
</tbody>
</table>
Table 15. Support given to participants in the whole-farm budget case study at the various decision-making stages described by Janis and Mann (1977). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Decision-making stage</th>
<th>Level of support for decision stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appraising the challenge</td>
<td>At each session, farmers and researchers discussed the contemporary issues and opportunities. This provided good grounding for the work that followed. Many of the challenges were seen to be systemic rather than enterprise-based.</td>
</tr>
<tr>
<td>Surveying alternatives</td>
<td>In most cases, a few alternatives were discussed. However, this should probably have received more attention. Both farmers and researchers were keen, perhaps too keen, to get to Weighing alternatives.</td>
</tr>
<tr>
<td>Weighing of alternatives</td>
<td>Lots of time was spent assessing alternatives and discussing the possible responses in the farming system to the alternatives.</td>
</tr>
<tr>
<td>Deliberating about commitment</td>
<td>Many farmers were interested in sensitivity analyses. In general, they would only commit to a system change or new technology if it was estimated to be profitable under conservative assumptions. There were some exceptions - on one occasion, I saw a farmer group make very bullish assumptions about the gains available from some technology (controlled traffic). I found that they had already been committed to that technology (at least mentally if not financially) and were exploring its potential gains under ideal conditions.</td>
</tr>
</tbody>
</table>

Findings and propositions:

1. The decision stage framework was useful for interpreting the behaviour of decision makers. Many farmers and consultants used FARM to explore options, and never moved through to the weighing alternatives stage. As in case 1 (N fertilisers), there was evidence that quick, representative parameterisation of a relatively “crude” model was sufficiently revealing for them to explore new management options to a depth that was satisfactory. It was much more likely to be researchers, with narrowly defined purposes (mostly theoretical) and optimisation as goals, who suggested the addition of detail to the DSS. As well as an inherent interest in detail and skills in reductionism, this behaviour may also be a researcher’s compensation for their lack of experience and skills in farm management. Farmers and consultants may be able to explore and make appropriate decisions about management options quickly and without detail.

2. A framework that let farmers explore the quantitative implications of their own perspectives, biases and values was empowering for farmers. As Ridge and Cox (1996) suggested, the advantages of researchers’ models are likely to be their quantification of factors, and the advantages of farmers’ models includes a substantial basis in experience and skill. This model provided a framework for capturing experience and skill, without introducing excessive reductionism or counter-intuitive processes. Of course, there was a range of acceptance among the farmers and
consultants concerning the DSS, but the main concerns were about excessive maths and input parameters, not the limited capacity for analysis. A question arising from this is how to determine, and who should be determining, the right amount of analysis and learning for a problem? In the context of action learning cycles, the goal would be to maintain an effective double learning loop, monitoring progress, and call a halt when needs are met. I suspect, however, this is much more difficult in practice, due to institutional and other factors, and explains why Lynch et al. (2000) and others find that DSS use is often self-serving. I was most fortunate in the WFSP that I was not committed to particular methods or DSS or a timetable.

3. Some farmers and consultants were interested in using the DSS to explore management in an environment free of financial risk or climate variability. These users explored options that surprised many of the other workshop participants, and added considerably to the learnings of the group. As in the first and second case studies, this highlighted that single loop learnings of individuals could be effectively translated into double loop learnings for a wider group. Simulations of farm management appear to be an effective means of learning, not only for farmers and consultants, but for researchers as well (Stewart et al. 2000).

4. An essential part of the system was to go through many iterations of both the single loop and double loop learning. It would be naïve to expect that experienced farmers and consultants would be interested in analysing only one or two management options. Yet that is what is expected where real-time simulation and analysis are offered to decisionmakers as support systems. Instead, I suggest that systems that iterate through multiple seasons, multiple decision points etc, will encourage greater learning by developing more double loop learning, rather than learning about a small collection of single points. As found by Stewart et al. (2000) and Hochman et al. (2000), accelerating the experiences increased the learnings, even if they were virtual experiences.

5. From a time when it was enthusiastically embraced, FARM has declined into relative disuse. FARM is accessible via the WWW, and is downloaded a few times per month. Only recently has logging of the downloaders and their interests begun. Reflecting on the “life cycle” of FARM is informative. As explained in the case study, FARM was developed relatively quickly and inexpensively (perhaps $100,000 total cost) relative to other models of farming systems. Although once favourably compared with those more complex and expensive cropping systems models by farmers, consultants and researchers, it is rarely used. This is undoubtedly due to a lack of promotion. It is more than four years since it has been promoted or supported by more than the web presence. Similarly, Hayman and Easdown (2002) found that promotion, and a DSS “champion” were critical to the success of the Wheatman DSS. They found that its use declined due to promotion of a competitor and a loss of institutional support. This “life cycle” of DSSs, where they are mostly unable to be self-supporting without external supplies of funds and researchers, is suggestive of
one or more of these: (i) unwise development of irrelevant DSS, (ii) unwise non-adoption of relevant DSS, or (iii) the researcher-technology-DSS “package” being the attraction, resulting in disadoption of the DSS when it is offered alone.

6. This DSS developed at a time when spreadsheets were becoming familiar technology to researchers and consultants. A critical success factor in the development of FARM was that consultants and researchers could explore the mathematical semantics of the system, and the farmers and consultants could explore the purpose of the system. Today, spreadsheet skills are more common, and there would probably be less technological appeal (i.e. novelty) in developing and applying such a system.

These propositions and learning are followed up in the discussion.
Case 4: Value of the southern oscillation index (SOI) for crop management

This case was developed through interaction with farmers and one farmer group in particular (in the Roma area) who were familiar with the use of the SOI as a climate-forecasting tool. The case study examines activities beginning in 1999 with a discussion between farmers from the Wallumbilla area (approx. 50km east of Roma) and researchers, and finishing in 2002 with the publication of a scientific paper indicating that the value of the SOI had been overestimated (Robinson and Butler 2002).

Scientific publications had shown the merits of using the SOI for crop management (Meinke and Hammer 1995, Hammer et al. 1996). Because the effects of the SOI were regarded as localised and the validity of methods used to value the SOI had been assumed rather than tested, this study involved estimating the value of the SOI at St George in the study region and Dalby, a major grain-growing centre in the northern grainbelt where previous studies had valued the SOI.

Introduction

The 5 phases of the Southern Oscillation Index (SOI) are well-known climate indicators; a survey by Hayman and Alston (1999) indicated that 10% of wheat farmers in the northern New South Wales always or often use climate forecasts in their N fertiliser decision-making. The phases have been shown to be useful through their associations with changes in the frequency distributions of rainfall amounts (Stone and Auliciems 1992) and frost incidence (Stone et al. 1996).

Studies of managing wheat crops according to the phases of the SOI have reported major benefits. Hammer et al. (1996) found “Significant increase[s] in profit (up to 20%) and/or reduction in risk (up to 35%) were associated with tactical adjustment of crop management of N fertiliser or cultivar maturity”. Other studies of the phases have also found that they are valuable in making crop management decisions (Abawi et al. 1995, Meinke and Hammer 1995, Meinke and Stone 1997, Meinke et al. 1998).

However, while these studies identified improvements in the mean and distributions of outcomes from SOI targeted management, these benefits were estimated from the same data used to identify the optimum management strategies. The outcomes are probably optimistic because the chosen management strategies are optimal for the data; but would not necessarily be so for new (independent) observations.

To realistically assess the benefits, if any, of SOI-targeted management for independent data, two methods of testing are available: (i) test new data as they arise on an annual basis, or (ii)
use part of the data to develop an optimum management strategy and the remainder to assess its value. We have followed the latter strategy below because it avoids waiting several years for even a small amount of test data to accumulate.

The aim of this case study is to assess the economic value of SOI-targeted management strategies in the northern grainbelt when applied to observations not used in the derivation of those particular management strategies. Comparisons will be made between assessments of the value of the SOI based on the previous method and the new method, and the value of the SOI in six case studies will be benchmarked.

Methods

Six case studies are analysed to assess the value of the SOI-targeted management: selecting N fertiliser rates at Dalby in 2 cases with different levels of plant available soil water (PAW) at sowing, selecting N fertiliser rates at St George in 3 cases with different levels of PAW, and a case of selecting wheat varieties at Dalby. Outcomes for the management options were simulated with a wheat model (Iwheat, Meinke et al. 1997) for the period 1888 - 1997. Soil nitrogen, soil moisture and other factors were simulated in various modules within the Agricultural Production System Simulator (APSIM, McCown et al. 1996). Profit was calculated from the yield, protein content, and assumptions about costs and commodity prices (described below).

At Dalby, variety Hartog was simulated with either 60 or 90 cm depth of moisture in a black vertosol at sowing (plant-available water capacity, PAWC= 321 mm). Soil nitrate at sowing was 89 kg N/ha. Six fertiliser rates (0, 20, 40, 60, 80, and 100 kg N/ha) were simulated in each case. A third case at Dalby (Dalby variety) involved three varieties (Hartog and two longer-season varieties, with 90 cm depth of wet soil and 40 kg N/ha of fertiliser), and simulation of frost, by the method of Hammer et al. (1996). At St George, three cases (St George 60, 90, and 120) involved sowing with 60, 90, or 120 cm of wet grey vertosol (PAWC=215 mm). Soil nitrate equal to 59 kg N/ha and three rates of fertiliser (0, 20, and 40 kg N/ha) were simulated in each case.

The simulated sowing date was 1 June. Profits (AUS/ha/year) were calculated from the following data. Fertiliser cost $1.00 per kg N, and for rates of 40 kg N/ha and higher, an extra pre-plant application cost of $10/ha was included. Wheat prices, net on-farm, varied with grain protein: < 10% = $120/t, >10% and < 11.5% = $150/t, >11.5% and <13% = $175/t and >13% = $200/t. Annual non-fertiliser variable and fixed costs were assumed to be $100/ha each for St George, and $150/ha and $200/ha respectively for Dalby.
In each month of each year, the SOI can be in any 1 of 5 phase states: 1, consistently negative; 2, consistently positive; 3, rapidly falling; 4, rapidly rising; 5, near zero (Stone and Auliciems 1992). This study assessed the phase states in both March-April and April-May of each year, initially concentrating on April-May because it is considered a better indicator of subsequent seasonal conditions (Roger Stone, pers. comm.).

APSIM was used to estimate yield, protein and profit for each N rate or variety in each year. The economic value of SOI-targeted management, over and above the most profitable long-term (“fixed”) N rate or variety, was calculated from these data by two separate methods:

1. Fitting values. The annual value ($/ha/year) of adjusting the fertiliser rate or variety was assessed against the best of the fixed management strategies (i.e. across all 5 phases). The annual value is the extra profit for each year (1888 - 1997) from using the best strategy for each phase instead of the fixed strategy. Best management strategies were taken to be the ones with the highest average profit for each phase. We calculate an empirical distribution function (EDF) from these profit values, that are referred to subsequently as the fitted outcomes (F).

2. Predicting values, where the SOI-targeted management strategy is determined for all but one year, then it is valued by application to that one year. The process is repeated for all years (1888 – 1997), and then an EDF of the profit values is calculated in the same way as the fitted outcomes. This is analogous to the leave-one-out method of cross-validation (Efron and Tibshirani 1993, Chapter 17). These are subsequently referred to as predicted values (P) because the predictors are distinct from the predictand.

To explore the range of potential outcomes that may occur by simple chance from the two methods in the six examples studied, 100 sets of randomly selected phase labels (i.e. dummy labels) were valued. The resultant EDFs of profit from random number-targeted management are denoted F and P below (fitted and predicted values, respectively). Of course, sound methods of valuing SOI-targeted management will not attribute value to management strategies based on random numbers (when compared with the optimal long-term strategy). Methods that over-value strategic management, such as those calculating economic benefits from random number-targeted management, are often affected by what is known as artificial skill. Methods that segregate the predictors and outcomes (such as our method P, above) may be less affected by artificial skill than methods that do not (such as the previous method F, above).

Results
The EDFs of the fitted (F) and predicted (P) outcomes for the April-May SOI phase vary in central tendency, range and skewness between phases for all cases except St George 120 (Figure 27). Not surprisingly, there is also considerable variation between cases in the central tendency, range and skewness of outcomes. Estimates of the average value of each phase for the data in Figure 27 are given in Table 16. The value of the phases varies widely between examples and is not always positive. The estimated long-term values are consistent between fitted and predicted outcomes for phase 1 in all cases, and for various other combinations of cases and phases. Where the distributions differ in range and/or skewness there is a general tendency for the average value of the fitted outcomes to be optimistic relative to the predicted values (Figure 27 and Table 16).

![Figure 27. Box-whisker plots of the distributions of fitted (F) and predicted (P) outcomes (X axis, AU$/ha). AU$0/ha indicates an outcome equal to the best fixed management strategy. (Source: Robinson and Butler 2002)]](image-url)
In Figure 27, the box, whiskers and stars represent the mid quartiles (lowest 25 % to highest 75 % of values), the mid 95 % of values, and outliers, respectively. Different scales are used for each case. Note that differences between the outliers account for the main differences between the pairs of distributions (F and P) in several instances.

Table 16 The mean value (AUS$/ha/year) of the fitted (F) and predicted (P) outcomes of SOI-based management of N fertiliser rates or wheat varieties. (Source: Robinson and Butler 2002)

<table>
<thead>
<tr>
<th>Case study</th>
<th>Method</th>
<th>SOI phase</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
<th>(all years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Dalby 60 cm of wet soil</td>
<td>Fitted</td>
<td>37.10</td>
<td>0.00</td>
<td>38.60</td>
<td>5.80</td>
<td>5.10</td>
<td><strong>13.70</strong></td>
</tr>
<tr>
<td></td>
<td>Predicted</td>
<td>37.10</td>
<td>-24.60</td>
<td>38.60</td>
<td>-0.20</td>
<td>-1.00</td>
<td><strong>5.50</strong></td>
</tr>
<tr>
<td>Dalby 90 cm of wet soil</td>
<td>Fitted</td>
<td>14.40</td>
<td>0.00</td>
<td>0.00</td>
<td>3.30</td>
<td>0.40</td>
<td><strong>3.20</strong></td>
</tr>
<tr>
<td></td>
<td>Predicted</td>
<td>14.40</td>
<td>0.00</td>
<td>-13.40</td>
<td>-2.10</td>
<td>-11.90</td>
<td><strong>-3.00</strong></td>
</tr>
<tr>
<td>Dalby Variety</td>
<td>Fitted</td>
<td>25.30</td>
<td>27.00</td>
<td>33.10</td>
<td>0.00</td>
<td>0.00</td>
<td><strong>14.00</strong></td>
</tr>
<tr>
<td></td>
<td>Predicted</td>
<td>25.30</td>
<td>27.00</td>
<td>33.10</td>
<td>-46.40</td>
<td>0.00</td>
<td><strong>3.00</strong></td>
</tr>
<tr>
<td>St George 60 cm of wet soil</td>
<td>Fitted</td>
<td>4.90</td>
<td>0.00</td>
<td>0.00</td>
<td>5.60</td>
<td>0.00</td>
<td><strong>2.10</strong></td>
</tr>
<tr>
<td></td>
<td>Predicted</td>
<td>4.90</td>
<td>0.00</td>
<td>-6.90</td>
<td>5.60</td>
<td>0.00</td>
<td><strong>1.20</strong></td>
</tr>
<tr>
<td>St George 90 cm of wet soil</td>
<td>Fitted</td>
<td>0.00</td>
<td>3.20</td>
<td>0.00</td>
<td>2.40</td>
<td>0.50</td>
<td><strong>1.40</strong></td>
</tr>
<tr>
<td></td>
<td>Predicted</td>
<td>0.00</td>
<td>-16.50</td>
<td>-9.10</td>
<td>-18.70</td>
<td>-23.10</td>
<td><strong>-15.10</strong></td>
</tr>
<tr>
<td>St George 120 cm of wet soil</td>
<td>Fitted</td>
<td>6.50</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td><strong>1.10</strong></td>
</tr>
<tr>
<td></td>
<td>Predicted</td>
<td>6.50</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td><strong>1.10</strong></td>
</tr>
<tr>
<td>Number of years</td>
<td></td>
<td>18</td>
<td>23</td>
<td>14</td>
<td>26</td>
<td>29</td>
<td><strong>110</strong></td>
</tr>
</tbody>
</table>

Management was based on the April-May phase of the SOI. Values rounded to nearest $0.10/ha/year.

In all cases the average fitted values are positive in all phases, and range from $1.10 /ha (St George 120) to $14.00 /ha (Dalby Variety) (Table 16). The average predicted values include losses in some phases, and the averages are considerably lower (-$15.10 to $5.50), with economic losses for both Dalby 90 and St George 90 examples.

The March-April SOI phases are acknowledged as having less predictive skill with respect to rainfall amounts in the subsequent cropping seasons (Roger Stone, pers. com.). Results for the predicted values are consistent with this principle: they indicate the March-April phase is less valuable than the April-May phase: using these phases was more profitable than fixed management in only 1 of the 6 cases (St George 60), while the phases in April-May produce an increase in overall profit in 4 of the 6 cases, ranging up to $5.50/ha/year (Table 16). However, fitted values for the March-April phases compared favourably with the April-May
phases in 3 of these cases (Dalby variety selection, St George 60 and St George 90, data not shown).

All changes in profit were small, especially in relation to the annual variability. The annual sequence of predicted outcomes (P, $/ha) for the phases in April-May for Dalby 60 is shown in Figure 28. This case, where SOI-adjustments were most profitable (Table 16) demonstrates the occurrence of both frequent annual losses (41% of years) and gains (42% of years). The overall gain is strongly influenced by the benefits of phase 1 and phase 3 years (Figure 27). The small size of most of the losses is because they represent expenditure on fertiliser that does not result in a yield or protein/price response (commonly -$20/ha for 20 kg N/ha applied without economic benefit). However, the long-term average increase in profit of $5.50/ha/year is obviously small relative to the annual variability (Figure 28). Short-term profit (2 – 20 years) from targeted management will be strongly affected by annual variability in cases such as this. For example, some 10-year totals of the values shown in Figure 28 are: 1900-09, $93/ha; 1910-19, -$59/ha; 1920-29, -$204/ha; 1930-39, -$5/ha; 1940-49, $217/ha. The highest 10-year total in this case was $247/ha from 1972-81 and the lowest -$328/ha from 1912-21.

![Figure 28. The predicted value (extra profit, $/ha) of the SOI phases for N fertiliser management in wheat at Dalby (60cm of wet soil at sowing). (Source: Robinson and Butler 2002)](image)

There was considerable variability in predicted values of the phases for managing N fertiliser decision-making at St George. An overall loss of $15.10/ha/year was calculated for the St George 90 case using the April-May SOI. This value was because less profitable decisions would be made in 47% of years and there was a high average cost of these losses. SOI-adjusted management increased profit in only 9% of years in this case, which was the only
one where management targeted at phase 1 was economically neutral. Economic benefits in the cases with 60 cm or 120 cm of wet soil were also modest, especially in relation to the annual variability. All phases except 1 were economically neutral at St George 120.

The results for the random phases (Rf and Rp, Figure 29) show the average estimated returns are consistently lower and the variance higher for the predicted values. The differences are an indication of the potential for artificial skill in these 6 cases if SOI-targeted management was assessed in the absence of independent validation data.

![Box-whisker plots of the distributions of fitted (F) and predicted (P) outcomes for dummy (random) SOI phases in the 6 case studies. (Source: Robinson and Butler 2002)](image)

**Discussion**

When using the predicted (P) method, the variability between years within a phase is sufficient that when each individual year is excluded from the data, a diversity of “optimum” management strategies appears within each phase. Not surprisingly, this leads to many annual outcomes that are less profitable than those obtained from a single strategy optimised over all years in each SOI phase, as in the fitted method (F). The difference in all-years value across the cases between the fitted and predicted outcomes ranged from $0 /ha/year to -$16.50 /ha/year. Although it would be unwise to generalise, the cases presented in this study indicate that the value of managing according to the SOI phases may frequently be less than previously estimated, due to the bias in the previous method where strategies were fitted to the data and then valued without independent data.

When viewed across all phases there seems little or no extra profit to be made from SOI-targeted management. However, this simplification may obscure potential benefits that seem to exist in specific phases and cases. For example, targeted management for phase 1 was neutral or profitable in all 6 cases studied here. Although this result is by no means
definitive, one response to this information could be to adopt an SOI-based strategy for phase 1 years, and adopt a neutral or more conservative approach otherwise.

The positive fitted values (F) attributed to intrinsically valueless random numbers (Figure 29) suggest that the methods used in previous studies resulted in overestimates of the value of SOI-targeted management. In all 6 cases, that method attributed positive economic values to numerous sets of random numbers. However, while this casts considerable doubt on the appropriateness of the method used in previous studies, this result (on its own) does not imply there is no value in the phases of the SOI for crop management. In fact, the average results for some of the case studies (Table 1) tend to fall in the positive tail of the distributions in Figure 29, providing some evidence of forecasting skill above that contained in random numbers. For example, for Dalby 60, the mean of F = $13.70/ha/year and the mean of P = $5.50/ha/year, both of which are in the top quartile of the distribution of outcomes for sets of random numbers. Examination of Table 16 and Figure 27 suggest that SOI-targeted management in phase 1 is largely responsible for benefits over and above those of random numbers.

What are the sources of the differences between the fitted and predicted values? Figure 27 shows that the central ranges of values of F and P are usually similar. The differences in the mean values of F and P (Table 16) are mainly caused by combinations of (i) failing to make some of the highly profitable choices of F (e.g. St George 90, phases 2, 4 and 5) and (ii) making some large losses under P (e.g. Dalby variety, phase 4). These differences between F and P hinge on the differences in the datasets used and the consequences of different choices. Although the rule-making datasets differ only by single year, the differences were sometimes considerable because of the small number of years and high variability in each SOI category (Table 16). The consequences of choice also varied considerably between the cases. For example, choice could be very important in the Dalby variety case, where a poor choice of variety could lead to frost damage and a total loss of yield (see the negative outlier in phase 4, Dalby variety, Figure 27). Overall, in the 6 cases studied, the associations between the SOI phases and management options are not sufficiently uniform to consistently make gains or avoid losses. Given the variability of the outcomes, there is a relatively high likelihood, and near equal chance, of either substantial economic gains or losses from tactical management in the short-term, as shown for the Dalby 60 case in Figure 28.

To gauge the relative merits of managing fertiliser rates and varieties according to the SOI, it can be compared with the value of other management changes or resources. In the northern grainbelt, good fallow management is important to accumulate and conserve soil moisture. Data from these case studies can be used to show that an extra mm of soil moisture available at sowing is worth about $5/ha/year of extra profit at Dalby and St George. For example, the average difference in profit between Dalby with 60 cm of wet soil and 90 cm of wet soil is $366/ha/year (at 40 kg fertiliser N/ha/year). The difference in PAW at sowing is 69 mm, so
the return from extra PAW in this example is $5.30/ha/year/mm. Comparison with the most profitable cases of phase-targeted management in Table 16 shows that the benefits are approximately equivalent to storing 1 mm and 0.25 mm of PAW at sowing at Dalby and St George, respectively.

From a farmer perspective, it could not be recommended to use the SOI phases to adjust management in cases such as those examined here.

Technical summary

Previous studies have identified structure and economic value in the distribution of outcomes from SOI-targeted management, but may have overestimated the value of tactical management because of the lack of independent evaluation data. The method described here attempts to overcome this by evaluating apparently optimal management strategies on years not included in the development of the rules. This approach recognises the heterogeneity within phases and that the (apparently) optimal rule for a given phase may change with the composition of the phase.

Although the results show that SOI-targeted management could not be recommended in these cases overall, there were also indications that a relatively reliable benefit may be obtained from altering N fertiliser and variety management in years with an April-May SOI phase of 1 (consistently negative). However, the relationship requires further investigation and wider evaluation.

FSR learnings and summary

This research had a considerable effect on the FSR community, especially conflict created between groups of researchers who had chosen different levels of enthusiasm for the use of the SOI phases for crop management. In contrast, there was almost no effect in the farming community. Few, if any, farmers in the grower groups had been “devoted followers” of the use of the SOI. At first, this seems inconsistent with the survey of Hayman and Alston (1999) who found that 10% of farmers take the SOI into account. However, the farmers may consider many things without being convinced that they are effective for guiding management. I can only assume that this was the case here, because the news that the SOI could not be used to more profitably manage their winter crops was not very surprising to most farmers. There had been a range of positive and negative experiences in trying to use the SOI, so it was not surprising that some farmers saw my work as corroborating their experience of variable results, which had previously been puzzling in the context of institutional and personal advocacy for the SOI.
Among a few farmers and myself, there remains an active interest in the prospects for some increased profit through better forecasting tools and new management situations.

Despite four years already having passed since this research and analysis were first debated, some of my peers are still uncomfortable with these results, the communication processes and the threat this posed to their status. There was an interesting dichotomy in the response of some of the scientists who obviously went beyond reliance on empiricism and deductive reasoning to reach positions concerning the value of the SOI. Their opinions were immutable – or at least untouched by the evidence. There seems to have been a shift in some people from thinking that the SOI had value to believing it (i.e. as an act of faith). Most farmers, on the other hand, had never believed, or had a more pragmatic or rational interest in the value of the SOI – relying less on faith and having a more flexible approach to the new evidence.

Which of the criteria were useful in this case?

Table 17 shows scores for the criteria, and Table 18 contains extra discussion of several criteria that were particularly relevant in this case.

Table 19 breaks the process into decision-making stages, from the farmers’ perspective.

Findings and propositions:

1. Janis and Mann’s (1977) framework again proved valuable for increasing understanding of the role of the hard systems analysis. Most farmers were appraising the SOI as a means for reducing the impact of seasonal and annual variability, or were deliberating about commitment to the SOI. Detailed analysis of options was not appropriate for their stages of the decision-making process.

2. Some of the scientists had a mind closed to the results, while most of the farmers were open and interested. Understanding the culture of both groups could have minimised or bypassed the conflicts that developed concerning the results.

3. The researchers and a few farmers had very strong emotional and intellectual bonds to prior results and beliefs concerning the value of the SOI. This parallels the suggestion of McCown et al. (2002) that developers of DSSs feel great attachment to, and affection for the products of their labour. Given that such attachments have impeded the advancement of honest evaluation of the SOI, it seems likely that the impact of such attachments on honest evaluation and better development of DSSs may be very large.

4. The process did not resemble the action learning cycles, and was more like traditional research and extension. However, the process was very effective. Farmers did not express any interest in being involved in the research component of this case. The participation consisted mainly of obtaining a clear perspective of farmer’s questions
and decisions, and dialogue concerning the results. The participants did not wish for the action-learning process and more participation by farmers in this case. From this I have learned to be cautious of RD and E that prescribes a research process in relation to a pre-determined preference, and expects certain amounts and levels of participation.

These propositions and learning are followed up in the discussion.
Table 17. Scores on the criteria for the study valuing the SOI. Meeting the criteria does not predict success in this case study, because the study was ineffective. (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria for DSS success</th>
<th>DSS</th>
<th>Process</th>
<th>Meaningful for this case study?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Data must be available for specifying processes</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Biophysical representations must be dynamic not static</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Complexity and cost should be avoided</td>
<td>+</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Uncertainty must be represented</td>
<td>++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Farmer preferences and goals must be represented</td>
<td>+</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage of the elements relevant to a decision maker</td>
<td>+</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Involvement of the decision maker</td>
<td>+</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Customisation of the problem representation</td>
<td>+</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Used by participants, not researchers</td>
<td>+</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Capacity for comparative analysis</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>High relative accuracy, not necessarily absolute accuracy</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Tangible variables should be emphasised</td>
<td>+</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Intangibles require graphic representation</td>
<td>++</td>
<td>++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Tools must be open to validation and interrogation to establish trust</td>
<td>++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the purpose</td>
<td>+++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the culture</td>
<td>+</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the process and performance</td>
<td>++++</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the people</td>
<td>+</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td>McGown</td>
<td>Degree of realism must be high</td>
<td>+++</td>
<td>NA</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Must be easily parameterised to a specific site and situation</td>
<td>++</td>
<td>NA</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Ability to research management options with farmers must be high</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Depth to the user participation</td>
<td>+</td>
<td>+++</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Participation oriented to the user’s perspective</td>
<td>+</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>A high degree of user influence on the system design</td>
<td>+</td>
<td>NA</td>
<td>No</td>
</tr>
</tbody>
</table>
Table 18. Selected criteria and interpretations from the case study concerning the value of the SOI for crop management. (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Uncertainty must be represented</td>
<td>Although the model was a deterministic one, uncertainty was represented through the application process, and especially the communication process. This was important in aligning the researcher’s perspectives with farmers’ perspectives.</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Involvement of the decision maker</td>
<td>The decisionmakers had ownership of the issue and interpretive input concerning the usefulness of the SOI. This was despite the modest amount of their participation in the process. Some farmers had concerns that advocates of the SOI were treating farmers like “guinea pigs” rather than peers.</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Tools must be open to validation and interrogation to establish trust</td>
<td>In this case, it was important to researchers that the model and process were valid. For the farmers, it was only important that the people and processes were honourable and valid. Obtaining validity for the DSS by association might be underestimated in cases such as these. Conversely, my lack of experience in climate research led to considerable disbelief in my results among some experts.</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the purpose</td>
<td>There was a complex and powerful mix of science, politics and economics in this case study. Not for the farmers, but for the scientists. I naively assumed that the evidence and facts would prevail, and that my peers and our institutions would work together to serve the farming community.</td>
</tr>
<tr>
<td></td>
<td>Know the culture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Know the process and performance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Know the people</td>
<td></td>
</tr>
<tr>
<td>McCown</td>
<td>Degree of realism must be high</td>
<td>The model was a convenient means of estimating responses to N fertiliser rates and different wheat varieties. Any system that could provide those estimates would have shown that the SOI had been overvalued. It is unimportant in the larger picture to prescribe exact values to the SOI.</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Participation oriented to the user’s perspective</td>
<td>This was essential because of the complex technical nature of the work. Keeping farmer participation separate from esoteric researcher interests was very useful and effective.</td>
</tr>
</tbody>
</table>
Table 19. Support given to participants in the SOI case study at the various decision-making stages described by Janis and Mann (1977). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Decision-making stage</th>
<th>Level of support for decision stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appraising the challenge</td>
<td>Some. The challenge is the cost of high seasonal and annual variability.</td>
</tr>
<tr>
<td>Surveying alternatives</td>
<td>Some attention was given to this, but the choices were seen as simple - to use the SOI or not.</td>
</tr>
<tr>
<td>Weighing of alternatives</td>
<td>This was the focus of the study. Comparison of SOI-based and conventional management. It was important to use enough sites and management examples to gauge the effectiveness of SOI-based management for farmers in different situations.</td>
</tr>
<tr>
<td>Deliberating about commitment</td>
<td>Some. For those farmers who were enthusiastic about the SOI, the results and discussions impacted on their perspectives and prospects for benefits.</td>
</tr>
</tbody>
</table>
Case 5: Summer cropping opportunities in western farming systems

This case study examines activities in 1999 centred on a meeting with growers at Meandarra, in the central-east of the study zone. Other activities were conducted at Warren and Moree, but those activities won’t be reported in this thesis because they occurred outside the study zone and produced similar outcomes to the Meandarra activities. These activities began with an approach by the coordinator of the Grains Research and Development Corporation’s Grower Updates to speak to farmers and consultants at their annual meetings in the northern region in 1999. The proposed topic was summer cropping opportunities and I was asked to use my work with APSIM for analyses that would inform the audience. This was a good opportunity to utilise APSIM and interact with farmers and so I went ahead.

Background

Cropping on the western Downs and Maranoa has traditionally been based on sowing wheat in late autumn or winter, and fallowing post-harvest to store soil moisture from summer rain. However, there are significant disadvantages in this system, including:

- An increase over time in some pests and diseases (such as crown rot and nematodes),
- Problems with winter weeds, such as wild oats (*Avena spp.*)
- Heavy reliance on wheat prices, and
- Run-down in soil health and fertility.

Alternative winter crops and summer opportunity crops can alleviate some of these problems and may lead to more sustainable and profitable cropping systems. Acquiring new skills and knowledge, and economic costs such as machinery modification or purchase weigh against the use of summer crops.

The keys to workable systems that utilise the alternative crops are to have flexible timing and to utilise an appropriate mixture of crops (e.g. neither too few nor too many pulse crops). It is also worth noting that because wheat is one of the most reliable crops, some of the alternative systems may have more risks associated with them than wheat-dominant systems. The extra risk derives from increased production risks, such as the risk of weather damage to grain, and increased marketing risks, such as wide variation in prices.

This study explored some of the benefits and risks of the major alternative crops to wheat. Unfortunately, at the time this study was done, historically low prices for sorghum and cotton were having a significant impact on grower interest in summer crops.
Methods

The potential benefits of alternative crops were assessed by simulating historical crop yields with the APSIM model for a variety of locations. These locations were:

- Roma, Miles and Dalby in the north (low to high rainfall),
- St George and Goondiwindi near the NSW-Qld border (low and high rainfall),
- Walgett and Narrabri in northern NSW (low and high rainfall), and
- Warren, Trangie and Dubbo in central NSW (low to high rainfall).

At each of these sites, sorghum yields were simulated under three scenarios of plant-available soil moisture at sowing: low (75mm), medium (125mm) and high (185mm). In the scenario with a high level of available soil moisture (185mm), the simulated plant density was increased (from 5 plants/m² to 10 plants/m²) and extra N fertilisation was simulated (100 kg N/ha/crop versus 60 kg N/ha/crop). Because mungbeans are frequently grown where the available soil moisture is limited, their yields were simulated only at the low (75mm) level of plant-available soil moisture at sowing. In all cases, the soil simulated was a cracking grey clay, similar to that at the Nindigully trial site except for a lower plant-available water capacity (185 vs. 215 mm).

Results

Figure 30, Figure 31 and Figure 32 show the means as well as deciles 2 and 8 of the simulated yields for sorghum. One of the most surprising results was the relatively small difference between the northern and southern sites. This is likely to be due to the longer growing season and resulting increased radiation receipt of crops at higher latitudes (M. Foale, pers. comm.). Sorghum crops grown on the Liverpool plains (south of Narrabri) are known to regularly achieve high yields when adequate soil moisture is available.

Comparison of the three figures (Figure 30, Figure 31 and Figure 32) also reveals a large response in yields to increasing plant-available soil moisture at sowing at all sites. For example, at Dalby the mean yield increased from just over 2 t/ha with 75mm PAW to 2.5 t/ha with 125mm PAW. This is a marginal water use efficiency of approximately 10 kg/ha/mm, which is consistent with expectations.
Figure 30. Sorghum yields with 75 mm plant-available moisture at sowing.
(Source, Robinson, this thesis)

Figure 31. Sorghum yields with 125 mm plant-available moisture at sowing.
(Source, Robinson, this thesis)
Another key feature of these results is the higher variability (decile 8 – decile 2) in simulated yields at the southern sites. At Narrabri, the variability is approximately 50% greater than at Dalby, and at Dubbo the variability is about 100% greater in all scenarios. This corresponds to a decrease in the proportion of annual rainfall that falls in the summer cropping period. It may be this variability in yield rather than a decrease in average yields that has led to limited use of summer crops in dryland cropping south of the Liverpool Plains. It is also worth noting that summer cropping under irrigated conditions extends as far south as northern Victoria (e.g. irrigated maize), indicating that the limiting factor for summer cropping is probably soil moisture availability rather than any other physiological limitation.

Figure 33 shows the results of the mungbean simulations. These results also show that the southern and western sites have considerable yield potential, and that mungbeans have the potential to average approximately 0.5 t/ha/year, even when sown onto a small bank of available soil moisture.
One of the main concerns of growers with respect to opportunity cropping is a concern that crops grown in rapid succession will be sown onto less soil moisture, and hence have a greater chance of crop failure and low yields. Another concern is that fallows might become excessively long because a greater crop frequency is reducing the available soil moisture at harvest.

Figure 34 shows these effects for opportunity cropping with sorghum in a wheat-based system. Fallow lengths were estimated from rules for sowing crops based on rainfall and plant-available soil moisture. If the opportunity cropping system (wheat & sorghum) had negative effects, by extending the fallows and resulted in lower soil moisture at sowing, the coordinates for that system in Figure 34 would be shifted to the right (longer fallows) and down (less soil moisture) in comparison to the monoculture wheat system. Only a few fallows are extended in length, and many short fallows (less than six months) are introduced to the system. With only a few exceptions, crops continue to be sown onto at least 100 mm of available soil moisture, which is considered an adequate amount. Therefore, no major disadvantages arise in the opportunity cropping system with respect to available soil moisture at sowing and fallow length.
The yield potential of sorghum in the western cropping area is very good, given adequate soil moisture at sowing. Mean yield with adequate soil moisture at sowing is quite high as far south and west as Dubbo and Warren. Variability in annual yields increases in the south and west, and is not significantly reduced by additional soil moisture available at sowing.

**FSR learnings and summary**

I was initially concerned that the results of the model would be insufficiently accurate to present to growers. In practice, this was not a concern for a number of reasons:

- The timing of the release of the results was incompatible with encouraging any further summer cropping in the short-term (the meetings were held in February and March).
- Those growers that had successfully grown summer crops were not surprised by what was generally considered a favourable view of summer crops. This group considered their current practices were already consistent with the results.
- Those growers that hadn’t tried summer crops regarded them as unsuitable for reasons other than yield and economic returns. For example, some commented that they didn’t own suitable machinery so they were fundamentally not interested in summer crops. But is such a position a justification for adhering to an existing position or an
A few may have examined the results in terms of weighing alternatives, but there was no significant indication that practices would change. In general, using the model in this way had not been effective at developing new ideas and approaches to summer cropping.

**Which of the criteria were useful in this case?**

Table 20 shows scores for the 24 criteria, and Table 21 contains extra discussion of several criteria that were particularly relevant in this case.

Table 22 breaks the process into decision-making stages, from the farmers’ perspective. This table shows that many comparisons were made, but the effectiveness of these comparisons was very low. Comparisons between sorghum and mungbeans at different sites were of limited relevance to farmers, who have a dominant interest in one site. Also, the farmers were interested in many parameters besides yield and yield variability.

**Findings and propositions:**

1. A richer picture of the costs and benefits of summer crops may have encouraged a more realistic assessment of their potential role in these farming systems. Farmers’ priorities for information would have addressed questions such as: Do I need a zero-till planter and how much does one cost? What are the pests of sorghum? Will I need to use many chemical sprays? I was distracted by the availability of a model that calculated crop yields, and adopted it because yields appeared important. However, the farmers were already well-informed concerning yields.

2. The timing was wrong. It was no use doing an analysis that wouldn’t be acted on for 9 months. This is because the price and environmental conditions of the farming system are highly random and chaotic (Anderson and White 1991), and 9 months of variable weather and prices would be enough to erase almost all value of pre-planning for a summer crop. For example, if conditions were ideal for a winter crop, little land would be left unplanted and available for a summer crop.

3. On reflection, this was an example of some of the worst of my work in decision support. First, following a prescribed (by the workshop organisers) course of action was a significant mistake. Other faults were: (i) not confirming the relevance of the
topic and my knowledge to the audience, and (ii) not entering into pre-meeting discussions with the audience to learn about their situation, knowledge, decisionmaking and practice.

4. It was no reflection on the participants that the information and model were of little relevance. Understanding their decision-making needs should have been the first step taken in the process. I made an insufficient diagnosis of the system issues, and instead tried to grab insights mid-process. In all, the model and I contributed little to the farmers’ understanding. I later reflected on how it went wrong, and recognised the relevance of the question McCown et al. (2002) posed: “What would need to happen for farmers to value these tools in their decision-making?”. In this case, I simply should have used better process; greater and earlier engagement of the decision-makers. That a poor process of engagement gave poor result is clear.

These propositions and learning are followed up in the discussion.
Table 20. Scores and judgment for the DSS and processes used in the case study of Summer cropping (+ = not met, ++++= fully met, NA=not applicable). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria for DSS success</th>
<th>DSS</th>
<th>Process</th>
<th>Meaningful for this case study?</th>
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</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Data must be available for specifying processes</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Biophysical representations must be dynamic not static</td>
<td>+++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Complexity and cost should be avoided</td>
<td>+</td>
<td>++++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Uncertainty must be represented</td>
<td>++++</td>
<td>++++</td>
<td>Yes</td>
</tr>
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<td>Farmer preferences and goals must be represented</td>
<td>+</td>
<td>++</td>
<td>Yes</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage of the elements relevant to a decision maker</td>
<td>+</td>
<td>++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Involvement of the decision maker</td>
<td>+</td>
<td>++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Customisation of the problem representation</td>
<td>+</td>
<td>+</td>
<td>Maybe</td>
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<td>High relative accuracy, not necessarily absolute accuracy</td>
<td>+</td>
<td>NA</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Tangible variables should be emphasised</td>
<td>+</td>
<td>++</td>
<td>Maybe</td>
</tr>
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<td>Intangibles require graphic representation</td>
<td>++</td>
<td>++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Tools must be open to validation and interrogation to establish trust</td>
<td>+</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the purpose</td>
<td>++</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the culture</td>
<td>++</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the process and performance</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the people</td>
<td>++</td>
<td>++</td>
<td>Maybe</td>
</tr>
<tr>
<td>McCown</td>
<td>Degree of realism must be high</td>
<td>+++</td>
<td>NA</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Must be easily parameterised to a specific site and situation</td>
<td>++</td>
<td>+</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Ability to explore management options must be high</td>
<td>++++</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Depth to the user participation</td>
<td>++</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Participation oriented to the user’s perspective</td>
<td>+</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>A high degree of user influence on the system design</td>
<td>+</td>
<td>NA</td>
<td>No</td>
</tr>
</tbody>
</table>
Table 21. Selected criteria and interpretations from the case study concerning Summer cropping options. (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Farmer preferences and goals must be represented</td>
<td>In this case study I failed to represent the key criteria on which farmers would judge Summer crops. This was because I failed to understand the system and the farmer’s perspective.</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage of the elements relevant to a decision maker</td>
<td>There was a mismatch between my narrow perspective (i.e. yield) and farmers’ broader perspective (labour, chemicals, markets, etc.). In hindsight, for many farmers, a soft-systems evaluation of summer crops in these farming systems would have been best.</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Intangibles require graphic representation</td>
<td>It was a mistake on my part to assume that the graphs of yield would have substantial meaning for the growers. Even to trained eyes, the differences in and between the histograms appeared slight. More meaningful (and responsive) variables like gross margin ($/ha) should have been shown. Other intangibles, like chemical use and cost could have been represented.</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the purpose Know the culture</td>
<td>As noted above, I did not understand the farmers’ purpose and perspective.</td>
</tr>
<tr>
<td>McCown</td>
<td>Ability to research management options with farmers must be high</td>
<td>I didn’t utilise very much of the model’s capacity to seek out crop responses to novel management.</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Participation oriented to the user’s perspective</td>
<td>This was central to the lack of impact of this work. Part of the problem was that the meetings and my contribution treated farmers as learners and listeners, while the researchers were the experts and speakers. To recognise farmers’ prior knowledge and facilitate discussion around that knowledge would have produced better outcomes.</td>
</tr>
</tbody>
</table>
Table 22. Support given to participants in the Summer crop options case study at the various decision-making stages described by Janis and Mann (1977). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Decision-making stage</th>
<th>Level of support for decision stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appraising the challenge</td>
<td>Many in the audience were uninterested in the topic because for them, there was no challenge. They needed no outside help or perspectives to understand the system.</td>
</tr>
<tr>
<td>Surveying alternatives</td>
<td>Little. Sorghum and mungbean crops with conventional agronomy were assumed the best options for most farmers. In haste, I rushed to the assumption that farmers take interest in, and will grow crops with high yields and high gross margins. I also see this same mistake made regularly by my peers. What I have learned is that the goal for many or most farmers was a certain area of Summer crop that had a good “fit” with their other crops and livestock and maximised the profitable use of resources (such as rainfall, labour and machinery). Virtually all farmers already knew that sorghum and mungbeans were the suitable Summer crops, and probably already had an idea of their yields.</td>
</tr>
<tr>
<td>Weighing of alternatives</td>
<td>Lots of comparisons, but not much effective support for the farmers, for the reasons explained above. Because I had not taken the farmers’ perspective, I was using the wrong model/DSS and making comparisons that had limited value.</td>
</tr>
<tr>
<td>Deliberating about commitment</td>
<td>None.</td>
</tr>
</tbody>
</table>
Case 6: Long-term changes in rainfall and potential wheat yields at St George

This case study arose following discussions with farmers in the St George area in 2000 about the long-term viability and variability of cropping in the region. Some of the discussions overlapped with those concerning the use of the SOI reported in Case study 4. Farmers in the St George area were interested in climate cycles and changes. Some were confident that cycles and changes were occurring. In these discussions, I mentioned that it was a relatively easy task to examine long-term rainfall records, and that APSIM would allow us to convert the rainfall record into potential wheat yields. Technical information from this case study was published in Robinson and Freebairn (1999).

Methods

Long-term rainfall records were obtained from the Department of Natural Resources’ “Patch Point Dataset”. In the case of St George, this contained mostly actual records, with a small amount of “patching” to cover periods where records were missing or averaged.

Wheat yields were simulated using standard modules in APSIM, and parameters for the Nindigully soil, as described in Case Study 1, above.

Results

Potential wheat yields

Figure 35 shows the 10-year moving averages of potential wheat yields. Note the change around 1945 and consistently higher averages since then. The two horizontal lines show the averages for 1891 to 1945 and 1946 to 1996. In spite of the averaging, there is still considerable variability, and there are noticeable cycles and trends. A major feature is the general increase that occurred in the late 1940s. 10-year averages appear to have been consistently within a higher range since this increase. Since 1950 the lowest of the 10 year averages have been higher than most of the previous averages. These higher potential wheat yields suggest that the weather during the last 50 to 55 years has been better for wheat production than before. This was contrary to the expectations of many farmers.

The 1950s had the highest potential yields (2.8 t/ha/year) and the 1930s had the lowest (average 1.5 t/ha). 1955 and 1956 had very high potential yields, while droughts in 1933 and 1936 meant that no crop would have been sown (individual years are not shown in Figure 35). The 1980s were variable, with droughts in 1980 and 1982, and good years in 1988 and 1989. The average for the 1980s was 2.6 t/ha.
Rainfall data were also examined for long-term changes - rainfall and temperature are the two of the main “driving” factors in the yield data presented in Figure 35. Some comparisons of rainfall and agronomic conditions and potential wheat yields before 1946 and from 1946 on are shown in Table 23. Differences between the 2 periods include: an increase in annual rainfall of approximately 70 mm (14%), an increase in rainfall during the period when most fallow soil moisture is accumulated (October to May) of approximately 60mm (18%), and an increase in potential wheat yield of 0.7 t/ha/year (40%).

Table 23. Comparisons of rainfall, soil moisture storage and potential yields before 1946 and since 1946. (Source, Robinson, this thesis)

<table>
<thead>
<tr>
<th>Period</th>
<th>Annual rainfall (mm)</th>
<th>October to May rainfall (mm)</th>
<th>Soil moisture storage (mm)</th>
<th>Zero yield (% of years)</th>
<th>Average potential yield (t/ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 1946</td>
<td>479</td>
<td>330</td>
<td>71</td>
<td>20</td>
<td>1.74</td>
</tr>
<tr>
<td>1946 on</td>
<td>546</td>
<td>388</td>
<td>86</td>
<td>12</td>
<td>2.46</td>
</tr>
</tbody>
</table>

Figure 36 shows the 10-year moving averages of annual rainfall. Again, averaging removes year-to-year variability and exposes underlying trends and cycles in the rainfall data. Figure 36 shows that, in general, the early part of the 20th century had less rainfall than the latter part. However, averages for the late 1960s to mid 1970s and mid 1990s are low in comparison with most of the post-war period.
Figure 36. Running 10-year average rainfall at St George (mm). There is a substantial increase after 1945 and higher averages since. (Source, Robinson, this thesis)

Figure 37. 10-year running average averages of the number of rain days at St George. (Rain days are days with more than 0.2 mm of rain). (Source, Robinson, this thesis)
10-year moving averages of the number of days with rainfall are shown in Figure 37. There are some interesting features in this graph, including an increase in rain days during the 1940s. The number of days with rainfall has remained high since the 1950s.

The figures above show that there have been major changes in rainfall over the last century at St George. Although some of these differences could be due to different personnel collecting the data, or the position and condition of the rain gauge and thermometers, the differences are quite large and are similar to changes at other locations in southern Queensland and northern New South Wales. This strongly suggests that the changes are not artefacts of the measurements.

What caused the changes in weather and yield potential? The drivers are not known. Farmers have asked whether more changes will occur in the future. Preliminary research indicates that the enhanced greenhouse effect might cause ENSO cycles to become more rapid (with a 3 year average) than they are at present (5 year average). Also, extreme events may be more common in the future (Australian Greenhouse Office 1999). A lack of technical understanding strongly limits our ability to predict future climate. While the drivers are poorly understood, a return to the low yield potentials of the early 20th century, or a shift to new levels cannot be discounted. Lower yield levels would have a devastating impact on the economics of farms in the study region.

Technical Summary

Computer simulations of crop production can be used to answer questions such as; are there cycles or trends in the weather that affect crop yield? Long-term computer simulations use the climate information that has been recorded at post offices and other places for over one hundred years. Rainfall and temperature have been recorded at most rural towns, providing an accurate record of conditions in past seasons. This study analyses the weather records for St George, and indicates that the climate and potential wheat yields have changed in the past. In particular, long-term averages (10 years or more) of rainfall and potential yields increased sometime around 1945, and have remained higher since 1945 than they were in the early part of this century. The cause of the change in climate is not known.

For research, these results have significant implications. How should a researcher choose a representative sample of the weather record on which to base an analysis? This dilemma is addressed in some detail in Appendix 4.

FSR learnings and summary
These results were discussed with farmers in the St George area, who expressed interest in the results. What soon became obvious was the lack of action that farmers could take. In terms of Bennett’s hierarchy (Bennett and Rockwell 1995), the farmers were participating, reacting and acquiring knowledge, but not changing attitudes or aspiring to manage differently. This was because of a failure to adequately assess the challenge, and identify what the consequences of increased knowledge would be. The interest expressed by the farmers in these results had concerned knowing the status of their system - information that was important for understanding how their farming system worked, and what processes were at play, but which had little or no short-term management value. As discussed in Chapter 2, scientists and researchers often seek this type of knowledge. When the farmers obtained the information, they were not very enthusiastic about its implications, and moved on to other discussions. I also realised that my interest in the issue had encouraged further development of this work than may otherwise have occurred.

Which of the criteria were useful in this case?

Table 24 shows scores for the 24 criteria, and Table 25 contains extra discussion of several criteria that are the most relevant in the case study. Table 26 breaks the process into decision-making stages, from the farmers’ perspective. It shows that the analysis was weighted towards assessing the challenge, and shows that the process did not proceed to later stages because farmers perceived that they had few, if any, management options that could take advantage of the newly understood climate patterns.

Findings and propositions:

1. The farmers were keen to have a researcher investigate this, and I had enthusiasm for increased understanding, so there was plenty of motivation. Although the process was more like traditional research and extension than action learning, I was confident that the process was a good one, and the results were as good as could be achieved with the resources.

2. Making it to stage 5 of the decision model doesn’t mean that action will take place. This case study showed how important it can be to understand the management context of information and learning. If the goal of the learning is action, an assessment of limitations to action needs to take place. Bennett’s hierarchy (Bennett and Rockwell 1995) is likely to be useful in understanding some of the pre-requisites to changed practice.

3. A decision-tree or similar framework might have been more effective in revealing that farmers have few decisions to make concerning inter-annual climate change. Despite climate change during events such as El-Ninos, most farm management is concerned with weather and past climate rather than climate futures. Climate change is generally indistinguishable in terms of farm management from variable weather. El-Nino and
La-Nina were only re-discovered and studied in the 1980s, whereas farm management has been adapting to these factors since agriculture began in Australia in the 1780s. These propositions and learning are followed up in the discussion.

Table 24. Scores and judgment for the DSS and processes used in the case study of summer cropping (+ = not met, ++++= fully met, NA = not applicable). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria for DSS success</th>
<th>DSS</th>
<th>Process</th>
<th>Meaningful for this case study?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Data must be available for specifying processes</td>
<td>++++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Biophysical representations must be dynamic not static</td>
<td>+++</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Complexity and cost should be avoided</td>
<td>+</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Uncertainty must be represented</td>
<td>+</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Farmer preferences and goals must be represented</td>
<td>+</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage of the elements relevant to a decision maker</td>
<td>+</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Involvement of the decision maker</td>
<td>+</td>
<td>++</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Customisation of the problem representation</td>
<td>+</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Used by participants, not researchers</td>
<td>+</td>
<td>NA</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Capacity for comparative analysis</td>
<td>+++</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>High relative accuracy, not necessarily absolute accuracy</td>
<td>+++</td>
<td>NA</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Tangible variables should be emphasised</td>
<td>+</td>
<td>++</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Intangibles require graphic representation</td>
<td>++</td>
<td>+++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Tools must be open to validation and interrogation to establish trust</td>
<td>+</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the purpose</td>
<td>+</td>
<td>++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the culture</td>
<td>+</td>
<td>++</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the process and performance</td>
<td>+++</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the people</td>
<td>++</td>
<td>++</td>
<td>Yes</td>
</tr>
<tr>
<td>McCown</td>
<td>Degree of realism must be high</td>
<td>+++</td>
<td>+</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Must be easily parameterised to a specific site and situation</td>
<td>+</td>
<td>++</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Ability to research management options with farmers must be high</td>
<td>+</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Depth to the user participation</td>
<td>++</td>
<td>++</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>Participation oriented to the user’s perspective</td>
<td>++</td>
<td>++</td>
<td>Maybe</td>
</tr>
<tr>
<td></td>
<td>A high degree of user influence on the system design</td>
<td>+</td>
<td>++</td>
<td>Maybe</td>
</tr>
</tbody>
</table>
Table 25. Selected criteria and interpretations from the case study concerning long-term variation in rainfall and yield potential. (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Biophysical representations must be dynamic not static</td>
<td>This case explored dynamics at a longer timescale than the other cases, and raises the issue of dynamism at one scale appearing static, or nearly so, in a broader perspective. Although the wheat yield estimates were obtained from a dynamic model, little accuracy would have been lost if a simpler, cheaper static model was used.</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage of the elements relevant to a decision maker</td>
<td>Understanding the “decision points” and management options available to farmers may have forewarned everyone of the limited options available for reducing the effects of interannual climate variability.</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Intangibles require graphic representation</td>
<td>Better graphical representations of the results (rainfall and simulated wheat yields) as well as the potential climate forcing factors (SOI, sea surface temperatures, volcanic activity, atmospheric CO$_2$ concentrations, etc.) may have increased the learnings from this study, and encouraged more dialogue.</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the purpose, Know the process and performance</td>
<td>I failed to see that increased knowledge would be poorly linked to management opportunities and action in this case. Better understanding of the process/purpose may have improved the outcomes considerably.</td>
</tr>
<tr>
<td>McCown</td>
<td>Ability to research management options with farmers must be high</td>
<td>The biophysical management options were limited, and having a wide management capacity in the model would not have improved the outcomes.</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Participation oriented to the user’s perspective</td>
<td>This may have assisted in identifying the limited management options available to farmers regarding interannual climate variability.</td>
</tr>
</tbody>
</table>
Table 26. Support given to participants in the historical rainfall and potential wheat yield changes case study at the various decision-making stages described by Janis and Mann (1977). (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Decision-making stage</th>
<th>Level of support for decision stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appraising the challenge</td>
<td>Most. Many farmers felt that the current weather and climate were particularly difficult. Some felt that there was a challenge and opportunity to understand the climate and through this would be able to manage their resources more effectively.</td>
</tr>
<tr>
<td>Surveying alternatives</td>
<td>Little. The results failed to identify situations that could be better managed. There was a significant gap between understanding the system and being able to better manage the system.</td>
</tr>
<tr>
<td>Weighing of alternatives</td>
<td>Little. Only assessing whether cycles and changes were happening or not.</td>
</tr>
<tr>
<td>Deliberating about commitment</td>
<td>None. There was no prior commitment. No farmers were at this stage.</td>
</tr>
</tbody>
</table>
Chapter 10. Discussion

This chapter integrates information from the literature review with the learnings from the case studies, in order to critically assess the five propositions (H1 to H5). The assessments are aimed at accepting, rejecting, or modifying the propositions, and then to develop principles regarding understanding and applying DSS:

(i) Differences between previous DSS evaluation by DSS developers and my evaluations are discussed, primarily from a DSS user perspective,
(ii) Conflicts between researcher and farmer models and decision culture are discussed,
(iii) The importance of a sound epistemological approach to participation is discussed,
(iv) Relevant audiences for DSS are defined, and
(v) Mind and model-based analyses are contrasted and synergies are explored.

The propositions are shown in bold.

H1. Criteria exist, or can be developed, that encourage effective development and application of DSS in FSR

Table 27 shows the criteria and the assessments of their relevance and value in each of the case studies. The assessment was based on ratings of each criterion for each case study. The overall results show that most criteria were relevant in most cases. The criteria that rated well for many of the six case studies were concerned with technical details concerning the representation of the system, and engagement with the farmer participants.

Several criteria were useful in fewer of the case studies. These less relevant criteria (that rated less than four scores of “yes” in Table 27), were:

1. Customisation of representation,
2. Used by participants, not researchers,
3. Tangibles emphasised,
4. Open to examination,
5. Degree of realism must be high,
6. Easily parameterised to a site, and
7. Users influence the system design.

With the possible exception of “Easily parameterised to a site”, these criteria share a common theme: they involve values that aim to maximise users’ interactions with the DSS.
Table 27. The scores for each of the criteria for the six case studies. (Source: Robinson, this thesis)

<table>
<thead>
<tr>
<th>Author</th>
<th>Criteria</th>
<th>N fertiliser</th>
<th>Fallow length</th>
<th>Whole farm</th>
<th>SOI value</th>
<th>Summer cropping</th>
<th>Rainfall and wheat</th>
<th>Mostly OK?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillon</td>
<td>Data available for processes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Dynamic not static</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Avoid complexity and cost</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Uncertainty must be represented</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Farmer preferences and goals</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Malcolm</td>
<td>Broad coverage</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Involve the decision maker</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Customisation of representation</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
<td>Maybe</td>
<td>No</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Hamilton</td>
<td>Used by participants</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Suits comparative analysis</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>High relative accuracy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Tangibles emphasised</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Maybe</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Graphics for intangibles</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Open to examination</td>
<td>No</td>
<td>Maybe</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>–</td>
</tr>
<tr>
<td>Cox et al.</td>
<td>Know the purpose</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the culture</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</tr>
<tr>
<td></td>
<td>Know the process/performance</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Know the people</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>McCown</td>
<td>Degree of realism must be high</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Maybe</td>
<td>Maybe</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Easily parameterised to a site</td>
<td>Maybe</td>
<td>Maybe</td>
<td>No</td>
<td>Yes</td>
<td>Maybe</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Farmer-management research</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Lynch et al.</td>
<td>Depth to the user participation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>User’s views for participation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Users influence the system design</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
</tbody>
</table>

+ - yes = “yes” for 4 or more case studies, ~ = “yes” for 2 or 3 case studies

If we assume that the criteria were sound for the studies in which they were developed, what might the reasons be for the lower level of relevance of these seven criteria? A likely cause is that the area of user interaction with the DSS requires very detailed and specialised criteria – criteria that need to vary on a case-by-case basis. This is consistent with another feature of the seven criteria - the over-representation of Hamilton’s and McCown’s criteria. They were more concerned with interactive learning than the other authors. Hamilton was concerned with participative and highly interactive learning, using both computer-based and physical tools. It is not surprising, then, that his criteria emphasised “tangibility”. McCown was
focussed on using a farming system model as a management simulator. This was quite a different context to my case studies, except for the development and use of the FARM spreadsheet. Therefore, these criteria were not critical success factors in some of my case studies because I used a different approach to user-DSS interaction to that used by the authors proposing the criteria. For a well-constructed criteria to have relevance, it must be effective from both the perspective of the DSS user/evaluator and for the technical sense in which the DSS is being used.

This may appear an unremarkable conclusion, but has important implications. Different case studies bring forth specific problems, particularly for interactions between the DSS, DSS developers and the decision-maker, and specific criteria are required for particular circumstances. Therefore, **a “one-size-fits-all” approach to guidelines for developing and applying DSS will not work.** Criteria will need to be developed as principles rather than recipes.

Given this assessment, the proposition needs to be modified – **Specific criteria exist and may be developed that are relevant to the effective development of the technical components of DSS, but not to participation and learning. Participation and learning require general principles for their effective development and application of DSS.** The latter finding is consistent with King (2000) who found that “recipes” in participatory learning had many inadequacies.

Unfortunately, even the technical criteria are relatively incomplete and have many limitations. This is consistent with the criteria never having been used (as far as it is possible to know from the literature, and discussions with developers of DSS). Therefore, we should ask - Why haven’t the existing criteria been more influential or useful for DSS developers and users? Some reasons why I found them difficult to apply, and in many cases even to rate are:

1. All criteria except McCown’s Easily parameterised to a site, Farmer-management research, and Lynch et al.’s 3 criteria aim at “high-level”, abstract, subjective goals of DSS design and FSR, not “low-level”, concrete, practical elements. The problem of ensuring that a DSS and its application are meeting some abstract design principles is obviously difficult. The problem of abstraction is also associated with point 2, below.
2. All criteria except for Lynch et al.’s were not easily quantified or coded. This is partly because they are subjective and qualitative, and because the authors all embedded significant biases in the criteria and their studies, making the task of rating the criteria quite difficult. As discussed earlier, some of the obvious preferences of the authors include: (i) better technical representation of the problem (Dillon 1979), (ii) less zealous theoretical and technical analysis (Malcolm 1990), (iii) bridging the “learning gap” by having researchers understand farmers (Hamilton 1995), (iv) researching the “gap” between management and science (McCown 2001b, 2002), (v)
reducing reductionism and scientific over-confidence (Cox et al. 1996), and (vi) greater participation by farmers in the development and use of DSS (Lynch et al. 2000).

3. Some of the criteria were not related to the usefulness of the overall system because they were concerned with details or components rather than the whole system of development and application. Criteria that had these faults included Dillon’s Data available for processes, Dynamic not static, Avoid complexity and cost, Uncertainty must be represented, Hamilton’s Suits comparative analysis, High relative accuracy, Tangibles emphasised, Graphics for intangibles, all of McCown’s, all of Lynch et al.’s.

4. Except for Hamilton’s Tangibles emphasised, Graphics for intangibles, Open to examination and other criteria that indirectly alluded to user participation in development and use, the criteria didn’t query aspects of communication and learning from the DSSs. Most sets of studies and criteria assumed away diversity in the decisions and decisionmakers using these DSS.

As noted in 1, above, most of the criteria are in fact wishes or aims, containing little or no helpful information that could guide a user to achieving those aims. This cannot have aided their effectiveness.

New technical criteria and participatory principles are proposed and discussed after assessment of the other propositions.

**H2. DSS are effective catalysts of change and action**

As described earlier, farmers are rarely or never simple actors in the system, translating knowledge to action (e.g. Ridge and Cox 1996, King 2000). Janis and Mann’s decision model (1977) and Bennett’s hierarchy (Bennett and Rockwell 1995) tell us that action has decision-stages and prerequisites such as changes in attitudes, skills, and aspirations. Even where the DSS facilitated an increase in knowledge, a disconnection between knowledge and action was found in some of the case studies. In particular, the analysis of summer crop options showed that the model results could be informative, but have low relevance because they were more concerned with the researcher’s perceptions (in this case my perceptions) of the decision than the farmers’ perceptions. The simple mistake was to assume that summer cropping was mainly concerned with crop yield (and possibly economics), while the farmers’ concerns were with timeliness, scheduling, labour requirements, machinery requirements, prices, chemicals and other factors. This may be common. King (2000, p. 123-125) reported several examples of misunderstandings in farmer-scientist, cross-cultural and cross-gender contexts, even where the perceptions of the stakeholders in that dialogue were that understanding and communication were excellent.
Just as other FSR technologies developed for farmers can fail without quality participation (Jiggins 1993, King 2000), the evidence from the unsuccessful case studies here indicate that DSS developed by researchers for farmers fail to capture farmers’ perceptions of decisions and decision contexts. These poorly designed DSS require high-quality, complementary soft systems processes to re-engage farmers with such technologies. Re-instating or developing communication and understanding late in the process may be difficult and inefficient.

Therefore, the theoretical and practical evidence of the need for DSS to be accompanied by appropriate soft systems processes lead me to reject the proposition and conclude that DSS are not by themselves effective catalysts of change and action. This is consistent with the position Ridge and Cox (1996) and Ridge and Cox (2000).

Of course, in the case studies I have considerable evidence the DSS have been useful to farmers. Where relevance and utility was greatest, there was more likely to have been a learning process whereby farmers had been able to integrate information from DSS and other sources into their more holistic decision-making processes.

### H3. Detailed models are more effective sources for DSS than simple models

Detailed FSR models are those that arise from theory and provide numerical representations of a large number of processes. Usually, the inputs and outputs consist of large datasets, often representing abstract processes (such as hydraulic conductivity or amortisation). Such models are useful for understanding biophysical and economic processes, because they represent several layers of the system, from which emergent properties may be revealed. They differ from simple models, which are relatively simple empirically based predictors of partial system behaviour.

The following studies indicate either directly or circumstantially that detail and complexity are problematic in models:

- Malcolm (1990 and 2000) asserting that tools should be relatively simple and flexible,
- Dillon (1979) prescribed tools of low cost and complexity,
- Hamilton (1995) advocated system transparency and open validation of tools, and
- Lynch (2003) proposed user involvement and influence in the design of the system.

Why, then, have complex models persisted as the basis for DSS? The problems (increased error, bias, incompleteness) associated with overly simplistic models and DSS are easily identified and strongly disliked by scientists who may be unaware of the problems of complexity. As discussed earlier, the goals of science and management are often very
different. Views of the trade-offs between problems of complexity and problems of simplicity may be different for DSS developers and users. Long-running disagreements concerning the usefulness and scientific veracity of simple models such as that of French and Schultz (1984a,b) for yield estimation indicates that individual’s opinions are often strongly held concerning these matters. Although absent from the literature, critical assessment of the merits of DSS based on models of different complexity begs inquiry. My experience indicates that complex systems are effective where resources include expert intermediaries as users. Many of the case studies would have been less successful if I had not been an intermediary that understood (to the best of my ability) the language and operations of both the DSS and the farmers. Where such resources do not exist, simple models are used. In the field, it is rare to hear a request for extra complexity or extra functionality from models.

A further complicating factor in assessing the value of the complex models is the social setting that has accompanied their implementation. Ridge and Cox (1996, 2000) have described the lack of recognition of farmers’ simple models and decision-making skills by DSS researchers whose experience consists of using complex scientific models. Failing to recognise the existence, implementation and roles of simple models can only inflate the apparent importance of complex models for those researchers.

Also consider the history of FME models, where success was very different for simple and complex systems (Malcolm 1990, 2000). Complex theory failed to deliver results in practice. However, simpler budgeting techniques have lasted and continue to flourish – compelling evidence that has been ignored in the development of many DSS on the back of complex models.

Simple spreadsheet models might have succeeded partly because the software has advantages:

- Spreadsheets are familiar to millions of people, largely through simple but necessary applications such as budgeting. The way they code and store information has been thoroughly researched and developed. In-house software development results in very few copies, so using the software requires specialist skills.
- Large multi-national corporations support commercial software. In-house software marketers cannot provide the same level of commitment.
- Spreadsheets and comparable tools (e.g. databases) are cost effective and simple to apply. They are cheap and practitioners can quickly develop models using this technology. This enables the facilitator of the application process to be the system developer – obviating the need for communication between software developers and model users.
The commonly available commercial software tools have evolved through competitive commercial pressure. For example, spreadsheets support a vast amount of commercial business activity and decision-making.

But what evidence is there in the case studies that detailed models were less effective than other types of models or tools? In case study 6, concerning inter-annual climate signals, my choice of a complex scientific model (APSIM) was not very effective. Could I have achieved the same results with a simple tool (e.g. rainfall graphs instead of a crop model)? Yes. The same was true for the summer cropping case study. The tool was complex and off-target (i.e. calculated yields when other factors were more important). A simpler tool would have been equally effective, and a simpler tool applied with better understanding of the decision-makers’ needs would have been much more effective and efficient. Like many researchers, I carried a certain amount of power and conceit into these interactions with farmers. I thought that the model (my model) I was bringing to the problem or question was going to be what they needed. Instead, the need was for a targeted, relevant model, of sufficient complexity to assist the decision-makers, and of sufficient simplicity to be understood by the participants.

While the trade-off between sufficient complexity and sufficient simplicity can be affected by the quality of delivery and communication processes, complex models will usually require greater implementation effort and skill (e.g. APSIM in FARMSCAPE, Hochman et al. 2002). DSS such as WhopperCropper (Nelson et al. 2002) and HowWet? (Freebairn et al. 2001) have advantages in implementation relative to their more complex “parent” models, APSIM (McCown et al. 1996) and PERFECT (Littleboy et al. 1989) (H. Cox, pers. comm., D. Freebairn, pers. comm.).

An important question concerning the use of simple and complex models is that of efficiency. If a large, complex DSS requires more resources than a simple, small one, it is reasonable to expect greater productivity from it. Alternatively, there is no reason why one complex DSS should be built if two simple DSS would be more productive. DSS development in FSR has historically included large systems (SIRATAC, SIRAGCROP, WheatMan, MIDAS, APSIM), many of which have failed to evolve.

There are some important differences in efficiency between applications of the DSS for groups and individuals that affect efficiency. In the case study concerning N fertiliser rates, farmers were clear that group discussion concerning rates for a typical paddock was sufficient learning to meet their needs. Likewise, the other case studies emphasised group interactions so that individuals would learn something of the underlying biophysical processes. This is to place the DSS in a different epistemology to that of FARMSCAPE, where the DSS is parameterised in individual paddocks, and results are developed for farmers to interpret literally. Evaluating the biophysical and socio-cultural outcomes of engaging farmers in the two processes would make fascinating research. However, the latter approach requires
resources well beyond those available in the WFSP. In general, the more detailed the DSS model, the higher the cost of each parameterisation, and the fewer biophysically based simulations are affordable. However, outside the context of a publicly funded FSR project, this situation is obviously different, and the user can pay what the user can afford.

An interesting example of low-cost individualisation of a model is that of WHEATMAN (Woodruff, 1992, Hayman and Easdown 2002). Early versions used farmer yield and protein data to place a paddock in a range of nitrogen fertility categories, foregoing the expenses of soil coring. However, even the simple paddock recording that provided greater performance for committed users proved a deterrent for casual users (Hayman and Easdown 2002), who concluded:

“Despite its ability to integrate many factors and to positively affect both operational and strategic management of wheat, simpler forms of decision support seem to have more appeal.”

Evidence in the literature (e.g. Lynch et al. 2000), and case studies that the complex scientific models have significant disadvantages (familiarity, relevance), show that detailed FSR models are not more effective than simple models for use in DSS.

Further, detailed FSR models may be less effective and less efficient than simple models in DSS, especially where factors such as simplicity, flexibility, low cost, low complexity, transparency, open validation, user influence in the design, and collaboration between farmers and researchers are important.

There is little doubt that researchers have found their complex models very effective in positivist inquiry. Consequently, they may have deep-seated associations between the use of complex models and successes in solving biophysical problems. However, positive feelings concerning the application of complex models in science are not relevant to the application of models in decision support and FSR, which require different outcomes and use different epistemologies. Also, past use of science-based models by researchers may reflect a long tradition of researchers imposing their worldview on farmers. The current emphasis on participation and co-learning in FSR and in agriculture generally (Christodoulou 2000, King 2000, Fulton et al. 2003) will eventually encourage a more balanced view, where farmer’s models are considered more relevant, valid and effective than they are at present. This is further discussed after assessment of the propositions.

**H4. Sufficient knowledge of farmer decision-making processes exists to make DSS efficient and effective**
Cox et al. (1996) suggested that much needed to be done to gain effective knowledge of farmer decision-making. Similarly, McCown (2001b) proposed that knowledge is deficient and that research in a co-learning context with farmers is required to acquire this type of knowledge. But are different co-learning methods equally effective, and if not, what makes for effective co-learning?

According to Fulton et al. (2003) there are many personal, social and cultural factors that are barriers to participation in co-learning, and research on these barriers is limited. Christodoulou (2000, p.98-109) found that developing appropriate participative processes had advantages for all learners (farmers and researchers). He described a hierarchy of participation, where different outcomes are achieved at different levels. The type of participation that is likely to increase understanding of decision frameworks by farmers and researchers is an “Interactive” level (and perhaps at a simpler “Functional” level). Interactive participation is indicated by:

- Co-working
- All contributors welcome
- Dialogue development
- Systemic and structured learning processes
- Stakeholders self-navigate the learning
- Experiences and knowledge shared
- Individuals are interdependent
- Acceptance of difference and criticism
- Disclosure of values and bias
- Emergent issues and needs are welcomed

It is intuitively plain that practice at this level is important in gaining knowledge of farmer decision-making processes. In colloquial terms, it is necessary to “walk a mile in the shoes” of the decision-maker and observe the same choices and dilemmas that they face. As Dwight D. Eisenhower said: “Farming looks mighty easy when your plow is a pencil and you're a thousand miles from the corn field.” Beyond such empathy, the decision-making framework must also be well assessed and understood. It was for that reason the decision-making model of Janis and Mann (1977) and other systems were explored early in this thesis.

Theoretical understanding from those models allowed interpretation of actions and processes and development of understanding that will make future applications of DSS more effective. For example, in at least two case studies I did not understand the decision processes adequately. In the case study of fallow length on red soils, there was a rush to weigh alternatives when the farmers’ goals were concerned with reinforcing their prior decisions. Similarly, in the case study concerning the value of the SOI, the farmers were interested in appraising their options for reducing the impact of seasonal and annual variability, or were
deliberating about commitment to the SOI, not in weighing alternatives, as I had assumed. Without a model that separates and identifies relationships between the different decision stages, the experiences of these case studies would have been much more difficult to interpret.

So, while Cox et al. (1996), Christodoulou (2000) and McCown (2001b) have indicated the types of interactions where knowledge of farmer decision-making processes may be found, gaining knowledge of interactions has been achieved through using suitable theoretical models of decision-making to interpret experience. The theoretical models of decision-making were the catalysts to many of the learnings. In this thesis, the model of Janis and Mann (1977) has played a very important role. However, decision-making is a difficult subject, rooted in convoluted psychology but expressed in superficially simple behaviour. It will not be simple for DSS developers or users to obtain relevant and high quality information. As shown in the literature review, most of the information on decision-making comes from across discipline boundaries to FSR, which is a significant challenge.

In summary, there is sufficient theoretical knowledge of decision-making to support the proposition, but it is not being applied in FSR practice, despite this being the long-term goal of DSS projects (e.g. FARMSCAPE). The barriers to transferring knowledge from decision theorists to DSS practice have prevented progress in DSS application, and are worthy of study elsewhere.

Therefore, I reject the proposition, and conclude that sufficient knowledge of farmer decision-making processes does not exist to make DSS efficient and effective.

H5. Interactions between DSS and learning processes are well understood

Hamilton (1995) recognised the importance of catering for different communication and learning preferences. This is likely to be true for the developers of DSS as well as farmers. This has received little attention because researchers have been the owners of the DSS, and have assumed that a logical positivist approach is effective. However, the work of Hamilton (1995) and others has shown this to be false. Logical positivism has limited leverage in dealing with socially constructed abstract concepts (McCown 2001b).

As noted by Cox et al. (1996) and McCown (2001b), there has been a separation of DSS and science-based methods into one knowledge domain, and co-learning and personal interactions into another. Hence science-based researchers, and sometimes computer programmers develop participative DSS and FSR activities. Given the differences in skills and epistemologies between science and FSR, an effective DSS development and application team will need a cluster of complementary skills. What do the case studies indicate?
In the cases studies concerning N fertiliser rates and fallow length on red soils, the DSS model was unsuited to direct use or exploration by the farmer, but the process resulted in a high level of cooperation and learning. So, if soft systems processes are highly effective, a comparatively ineffective model can nevertheless be made to deliver a quality result. By this, I mean that when problems are encountered with the DSS (as they invariably do), a good process will capitalise on the opportunity for discussion, and maximise learnings in spite of the technical limitations of the DSS. Can good process be defined? As discussed above, Christodoulou (2000, p. 102) describes a typology for participation between researchers and farmers that is useful. Also, Lynch (2003) has explored participation as an indicator of successful DSS development. The literature, the case studies and twenty years of experience lead me to conclude that quality processes lead to successful DSS implementation.

To be more specific, it was when iterative, rapid cycling of double loop learning was happening that farmers were being challenged, paradigms were being examined, and change was a possibility. At the user-level, Hättenschwiler (1999) differentiates passive, active, and cooperative DSS. When the DSS were used less frequently, and less actively, the learnings were much less than when decisionmakers were interacting frequently and actively with the system. A clear example of this was the active participation between the DSS developer, DSS, and the decision-maker in the participatory development of the FARM model. For other successful case studies, the essence of active participation was quality dialogue with the farmer-decisionmakers.

The case study concerning N fertiliser use showed that despite being constrained by time, interactions with farmers might be effective and powerful. There may be a poor correlation between the quantity and quality of interactions (Reeve and Black 1998). Farmers, in general, are busy people, oriented to concrete achievement. So how do they get maximum learning from their time? Alexander and McKenzie (1998) examined the extent to which learning processes are effective, and found the most important factor was the design of the learning experiences (relative to project planning, funding, management, execution or evaluation). These insights should be used to improve the implementation of DSS, which often assume away the complexities of learning. Where DSS are used as predictors of biophysical conditions, the connections between choices and consequences need to emphasised as a means of learning about the functioning of the farming system.

I conclude that **Interactions between DSS and learning processes are partly understood, but the knowledge is not enacted effectively.**

Having assessed all of the propositions, the following sections discuss some of the broader ramifications of the results and issues that were not dealt with in the propositions.
DSS evaluation: different perspectives

There is a culture in hard FSR of seeing the world from the perspective of the DSS and its developers. Farmers are “clients” or “users”, while researchers and the DSS are the “problem-solvers”. Studies such as those of Lynch (2003) enquire as to the value of the DSS, from the perspective that a widely and frequently used DSS has impact. However, for a DSS using individual, the effectiveness of a DSS is indicated by the amount and quality of support they received from the system.

This contradiction is shown in the high ratings for the DSS in Table 27. Given the concerns of Lynch et al. (2000), McCown (2001b) and others about the low impact of DSS, one might have expected low scores. Alternatively, have I been over-optimistic in my assessment of the impact of DSS and the processes? Has my experience and perspective in assessing these tools been very different to the previous authors?

Part of the difference can be explained by the methods used to evaluate the DSS. The approach of Lynch et al. and McCown was to assess the DSS in terms of how many users there are and how much they use it, while my evaluation is oriented to the output from several simple examples of DSS applications in participative FSR. I have not attempted to justify the investment in developing the tools, or look at how often the tool was used, or how many copies were in existence. Indeed, these measures had already been discounted by Ridge and Cox (2000) as poor indicators of impact. Instead, I assessed the relevance and benefits of the DSS and associated learning processes in terms of my interactions with farmers. Positive outcomes from most of the case studies are also consistent with my 20 years of experience with similar farmers, issues and DSS. Finally, DSS are not separable from the context of their use and their users (which is sometimes implied in the DSS literature). Experience in the DSS user is undoubtedly a success factor, and DSS facilitation is a talent. For example, Peter Carberry has been recognised as a master of APSIM applications, and had a well-earned reputation for informing and entertaining farmers in the northern cropping zone in the 1990s.

Therefore, evaluations of the effectiveness, relevance and impact of DSS need to be clear concerning their perspective. The subjective nature of evaluations can all too often lead to either self-promotion or destructive criticism. The criteria and principles provided below might help to balance evaluation of DSS, based on the literature and experiences reported in this thesis.

Farmer’s models and decision processes

Cox et al. (1995) considered the role of researchers and the role of farmers’ models:
“they must develop and maintain regular activities for system diagnosis. Otherwise there is a real danger that interventions will be only marginally effective because they fail to address the most important needs of farmers for information and decision support. But it may also be that performance could be lifted most effectively and efficiently by more widespread application of rule sets already used by the most productive farmers.”

Ridge and Cox’s (1996) call for recognition that “farmers have models too” was an attempt to generate a (somewhat radical) shift away from the “scientific models are best” paradigm that existed in 1996 and still persists despite evidence that farmers’ models are relevant and useful and their decision-making is competent. They concluded that many farmers’ models were largely “intuitive” and researchers’ models were largely “explicit”, and that each could benefit from a better understanding of the other, or incorporation of some of the principles of the other.

What evidence comes from the case studies in this thesis that farmer’s models and decision-frameworks are useful? Except for the case study involving the FARM model, farmers had prior conceptions of the results. Typically, these were that:

- “Old” farming country (about 20 years cultivation) probably needs N fertiliser (20 to 40 kg N/ha/year),
- Red soil does not need to be fallowed before the new year,
- The SOI is not much value for managing cropping,
- Summer crops are very useful components of systems dominated by winter crops, and
- Climate is unstable, and trends and changes affect the farming system.

ALL of these concepts are consistent with the conclusions of the results from DSS based on complex, scientific analyses. This contradicts the popular assertion that farmers’ limited experience (30 to 40 years) and biased memory is a constraint to understanding the system and optimising management. This evidence also raises questions concerning the benefits of introducing the DSS to the decision support process. Indeed, farmers did not ask me to use a DSS, nor would I ever expect them to. Simulators are researchers’ tools. However, farmers expected me to get involved in their decision-making, and they were not averse to the use of a simulator, so long as it helped. So far as the farmers were concerned, any approach relevant to their decisions or prior concepts was useful.

The case studies and my experience lead me to conclude that a technology-driven approach diverts and detracts from effective participation and decision support, which require issue-based or decision-driven approaches. The technology should support the decision-making, never vice versa.
**Epistemological issues**

A decision-based approach necessarily involves a plural, constructivist epistemology, because it deals with constructions of the decision reality that has many social aspects. Such social constructions are necessarily individual for each farmer and researcher. To take a position of logical positivism would simply result in the dominance of one view of the problem and solution over others (or more likely, for participants to abandon the process because the dominant view differs from theirs). My experiences of constructivist implementation of a DSS or model in a participatory framework indicate that a few ingredients are very important. They are:

- Discussing strengths of the model or DSS,
- Discussing weaknesses, and
- Offering the model or results as an addition to their prior information and experience.

Although one may argue that constructivism carries a danger of undervaluing hard-won technical information, this did not occur in the case studies. Farmers have a well-balanced view of the merits of different sources of information, and high regard for the value of technical information, that prevents a constructivist approach becoming an opinion-based approach (see Hamilton 1995 for discussion and examples).

In summary, constructivism has substantial advantages for implementing DSS over logical positivism.

**Support for farmer decision culture**

Hard FSR has a history of research models dominating farmer models, and a culture of viewing farmers as the needy clients or users, while researchers and the DSS are the providers and problem-solvers. Continuing this practice of using the researchers’ models, language and symbols, seriously degrades collaboration and participation. A more effective approach will replace this widespread “researcher first” or “technology first” approach with an egalitarian “decision first” approach. Therein exists a great opportunity to recognise, validate and implement farmers’ models. However, neither traditional farmers nor traditional researchers are skilled to achieve this, because they belong to distinct cultures. Farming systems facilitators may be best equipped to work as intermediaries between a reductionist, logical positivist research culture and a holistic, constructivist farmer culture. Similar concepts have already been examined by Hamilton (1995) and McCown (2001b).

McCown (2001b) proposed that it is difficult for scientists to understand farmers:
“Gap-bridging research paradigm shifts undertaken by individual scientists, might be expected to be difficult and rare”

Hamilton’s (1995) view is different, based on case studies showing it is a challenge, but far from impossible, to get scientists to view situations from multiple perspectives. Can the differences between the views be reconciled? McCown’s team were mainly science-trained researchers, studying management and extension, and equipped with a complex simulation model. Hamilton’s team had a broader background, and arguably more experience in FSR. Hamilton found that the main requirement for success was a shift from a reductionist, rationalist epistemology to a constructivist epistemology. Hamilton’s team:

“acquired some skills which proved valuable, indeed essential throughout the duration of the project. These skills included active listening and semi-structured interviewing”

As revealed in this quotation, an essential requirement for implementing a constructivist epistemology is listening and appreciating the views of others, and their systems of acquiring and utilising knowledge. Two of the case studies failed because I lacked of appreciation of farmers’ perspectives (fallowing on red soils and summer cropping). Any of the other case studies could also have failed if not for a substantial effort to engage farmers and respect their views.

However, communication, understanding and respect are easily espoused and difficult to enact (King 2000). As mentioned above, many contemporary interactions between high-status DSS developers and their low-status clients are based on participation tainted by education, society and institutions. From reflection on the case studies and other experience, I recognised a means for reducing the negative impacts that arise in farmer-researcher cross-cultural participation. This simple system is described below.

Figure 38 shows a typical, idealistic action learning cycle. As King (2000) noted the ideal cycle is subject to many variations in practice. The alternative split cycle that I’ve used requires and benefits from a disconnection between the two cultures (Figure 38). Note that the researchers and farmers should participate in all components of the cycle – this is NOT a return to a transfer of technology paradigm. There is a distinct need for a change in cultural dominance between the farmers’ “side” and the researchers’ “side” of the cycle. Identifying with such a system makes the differences between the cultures explicit, and reduces the likelihood that each group will discount the opinions of the other. In this system, farmers and researchers have two roles: one on “their” side of the cycle and another on the “other” side of the cycle. One is familiar and the other a challenge.
Unfortunately, migrating ideas across the disconnection is problematic because it involves translating the language, symbols and mannerisms of one culture to the other. Only experienced practitioners are likely to have a balanced understanding of both research and extension cultures, and the skills to allow the participants to marry their insights in an self-directed setting.

![Typical action learning](image1)

**Typical action learning**

- Plan
- Act
- Reflect
- Observe

**Research culture**

**Farmer knowledge and perspectives get suppressed by research culture.**

**Alternative action learning**

- Plan
- Act
- Research culture
- Farmer culture
- Reflect
- Observe

**Research results are blended with farmer knowledge and perspectives on farmers’ terms.**

Figure 38. Ideal and alternative action learning cycles. The alternative cycle has beneficial disconnections between research and extension, highlighting a shift from research culture in research to a farmer culture in extension.

Figure 38 warrants further explanation in terms of DSS implementation. The advantages of the “ideal” cycle include maximum interaction between all participants at all stages, and co-development of tools. It is a discrete, interactive implementation of an action learning cycle. However, a major disadvantage of this cycle is that it requires either co-development of the tool, or, if a model is brought from outside, it must be simple and an excellent “fit” for the problem, because everybody uses and learns from the tool. The case study of developing the FARM spreadsheet was a successful example of this type of action learning. The FARMSCAPE team has also employed a mix of action research and transfer of technology within a research culture. This has successfully introduced technical skills and research concepts to groups of farmers in the northern grainbelt (e.g. Hochman et al. 2002). However, the resources required for that approach are rarely available in FSR projects, and so high resource requirements and low resource-use efficiency will prevent the use of their approach, even if their outcomes are considered desirable.
The alternative cycle shown in Figure 38 relies heavily on communication between the two half cycles. The main advantage of the half cycle is that a distinct biophysical, social and cultural connection is placed between the researcher doing the research (plan, act) and the decisionmakers/learners (observe, reflect). This connection is a place for interpreting of technical or abstract information (e.g. making results “tangible”). Also, there is a clear boundary between research culture (goals, language, learning styles, etc.) and farmer/extension culture. As discussed above, one of the disadvantages in this system is its reliance on good facilitation between the researchers and farmers-decisionmakers. Case studies concerning N fertiliser rates, fallowing on red soils, the value of the SOI, summer cropping and long-term rainfall changes all successfully used an action learning cycle that was split in this way. In two cases – fallowing and summer cropping – poor communication led to a failure in implementing the DSS with this system.

There are also many possible combinations and variations from the two systems described above. For example, DSS that are more easily used than the complex models are likely to be left un gover ned in the domain of the farmer. An example of this is downloading a program such as HowWet? (Freebairn et al. 2001) from the internet. In such a case, there will be trade-offs between failing to communicate with the user and directing their interactions with the tool.

**Finding an audience for DSS**

The literature contains many implications that DSSs can be beneficial, even desired, by farmers. As McCown et al. (2002) suggests, the potential acceptability of DSSs is obvious, if untested:

“The pure DSS idea is elegant – easy-to-use software on a computer readily accessible to a manager to provide interactive assistance in the manager’s decision process. There existed a plausible theory for both the need and mechanism for decision support.”

Reducing this theory to a few of its components, we are presented with a DSS that is:

- Easy to use
- Accessible to a manager
- Provides interactive assistance

However, DSS are:

- Questionable in terms of ease of use, and may fail to provide cost-effective responses to implementation, and
- Variable in their suitability for providing interactive assistance.
While the more complex DSS are not easy to use, they may be implemented through skilled intermediaries (e.g. Hochman et al. 2000). As noted above, this greatly improves their effectiveness but reduces their efficiency.

So, is there a failure of DSS to provide interactive assistance? To answer this, we may ask: Do farmers already have an easy-to-use, interactive system for their decision-making? In some cases, this question becomes; What is a decision-maker’s position concerning their own decision-making abilities?

Researchers associated with non-adopted DSS may have failed to understand the lack of adoption process. Ironically, this is a decision process, into which DSS developers should have had considerable insight. By placing the “non-adorption of DSS” issue (McCown et al. 2002) in terms of the decision model of Janis and Mann (1977) it becomes clear that most farmers take a position of unconflicted adherence and do not progress to evaluate DSS. Only those farmers feeling conflicted (by evidence of their mis-management etc.) will consider using a DSS.

In summary, without some pain and conflict in the audience concerning the status quo of decision-making, DSS are not going to be considered for “adoption”.

Conversely, DSS should be adopted or well regarded by farmers who feel they need guided or assisted management. There is evidence from the literature and my case studies supporting these propositions. An example of conflicted farmers being interested in a DSS comes from the FARMSCAPE and related processes. Those farmers were interested in “the replacement of gut-feel, general principles and general data by hard data, specific to individual farms or paddocks” (van Beek, cited in Carberry et al. 2002). However, as Carberry et al. (2002) explain it, these are not average farmers – they gathered farmers from “the top 10%” through a process that selected interested individuals. Those individuals were actively seeking to replace their current farm management with better management, and were actively sought out by the FARMSCAPE team.

Mind versus machine

Some literature concerning agricultural DSS depicts farmers (and researchers) as flawed decisionmakers who could not possibly perform the necessary calculations and integrations necessary to achieve useful results. Although the cognitive limitations of decision-makers are considerable (Plous 1993), this is not sufficient reason for decision-makers to want to use a DSS. Farmers have self-belief in their decisions, and have networks and systems available to
assist them. Ridge and Cox (2000) suggest farmers can also spend time making decisions work for them after the choice.

Consider those DSS developers who mistakenly believe that farmers lack the cognitive powers to manage their farms. This is a common assumption among DSS developers (Stabell 1987). The DSS developers then believe that many of those under-equipped farmers would, if given the chance, improve their decision-making. From this theory, one may deduce that farmers who are pro-active concerning their farm management will be adopters of DSS, and the remainder are both poor managers and uninterested in improving management.

Do such views exist among DSS developers? According to Hearn and Bange (2002):

“A Luddite mentality towards DSS persists among some farmers and consultants despite changes in CottonLOGIC, betrayed by the statement ‘you don’t need a machine to tell you what to do’. Although machine power replaced muscle power long ago without the farmer surrendering control, latter day Luddites apparently feel threatened when machine power replaces brain-power in DSSs”

Indeed, there are very few examples of DSS development, or analyses of the failure of DSS, which proceed from an assumption of the farmers as effective decisionmakers.

One such view (Pannell 1996) comes from a review of 10 years of whole-farm modelling, where the situation was summarised thus:

“Despite the apparent difficulties, farmers in general seem to cope well with their planning and day-to-day management decisions. Many are enthusiastic collectors of information and ideas. They do agonize over some decisions, but they are not defeated by the intractability of the problem. They appreciate that their decision making processes are not rigorous and formal, but they must be careful not to spend too much time on formal analyses because there are so many decisions to make and most of their time is required for the many physical tasks which are needed to run the farm. Very important decisions may have to be made (or at least finalized) during times when the time available for contemplation and analysis is at a minimum; i.e. during crop seeding. They manage by using judgment, guesses, hunches, outside advice and some limited numerical analysis and they can do so because of their intimate knowledge of their farms (Malcolm).

In my judgment, farmers’ decisions made in this ad hoc way are usually very good. They are not perfect (farmers are human!) but they are usually near enough to the theoretical ideal for their particular circumstances to obtain most of the potential benefits. They are helped in this by the forgiving nature of many agricultural decisions; often there is a range of strategies around the optimum which give near-optimal levels of profits (Anderson).”
Another example is Hayman and Easdown (2002), who refer to perceptions of the system and characteristics of the decisions as important factors in the unsuitability of DSS for many farmers:

“On their own these [well designed software, focussed development, access to hardware and user involvement] are not sufficient requirements for widespread adoption or impact. We argue that the perception of farmers of the nature of dryland cropping in general, and the specific decisions addressed by WHEATMAN are the primary limitations to the routine use of a computerised DSS for tactical decision making.”

Figure 39. Diagram of the analytic processes of numerical models and farmers.

Numerical models have large, undifferentiated, static, non-discriminatory system of functions and logic. These characteristics are disadvantageous.

(Source: Robinson, this thesis and Lindsay and Powell 1997 with modifications)

Figure 39 represents the systems for information processing in computer models and in the mind. As represented in the figure, the mind is attentive to only a few factors, but it is highly dynamic with respect to choosing those factors and the ways in which they are used (“adaptive”, Ridge and Cox 2000). In addition, the mind is able to call upon many other systems for information, if required (phone, fax, web).

Therefore, the two systems shown in Figure 39 are different in structure, processes and capabilities. Any audience for a DSS already has a mind. Why will they desire the model? Because the model gives:
- Access to specific information among a large collection of information, and
- Minimum bias in its representation of a biophysical reality (ideally).

When viewed from this perspective, it is clear that the new mission for DSS developers should be to offer a well-differentiated analytic process to that used in the mind of decision-makers. This is consistent with Ridge and Cox's (1996) conclusions that farmers' models were largely “intuitive” and researchers’ models were largely “explicit”, and that each could benefit from a better understanding of the other.

However, even where DSS are shown to be useful complements to the mind, there is also an “emotional inertia” associated with changing management and management systems. Changing to using a DSS is not incremental and insignificant. Unless there are significant improvements in the outcomes from decision-making with a software package, change is unlikely. Concerning the potential to change farmer decision-making methods, Lynch et al. (2000) concluded:

“If farmers are currently making their farm management decisions by ‘gut feeling’ or by chatting with the next door neighbour then they are unlikely to move easily from this decision making style to one using software packages”

The 2002 special issue of Agricultural Systems; “Probing the Enigma of the Decision Support System for Farmers: Learning from Experience and from Theory” repeats the well-worn chronology that blames: (i) technology (“PC usage” and “user-friendly”) in the 1980s, and (ii) user engagement and farmer-scientist interaction (“ownership”) in the 1990s. McCown et al. (2002) see opportunities to re-apply slightly modified DSS because constraints (i) and (ii) have been alleviated somewhat.

However, as shown by the literature and the case studies in this thesis, considerable success can be achieved by matching the DSS application to farmers’ existing decision-making systems, making them culturally familiar, and providing analysis from the users’ perspective. Complex DSS are too inefficient to be adopted by users, but they can be applied by trained intermediaries, given the right circumstances. Simple DSS that are not loaded with the language, symbols and methods of research can be adopted given a demand for additional experience concerning a decision.

**Criteria and principles for planning, developing and implementing DSS in FSR**

The technical criteria are:
1. Use DSS strategically (relevant purpose, relevant farmers, limited time) for key decisions. Every significant problem is a network of interdependent issues, and will require decision-makers to pass through a number of stages,
2. Use flexible, simple, understandable, time-effective, cost efficient and problem-free DSS, and
3. Consider the broader technical system and the changes needed to re-configure the farming system.
4. Match DSS type to issue. Remember the trade-off between simplicity and complexity. Don’t crack walnuts with a sledgehammer or bricks with a nutcracker.

The participatory and socio-cultural principles are:
1. Design the learning experiences carefully. Maximise the experiential aspects, especially those with feedback to emotions or thinking. Check that double-loop learning is being achieved.
2. Complement farmer decision-making. Do not conflict with it. Farmers are already good decision-makers because: (i) farmers are good learners, using a variety of sources of information, (ii) the majority of decisions are simple (intuitive/pre-attentive), (iii) biophysical response functions are forgiving, and (iv) there is little time and few skills available for detailed analysis anyway.
3. Constructivist epistemologies are needed to deal with multiple views and opinions.
4. Do not frustrate and dominate farmers with the unfamiliar culture of research and science. Farmers already have language, symbols and other tools that are effective and efficient.
5. Learning from DSS empowers users and leads to less DSS use.

The future, including applying the principles

According to Brennan and McCown (2001), the researchers who develop DSS are poor learners and reviewers of history:

“the lessons from the rise and fall of the FMR era seem to have gone largely unnoticed by conventional agricultural research”.

Even the simplest lesson - the counterproductive lure of complexity (Malcolm 1990, 2000, Brennan and McCown 2001) - has failed to dampen the enthusiasm of McCown (e.g. 2001a) for complex DSS. McCown is not alone. So there is much learning to do by many of us.

Given the evidence that history is either not understood or not acted upon, lessons regarding DSS are likely to be learned hard from experience (a familiar concept by this stage of the thesis!). Fortunately, DSS applications are not yet dead, and there are many opportunities for
learnings to come from future applications of the DSS. Using the action learning cycle, watching for the critical success factors in the deployment of the tools, and making those second-loop learnings will be critical to greater success with DSS.

**Back to the future**

> “Models and their output are the starting rather than the end point to decision making under risk”

Woodruff (1985)
IV. CONSEQUENCE

Chapter 11 Conclusions

The goal of this thesis is to identify ways of improving the effectiveness of the development and application of DSS in Australian FSR.

Decision support

Decision-making is not the logical, information-starved process depicted in the agricultural decision support literature. It is a complex process, and has different treatments in different disciplines. In psychology, it is seen as the result of experiences that contribute to layers of conscious and unconscious connections between choices and consequences. Simple studies show us that those connections are far from perfect, containing biases and gaps (Plous 1993). In business, decision-making has been studied empirically because it is an essential ingredient in good management. Models of decision-making, such as the model of Janis and Mann (1977), have been cornerstones of business management for decades. While experienced extension workers almost certainly develop their own mental models of these processes, formal decision models have not interested or have escaped the attention of those supporting biophysical decision-making. Ideally, the future will see greater understanding and application of decision theory in FSR.

What sort of DSS to use and develop in FSR?

Without intermediaries such as expert researchers, complex DSS fail in FSR for the same reasons that FMR/FME failed. The methods are too complex, inflexible, unfamiliar and time-consuming for real management (Malcolm 1990, 2000), and often deliver only marginally better performance than farmer decision-making or very simple tools (Hayman and Collett 1996). Klein (1980) showed that when experts follow explicit procedures their decision-making performance is reduced.

Simple DSS avoid some of the drawbacks of complex DSS, resulting in both a better “fit” with farmer’s existing management systems, and less effort for getting returns from the system (Hayman and Easdown 2002). Simpler tools derived from complex models, such as Whopper Cropper (Nelson et al. 2002) and HowWet? (Freebairn et al. 2001) provide management-oriented subsets of information. Whether these tools are more effective than their more complex counterparts will depend on the quality of the learning environments they make possible. Their efficiency is undoubtedly superior to the complex tools, as evidenced
by the uptake of such tools by unresourced farmers who require only an introduction to the software or are self-taught.

Whether it is financially or ethically (for reasons of efficiency) sustainable for institutions to resource interventions based on complex DSS is a topic worthy of review. Historically, the development of many complex DSS has been subsidised by research organisations that have viewed their existing research models as suitable for decision support. This should have made the implementation of complex DSS highly cost-effective. However, this has not occurred in general because of their requirements for high levels of resources (including expert users), their limited relevance and appeal to farmers, and poor implementation.

There are theoretical grounds for combining machine-based systems with human understanding:

- Decision-makers are not usually attentive of the full complexity of problems when making decisions (Gladwin and Murtaugh 1980),
- Decision-makers have biased perceptions of environmental factors affecting decisions, and consistently overestimate their decision-making skills (Plous 1993).
- Machines might be “dumb”, but they never forget, and may be able to fill these “gaps” due to their ability to store a tremendous breadth of information.

**Improved learning from DSS**

Action and experiential learning have advantages over delivering information to decision-makers. The application of DSS within action learning or co-learning frameworks has been proposed by McCown et al. (2002), and implemented to a degree (e.g. Hochman et al. 2002). However, existing approaches could be greatly improved by: (i) increasing the value and role of experience (virtual and real), and (ii) moving beyond workshops and interactions that are a thinly disguised transfer of researcher knowledge and culture.

Simple principles of educationalists such as Vygotsky (1962) are highly relevant in DSS implementation:

- Assume the learner is competent
- Know the learner
- Share an interest with the learner
- Follow the learner’s lead
- Capitalise on uncertainty

Truly participative programs will neutralise DSS researchers’ relegation of farmers to positions of low-intellect, low-status receivers of research information and technologies. DSS will become aids to competent, but time-constrained and informationally overloaded
managers. Empowered farmers will feel free to be critics of researchers, and *vice versa*. Empowered researchers will also understand that it is a difficult and complex task to be relevant and important to the work of farmers.

FSR combines (i) biophysical, hard systems approaches, based on realism and a logical positivist epistemology, and (ii) socio-cultural, soft systems approaches, based on constructivist and related epistemologies (Ison *et al.* 1997). Employing DSS in an epistemological setting of constructivism offers tolerance and diversity, and has considerable benefits over the older positivist approach of using DSS to derive results that were either implicitly or explicitly considered true.

**The implementation and learning environment**

Hamilton (1995), Ridge and Cox (1996), Lynch *et al.* (2000), Christodoulou (2000), McCown (2001b) and others have all commented favourably on the impact of quality participative research. One of the reasons for effectiveness in participation is empathy, which is misunderstood and uncommon (Wittgenstein 1968, King 2000). Freebairn (pers. comm.) has summarised how empathy leads to relevance, consequence and a plan for supporting decisions:

“To be useful to decisionmakers requires getting into their shoes. For any DSS to be useful, it needs to provide information that is relevant to at least one decision —this means we need to be explicit about which decision, when this decision needs to be made, and in a form that is accessible when the decision point arrives. How many decision points are there in agriculture? I suspect not that many. For example, in the northern grain belt, there are three key periods; winter crop planting, early and late summer crops planting. While each season is different, after a few years, the number of new situations arising decreases, as we should have dealt with the main issues at least once.

“Experience has taught me some simple rules for identifying the relevance of DSS to decisions and the necessity or otherwise of decision support. The following two-step test is remarkably effective:

- Imagine that the proposed DSS is the answer or key to a problem. Is it the answer to that problem? (i.e. not just one of many answers).
- Now consider the problem. Does it cause considerable or regular conflict?

If the DSS is the answer and the problem causes conflict, the proposed DSS will be relevant and worthwhile. Otherwise, proceed with great caution.
Stewart *et al.* (2000) used farm simulation out of the context of any particular decision. By repeated simulations of farm management, across season types and across farm management strategies, effective learning was achieved concerning not only bioeconomic choices, but also about decision-making itself (e.g. that good decisions do not always achieve good outcomes). The key to learning for Stewart *et al.* was iterative testing over time in a game. Gaming provides strong feedback concerning the strategies being used to achieve goals, whereas optimisation methods provide close-to-ideal answers with little feedback. In this, the systems with least feedback and transparency are linear programming, dynamic programming and such. However, simulation-based DSS may also be used to seek ‘optimum manage’ in research-oriented process that minimise farmer experience, experimentation and feedback. Such circumstances are unsuitable for effective learning.

*For future DSS developers*

I produced some principles and outlined some steps that might be taken when developing or re-engineering DSS:

- **Identify your audience.** They must want to be engaged concerning the decisions. If technology and science is their interest, other courses are available. They must be committed to trying the system and being realistic critics. If they can’t criticise the system, its development will stall.

- **Identify critical decisions.** These are not decisions about which perfect information is desirable, but decisions that have alternative that are difficult to weigh up. Changing the outcome from a poor one to a good one has a substantial effect on the farming system. Typically, continuously variable factors such as fertiliser and herbicide rates do not involve critical decisions.

- **Consider the aim.** Learning is the aim of all decision support. Learning is achieved by cooperation, experience and persistence. Sales of DSS and use of computer technology are not aims of decision support. DSS use and modelling experiments should aim to broaden and diversify farming opportunities, not restrict, optimise or simplify farming. They are points of departure, not arrival.

- **Consider efficiency.** Because experience is an important teacher for adults, maximise experience. Using familiar language and symbols makes communication easier. Use tools many times. Simple, interesting, repetitive games with ample feedback are successful.
• Accommodate the prior decision culture. Intuitive decision-making systems may be imperfect, but they are flexible and convenient. Concord and accommodation with such systems succeeds where conflict fails.

Last words

The answers to many of the questions posed in this thesis have already been answered in parts. A large part of the problem has been the fragmentary approach to DSS development and application in Australian FSR. Much of what I have achieved has been to integrate information and perspectives from across disciplines, authors and opinions.

As a final example of what lies buried in literature, let me juxtapose McCown et al.’s (2002) succinct question concerning DSS failure and Bill Malcolm’s (2000) equally excellent partial solution:

“What would need to happen for farmers to value these tools in their decision-making?”

“Sophisticated thinking and simple figuring is the rule.”
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Appendix 1 Exploring hard and soft systems views, beliefs and methods

Some ideas on how hard and soft systems approaches relate to the physical and mental

Davidson (1984) has done a great deal of work concerning philosophical aspects of the application of scientific methods, and logical positivism. Concerning the limits of application of logical positivism, he concluded, “There are no strict deterministic laws on the basis of which mental events can be predicted and explained”. This is known as the “anomalism of the mental” principle. In simple terms, this principle implies that unlike physical phenomena, the thoughts and consequent actions of people cannot be predicted or forecast from physical measurements. Conversely, to understand thinking and attitudes requires assessment and examination of mental states, not measurements of the physical world.

The principle of the anomalism of the mental demonstrates a basic difference between hard systems, which deal with physical properties and measurements, and which are deterministic and predictive, and soft systems, which deal with people’s thoughts and attitudes, which are necessarily subjective and variable.

<table>
<thead>
<tr>
<th>One of the consequences of this for FSR and participatory learning is that the outcomes of communication, observation and reflection, by virtue of their mainly mental composition, cannot be prescribed or predicted by any of the participants, or any observers of the process.</th>
</tr>
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<tbody>
<tr>
<td>In spite of the desire for hard systems workers to know in advance the outcomes of interactions with colleagues and producers, there will always a high degree of uncertainty in the outcomes as long as freethinking occurs.</td>
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<tr>
<td>All that can be done to guide interactions is to build a clear process or framework. Soft systems analysis captures and utilises the unpredictable nature of thought by using emergent processes and frameworks. These profit from whatever mental productions and inclinations appear along the way.</td>
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In practice, it is not surprising that hard systems research workers are realists and positivists, believing in a concrete reality that is both universal and able to be understood through universal truths. Soft systems workers in general emphasise personal perspectives on real-world situations. Improvement of a situation is best done directly by considering people’s thoughts and attitudes, as well as indirectly by manipulating the real-world situation (that will eventually change people’s thoughts and attitudes).
One of the implications of Davidson’s work is that propositions of fact or statements of truth cannot define people’s thoughts. For example, the positivist statement that “the night is black” conjures up not just one, but many different mental states in different people. Some people might hope that the night is black, while others will fear it. Therefore, while the hard systems worker deals with repeatable facts and measurements, the soft systems worker deals with a whole range of cognitive attitudes (such as hope, fear, desire, etc.). This may be one reason why hard systems scientists have so much leverage over physical situations, while the soft systems researcher has so little leverage on thoughts and attitudes.

Note also that hard systems approaches (e.g. measuring the blackness of night) cannot predict any of the mental states (concerning the blackness of night) that might arise. Likewise, no amount of soft system study, such as measurement or knowledge concerning attitudes (e.g. towards the blackness of night) can predict the outcome of physical measurements (e.g. of the blackness of night).

But how might this be useful in FSR? I see a great deal of confusion in various FSR projects because workers continually attempt to measure and prioritise biophysical issues though the thoughts and attitudes (rather than the physical situation) of farmers. The FARMSCAPE project went to great lengths to evaluate the opinions of participants, supposedly to provide “hard” evidence of the impact of the projects. Although such evaluation is undoubtedly important in quantifying opinions and values, it can only ever be indicative (i.e. not predictive) of behaviour change, and cannot be used to evaluate changes in the technical components of farming systems.

Similarly, dialogue might be very valuable in conveying and comparing thoughts and attitudes, and is highly valued in FSR. However, dialogue is unable to produce physically valid assessments of systems if it is centred on attitudes and personal perspectives rather than physical measurements. That is not to say that that dialogue with producers is over-utilised. It is easy, however, for FSR workers to mistakenly use mental assessments as indicators of biophysical problems.

In the western farming systems project (WFSP), we have spent a great deal of time and effort to describe many physical attributes of the farming systems of southwestern Queensland (e.g. weather, soils and crops). In particular, we can describe in minute detail the biophysical conditions at experimental sites, and can sometimes predict the outcomes of experiments. However, we have much less understanding of farmers’ attitudes towards production and natural resource management issues (e.g. soil fertility decline, salinity, sodicity, ley farming, alternative crops, etc.) On balance, then, it is obvious that we research and understand the physical (hard) systems much more than the people (soft) systems. One of the main reasons
for this imbalance is probably that we arrived at this project with a hard systems view and hard systems skills, and had some success treating the system as a set of objects that can be manipulated to increase effectiveness and efficiency. When the project was reviewed in 1998, we were primarily asked for evidence that the physical system had changed, and virtually no interest was taken in the skills, attitudes and thoughts of the farmers. Indeed, whether it is natural or not for farmers to hold a hard systems view of the world, we have expected them to share this limited view to a considerable degree. We assume, often correctly, that if we show producers how to increase yields, they will do whatever we believe is rational for them to do. In such cases we are usually correct in assuming that many farmers hold the same goals and values that the project staff hold (survey data, not shown). However, we have only explored in a very simplistic way those situations where farmers attitudes, or those among the staff) are likely to be at odds with what is espoused at a project level. For example, one attitude that is espoused by the team as a whole is that “Soil organic matter decline is a problem and is a bad thing”. Yet most farmers are continuing to use systems that contribute to such a decline. For them, the decline may not be seen as a problem at all. Because of other factors (such as saving on fertiliser costs, perhaps) soil organic matter decline might be considered acceptable, or even as a beneficial thing. It is clear that we (the project staff) don’t understand many of the thoughts and attitudes of farmers concerning important issues.

The different epistemologies of hard and soft systems inquiry

Because the hard systems and soft systems approaches deal in different types of knowledge, they have evolved different systems for obtaining and understanding knowledge. Hard systems approaches are closely aligned with scientific epistemologies, while soft systems approaches are aligned with modern and post-modern epistemologies. The following sections summarise some of the main differences between the different approaches to knowledge.

Scientific epistemologies have their origins in the Renaissance, when they replaced simpler approaches, such as naturalism (where object have certain properties or behave in certain ways because it is “natural” for them). A new guard of rationalists, including René
Descartes, Baruch Spinoza, and Gottfried Leibniz sought to understand cause and effect, and began to question both naturalistic and religious explanations of reality. Descartes in particular was influential in the derivation of the scientific method. The object-reasoning epistemologies were subsequently challenged and refined by Hume, Hegel, Popper, Habermas and others. However, the basic tools and tenets have remained the same: logical reduction, experimentation and scepticism.

Scientific epistemologies are well suited to inquiries concerning physical phenomena, and the technical and scientific knowledge developed in this thesis comes from those epistemic systems. However, it has long been suggested that scientific knowledge may not be the only form of knowledge. Other forms of knowledge are the focus of *modern and postmodern* epistemologies.

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**Deductive reasoning**

Deductive reasoning is the process of concluding that something must be true because it is a special case of a general principle known to be true. For example, because the sum of the angles in any triangle is 180 degrees, it is fair to conclude that the sum of the angles in any triangle you draw is 180 degrees (though this alone obviously isn’t telling you much). Deductive reasoning is the basis of determining what is, or can be, true.

**Inductive reasoning**

This is a kind of reasoning whereby a *principle* is said to be true because special cases of its application are known to be true. For example, if all of the sorghum crops you’ve ever seen were grown in summer, you might conclude that sorghum crops are grown in summer. Inductive reasoning can never form a final proof.

If it is clear that inductive reasoning is not logically valid for producing proofs, can it have some other value? Yes; inductive reasoning plays a major role in the discovery of everyday truths. For example, in spite of the possibility that sorghum may be grown somewhere, sometime in winter, we can assume *from multiple observations, and for pragmatic purposes*, that sorghum is a summer crop.

Because inductive reasoning is less onerous, but relatively inconclusive, it has benefits and costs that need to be weighed up, and can be manipulated in research frameworks. One such framework that uses inductive reasoning is action research, where inductive as well as deductive reasoning is likely in the “reflection” step.
Modern epistemologies

These epistemologies are concerned with both the forms and use of knowledge. In particular, the knowledge revealed by natural language, and gained by everyday experience, are often emphasised. For this reason, these epistemologies are well suited to inquiries concerning literature, political, social and philosophical systems.

Ludwig Wittgenstein not only refined scientific empiricism into what is known as logical positivism, he also devised a new type of epistemology - linguistic philosophy.

It explores the linguistic and social contexts in which terms are used. It is a kind of “inversion” of other epistemologies, which usually define the terms, and then explore their legitimate use (Wittgenstein 1974).

One of Wittgenstein’s concerns with modern epistemologies was the lack of consideration of "forms of life" (Wittgenstein 1968). Depending on one's environment, one's physical needs and desires, one's emotions, one's sensory capacities, and so on, different concepts and knowledge would be more or less natural or useful. What matters to you depends on how you live (and vice versa), and this shapes your experience. Wittgenstein says if a lion could speak, we would still not be able to understand it. We might hear them talking about zebras, but we would not understand lion ethics, politics, aesthetic taste, religion, humour and such like (if lions have these things). We could not honestly say, "I know what you mean" to a lion.

According to Wittgenstein, communicating with others involves empathy. Empathy that different people do not necessarily share. This rejects Kant’s previous notion that concepts (such as right and wrong, up and down) are common to all people, and sharing knowledge simply involves its transfer from one person to another.

This has implications for knowledge acquisition and sharing in farming systems contexts where it is often assumed, perhaps incorrectly, that people such as farmers and researchers, have affinity for one another and that communication and understanding are natural and easy.

In the mid 20th century, Martin Heidegger argued that epistemology had been biased into mainly exploring the knowledge of things, and had overlooked the knowledge of action. Although his writing is strange and cryptic, it is clear that he rejected Plato and Descartes' separation of subject and object. According to Heidegger, doing is more natural and important than observing and reasoning. Therefore, people are actors in the world, not observers or researchers of reality (Schurmann 1987).
Some of my experiences in FSR are consistent with Heidegger’s proposition that people are actors as much as they are thinkers. In general, I have found that the majority of farmers I deal with find knowing what to do is far more satisfactory than knowing about things. For example, there is often a surprising level of disinterest in finding out why a solution works (whereas that is the most interesting part for me, personally).

Given the choice between experiencing something new and objectifying and understanding something new, the majority of farmers undoubtedly favour the former.

Having this knowledge leads me to conclude that many of our FSR workshops and field days are somewhat misguided. We tend to emphasise the fundamental reasoning behind making choices, whereas many farmers are interested in short cuts to action (“recipes”).

There are obviously disparity between this epistemology and the epistemologies, theories and practices that value learning in agricultural extension (e.g. King 2000).

Claude Levi-Strauss is known for showing that much knowledge is inseparable from culture and society. He is best known for his works on structuralism in linguistics and storytelling, such as Structural Anthropology (1959). Structuralism purports to show that many stories and types of knowledge are embedded in culture. In a FSR context, this implies that there may be cultural common ground and communication between groups such as researchers and farmers, even if “translation” of the language is required. However, according to Levi-Strauss, there are also opportunities for the domination, or “pollution” of one knowledge culture by another. For example, farmers are so used to being dominated intellectually by researchers and their research culture, that it may be difficult to establish truly cooperative and communicative experiences between them.

Postmodern epistemologies

If the later modern epistemologies included minor attacks on logical positivism, postmodernism might be considered an all-out assault. Postmodern epistemologies probably originated in the works of Friedreich Neitzsche, but were not developed significantly until the mid 20th century, when Lyotard, Derrida, Foucault and others significantly expanded the concepts and appeal.

Postmodernism is founded on epistemologies of materialism, power, concealment and more. As an example, Michel Foucault added some interesting and provocative elements to the area of linguistic epistemology in the 1970s and 1980s (Horrock and Jevtic 1999). To Foucault,
the linguistic and cultural dimensions of knowledge had deeper causes. The basis of expressions such as truth and knowledge were explained in terms of power and the human relations of power. Foucault claimed that truth begets power and power begets truth. From this perspective, history and facts (as accepted by society) are merely the product of the people and systems that produced them. For example, Winston Churchill is reputed to have said concerning his role in World War II: “The facts will show me in good light, for I shall write them”. Manipulating information, knowledge and the truth is what scientists and FSR workers do.

But what is power? In Foucault’s terms, power is anything that changes or destroys possibilities (Foucault 1981). In terms of people, it is in any action that changes other peoples’ actions, now or in the future, either actually or potentially.

Foucault (1977) also argued that literature was not so much about information and knowledge as power, persuasion and the re-writing of history. He saw authorship as less about authority than about social and historical circumstances that both promote particular authors and limit their knowledge. Foucault also cited governments and religions as inventors of knowledge aiming to gain power or act expediently.

Jackson (1991) summarises (antithetically) post-modernism:

“Post-modernism seeks to puncture the certainties of modernism, particularly the belief in rationality, truth and progress; and it delights in doing so.”

Post-modernism and validity

Post-modernism boasts a new, powerful scepticism concerning the meta-narratives of modernity, including science, objectivity, etc. However, post-modern meta-narratives often share an untrustworthy “connect anything with anything” epistemology (Gross 1998). Post-modern theorists have been accused of following deceptive patterns: (i) to cry about the smoke without showing the fire, or (ii) to “borrow” concepts from across discipline boundaries, generalise and extrapolate to produce new, unfounded theories (Boghassian 1998). This was demonstrated in the Sokal hoax, where meaningless texts were published by scientists in reputable journals of post-modern literature.
Appendix 2 Conscious and subconscious elements of decision-making

This appendix sets out to explore some of the sources of “satisfaction” of decisionmakers. Seeking satisfaction has been described as one of the main ways that people are motivated to make decisions (Simon 1956, 1976). However, “satisfaction” is a superficial term that warrants further examination. There are well-understood emotional and psychological rudiments that help usefully describe what brings satisfaction.

Learnings from psychology

Freud

Sigmund Freud’s theories of psychology were perhaps more powerful at the time than the other revolutions of modernism, such as quantum theory and abstract art.

Freud (1901) revealed structure and detail in the human mind (or “self”): the knowing and decision-making observer in dualistic epistemologies such as logical positivism. He revealed the power of the subconscious in human behaviour, and identified three levels of self, each with different character. These “persons within” are the Ego, Superego and Id (Freud 1923), and their separation created opportunities for increased understanding of the mind, and lead to greatly enhanced opportunities for intervention where psychological problems exist.

Freud's structural theory of the mind describes the id, the ego and the superego functioning at different levels. Human behaviours and impulses emerge from various layers in rapid succession, and the layers are in constant check-and-balance. The id is the unconscious reservoir of drives, which are constantly active. If there could be said to be a place from which farmers’ desires originate, it is here. We all learn, adopt or change due to these subconscious drives. Conversely, if our drives do not lead down a path for learning adoption or change, we will engage ourselves otherwise. Given, then, that the id is the source of human motivations, and presumably the progenitor of progress, it might serve us to consider the id and its descendants; ego and super-ego:

- Id is ruled by the “pleasure principle”; it demands immediate satisfaction of its urges, regardless of undesirable effects.
- Ego operates mainly in conscious and preconscious levels, although this delineation is not always clear. The ego is ruled by the reality principle, and takes care of the id urges as soon as the adequate circumstance is found (if found). Inappropriate desires are repressed by the ego.
Superego is partially conscious, and serves as a censor on the ego. This constitutes the individual's ideals derived from the values of his family and society. These values are the source of guilty feelings and fear of punishment.

Berne

Berne (1964) produced a typology of people’s interactions now known as transactional analysis. In this, he emphasised three mind-states of people, and demonstrated the importance of the mind-state in social organisation and communication. The three mind-states were:

- The Parent; a huge collection of childhood memories of unquestioned or imposed external events. There are mostly “Don’t do that” memories and many “If you do this (or are this), you are good” memories. These memories become our ingrained “truths”. They are social conventions, habits, biases and abuses passed from parent to child.
- The Child; a collection of memories of internal events. These are the feelings and thinking and emotions of childhood years. These emotion-charged memories of situations range from feelings of powerlessness (and possibly abuse) to feelings of love and support.
- The Adult; concerned not with memories, but observation and formulating ideas. The Adult is different from the Parent, in that it doesn’t pre-judge situations or use borrowed or archaic standards. It is also different from the Child, in that the Adult doesn’t make a rapid, emotional reaction to stimuli.

In spite of the differences between Freud’s and Berne’s types, there are many similarities, too. The Superego, Ego and Id are comparable in many ways with the Parent, Adult and Child types of Berne. Berne (1964) and Harris (1967), do, however, go much further than Freud, Jung and earlier workers, in that they emphasise what constitutes a rational and a realistic state of mind. Berne and Harris conclude that interchanges between people operating from their Adult sub-psyches are more constructive and healthy than other interchanges. For example, the Child type has preponderance for taking a “mine is bigger than yours” attitude into discussion. Participatory FSR benefits from as much Adult-Adult interaction as possible, but given the complexities of farmer groups, there are always a few people who will tend to be “parents” or hear others talking like “parents”. Likewise, others are easily defaulting to being “child-like” or hearing others talking like “children”.

Life scripts

Another concept of social and personal interactions drawing upon the studies in transactional analysis by Berne (1964) and Harris (1967) is that of life scripts. This concept proposes that
individuals form an internally consistent image of themselves that leads to repetitive, reproducible and largely unavoidable relationships with others. There are four basic life positions that can be held by an individual with respect to another individual or society (Harris 1967):

1. I’m not OK – You’re OK
2. I’m not OK – You’re not OK
3. I’m OK – You’re not OK
4. I’m OK – You’re OK

We can immediately think of many situations where these life positions apply. The noisy objector in a public meeting is often expressing a position “I’m OK – You’re not OK”. Or, to the annoyance of all, the chronic “whinger” in the meeting takes on the “I’m not OK – You’re OK” position. Hence group dynamics and individuals are more easily understood by considering the life scripts being played.

In my experience, in some discussion groups there are enough people in positions 1 and 2 to disrupt normal, adult, progressive communication. This seems to happen due to either a lack of participation (they feel that they don’t deserve to contribute – “children should be seen and not heard”) or their participation is distracting or destructive.

Harris (1967) relates the fourth position to overcoming poor decision-making and negative actions. He also explains it in terms of the Parent, Adult, Child typology outlined above:

“Finally, it is essential to understand that I’M OK – YOU’RE OK is a position and not a feeling. The NOT OK recordings in the Child are not erased by a decision in the present. The task at hand is how to start a collection of recordings which play OK outcomes to transactions, successes in terms of correct probability estimating, successes in terms of integrated actions which make sense, which are programmed by the Adult, and not by the Parent or Child, successes based on an ethic which can be supported rationally. A man who has lived for many years by the decisions of an emancipated Adult has a great collection of such past experiences and can say with assurance, ‘I know this works.’ The reason I’M OK – YOU’RE OK works is that instant joy or tranquillity is not expected”

*The Parent, Adult and Child in decision-making*

The three psychological sub-types (Parent, Adult and Child) discussed above each have important and separable effects in communication and decisionmaking. It is the Adult that leads to decision-making where observations and experiences are impartially considered.
The biases of the Parent and the feelings of the Child are balanced and placed in context. However, this is not always the case.

Figure 40 shows how the Parent and Child can adversely impact on the Adult.

![Figure 40. Interactions between the Parent, Adult and Child in decision-making (Source: Modified from Harris 1967).]

There is a further, important means by which the Parent and Child can “sabotage” decisionmaking. That is to obstruct the Adult from collecting further information before making a decision (Harris 1967, p. 56). Because the Parent and Child reside in memory, they have no need for new information; their responses are always the same and they are always correct as far as the Parent or Child is concerned.

However, is this system for understanding interactions and communication of any use in FSR? Consider the exchanges below, provided by Hamilton (1995, p. 81), and interpreted in the Child, Parent, Adult framework:

“An influential farmer, who was a member of a major funding body, had expressed doubts about the effectiveness of activities like the rainfall simulator to assist farmers make better decisions and change their farming practice”.

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This is a reasonable expression of doubt; a genuine Adult enquiry (“I’m OK – You’re not OK”), maybe with some Parental bias (ie some conditioning that genuine tests need larger plots sizes, etc.).

Hamilton decided, however, that:

“This made him a prime target to host a rainfall simulator activity”

This is the response of the Child (i.e. a quick, emotional response - “I’m OK – You’re not OK” - rather than a planned outcome).

After the demonstration:

“Our targeted influential farmer said ’Well, you’ve convinced me.’ He went out that afternoon and bought himself a zero till planter”.

Hamilton (1995, p. 81) interpreted this as success, but it could be interpreted as the farmer making a hasty decision over an expensive piece of equipment. Also, it seems worrying the farmer said “You’ve convinced me” rather than “I’m convinced”, perhaps indicating that they are not identifying themselves as the decision-maker and taking responsibility for the outcomes.

Understanding these types of exchanges, especially between researchers and farmers, provides insight that helps understanding and communication.

*Myers-Briggs*

Following the work of Myers-Briggs, Jung and others, Kiersey (1998, p. 333) found that:

“...People are either more observant than introspective, or more introspective than observant. Observers (Guardians and Artisans) seem more at home when looking after the particulars of everyday living, attending to concrete things – food, clothing, shelter, transportation - and to practical matters such as recreation and safety.... Introspectors (Rationals and Idealists) tend to be more content when these concrete concerns are handled by someone else and they are left free to consider the more abstract world of ideas.”
“To put this difference in another way, Observers [Guardians and Artisans] might be called “earthlings” or “terrestrials,” concrete, down-to-earth beings who keep their feet on the ground. These persons see what is in front of them and are usually accurate in catching details... Observers want facts, trust facts, and remember facts, and they want to deal with the facts of a situation as they are, either in the here and now, or as recorded in the past. They focus on what is happening, or what has happened, rather than anticipating what might be, what would happen if, or what might occur in the future. In contrast, Introspectors [Rationals and Idealists] might be called “extraterrestrials,” abstract beings who live with their head in the clouds, strangers in a strange land who wonder about the curious antics of the earthlings. Absorbed as they often are in their internal world, Introspectors tend to miss a great deal of what’s right around them – current reality is merely a problem to be solved, or a stage of development toward some future goal.”

“Because of their tenuous grasp of reality, Introspectors [Rationals and Idealists] can appear to Observers [Guardians and Artisans] as flighty, impractical and unrealistic – the dreamer or absent-minded professor who can’t be bothered with the nitty-gritty of living. For their part, Observers [Guardians and Artisans] can seem to Introspectors [Rationals and Idealists] as unimaginative, concerned only with trivial pursuits, and exasperatingly slow to consider implications and possibilities. Both views are exaggerations. Indeed, both kinds of people are capable and even creative in their own way – it’s just that they attend to very different sides of life, with the other side getting short-changed.”
Table 28. Traits of temperament and character. (Source: Kiersey 1998)

<table>
<thead>
<tr>
<th>Type</th>
<th>ARTISAN</th>
<th>GUARDIAN</th>
<th>IDEALIST</th>
<th>RATIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communication</strong></td>
<td>Concrete</td>
<td>Concrete</td>
<td>Abstract</td>
<td>Abstract</td>
</tr>
<tr>
<td>Implementation</td>
<td>Utilitarian</td>
<td>Cooperative</td>
<td>Cooperative</td>
<td>Utilitarian</td>
</tr>
<tr>
<td><strong>Interests</strong></td>
<td>Education</td>
<td>Commerce</td>
<td>Humanities</td>
<td>Sciences</td>
</tr>
<tr>
<td></td>
<td>Preoccupation</td>
<td>Morality</td>
<td>Morale</td>
<td>Technology</td>
</tr>
<tr>
<td></td>
<td>Vocation</td>
<td>Material</td>
<td>Personnel</td>
<td>Systems</td>
</tr>
<tr>
<td><strong>Social role</strong></td>
<td>Mating</td>
<td>Helpmate</td>
<td>Soulmate</td>
<td>Mindmate</td>
</tr>
<tr>
<td></td>
<td>Parenting</td>
<td>Socializer</td>
<td>Harmonizer</td>
<td>Individuator</td>
</tr>
<tr>
<td></td>
<td>Leading</td>
<td>Stabiliser</td>
<td>Catalyst</td>
<td>Visionary</td>
</tr>
<tr>
<td><strong>Self-image</strong></td>
<td>Self-esteem</td>
<td>Artistic</td>
<td>Dependable</td>
<td>Empathetic</td>
</tr>
<tr>
<td></td>
<td>Self-respect</td>
<td>Audacious</td>
<td>Beneficent</td>
<td>Benevolent</td>
</tr>
<tr>
<td></td>
<td>Self-confidence</td>
<td>Adaptable</td>
<td>Respectable</td>
<td>Authentic</td>
</tr>
<tr>
<td><strong>Intellect</strong></td>
<td>Directive role</td>
<td>Tactical</td>
<td>Logistical</td>
<td>Diplomatic</td>
</tr>
<tr>
<td></td>
<td>expressed</td>
<td>Operator</td>
<td>Administrator</td>
<td>Mentor</td>
</tr>
<tr>
<td></td>
<td>reserved promoter</td>
<td>supervisor</td>
<td>teacher</td>
<td>fieldmarshal</td>
</tr>
<tr>
<td></td>
<td>craftsman inspector</td>
<td>counsellor</td>
<td>mastermind</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Informative role</td>
<td>Entertainer</td>
<td>Conservator</td>
<td>Advocate</td>
</tr>
<tr>
<td></td>
<td>expressive performer</td>
<td>provider</td>
<td>champion</td>
<td>inventor</td>
</tr>
<tr>
<td></td>
<td>reserved composer</td>
<td>protector</td>
<td>healer</td>
<td>architect</td>
</tr>
<tr>
<td><strong>Values</strong></td>
<td>Being</td>
<td>Excited</td>
<td>Concerned</td>
<td>Enthusiastic</td>
</tr>
<tr>
<td></td>
<td>Trusting</td>
<td>Impulse</td>
<td>Authority</td>
<td>Intuition</td>
</tr>
<tr>
<td></td>
<td>Yearning</td>
<td>Impact</td>
<td>Belonging</td>
<td>Romance</td>
</tr>
<tr>
<td></td>
<td>Seeking</td>
<td>Stimulation</td>
<td>Security</td>
<td>Identity</td>
</tr>
<tr>
<td></td>
<td>Prizing</td>
<td>Generosity</td>
<td>Gratitude</td>
<td>Recognition</td>
</tr>
<tr>
<td></td>
<td>Aspiring</td>
<td>Virtuoso</td>
<td>Executive</td>
<td>Sage</td>
</tr>
<tr>
<td><strong>Orientation</strong></td>
<td>Present</td>
<td>Hedonism</td>
<td>Stoicism</td>
<td>Altruism</td>
</tr>
<tr>
<td></td>
<td>Future</td>
<td>Optimism</td>
<td>Pessimism</td>
<td>Credulism</td>
</tr>
<tr>
<td></td>
<td>Past</td>
<td>Cynicism</td>
<td>Fatalism</td>
<td>Mysticism</td>
</tr>
<tr>
<td></td>
<td>Place</td>
<td>Here</td>
<td>Gateways</td>
<td>Pathways</td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>Now</td>
<td>Yesterday</td>
<td>Tomorrow</td>
</tr>
</tbody>
</table>
Learnings from adult learning

Experiential or activity-based learning is different to traditional education and training. It is:

- Organized around experience. Through a high degree of participation, direct "hands on" experience provides the data for powerful learning. These experiences have been called "serious play," based on the premise that this type of learning can be fun.
- Learner-based, rather than teacher-based. Activity-based learning starts with the experience the learner is having and goes at the learner's pace, with latitude for unplanned but relevant material.
- Personal, not impersonal in nature. The feelings, values, and perceptions are as important as the subject being studied.
- Process- and product-oriented. How the learner arrives at the conclusion or answer is as important as what that conclusion or answer is.
- Emphasis on holistic understanding. The integrated "complexity" of the situation is stressed over the simple, fragmented understanding.
- Perception-based rather than knowledge-based. Emphasis is on the learner's ability to justify or explain a subject, rather than recite an expert's testimony.
- Individual-based rather than group-based. Emphasis is on individual progress, rather than competition or comparison with other participants, classes or expected outcomes.
- Self-directed evaluation. Learners participate in their own evaluation, hence there's an emphasis on personal responsibility.

But there are problems with the method, too. It is:

- Too long and drawn-out for sharp, abstract thinkers who prefer a quick lecture ("just the facts, please!"), and has
- Too many inconsistencies for them to be sorted out; it's always relativistic, which some people don’t like.

Some examples of successful experiential learning programs in Australia include:

- Paired-paddock assessment of pasture improvement (Trompf and Sale 2000),
- Soil nitrogen and water workshops (Lawrence et al. 2000), and
- Rainfall simulator field days (Hamilton 1996).

Contemporary theories of learning and cognition
A contemporary theory of learning relevant to this thesis is situated learning theory (SLT). King (2000) lists some of the characteristics and hypothetical benefits of SLT in Australian SLT. SLT:

- “Seeks to overcome mind-body dichotomy and attempts to construct a theory that encompasses mind and lived-in world, treating relations among person, activity, and situation, as they are given in social practice.”
- “Learning is not an individual’s problem, but rather sees phenomena like “failure to learn”, as it occurs within formal education systems, as a product of such systems, and the social practices of its educational professional.”
- “Rejects that formal educational contexts are the site of the culturally significant learning processes.”
- “Research is not necessarily directed towards improving practice of educationalists since it is not necessarily directed at the formal institutional sites of learning.”
- “Does not see “mind” as a container to be filled up but sees mind-in-action in the everyday world, creating knowledge and learning simultaneously in interaction with the social and material aspects of the lived-in world.”
- “Sees the learning process as a generative process of knowledge production which is indissociable from the situated, contextual, social engagement with the material lived-in world.”
- “Sees professionally produced knowledge to be rooted in socially, materially situated contexts as much as lay knowledge.”
Appendix 3. How accurate are the detailed models of farming systems reality?

This appendix includes information about the reliability of information produced from the use of detailed simulation models. To be used as “field simulators”, as envisaged by McCown (2001b) and others, the results from such models need to be as realistic as possible. This study compares simulated crops with field measurements, and compares two different crop modules used in the APSIM (McCown et al 1996) model.

Introduction

APSIM (McCown et al. 1996) has been used under a wide range of conditions in numerous studies to simulate crop production from soil, crop and weather and management data. It contains two alternate models of wheat production, Nwheat (Probert et al. 1995), and Iwheat (Meinke et al. 1997), as well as software to simulate soil moisture and fertility, pasture, crops other than wheat, runoff, drainage and soil erosion. APSIM and Nwheat were used by Robinson et al. (1999) to simulate long-term average responses to N fertiliser in south-western Queensland, but the model was tested using only 1 year of data. Four years of data (1996 to 1999) and two models are now available for testing, and this study reports the results of this wider testing.

Methods

Nwheat and Iwheat were used to simulate wheat yields and proteins in an experiment at Nindigully, near St George. Simulated and observed yield and protein results (1996 to 1999) were compared graphically and by linear regression. To determine whether the models were sensitive to factors affecting the growth and development of the crop, simulated and observed leaf area indices (LAI) and above-ground biomass (DM, kg/ha) at anthesis were also compared.

A range of seasonal conditions occurred in the period 1996 to 1999, resulting in a wide range of yield and protein outcomes. Treatments in the experiment included four fertiliser rates each year. Also, in 1997, 1998 and 1999, 2 additional fertiliser rates were applied in combination with two tillage treatments (zero and conventional tillage), giving a total of 28 treatments × years of observations.

The APSIM model, Nwheat and Iwheat were used to simulate crop growth and grain yield and protein for each treatment. Each simulation used measured pre-plant soil moisture and nitrate concentrations for that treatment, as well as the relevant fertiliser rate. Other factors
were based on either measured values (plant density, variety, soil organic carbon, runoff curve number) or values that have proved reliable in other studies.

Results

Figure 41. Wheat yields (kg/ha) and grain protein content (%) simulated by Nwheat (top) and Iwheat (bottom) and those observed at Nindigully. (Source: Robinson et al. 2001)

Figure 41 shows the simulated results from the models and the observed yield and protein data at Nindigully. Nwheat simulated yields in 1996 quite well, but underestimated yields in 1997 and 1999, and overestimated 1998. Iwheat simulated yields well in 1997 and 1999, but overestimated yields in 1996 and 1998. The mean absolute errors in the simulated yields (|observed – simulated|) were 1447 kg/ha for Nwheat and 1358 kg/ha for Iwheat. The mean of the observations was 2595 kg/ha. Both models over-predicted yields by large amounts in 1998, probably due to effects of disease (yellow spot) and waterlogging reducing yields in the experiment. Unfortunately, there appears to be no a priori means of knowing or compensating for such errors.
Protein contents simulated by Nwheat fell predominantly in a range between 8 to 10 %, which underestimated many observed values by between 3 and 6 %. The mean absolute error was 2.6 %. Iwheat was better at simulating higher protein contents, and had smaller errors (mean = 1.7 %). Protein was severely underestimated by both models in 1998, probably as a consequence of the yield over-prediction mentioned above.

Table 29 shows that the model estimates were not significantly correlated with the observed variation in yield ($R^2 = 0.0$ for Nwheat, $R^2 = 0.0$ for Iwheat) and protein ($R^2 = 0.0$ for Nwheat, $R^2 = 0.13$ for Iwheat). None of the relationships had a slope near the ideal value of 1, and all of the slopes were much less than 1, indicating that the models were not sensitive to the factors that produced the observed variations in grain yield, protein and N yield.

Figure 42 shows the relationships between simulated and observed LAI and DM. Nwheat was better at simulating LAI than Iwheat, which substantially under-predicted LAI in many instances. Iwheat was better than Nwheat at simulating DM (mean error = 1874 kg/ha). DM prediction by Iwheat was within +/- 30 % of the observed values except for the 1996 data and the treatments with high fertiliser rates in 1998. Nwheat rarely estimated DM within 20% of the observations (Figure 42). Table 2 shows the mathematical relationships between the simulated and observed LAI and DM data.

Table 29. Relationships between simulated yield, protein and N yield (X) and the observed values (Y) at the Nindigully experiment, 1996 to 1999. (Source: Robinson et al. 2001)

<table>
<thead>
<tr>
<th></th>
<th>Nwheat equation</th>
<th>$R^2$</th>
<th>SE</th>
<th>Iwheat equation</th>
<th>$R^2$</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (kg/ha)</td>
<td>2590 - 0.001 X</td>
<td>0.0</td>
<td>971</td>
<td>2403 + 0.058 X</td>
<td>0.0</td>
<td>967</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>12.2 + 0.11 X</td>
<td>0.0</td>
<td>2.15</td>
<td>5.38 + 0.57 X</td>
<td>0.13</td>
<td>1.98</td>
</tr>
<tr>
<td>N yield (kg/ha)</td>
<td>39.5 + 0.29 X</td>
<td>0.07</td>
<td>21.6</td>
<td>31.2 + 0.34 X</td>
<td>0.14</td>
<td>20.8</td>
</tr>
</tbody>
</table>

Table 30. Relationships between simulated (X) and observed (Y) leaf area index (LAI) and aboveground biomass (DM, kg/ha) at the Nindigully experiment. (Source: Robinson et al. 2001)

<table>
<thead>
<tr>
<th></th>
<th>Nwheat equation</th>
<th>$R^2$</th>
<th>SE</th>
<th>Iwheat equation</th>
<th>$R^2$</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAI</td>
<td>$Y = 1.0 + 0.28 X$</td>
<td>0.13</td>
<td>0.57</td>
<td>$Y = 1.41 + 0.003 X$</td>
<td>0</td>
<td>0.64</td>
</tr>
<tr>
<td>DM (kg/ha)</td>
<td>$Y = 4301 + 0.24 X$</td>
<td>0.09</td>
<td>1417</td>
<td>$Y = 3855 + 0.21 X$</td>
<td>0.05</td>
<td>1449</td>
</tr>
</tbody>
</table>
Although the models did not simulate the observed yields and proteins overall, some results were better than others. In particular, some of the largest errors concerned treatments with high fertiliser rates in 1998. It may be argued that 1998 was an exceptional year due to the occurrence of excess rainfall and plant diseases, and that the 1998 data are not as representative of the usual run of seasons as the other test data. By assuming that 1998 is not representative of seasons that would usually want to be simulated, these data could be omitted from the analysis. Results that exclude 1998 show that the errors in simulations are smaller, but still far from ideal (Table 31).

Nwheat produced a useful level of correlation with the observed yields in these data ($R^2=0.68$), but not for protein ($R^2=0.07$). Iwheat did not reliably simulate these yield data ($R^2=0.37$), but reproduced the protein data quite well ($R^2=0.74$). The results for N yield were substantially better than for the all-years data set.
Table 31. Relationships between simulated yield, protein and N yield (X) and the observed values (Y) at the Nindigully experiment in 1996, 1997 and 1999. (Source: Robinson et al. 2001)

<table>
<thead>
<tr>
<th>Yield (kg/ha)</th>
<th>Nwheat equation</th>
<th>R^2</th>
<th>SE</th>
<th>Iwheat equation</th>
<th>R^2</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein (%)</td>
<td>3.53 + 0.74 X</td>
<td>0.07</td>
<td>2.05</td>
<td>-3.08 + 1.29 X</td>
<td>0.74</td>
<td>1.11</td>
</tr>
<tr>
<td>N yield (kg/ha)</td>
<td>33.7 + 0.72 X</td>
<td>0.37</td>
<td>17.5</td>
<td>24.2 + 0.62 X</td>
<td>0.38</td>
<td>17.5</td>
</tr>
</tbody>
</table>

Discussion

These results show that these crop models would not be suitable for replacing or enhancing results from the Nindigully field experiment. The best results were from Nwheat, which simulated yield and protein in 1996, and Iwheat which simulated protein in 1996. However, overall, there are systemic problems in the models, as evidenced by the discrepancies between simulated and observed leaf area and dry matter at anthesis (Figure 41). Excluding data from 1998 improved the fit of the simulated yield and protein data, but not to a high level. These results show that the effects of disease, weeds, etc. can be very important, and it would be unwise to assume that the distribution between years of yields or proteins from the model is indicative of the distribution of results from experimental plots or farmers paddocks where such factors can affect yields.

The Nwheat simulations were approximately as accurate (SE = 971 kg/ha) in absolute terms as a previous study (Probert et al. 1995), where a SE of 937 kg/ha (R^2 = 0.30) was reported between simulated and observed wheat yields. The results here for Iwheat (SE = 967 kg/ha) are also similar to those (SE = 940 kg/ha) calculated from low-yielding situations (below 4 t/ha) in another study (H. Meinke, unpubl. PhD thesis). To achieve a SE equal to 20 % or less of the long-term average yield in the region, an SE of no more than 250 kg/ha is required. At present, the models produce errors almost 4 times larger than this.

The low accuracy of the wheat models at this site calls into question the conclusions of other studies that have assumed Nwheat or Iwheat and APSIM are accurate (e.g. Robinson et al. 1999, McCown et al. 1998). Depending on the circumstances, it may be hazardous to use APSIM to estimate the consequences of decision-making in this region.

These results contrast with the best results achieved at other locations. For an N fertiliser experiment at Condobolin, Iwheat simulated yield and protein with impressive accuracy (Robinson, unpublished data). The SE of yield and protein in those data were 141 kg/ha and 0.38 %, respectively (R^2 = 0.91 and 0.96). Further work is required to establish the causes of the disparity in accuracy between locations.
Conclusions

Testing the Nwheat and Iwheat models revealed that neither model was suitable for estimating wheat yields and proteins in southwest Queensland.

It would be useful to estimate the validity of APSIM in other regions and circumstances, and to use the information to continuously improve the software.

Summary

Two models of wheat production (Nwheat and Iwheat) are tested by comparing simulated and observed grain yield and protein content for an experiment where responses to N fertilisers were being investigated. Coefficients of determination ($R^2$) between the observed and simulated yields (kg/ha) were 0 for both Nwheat and Iwheat. For grain protein (%), the $R^2$ values were 0 and 0.13 for Nwheat and Iwheat, respectively. The models gave more accurate results when data for 1998, where the crop was affected by disease or waterlogging, were excluded. The $R^2$ for yields and proteins increased to 0.68 and 0.07 for Nwheat and 0.37 and 0.74 for Iwheat, respectively. In general, the models were poor at simulating the observed leaf area and dry matter at anthesis. The low average yield in this environment emphasised the errors in the simulated results. In other environments, the same quantum of error may be less important. A fourfold reduction in error is necessary before simulations could substitute for experimental results.

Comparison of two crop modules

Models are individualistic because the author of each model has a potentially large range of algorithms, processes and parameters from which to choose. Nevertheless, the aim of the model should be to arrive at the same end-point; accurate representation of the biophysical system. However, because models are, to some degree or other, associated with the particular choices of the author (concerning data sets, scales of representation, etc.) there is considerable scope for different models achieving different results when simulating the same situation.

Comparisons of results from different models can be used to identify invalid results from one or both or either model. Such an analysis follows.

Shortly after completing the study of wheat crop responses to N fertiliser (reported above) with the Nwheat model, the Iwheat model was adapted for use in APSIM and was available to replicate the simulations. Both of these models have origins in the Ceres-wheat model. The major differences in the models include their submodels for estimating leaf area.
development, and different approaches to estimating yield. For details of the two models, see Probert et al. (1995) and Meinke et al. (1997).

The results from the two models differ considerably, as shown in Figure 43. Under these circumstances, Nwheat predicts substantially lower yields than Iwheat, and the degree of the difference is associated with the amount of N-fertilisation.

![Graph of simulated yields at four rates of nitrogen fertiliser (0, 25, 50 and 100 kgN/ha) on a grey clay soil at St George (1960 to 1998 inclusive). (Source: Robinson et al. 2001)](image)

Although the lack of 1:1 correspondence in yield was a concern, the results for grain protein showed virtually no association in the results between the two models (Figure 44).
Given that yield rather than grain protein is the primary determinant of gross returns, it is not surprising that the relationship between crop gross returns calculated from the two models (Figure 45) is more like the yield comparison graph above (Figure 43) than the grain protein graph (Figure 44).

Figure 44. Simulated grain protein content at four rates of nitrogen fertiliser (0, 25, 50 and 100 kgN/ha) on a grey clay soil at St George (1960 to 1998 inclusive). (Source: Robinson et al. 2001)

Figure 45. Simulated returns ($/ha) at four rates of nitrogen fertiliser (0, 25, 50 and 100 kgN/ha). (Source: Robinson et al. 2001)
Conclusions

Given that these models use similar or equal representations of many crop physiological processes, it is somewhat surprising that they differ so much in their results. Comparisons suggest, for example, that the gross returns ($/ha) calculated from Iwheat results are likely to be 41% to 100% greater than the returns calculated from Nwheat results, with exceptional cases of up to 170% greater. If calculated in terms of gross margins or profit, these differences would be further amplified.

Unfortunately, it appears relatively simple for models to diverge from being realistic representations of crops, as even this simple analysis has shown. It seems that these complex models can easily become storehouses for mathematical functions and logic whose interactions become too complex for the developers and operators to understand and control. An extreme example of these inadvertent interactions comes from an application of the Iwheat model, which in one case increased wheat yields by 800kg/ha in response to the simulated addition of 1 kg N/ha (P DeVoil, pers. comm.).

It is concluded that the complexity and flexibility of modern crop models endows them with both the capacity for detailed and realistic representations of systems and the capacity to mask unforeseen interactions that can easily result in very unrealistic representations of physical systems.

Appendix 4 Crop management parameters for models: A sensitivity analysis

Introduction

This study examines the sensitivity of outcomes to variations in rules and their parameters that govern the management of crops and soil in a dryland farming system at Dalby on the Darling Downs, about 200 km west of Brisbane. It also explores some of the potential difficulties of specifying management rules and parameters from farmers’ perceptions of decision-making.

Simulation has emphasised physical farm resources, undoubtedly because successful farming is highly dependent on biological and physical relations between the climatic, soil, plant, animal and economic resources of a farm. However, the management of these resources also has a key role, even though it has received little attention. Although applied research is mainly aimed at producing decision rules or decision support systems (DSS) for farmers, there has been remarkably little effort in formally recording and analysing farmers’ management rules.

Not surprisingly, there are differences between the way that farmers view their decision-making and the views of researchers. It appears common for farmers to regard each decision as unique, while researchers search for commonalities between decisions; looking for a persistent, stable, decision framework. Researchers often use sets of rules to mimic the decisions made by farmers.

In this study, we assume that well-defined, quantifiable frameworks for crop management decisions exist, and analyse some of these. Some of the defects in this assumption are also examined.

Methods

The model

The APSIM model (McCown et al. 1996) simulates a soil management unit, on which can be grown various crops and pastures, and which may be subject to a range of management treatments, such as fertilisation or irrigation. In this study, three crops were simulated: wheat (Nwheat), sorghum (Sorg) and chickpeas (Chick).

A feature of APSIM is its “manager” file, which allows the construction of rule sets to control operations during simulation. Any simulated variable can be used to control operations such as tillage, planting, fertilisation, etc.
The benchmark simulation ran from 1900 to 1998, initiated with a history of wheat crops in the preceding two years (the cropping history affects what is sown). Dalby meteorological data and a black vertosol soil with 250 mm capacity of plant-available moisture were used. Each simulation traced dynamic variation in soil moisture, soil nitrogen, crop production and residue production and decomposition. Fertiliser rate depended on the crop sown and time of sowing. Other parameters were based on either measured values (plant density, variety, soil organic carbon, runoff curve number) or values that have proved reliable in other studies.

The Decision Framework

Standard rules and parameters for the management of the management system are given in Table 32 below. Parameter names and default values are shown in brackets. The aim of the default management rules was to produce rotations and conditions conducive to high productivity through avoidance of weeds and diseases, poor crop nutrition, rainfall runoff, etc.

During fallows, once the minimum number of days since harvest or the last tillage operation has been completed (TillPeriod, 30 days), tillage (spray or cultivation) will occur as soon as possible (ASAP) after receipt of a given amount of rain (RainTrigger, 30 mm) over a given period (RainPeriod, 6 days). Tillage is cancelled if a crop is to be sown in the next few days. ASAP is 7 rain-free days with mechanical cultivation and 4 rain-free days with spraying. Each ploughing reduced stubble cover by 30 %, with a depth of incorporation of 75 mm, while spraying reduced cover by 2 %, with a depth of incorporation of 5 mm.

Crop choice and sowing depended on the type of previous crop (and sometimes the crop before that), the length of the fallow, and soil fertility. These rules reflect management to avoid weeds, pests, fallow disorders and wasted financial opportunities (such as would occur if chickpeas were sown when available soil N was very high).

Chickpeas is a good example because the rules are relatively simple: they are the crop of choice given a minimum fallow period (ChickpeaFallow, 30 days), that the previous crop was not chickpeas, and a limit to the number of cereal crops (i.e. wheat and sorghum) has been exceeded (MaxCereal, 4 crops). However, if the quantity of available soil N is very high, the choice reverts to a cereal crop (CriticalN = 200 kg N/ha). Chickpeas are then sown after a delay (SowDelay, 7 days), if 30 mm of rainfall occurs over 3 days between 15 April and 30 June. The simulated cultivar was Amethyst, the density 25 plants/m² and the row spacing was 350 mm. Similar rules governed the sowing and management of wheat and sorghum.
Conventional Tillage (CT) and Zero Tillage (ZT)

Different tillage systems were simulated because they affect soil cover, fertility and the water balance. Conventional tillage was assumed to involve a chisel ploughing, which mixed 30% of crop stubble ($\text{Incorp}_{\text{CT}} = 0.3$) into the top 75 mm of soil ($\text{CultDepth}_{\text{CT}} = 75$ mm). Zero tillage was also simulated. Due to the low weight of spray rigs, weed control can usually be done on moister soil, and consequently earlier, than with conventional tillage ($\text{DryDays}_{\text{ZT}} < \text{DryDays}_{\text{CT}}$). There is minimal disturbance of the soil and stubbles ($\text{CultDepth}_{\text{ZT}} = 5$ mm).

Table 32. Parameters varied in the sensitivity analysis and their nominal ranges.
(Source: Robinson and Freebairn 2001)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>TillPeriod</td>
<td>20 +/- 10 (days since tilled)</td>
</tr>
<tr>
<td>(till) ASAP</td>
<td>7 +/- 4 (CT) (days)</td>
</tr>
<tr>
<td></td>
<td>4 +/- 2 (ZT) (days)</td>
</tr>
<tr>
<td>RainTrigger</td>
<td>30 +/- 10 (mm)</td>
</tr>
<tr>
<td>RainPeriod</td>
<td>6 +/- 2 (days)</td>
</tr>
<tr>
<td>ChickpeaFallow</td>
<td>30 +/- 15 (days)</td>
</tr>
<tr>
<td>WheatFallow</td>
<td>30 +/- 15 (days)</td>
</tr>
<tr>
<td>SorghumFallow</td>
<td>30 +/- 15 (days)</td>
</tr>
<tr>
<td>SowDelay</td>
<td>7 +/- 4 (rain-free days)</td>
</tr>
<tr>
<td>MaxSorghum</td>
<td>2 +/- 1 (sorghum crops)</td>
</tr>
<tr>
<td>MaxCereal</td>
<td>4 +/- 2 (cereal crops)</td>
</tr>
<tr>
<td>CultDepth$_{\text{CT}}$</td>
<td>75 +/- 25 (mm)</td>
</tr>
<tr>
<td>Incorp$_{\text{CT}}$</td>
<td>0.3 +/- 0.2 (proportion)</td>
</tr>
</tbody>
</table>

Nominal ranges in the uncertainty of some of these parameters are shown in Table 1. Although Table 1 is not definitive, it was considered a useful starting point. It was expected that system sensitivity would more often related to the role of parameters in the system than their nominal value. In any case, the range of the parameter values is large relative to their nominal starting values.

Using their nominal ranges shown in Table 32, parameters were combined into three sets for simulation: (i) standard parameters, (ii) a conservative system, producing less cropping, and (iii) an intensive system, with frequent cropping. All three systems were simulated in combination with both ZT and CT.
Sensitivity Analysis

To see if the results depended on the specific period simulated, different starting dates were tried. Soil conditions and water resources were assessed after 40 years of simulation to avoid effects of length of simulation on resource status, (e.g. the results for a start year of 1920 are taken from 1960, for 1930 from 1970, etc.).

Results

Table 33 shows some of the differences resulting from ZT and CT management. ZT was expected to reduce runoff and accumulate more soil moisture during fallows, allowing more intensive cropping, but the results show these effects were slight. The main effect was a shift to sorghum cropping and higher sorghum yields.

Figure 46 shows some results for baseline CT and ZT simulations started in different years. Starting year has a relatively large effect on the outcome. Relative to the variability, there is little evidence of a trend; instead the results “bounce” around chaotically. Closer examination of the results showed that interactions of the rules with weather and soil conditions resulted in complex and persistent changes in the outcomes. Divergences due to minor differences (e.g. double cropping due to extra soil moisture stored under ZT) were common (data not shown).

Table 33. Some baseline results for zero tillage (ZT) and conventional tillage (CT) scenarios. Simulations ran from Jan 1900 to 1998. (Source: Robinson and Freebairn 2001)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Final value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ZT</td>
</tr>
<tr>
<td>Sorghum yield (t/ha/crop)</td>
<td>4.07</td>
</tr>
<tr>
<td>Number of sorghum crops</td>
<td>58</td>
</tr>
<tr>
<td>Wheat yield (t/ha/crop)</td>
<td>2.48</td>
</tr>
<tr>
<td>Number of wheat crops</td>
<td>29</td>
</tr>
<tr>
<td>Chickpea yield (t/ha/crop)</td>
<td>2.38</td>
</tr>
<tr>
<td>Number of chickpea crops</td>
<td>14</td>
</tr>
<tr>
<td>Final soil organic carbon (OC, t/ha)</td>
<td>164</td>
</tr>
<tr>
<td>Final soil N (t/ha)</td>
<td>13.2</td>
</tr>
<tr>
<td>Transpiration (mm/year)</td>
<td>186</td>
</tr>
<tr>
<td>Runoff (mm/year)</td>
<td>28</td>
</tr>
<tr>
<td>Deep drainage (mm/year)</td>
<td>13</td>
</tr>
</tbody>
</table>
Figure 46. The sensitivity of crop frequency and wheat yields (t/ha/crop) to tillage and the starting year of simulation. (Source: Robinson and Freebairn 2001)

Figure 47. Simulated resource conditions with conventional (CT) or zero tillage (ZT), and either conservative (Con) or intensive (Int) bias in management parameters. (Source: Robinson and Freebairn 2001)
Some resource and crop yield results from the factorial management by starting year simulations are shown in Figure 47 and Figure 48. Uncertainty in the management parameters, as represented in the conservative and intensive options, led to large differences in outcomes for some parameters, such as drainage (Figure 47), while others such as sorghum yield were not greatly affected overall (Figure 48). As noted above, interactions between the management rules and the starting year leads to major differences in the ranking of the management systems in different starting years (Figure 47 and Figure 48).

The finding that starting year has a considerable and persistent effect on the results has parallels to the results of Cox and Chudleigh (2001), where starting year was found to be more important than either the starting conditions or management parameters in determining the subsequent profitability of cropping enterprises in central Queensland.

The results have implications for farmers and researchers testing crop rotations and management choices. The substantial effects of starting year and small differences in the timing of events shows that individuals would have great difficulty in separating the intrinsic
value of rotation choices from the effects of timing (‘bad weather and bad luck’). This is consistent with the belief of many researchers that rotation experiments need to be ‘phased’ to remove effects linked to seasons.

Conclusions

Even in a management system as simple as that simulated here, specific combinations of timing and management lead to unique outcomes. Weather is the driving force for these associations. What was usually the poorest management could be judged the best management given a starting date that is favourable. Chance (‘good luck’) was as important as management in providing good outcomes in some of the scenarios examined above.

Nevertheless, many questions remain: What are the other implications of the high degree of temporal variability? Are past distributions of results representative of future results if the physical processes are chaotic? Is there a relationship between the complexity of the decision framework and its stability? Would more rules be more or less stable?

Lastly, consideration of simulating management in a system such as APSIM reveals that defining and quantifying the parameters of management systems is problematic because of the many biases, inconsistencies and complexities of human behaviour. These present major challenges to biophysical modellers who may want to simulate real-world management systems.

Summary

This study examines the sensitivity of the APSIM (Agricultural Production systems SIMulator) model to soil and crop management rules in the northern grainbelt of Australia. APSIM is used in studies of cropping systems, but rarely in the analysis of long-term crop sequences based on flexible management rules (as used by many farmers). Rules considered here govern what crop to sow, whether to sow, when to sow, when to till and with what implement. Not surprisingly, some components of the system, such as runoff and deep drainage (mm/year), were highly sensitive to changes in parameters, while others, such as soil organic carbon (t/ha), were largely unaffected. Additionally, changing the period over which the simulations ran often changed the results, including the ranking of different management systems. This variability in results, for no other reason than favourable timing, makes it difficult to separate the effects of good management from good luck. As well as these difficulties in testing management systems, there are difficulties in specifying management, which involves intangible processes, often with strong psychological, social and or emotional elements. Quantification of a set of rules that represent these complex processes with any precision is likely to be difficult.
Details of this study were published in Robinson, J. B. and Freebairn, D. M. 2001. How sensitive are agricultural production systems models to farm management parameters? Proceedings International Congress on Modelling and Simulation, MODSIM 2001, Australian National University, Canberra.