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The FARMSCAPE approach to decision support: farmers', advisers', researchers' monitoring, simulation, communication and performance evaluation

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Abstract

FARMSCAPE (Farmers', Advisers', Researchers', Monitoring, Simulation, Communication And Performance Evaluation) is a program of participatory research with the farming community of northeast Australia. It initially involved research to explore whether farmers and their advisers could gain benefit from tools such as soil characterisation and sampling, climate forecasts and, in particular, simulation modelling. Its current focus is facilitating the implementation of commercial delivery systems for these same tools in order to meet industry demand for their access. This paper presents the story of what was done over the past decade, it provides performance indicators of impact, it reflects on what was learnt over this period and it outlines where this research is likely to head in the future.

Over the past 10 years, the FARMSCAPE team employed a Participatory Action Research approach to explore whether farmers could value simulation as a decision support tool for managing their farming system and if so, could it be delivered cost-effectively. Through farmer group engagement, on-farm trials, soil characterisation, monitoring of crops, soils and climate, and sessions to apply the APSIM systems simulator, FARMSCAPE represented a research program on decision support intervention. Initial scepticism by farmers and

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commercial consultants about the value of APSIM was addressed by testing its performance both against measured data from on-farm trials and against farmers' experiences with past commercial crops. Once this credibility check was passed, simulation sessions usually evolved into participants interactively inquiring of the model the consequence of alternative management options. These 'What if' questions using APSIM were contextualised using local climate and soil data and the farmer's actual or proposed management rules.

The active participation of farmers and their advisers, and working in the context of their own farming operations, were the key ingredients in the design, implementation and interpretation of the FARMSCAPE approach to decision support. The attraction of the APSIM systems simulator to farmers contemplating change was that it allowed them to explore their own system in a manner equivalent to learning from experience. To achieve this, APSIM had to be credible and flexible. While direct engagement of farmers initially enabled only a limited number of beneficiaries, this approach generated a commercial market for timely and high quality interactions based on soil monitoring and simulation amongst a significant sector of the farming community. Current efforts are therefore focused on the training, support and accreditation of commercial agronomists in the application of the FARMSCAPE approach and tools.

The FARMSCAPE approach to decision support has come to represent an approach to guiding science-based engagement with farm decision making which is being tested nationally and internationally.

Keywords: System simulation; Decision support systems; Participatory action research; On-farm research; Soil monitoring; Climate forecasts

1. Introduction

How should one evaluate the return on a significant investment in a decision support research program run over the past 10 years? As a scientific research team, we are certain to be assessed in terms of new knowledge of interest to our peers and the broader community. However, the team was established with the explicit goal of facilitating the implementation of improved farm management practices in our research mandate region and so expect to be judged on this primary criterion. The effort must be judged also in terms of whether the practices and processes in which we have invested have sustained relevance and application within our targeted agricultural systems. In this paper we reflect on our experiences in the dryland farming systems of northeast Australia in developing and delivering decision support systems (DSS) for farmers, i.e. computer-aided management systems which are based on scientific models developed with the purpose of enhancing farmer decision-making (McCown, 2002a,b). This complements earlier reports (eg. McCown et al., 1994, 1998, 2002b; Carberry, 2001; Hochman et al., 2000) by focusing on impact and learning against the criteria of changed farming practices, new scientific knowledge, improved research processes and sustained relevance.

Our research into developing and delivering decision support systems started in 1991, coinciding with the formation of the Agricultural Production Systems Research Unit (APSRU) and has since involved at least 15 related and complementary projects funded by industry and government. What began as a pilot, core-funded research program on four farms in northeastern Australia has grown into a portfolio of industry-supported research activities which have primarily addressed two research questions:

1. Can farmers value simulation as a tool in helping to manage their farming system?
2. If so, how then can it be delivered cost-effectively?

In 1995, the acronym FARMSCAPE (Farmers', Advisers', Researchers', Monitoring, Simulation, Communication And Performance Evaluation) was created as the title for a grains industry-supported project that featured farmers, advisers and researchers learning together about crop and soil management by conducting on-farm experiments and holding simulation-aided discussions. In 1999, we initiated a program to train and accredit agronomists from four agricultural consulting companies to use the FARMSCAPE approach to serve their clients in the northern grains/cotton region. In our view, FARMSCAPE has come to represent an approach to guiding science-based engagement with farm decision-making.

This paper presents the story of what we have done over the past decade, it provides performance indicators of impact, it reflects on what was learnt over this period and it outlines where our research is likely to head in the near future. Our intention is that this should be an honest and frank account of a significant research effort, the lessons from which will be of use to those concerned with systems thinking and systems practice in agricultural research.

2. Who were the research clients?

Dryland farmers and their industry advisers in the grain/cotton region of north-east Australia operate in an environment characterised by seasonal uncertainty and highly variable production, a fragile natural resource base and generally low world commodity prices, which are largely unsubsidised by the public purse. Consequently, improved management of the economic and environmental risks to crop production are at the forefront of industry demands for research investment.

This region of Australia is characterised by a wide variety in crop choice—wheat, barley, sorghum, cotton, maize, mungbean, sunflower and chickpea are the major crops grown in both summer and winter seasons. However, yield of any crop is strongly influenced by extreme variability in seasonal rainfall and so the prospects for any cropping season are often highly uncertain. Farmers can offset the risk of low in-season rainfall through reduced cropping frequency and storing soil water during fallow periods prior to planting. The mostly Vertiosol soils of the northern cropping region can store significant amounts of water in fallows of up to 2 years duration (Dalgliesh and Foale, 1998). This high risk environment makes many investment decisions such as fertiliser application difficult, and many agronomic decisions encompass trade-offs between options of low risk and return versus those with higher returns but commensurately higher risks. Since the early 1990s, dryland cotton has been increasingly recognised as a viable cropping option for the region, but one whose high potential returns are accompanied by high risks. This new challenge coincided with the initiation of our on-farm research activities and cotton risk management has since provided considerable impetus for this research.

A distinguishing characteristic of dryland crop management in this northern region of Australia is the propensity for farmers to engage the services of commercial agronomists. Increasingly, farmers are willing to pay for specialised agronomic advice. This is especially the case with cotton-growers where it is an industry standard to employ pest management consultants. A significant proportion of the commercial agronomists are employed by input supply companies who offer farmer clients access to their agronomists as incentive to maintain relationships and loyalty for their company services. For farmers in this region of Australia, the private sector has clearly become the key provider of the development and extension activities which were once the responsibility of public agencies (Wylie, 1992).

It was our belief from the outset that the dryland cropping region of northeast Australia was a place 'most likely' to respond to and benefit from research on improved approaches to decision support for farmers.

3. What did we do?

Our approach started with the desire to take our research on-farm and participate with farmers in exploring their real-world issues. By getting involved with and doing 'sensible things' with farmers an approach emerged which could be viewed as a rudimentary form of Action Research. Only later did we become aware of and acknowledge the parallels between our research practice and the theories of Participatory Action Research (PAR). Action Research has been defined as "production of knowledge that guides practice, with the modification of a given reality occurring as part of the research process" (Oquist, 1978; McCown, 2001). This approach acknowledges that science can not research the management of agricultural systems without meaningful participation of systems managers (Carberry, 2001). PAR is often depicted by the action research cycle consisting of iterative cycles of planning, action, observation, reflection which then lead on to other iterative cycles (Zuber-Skerritt, 1993). Within the FARMSCAPE project, action research cycles were formalised both around operational activities and over longer time periods, corresponding to distinct phases in the term of this research program. The following phases represent sequential action learning cycles whereby the design of the next phase was a consequence of evaluation and reflection of its preceding phase.

3.1. Formation of APSRU (1990–)

In 1990, CSIRO[1] and the State Government of Queensland[2] established a joint research team, the Agricultural Production Systems Research Unit[3] (APSRU), in

[1] Australia's Commonwealth Scientific and Industrial Research Organisation (http://www.csiro.au).
[2] http://www.qld.gov.au.
[3] http://www.apsru.gov.au.

order to bring together their relevant and diverse expertise in the computer simulation of farming systems. Prior to 1990, the CSIRO research team had been implementing a farming systems research approach in exploring the potential for dryland cropping in the semi-arid tropics of far northern Australia, as well as being involved in exploring management options for smallholder agriculture in semi-arid Kenya (McCown et al., 2002b). Such research efforts resulted in adaptation of crop models to Australian and Kenyan conditions and led to the initial development of the innovative AUSIM systems model which was focused on system performance rather than the yield of single crops (McCown and Williams, 1989). Likewise within Queensland State Departments, prior to the formation of APSRU, there had been significant effort in the development and application of crop models (Hammer et al., 1987) and the PERFECT cropping systems model had been developed to assist research on soil water balance and erosion processes in local farming systems (Littleboy et al., 1992).

The development of the Agricultural Production Systems Simulator (APSIM) (McCown et al., 1996; Keating et al., in press) has been a primary achievement of the combined resources within APSRU. Consequently, APSIM has formed the core technology that underpins much of APSRU's research agenda. The formation of APSRU had also created the expectation of further development of DSS products targeted at benefiting farmers in northeast Australia. At this time, despite the lack of local success for adoption of DSS products, there was a belief that DSS had not been oversold but rather been underdeveloped (Hamilton et al., 1991). APSRU was given the challenge to test this hypothesis. The CSIRO team within APSRU took prime responsibility for tackling this question, the outcome of which has not seen the development of new DSS software, but rather new understanding and insight about using simulation to support farm decisions.

3.2. Pilot on-farm research (1992–1995)

Our notion of decision support evolved from the directive to develop software for use by farmers to an emphasis on working closely with farmers in assisting them to learn about their farming system. This evolution began with the recognition of the low use by farmers of existing DSS. While there could be many reasons for low use, the key questions seemed to be whether farmers could value simulation as a tool in 'thinking about' pending actions and choices (McCown et al., 1994). As students of Farming Systems Research Methodologies (McCown, 1991), we decided to embark on an active program of on-farm research to address this question. This program involved:

1. collaborative experiments with farmers and their advisers in commercial paddocks on issues they identified as important;
2. monitoring the state of the major production variables of climate, soil water and nitrogen; and
3. using simulation models to go beyond the experiments in exploring the issues and options of interest to managers.

In essence, the farmer-negotiated trials provided relevance, the modelling generated insights and generality and the participation of existing farmer networks provided the type of communication required.

Our pilot on-farm program began in 1992 with two groups of farmers in Central Queensland and a third group in southeast Queensland. Group sizes ranged from 6 to 10 participants. The selection of treatments and the design of the on-farm trials were negotiated with each farmer group and their private consultants and/or local public extension officers to address relevant issues. Generally, the focus was on the best way to manage their soil water and nitrogen resources. About 15 experiments were initially conducted on-farm on dryland sorghum, cotton and wheat crops (Cox et al., 1993; Foale et al., 1993). Later, as interest in this approach increased, more farmer groups and on-farm trials were initiated. Centred around 10 locations throughout the northern grains region, over 60 farmers and seven advisers were involved, and in excess of 50 on-farm trial or commercial crops were monitored by the end of 1995.

Key components of the on-farm trial program were the characterisation of the soil for plant available water content (PAWC), regular sampling of soil water and nitrogen during the crop and fallow periods and the installation of either a logged or manual climate station to record daily weather data at the site. While such detailed data were justified initially as required inputs for the simulation model, the soil sampling to depth was readily recognised by the participating farmers and advisers as itself providing valuable new information in assisting them with management decisions. Consequently, in response to farmer requests, many more commercial paddocks beyond the initial trials were monitored for soil resource status and yield over this same time period.

Initial scepticism by farmers and commercial consultants about the value of models was addressed by testing model performance against measured data both from the on-farm trials and from monitored commercial crops. The latter often involved producing simulated yield prior to being informed of the actual harvested result. Once this credibility check was passed, 'kitchen table' simulation sessions usually evolved into participants interactively posing queries concerning the consequence of alternative management options, including choice of crop, planting date, planting rate, nitrogen fertiliser rate and crop rotation sequence. These 'What if' questions were contextualised using local climate and paddock-specific soil data, and the farmer's actual or proposed management rules. Most sessions ran for several hours, involving multiple simulations in response to persistent lines of questioning that required iterative and interactive responses from the researcher running the model. Many of these sessions were recorded and transcribed to assist with qualitative evaluation in order to document the different ways in which farmers and their advisers approached management issues, the farmers' response to this science-based service and the responses of advisers and consultants to the value of monitoring and simulation.

3.3. The Ridge–Cox report (1995)

Running alongside the pilot on-farm research project, but within our research group, was an initiative to undertake market research for decision support, led by

Peter Cox and Peter Ridge. This project started with the objective of studying farmers' decision-making in order to identify niches for professional contribution and to identify the shape of a successful decision aid. It seemed logical for these researchers to serve as observers/participants in the pilot on-farm collaborative research project, assisting in evaluation of the potential role for simulation in assisting the management of dryland farming systems. In a 1994 progress report, Cox then confirmed the approach being taken:

> It is not clear in what form simulation models will be used to assist advisers and farmers in planning and decision-making, but this participative approach is the key to reducing the chances of producing decision support packages that sit on shelves. Increasingly, we feel that contributions by professional agriculturalists and their models to improved paddock management are likely to be brought about through processes of co-learning and communication that are much more complex than simply the provision of software products aimed at aiding decision-making.

In 1995, however, the positions of Cox and Ridge had changed dramatically, with their draft final project report harshly attacking the approach of the pilot on-farm program and questioning the motives of their project colleagues—this draft was distributed widely to funders and select peers. Their principal accusation was that we were ignoring the real research needs of farmers by persisting with our research question of whether farmers could value simulation as a tool in helping to manage their farming system.

The draft Ridge–Cox report was a traumatic, but influential landmark for our group. It provided reason for deep self-reflection on the very basis of our research program. We emerged from this period with some valuable new understandings which provided us with renewed optimism and vigour to pursue our original research objectives.

Peter Cox exposed us to an emerging world view whereby scientists were under attack for their self-centred research programs and lack of concern for achieving purposeful change (Cox et al., 1996; Woods et al., 1997). While initially shocked by the severity of criticism from our colleagues, it is our current view that this episode was of net benefit to our team. We have become students of the broader systems literature as a means of understanding the philosophical context of our and others' research agendas (McCown, 2001, 2002a,b) and we have applied this learning to real-world problems (Carberry, 2001).

The original report has subsequently been published by Ridge and Cox (2001), with an addendum response from McCown et al. (2001).

3.4. FARMSCAPE phase 1 (1995–1998)

The aims of the FARMSCAPE project (McCown et al., 1998) were:

1. To develop networks of farmer groups, facilitated by consultants, advisers or extension officers to engage in on-farm monitoring of soil water and nitrogen;

and to train the facilitators in the use of the simulator (APSIM) to add value to data and aid discussion.

2. To find cost-effective ways for farmers, advisers and researchers not in active groups to benefit from the output of aim 1.
3. To evaluate the impact on participants of the co-learning and communication activity.

In addressing its first objective, FARMSCAPE researchers established direct working relationships with over 230 farmers, organised within 28 groups and with 15 farm advisers, and ran over 30 on-farm trials centred around 13 climate stations in northeast Australia. All crops monitored within the project were used to test APSIM simulations. Such testing confirmed that APSIM is able to simulate commercial crop production in most cases (Foale and Carberry, 1996). APSIM was subsequently used to extrapolate the results from field experiments in time to other seasons using historical weather data, in on-going interactive 'What-if? Analyses and Discussions' (WifADs) with collaborating farmers and advisers (see following section on WifADs). In addition, the FARMSCAPE team serviced requests for soil data and simulations for a significant number of farmers, mainly via collaboration with private agronomists but also on an individual request basis. Over 100 simulation scenarios were conducted and delivered in one year. In fact, the demand for APSIM simulations by 1998 had increased rapidly to the point where it could not be met, nor could an 'at-call' delivery service be justified by CSIRO.

One approach to addressing our second aim was to transfer the FARMSCAPE tools and capabilities to private consultants. Consequently, a series of soil characterisation, soil monitoring and climate station training days were conducted for adviser participants and their farmer clients. Likewise, 15 participating agronomists completed training courses on APSIM and received workbooks containing exercises covering a wide range of APSIM applications. Evaluation of the course showed a very high level of appreciation for the course, the workbook and the new user interface for APSIM (APSFront). However, the subsequent use of APSIM by consultants was limited due to its high competency requirements and steep learning curve. In an innovative response to a lack of consultants' in-house expertise, an APSRU researcher, Zvi Hochman, joined one commercial company for a 3-month period as a 'Scientist in Residence' in order to research the feasibility of an agribusiness firm, if it did have the capability, delivering APSIM services to its customers. Thereafter, APSIM simulations were used by 13 company agronomists and distributed to over 100 farmer clients. In a survey of 52 such clients, the APSIM information was rated overwhelmingly as 'very good'.

FARMSCAPE communication activities encompassed the production of a video describing the FARMSCAPE approach, the publication of a regular FARMSCAPE Insights Newsletter which is distributed to over 300 stakeholders, representation at most field days and industry information events and contributions to numerous print articles in the rural press and other sources. The video, entitled "Down to Earth: the FARMSCAPE story", was completed in April 1997 and disseminated to a wide range of stakeholders and peers. It underwent extensive evaluation locally, by audiences in other parts of Australia, and by some groups in India, Africa, USA and Europe. It remains available to interested individuals and groups upon request.

Concomitant with the objective of finding cost-effective ways for meaningful engagement amongst participants, a pilot program was initiated in 1997 to learn how the Internet could be used to provide useful support to APSRU clients in utilising simulation within their well-defined geographic and problem domains (Hargreaves et al., 2001). Accordingly, two modes of engagement were established–an asynchronous mode via a FARMSCAPE Website and a synchronous mode whereby WifAD sessions are conducted on-line. The Website (www.farmscape.cse.csiro.au) contains project information, news and events, farmer and adviser case studies, soil databases and climate records, and Web pages for individual farmer groups. The on-line sessions utilise Microsoft NetMeeting® to enable video, audio and screen sharing between FARMSCAPE researchers at their base and a farmer group convened at a host farm. Our research has been to evaluate the effectiveness of each Internet delivery mode in terms of (1) impact on client thinking and action, particularly relative to the costly but more personal mode of direct engagement and (2) improvements in the WifAD process.

In 1998, the clientele for FARMSCAPE research was broadened to also encompass the agribusiness value chain. This initiative was instigated by a group of farmers concerned by the then widespread perception that banks were either withholding funds or forcing clients into ill-advised planting decisions given the wide perception of an El Niño induced drought in September 1997. Such advice was despite APSRU information suggesting that seasonal prospects were not greatly affected if fallows had reasonable stored moisture ($>50\%$) or, in lower fallow moisture conditions, if planting date was delayed. Therefore, consistent with the on-going FARMSCAPE activities, this new initiative intended similarly to address the alternative market segment of the agribusiness financial and insurance sectors. APSRU researchers collaborated on several case studies in order to test the feasibility of an agribusiness firm, with adequate in-house technical expertise, being able to use seasonal climate forecasts and crop yield simulations in designing and implementing improved marketing, finance and insurance packages. The use of a Participatory Action Research approach meant that specific research activities were developed in response to industry interactions and opportunities as they emerged (Brennan et al., 2000).

3.5. FARMSCAPE phase II (1999–2002)

By the end of 1998, both internal and external evaluation was indicating the FARMSCAPE activity had created significant market demand for access to system simulation and our research had indicated that agronomic consultants potentially could play a leading role in extending monitoring and simulation to the grain and cotton industries of northeast Australia. The next step was to develop something with market potential into an industry-ready product available through a delivery system that could impact significantly on the commercial reality of the broader farming community. However, at this point, we reached an impasse in the form of a conflict between a private sector desire for exclusivity of access to APSIM versus public demand for equitable access, the latter driven not only by Government representatives but also by the agri-political bodies involved in research funding and representation of their farmer members.

Stakeholder meetings, attended by representatives of the APSRU partners, the grain industry research funding body, the participating agribusiness companies, the State farmer representative body and a number of interested farmers, were held during 1998, from which three options for the commercial delivery of APSIM were considered:

1. Distributed software—where APSIM was developed to the point where it could be distributed to individuals for their own use.
2. Central bureau—where a bureau service would be established to deliver APSIM simulations to paying customers.
3. Accredited users—where a number of users would be licensed to commercially deliver APSIM simulations to clients.

The first option of a distributed DSS was promptly rejected as incompatible with past experience and FARMSCAPE research findings. Likewise, the central bureau model received little support from stakeholders. Whilst acknowledging a bureau overcame the sensitive point of exclusivity, it introduced other problems, including the need to create yet another business entity and impracticalities such as how such a model could deal with peak times prior to sowing when everyone may want their job done. The third alternative of accredited users was strongly supported.

The FARMSCAPE Training and Accreditation project was initiated in 1999 to develop and construct a sustainable delivery system for the FARMSCAPE approach to supporting farmers' learning, planning and decision making. Seven commercial agronomists from four companies providing agronomic advisory services and two public extension officers enrolled in a training and accreditation scheme being developed and delivered concomitantly by APSRU. The project is developing six training modules which contain the materials necessary for professional advisers to acquire the skills necessary to implement the FARMSCAPE approach. Its delivery is via a combination of lectures, workshops, self-paced learning activities, on-job exercises and on-line Internet discussions. The accreditation and licensing scheme is targeted at transferring technology from a publicly funded research initiative to a successful commercial application in the farm advising and consulting industry. It is intended that the training resources and accreditation scheme developed and evaluated in this project may be reused in subsequent years. Following its completion, training may be offered, on a cost recovery basis, to other companies if there is sustained market demand for FARMSCAPE accreditation. As at January 2002, the first four of six training modules have been developed and delivered to participants.

Investment in researching the application of the Internet and within the agribusiness value chain is also continuing in the second phase of FARMSCAPE projects. After a successful piloting of real-time synchronous Internet engagements with several farmer groups, current emphasis has turned to conducting programs of

Internet-based interactions between farmers and professionals. The purpose is to develop a practical and commercially feasible methodology for facilitating learning programs for farmers, and an interactive on-line method for consultants to provide clients with customised soil monitoring and simulation support. These activities will also involve the development of on-line multimedia resources and an 'interested observer' program to actively demonstrate this approach to other researchers and stakeholders.

The exploration of commercial applications within the agribusiness value chain has also continued, with clear interest seen in some areas of engagement (e.g. insurance/loss assessment), while other collaborative efforts have only progressed some way to exploring the role for seasonal climate forecasts and simulation models within business operations (e.g. banking, portfolio analysis). Current research investment is concentrating on developing the means of servicing such clients via the FARMSCAPE Training and Accreditation program.

3.6. The WifAD

Interactive 'What-if? Analyses and Discussions' (WifADs) with collaborating farmers and advisers became a key ingredient to the FARMSCAPE approach to decision support. The idea started in 1993 with a suggestion from Bob McCown to Peter Carberry that he take his computer along to an upcoming meeting with a particular farmer in order to try running the simulation model interactively with the farmer. Up until that time, model runs were undertaken in the office and simulation outputs presented to farmers at group meetings held primarily to report results from the on-farm trial and soil monitoring program. The models we used then were precursors to APSIM, simulating sorghum, maize (Carberry and Abrecht, 1991) and cotton (Hearn, 1994) crops. They had no user-friendly front/back ends but rather employed input files containing multiple series of cryptic, fixed-format numbers. At the time there was no design nor effort to accommodate non-expert, non-researchers in their active use.

This initial meeting was held in farmer Ross Skerman's kitchen and also involved John Marshall, a local extension agronomist. The agreed purpose of the meeting was to review the on-farm trial results from the previous year's (1992/1993) dryland cotton crop. Two issues were of interest from this trial. The first was to review the risky decision to plant cotton very late (1 December 1992) on low starting soil water (52% of available soil water capacity). The second concerned the impact of a large 'bulge' of mineral nitrogen discovered at depth below this crop through soil monitoring. Neither Ross, John nor we researchers had expected 330 kg ha^{-1} of nitrate-N to be present under a crop on which we had imposed a nitrogen application trial! This N discovery was the initial motivation behind the "deep N bulge" story referred to in this paper and elsewhere (Ridge et al., 1996).

While Ross and John were initially sceptical about how much added value might come from running a computer model 'on the kitchen table', they patiently accommodated the idea. The session started with benchmarking the performance of the dryland cotton crop which yielded 1.9 bales ha^{-1}—the yield simulated at that time was 2.2 bales ha^{-1}. Pre-run simulations (done in preparation for the meeting) were presented to demonstrate no benefit from applying fertiliser to this crop with its large mineral N bulge at depth. Then, it happened. Ross asked that first important question: "*I wonder what would have happened if I could have planted my cotton at a more preferred time (early October)?*" We did the run—the simulation showed a higher yield for earlier planting in that season. Ross then followed on by inquiring "*I wonder how often a late cotton planting would succeed?*". The WifAD was born with the response of "*Hey, let's use the model to explore that question—we can take the last 10 years of your rainfall record and run the model to see what would have happened with late planting over the past 10 years.*" From then the questions flowed: "*How would sorghum compare for December planting dates?*"; "*At what date should I switch from cotton to sorghum?*"; "*How would the result change if I had higher starting soil water?*"; "*What if I had fallowed that paddock through to a winter crop?*" and so on for the next three hours. That first session only stopped due to the mental fatigue of the computer operator who had been cajoling his "unfriendly" models to be responsive to increasingly complex questions.

That first 'kitchen table' session was followed quickly by others, which stimulated similar reactions from farmer and adviser participants. A memorable early experience was a prominent farmer and agribusiness consultant arriving late to a session and declaring on entry that he was "*extremely sceptical of the value of these computer models.*" By the end of that one interactive modelling session, Glenn Milne declared he had been converted.

The over-riding memory of taking our user-unfriendly computer models out into the real world that first day with Ross Skerman was a feeling of great trepidation. Nine years later it is a distant memory and, on reflection, it was exactly the right thing to have done to provide the impetus for us to discover a role for computer simulators of agricultural systems. WifAD sessions have since been held with hundreds of farmers in much the same way as that first session evolved. Today, those involved in that first WifAD session remain greatly enthusiastic about simulation:

> A few years ago I may have taken a gamble, but today, no way. We're getting a better understanding of the science behind these computer models and it's giving us confidence to make decisions using the information. We're getting a handle on the situation rather than functioning on gut feeling—Ross Skerman quoted by Collis (1997).

> Jimbour farmer Glenn Milne cannot sing the praises highly enough of a crop growth computer simulation model developed by the Agricultural Production Systems Research Unit (APSRU) in Toowoomba. The model has provided him as well as associates, with far more confidence about planting decisions, which has in turn led to more confidence about marketing. From article by Lloyd (2000).

3.7. Evaluation activities

Evaluation has been a key component of our participatory research process to enable documentation and reporting of industry impacts and also reflection and planning within the Action Research process. Although more formal evaluation processes commenced with the FARMSCAPE project in 1995, many of our early engagements were also documented and some effort was placed in evaluation. Since 1995, baselines of farmer practices were established at initiation of any new project, mainly through the use of independent consultants who were contracted to interview project stakeholders to elicit information on both current and desired change to management practices. In addition, ongoing evaluation has included 'entry/exit' questionnaires at most interactive sessions; regular external interviews of key stakeholders to determine changed views longitudinally over time; targeted interviews with select stakeholders corresponding to particular events; mail surveys of farmers; and the FARMSCAPE Forum, held in December 1996 and in June 1998, aimed at reporting to stakeholders, summarising progress and agreeing to changes in direction and emphasis.

Several consultants have been used in our evaluation activities, although two were prominent in assisting the FARMSCAPE team. Dr. Jeff Coutts (Director, Rural Extension Centre, University Queensland, www.ruralextension.qld.edu.au) helped design and instigate the initial evaluation framework for the FARMSCAPE projects. In late 1995, he interviewed participants from the pilot on-farm research program in order to assess the results of these interactions, and published an internal report and a paper (Coutts et al., 1998). Peter van Beek, who had led a Systems Study Group within the Queensland Department of Primary Industries (e.g. van Beek, 1993) prior to starting his own company (SyTrec Pty Ltd.), has provided evaluation consulting services to a range of FARMSCAPE projects. Between 1996 and 1998, van Beek wrote five commissioned reports related to the FARMSCAPE phase 1 project: a 1996 report which benchmarked the then industry perception of the FARMSCAPE team and their activities, a 1997 interim report to provide feedback on project direction, a 1998 final report that established some consequence from the FARMSCAPE activities and two reports that targeted the influence FARMSCAPE projects had on collaborating institutions (one an agribusiness company, the other a sister research organisation). During the 3 years, he conducted over 100 detailed interviews with 49 people. Time trends in views were tracked with 30 interviewees, of which 21 were interviewed three times and nine twice.

Our approach to evaluation has been to concentrate on using an Action Research framework, whereby evaluation activities have sought data and feedback from stakeholders in a manner that can inform future directions. Consequently, the impacts have been mainly seen in documented change in practices within certain case studies rather than broad impacts as may be contained in a benefit:cost analysis across industries.

4. What is FARMSCAPE's impact?

The introduction to this paper asked how one should judge the return on investment from the FARMSCAPE research program run over 10 years. What has been the impact of undertaking this research effort? A number of changes in industry and research practices are claimed as significant outcomes from the FARMSCAPE portfolio of activities. In making these claims, we are declaring a significant contribution to each outcome, but certainly not the sole contribution—others beyond our team have also contributed to each outcome. However, in each of these nominated areas, the FARMSCAPE team have been a principal contributor to the activities that led to the nominated impact.

In 1996, van Beek's interviews with industry representatives noted that there were a number of issues routinely mentioned in association with the FARMSCAPE team:

1. Deep soil coring for measurement of moisture and nitrogen, and for location of roots.
2. Development and subsequent commercial production of relatively cheap deep-coring tools (hand held and hydraulic).
3. The increased awareness of bulges of nitrogen at depth in the soil profile that were frequently observed in farmers' fields.
4. The characterisation of soils for water holding capacity.
5. The computer simulation model, APSIM.

These five elements of the FARMSCAPE research program have together achieved a major impact on the cropping industry of northeastern Australia.

4.1. Soil monitoring as a key management practice

> We were finding there was a lot of N deeper down which we hadn't been accounting for, so obviously the N fertiliser rates could be reduced...using a hydraulic hoist on the back of ute, we took three soil cores to 120 cm in each of eight paddocks in a bid to determine soil moisture for winter crop planting. Farmer quote from article by Lloyd (2000).

> Survey data indicated that there was an exponential increase in soil testing, and greater awareness in the general farmer population of the value in soil monitoring. Commercial advisors successfully used new soil monitoring techniques and simulation models to enhance their value to leading farmers. Coutts et al. (1998).

Deep soil coring to quantify soil water and nitrogen resources before planting has become common practice within the last 10 years for agribusiness, and for many farmers in the northeast cropping region of Australia. Prior practice had been to use a simple penetrometer probe to indicate depth of wet soil (Fawcett et al., 1976) and to sample the surface 100–150 mm of soils for nitrogen (Dalgliesh and Foale, 1998). Now agribusiness has become active in providing water and N monitoring services to depth, with most agronomy service-providers using deep coring equipment, and several companies taking the next step of investing in drying ovens. Many farmers have also equipped themselves with coring equipment, and are doing their own coring and in some cases drying (using a microwave oven). Quantitative data on the number of soil samples undertaken for depths below 0.6 m analysed for nitrogen by a major fertiliser company in northern Australia have indicated an exponential increase in the practice of deep soil coring during the 1990s. Current industry recommendations for N sampling have changed to incorporate sampling to depth under circumstances where deep N is likely.

FARMSCAPE evaluation has documented numerous case studies where improved knowledge of soil water and nitrogen through deep soil sampling has resulted in benefits to farmers. In one case, the farmer nominated a saving of $A30,000 from not having to apply planned fertiliser rates because of newly discovered soil nitrate at depth. Given the widespread adoption of deep soil sampling, such benefits have extended to the broader farming sector in northeastern Australia.

Hydraulic soil coring rigs had been used by researchers prior to the 1990s and most agronomists had some prior exposure to such rigs in their careers. However, such technology had not been actively taken up by commercial agronomists, as little demand for deep coring was evident and the hydraulic soil coring rigs available at that time were expensive to build. Evidence from our evaluation indicated that the FARMSCAPE activity, principally through Neal Dalgliesh and Mike Foale, changed industry practice by:

- Demonstrating value in better knowledge of soil resources to depth.
- Designing and developing inexpensive soil coring equipment for use by hand or using hydraulics, and arranging for two local manufacturing companies to build and sell this equipment.
- Writing and publishing the '*Soil Matters*' manual (Dalgliesh and Foale, 1998) containing information on sound procedure to sample soils and interpret results and distributing it to farmers and agribusiness. The *Soil Matters* manual has also been published on-line[4] on the FARMSCAPE Website (www.farmscape.cse.csiro.au).
- Actively promoting these technologies through industry-sponsored publications and events.

To date, over 140 hand corers and 40 soil coring rigs have been built for and used by agribusiness and farmers. Over 700 copies of the manual *Soil Matters* have been distributed to farmers and agribusiness.

4.2. Altered the view of soil resources

> ...the family had always checked soil moisture by spearing a rod into the ground 'like everyone else. But that's a pretty rough way of doing it. It might tell you the ground's moist, but it doesn't tell you how much water's there' ...working closely with APSRU, (he) also calculated the water-holding

[4] The on-line version of the Soil Matters manual (http://www.farmscape.cse.csiro.au/productssupport/soil_matters.htm) was developed by Dr. Meri Whitaker, a collaborator on the FARMSCAPE program.

capacity of the soils on his own farm and assisted with calculations concerning the moisture required for a range of crops". Farmer quote from article by Lloyd (1997).

In addition to depth of wet soil as measured by a push probe, many farmers now actively refer to soil water as measured by soil coring in the same terms as they do rainfall—depth of water in millimetres. This changed view of soil water, from feet of wet soil to millimetres of available water required farmers to change their way of thinking about the soil to the concept of PAWC—defined as the difference between the maximum volumetric water content in the soil (after drainage) and the soil water content at which annual plants will die from water deficit.

More than 140 soil types in northeast Australia have been characterised for PAWC—these resource data are published as an adjunct to the *Soil Matters* manual (Dalgliesh and Foale, 1998) and are also available on the FARMSCAPE Website (www.farmscape.cse.csiro.au). While the majority of these soils were initially characterised by the FARMSCAPE team, increasingly individual farmers and agribusiness are characterising soils of particular interest to themselves and are making such data available for general usage. These data on measured water contents have been analysed by Hochman et al. (2001) to provide statistical estimates for the parameters of soils and crops yet to be characterised by direct measurement.

The available data on the exponential increase in numbers of deep soil samples indicate that many farmers in eastern Australia have recognised the value of deep soil resources, particularly water and N, and are now measuring it. Prior practice had been to measure the surface 10–15 cm of soil for mineral N analysis and assume that N content declined exponentially with depth. The discovery of large N bulges (>300 kg ha^{-1}) in deep sampled paddocks (Ridge et al., 1996) was a real surprise to many farmers and agronomists and led to the grain and cotton industries altering their recommendation for fertiliser applications and soil sampling procedures (Foale and Goode, 1998).

Farmers and their advisers have shifted their perception of the soil resource from a shallow soil surface viewpoint to one where the critical variables in the soil resource are now monitored over the rooting zone. The impact of this shift in perception not only incorporates knowledge about the availability of soil water and N resources but also has led farmers to discover for themselves sub-surface soil constraints, mainly high salinity and sodicity levels, which are present in many Australian soils. Often large N bulges had accumulated at depth due to sub-surface soil constraints and thus access to discovered deep N required selection of crops tolerant to such constraints.

4.3. Increased industry acceptance of modelling

Developing a better understanding of his soil is one of the greatest benefits from the APSIM model ... Together with his local farm adviser, (he) uses the model to determine realistic crop yields from each paddock at the beginning of the season. He then tailors his management to achieve those yields''. From article by Nicholls (1997).

the commercial adviser and consultants were sceptical at the beginning. They had seen large sums of money poured into non-performing or very limited-use computer-based models. However, they gained confidence and enthusiasm through seeing results from coring, soil characterisation and APSIM. Several have changed their advice as a result of involvement with APSRU, especially fertiliser recommendations .... They believe APSIM can help to reduce the margin of error in their advice which is of ever increasing economic importance—'test advice on computer before giving it to the farmer' and 'can put probabilities on advice, farmers happily accept a 7 out of 10 year probability' (van Beek report, April 1996, p. 11.)

When APSRU was formed in 1991, simulation modelling was widely viewed as being in the scientists' realm. Computerised DSS, some incorporating crop models, had been developed and promoted within industry at that time, for example, WHEATMAN (Woodruff, 1992). However, use of such products by farmers was very much lower than anticipated by their developers (McCown, 2001; Hayman and Easdown, 2002). In 1991, there was little enthusiasm within industry for simulation models and certainly little demand for access to simulation as a means of assisting crop management decisions.

By 2002 simulation modelling has become an established and valued source of information to aid management of dryland farming systems in northeast Australia. A three-fold growth in APSRU resources and staff over the last 10 years, an expansion funded primarily with industry support, provides a strong indicator of increased acceptance of modelling within industry. This mood change was also recognised and supported by our research institutions. The FARMSCAPE team has led APSRU's efforts to test simulation in real-world farming and advising practice.

Indicators of how simulation modelling has become mainstream within industry discussions and practice include:

- The establishment of a commercial FARMSCAPE Training and Accreditation program, in which four agribusiness companies have paid to participate and be trained in using APSIM within their commercial advisory services (Hochman et al., in press). This program was designed and initiated through active industry support and sponsorship (see section on FARMSCAPE phase II)
- Industry-led conferences, update meetings and training courses now actively incorporate simulation modelling as a key component to their programmes—examples include dryland cotton pre-season planning meetings, grains industry annual update meetings, accredited agronomist courses for chickpea and mungbean, and so on.
- Direct sponsorship of the FARMSCAPE team and its activities by two agribusiness companies. One company, in the grain transport sector, approached the FARMSCAPE team to offer their sponsorship for promoting monitoring

and modelling activities in the region. The stated rationale of this company was because it was impressed with the relevance and impact it had witnessed in the grains industry.

- Multiple interviews of FARMSCAPE stakeholders (farmers, commercial advisers, extension officers) as part of the evaluation activities in which increased appreciation for, and application of modelling, is expressed—reports of these interviews are contained in the paper of Coutts et al. (1998) and in the evaluation reports of van Beek.
- Expressions of interest from farmer groups elsewhere in Australia (outside APSRU's mandate region) for replication of FARMSCAPE interactions for their own regions, particularly in accessing APSIM simulations. Collaborative activities have already commenced with one group in southeast Australia in testing and applying APSIM and similar activities are being negotiated with farmer groups in Western Australia. All these new initiatives have evolved from interactions with local farmers and their private sector advisers.

4.4. *Developed and promoted the use of seasonal climate forecasting*

> The APSIM simulation had suggested to plant only if there was sufficient soil moisture given that 1997 was an El Niño year, and favoured planting sorghum in December, instead of September. [Commercial agronomist] interviewees said that about 10% of farmers who deal with [them] and intended to plant early, held off doing so. Most of these had half full profiles. Farmers with full profiles planted early. ... the season bore out the importance of stored moisture in El Niño years and increased the credibility of APSIM and the levels of confidence in its outcomes. (van Beek report, February 1998, p. 3.)

APSRU research is at the forefront of developing and demonstrating value in seasonal climate forecasting for dryland agriculture in Australia (Hammer et al., 2000) and elsewhere around the world (Stone et al., 1996). These forecasting systems are based mainly on the El Niño Southern Oscillation (ENSO) phenomenon, with the best-known approach being the use of phases of the Southern Oscillation Index (SOI) (Stone and Auliciems, 1992). The SOI has been widely promoted as a tool to help forecast seasonal rainfall, and farmers in northeast Australia are increasingly utilising climate forecast information in making management decisions (Meinke and Hochman, 2000).

While there have been many reports of normative research analyses having demonstrated potential benefits of SOI forecasts (e.g. Hammer et al., 1996; Meinke et al., 1996), it was the FARMSCAPE team who pioneered the linking of seasonal climate forecasting based on the SOI phase system with soil resource monitoring and simulation modelling at the paddock level. This has been done with farmers and agribusiness over the past 8 years in small group WifAD sessions aimed at exploring management options on participants' own farms. This participatory approach has been instrumental in making the SOI meaningful at a paddock scale and has contributed to its greater use by farmers and advisers.

4.5. Changed production expectations

> ... the model has shown him how many farmers are selling themselves short by not expecting enough from their country and not maximizing water use efficiency. The type of information required to run the APSIM program has helped him realize how much more he can get out of his cropping programme. From article by Nicholls (1997).

> Interviewees had used the APSIM runs to make decisions about major investments ... many interviewees have set themselves more ambitious goals ... some aimed for higher grades in wheat ... others set new targets for their physical production or profit, based on the model rather than on district averages. (van Beek report, August 1998, p. 7.)

In the western (inland) cropping zone of northeast Australia, grain yield expectations are relatively low as rainfall is marginal and erratic, and fertiliser usage infrequent. While soils were initially fertile, after many decades of cropping, soil organic matter had become seriously depleted (Dalal and Mayer, 1986). The region's comparative advantage in producing high protein grain had become diminished. However, since 1990, the area of cropland receiving fertiliser in this region has been increasing at a rate of 23% per year, with corresponding yield increases of 3 and 8% per year for wheat and sorghum, respectively (ABARE, 2002).

While not claiming to be the principal cause of the increase in crop yield and fertiliser usage, activities in the FARMSCAPE projects have contributed to these changes. In WifAD sessions, farmers and their agronomists have tested their target yield expectations against those simulated by APSIM over the length of their local climate records and, in the majority of cases, target yield perceptions for regions have been challenged as being too low, and the perceived risk of fertiliser returns unrealistically high. One agronomist servicing 60 farmer clients and covering over 160,000 ha of broadacre cropping has attributed the raising of yield expectations of his clients to be one of the key achievements from his involvement in FARMSCAPE projects. APSIM simulations have facilitated re-setting of target yield expectations by many famers and have identified appropriate water and nitrogen management practices most likely to achieve such targets.

4.6. Innovative changes to farming practice

> Two years ago when he wanted to plant corn but his country remained wet until mid October, he thought he had missed his chance. "But when the APSRU people did some runs on the model, given the Southern Oscillation Index (SOI) at the time and our soil moisture, and the model came up with yields increasing with a planting date right up until the end of October," he said. So that changed our whole decision and the result was very good. We averaged more than 7.5 tonnes a hectare. Farmer quoted in article by Lloyd (2000).

The FARMSCAPE program of research has influenced the management decisions of many farmers. The principal purpose of WifAD sessions with farmers has been to allow participants to explore their farming systems and experiment with changes to their system. The subsequent demand from farmers and agribusiness for access to APSIM is an indicator of interest from farmers wishing to explore change to their practices. While most requested simulations have involved simple technologies such as a shift in planting date or fertiliser rate of interest to individual farmers, there have been a number of examples where APSIM simulations have initiated the exploration of innovation to farming practices which have translated into industry-wide impacts. Two examples are:

1. The introduction of spring-planted mungbean as a new management option was initiated and progressed through a combination of APSIM simulation 'experiments' and on-farm trials. Robertson et al. (2000) reported in detail how upwards of 20% of mungbean crops are now planted in spring rather than the traditional summer planting time. This change in planting time of mungbean has impacted significantly on rotation and marketing systems.
2. Renewed interest in dryland maize in southeast Queensland was generated in 1998/1999 from APSIM simulations undertaken by request from a local agribusiness firm and their clients (Taggart, 2000). From the situation described in the earlier quotation, maize has since been transformed from being considered too drought-sensitive for this region to now being considered an attractive alternative crop option for traditional sorghum producing regions. How maize fits within the farming system is the focus of a current research project.

In both of these cases the role played by FARMSCAPE research in identifying the opportunities using simulation and in testing and evaluating performance in on-farm trials is recognised by both industry and research groups.

4.7. Commercial demand for FARMSCAPE tools

> The [agribusiness company's] agronomy team is now doing site-characterisation work. Interviewees said that there had been very fast dissemination of simulation and other results through [their] network which had created widespread discussions. It had also increased demand for services for advice and APSIM simulations, both locally and interstate, which outstripped [their] capacity to supply this. (van Beek report, February 1998, p. 5.)

In 1999, a program to train and accredit four agribusiness companies to use the FARMSCAPE approach to serve their clients in the northern grains/cotton region was established. An advertisement for expressions of interest attracted eight commercial companies ranging in size from large national agribusiness firms to a tender from a single independent agronomist. While tenders included those companies who had been closely involved in past FARMSCAPE activities, applicants also included companies which had been on its periphery, and others whose knowledge of the FARMSCAPE team and APSIM was based solely on industry reports and APSRU's reputation. Of the eight applicants, four companies were selected to nominate agronomists to become trained and accredited in the FARMSCAPE approach to support farmers' learning, planning and decision making. Criteria for selecting the four participating companies included a requirement to have variety in company size, business focus and geographic spread of client base in order to allow us to learn how FARMSCAPE tools and approaches might fit within different business systems. The four selected companies have each contributed funding and allocated staff to participate in the program which will be completed in June 2002 with the accreditation of agronomists.

The FARMSCAPE Training and Accreditation program was established as a means of addressing the market demand for the FARMSCAPE approach to resource monitoring and crop simulation. The test of its success will be how each of the four participating companies utilises these new tools within their business systems. As at January 2002, all companies are active in their participation in the training program and all are utilising soil monitoring and APSIM simulations with their farmer clients. APSRU researchers maintain a link with these clients through evaluation of the outcomes from their FARMSCAPE-related delivery to farmers.

APSRU has fielded several proposals for commercial applications of APSIM from companies with agronomic, marketing and insurance foci. Current negotiations are well progressed to establish a national commercial delivery scheme for APSIM with a planned start-up date of June 2002. This delivery system was instigated, designed and is being driven within the commercial agribusiness sector—APSRU's role in its design is to respond to the promotional and delivery ideas being proposed. This market-led initiative for access to APSIM is a valuable indicator of market demand for this technology.

5. What have we learnt?

In 1991 we started with two questions of whether farmers could value simulation as a decision support tool and, if so, how could it be delivered cost-effectively. The answer to the first question has been definitely yes. With few exceptions, the farmers and agronomists involved in the FARMSCAPE program have valued access to APSIM, assessed by evaluation feedback and continued demand for access. Our 'best guess' of the answer to the second question is the provision of a service by agribusiness consultants, and we are engaged in facilitating its design and delivery. Whether this approach is the complete or most viable answer is still to be determined—the indicator of success will be long-term sustainable demand for commercial access by farmers and agribusiness.

McCown et al. (2002a) claim that delivery of benefits to farmers via the DSS is in a state of crisis. Yet, concerning our own efforts here, we have strong evidence relating to farmers' declared and demonstrated interest in accessing systems simulation.

What might account for this difference? The FARMSCAPE research program has been primarily a case of Implementation Research (Stabell, 1987; McCown 2002a) that featured explicit positioning of management-relevant simulations in the context of a farmer's own farming situation. A complex, versatile simulator managed by a skilled intermediary enables simulations specified for a farmer's individual paddocks, the farmer can test its results against his/her own crop performance and it can be used to explore a broad range of issues raised by the farmer. We have found these features, which contrast to most DSS packages designed to be operated by farmers to deal with a narrowly specified issue and to require a minimum of localised data, to be crucial to being seen as relevant by farmers. But as pointed out by McCown (2002a), this might seem to be the completion of the circle of events that leads back to the point when the DSS was proposed as a *solution* to the "problem of implementation" of operations research. We argue that what makes this a spiral progression, rather than a circular return to a previous mode, is the substitution of a *participatory* approach for a *prescriptive* approach to manager learning and action. This is a shift in social paradigms for intervention in farming practice (McCown, 2002b).

This contemporary mode of Action Research is aimed also at researcher learning. Key learnings for the research team which have emerged from the FARMSCAPE program include.

5.1. Decision support and learning is most effective in a participatory process that combines the strengths of practical knowledge and scientific knowledge.

> A primary reason for involvement in the project by growers appeared to be the opportunity for a greater direct link with researchers. The desire to have access to a computer model/decision support aid was less of a factor (Coutts evaluation report, 1995).

The participation of farmers and their advisers has been a key ingredient in the design, implementation and interpretation of the FARMSCAPE program of activities. In fact, in more recent years, we have adopted a PAR approach to decision support. As the quotation states, at a time when farmers were sceptical about 'models', they valued interactions with the researchers. Their interest in our scientific tools only followed from this engagement.

Participation has the advantages of ensuring research activities and outcomes are well aligned with participants' expectations. There have been numerous examples of where participation of farmers and their advisers improved what we did. Farmers were the ones who recognised the value of deep soil monitoring and encouraged us to develop systems for them to use for themselves. Likewise, the presentation of simulation outputs has remained simple and flexible (mainly consisting of seasonal yields and gross margins presented as chronological histograms) as farmers either have wished to undertake their own financial calculations or to modify the gross margin we had calculated for them. Once a farmer was convinced of the credibility of the simulator, whenever APSIM poorly simulated a commercial crop's yield, interest was often in knowing "why?" This demand ensured that we collected sufficient soil, crop and climate data to be able to provide such explanation. Accumulated experience in this has led to the establishment of a minimum dataset we now generate for all monitored crops. Our initial exposure of APSIM to consultants highlighted the deficiencies in our user interface, which in turn led to the development of APSFront, the current user-friendly interface for APSIM. Now, as agribusiness has become increasingly serious about using APSIM commercially, it is leading the demand and specifications for an upgraded user interface better aligned with its needs.

The downside of a high level of participation is the high cost in researcher time and attention. For researchers used to working to their own timetables, it is a difficult transition to mesh research demands with those of the research clients whose sustained enthusiasm depends on prompt responses.

A common critique of the FARMSCAPE team has been that we have only worked with the most successful farmers (the top 10%). While we do not dispute this, it has occurred not because we sought it but because these top farmers are those most interested in working collaboratively with researchers. It was natural for us to explore a role for simulation with those farmers most likely to see its value, at least as a starting point. Our current emphasis on delivery systems within the commercial agribusiness sector is targeted at extending benefits seen by the best farmers to a broader sector of Australian farmers. This is the logical next step in our activities.

5.2. Context of one's own farm

> The most valuable FARMSCAPE product, mentioned by almost all farmers and commercially-based interviewees as the core one, is the 'replacement of gut-feel, general principles and general data by hard data, specific to individual farms or paddocks' (van Beek report, May 1997, p. 6.)

Initially, we collected detailed soil, climate and crop data on individual farms because we needed such data to parameterise and test our models. At the time, participating farmers were not interested in the models, but they quickly came to value the monitoring data as informing them about their own soil, climate and crops. Likewise, most farmers who came to value simulation wished to progress quickly from general scenario exploration relevant to their region onto their pressing specific issues and in the peculiar context of their own farm. In many cases, participants at WifAD sessions can gain value from simulation and discussion relating to a close neighbour with the same soil type and cropping system, but often nothing substitutes for being able to explore one's own precise circumstance.

Although participants have generally valued WifAD sessions with small groups of farmers and advisers, this approach was clearly not sustainable because of the high cost of scientists being so closely associated with farmers and advisers and the limited number of beneficiaries from each interaction. Our shift towards transferring the capability for monitoring and simulation to the agribusiness service sector provides the highest likelihood of delivering access to these tools to more farmers in a manner consistent with the need to provide customised analysis and advice. While the current training and accreditation program for commercial agronomists has emphasised this requirement, we expect each participating company to develop its own business model for delivering this type of service to their clientele. We will monitor and evaluate these emerging modes of service delivery and their impacts on clients' farms.

5.3. The simulator has to be credible and flexible

> ...if we weren't involved, if the computer model ever saw the light of day, it would have found the rubbish bin very quickly. Farmer quote from Coutts' evaluation report (1995).

> Interviewed farmers credited their participation in APSRU activities for helping them to reduce risk and increase confidence in their own decisions. All had started as sceptics, but had gradually gained confidence in the results from coring and from the model. Two important factors have been (1) the use of local data in a tested model, and (ii) the closeness of real results and the model's outcomes (van Beek report, April 1996, p. 9).

Our formal evaluation interviews show that, prior to their involvement, virtually every participating farmer and adviser was very sceptical about models and DSS being relevant to farm management. Over the 10 years of research, community attitudes toward models and simulation have become more favourable. This can be attributed in part to farmers' close encounters with simulation. Numerous on-farm experiments involving commercial crops have been conducted in which data for simulating the crop were collected and groups of farmers were involved in simulations of their crops. Together with subjective comparisons with their past experiences, this has left many with confidence that the model could represent aspects of their farming system.

Part of the early scepticism of farmers and advisers seems to have been due to a lack of understanding on how a model *could* adequately represent real-world behaviour of a cropping system. Appreciation that the models are driven by the daily weather and local soil conditions experienced by a crop greatly contributed to farmers' understanding and acceptance of models. The active demonstration, testing and explanation of APSIM by the FARMSCAPE team over 10 years has enabled many farmers and consultants to now regard APSIM as credible enough for relevant management 'experiments' on alternative actions and strategic management changes in the face of climatic risk.

Farmers and advisers have been aware of the related, more formal research on APSIM performance. Over the past 10 years, commercial dryland crops have been monitored and used to test simulations compared with data collected from cotton, sorghum, maize, wheat, chickpea, mungbean and lucerne crops. In most cases, such tests have confirmed that APSIM is able to simulate commercial crop production—for example, APSIM accounted for 87% of observed variation over 59 crops in one test (Carberry and Bange, 1998). For most of those crops where outputs were significantly different, we have been able to determine the reasons for the discrepancies. Most are due to the impact of factors not accounted for in the models (e.g. severe pest damage, harvesting loss; Robertson et al., 2000).

For simulation to become a practical tool in farm management its benefits have to outweigh its costs. Clearly the data required for specifying models as well as local inputs have to be affordable. We have found the following to provide a workable compromise between accuracy and affordability for most situations:

- Rainfall measured at the site; maximum and minium temperatures (preferably measured at the site); solar radiation sourced from a regional climate station.
- Characterisation of the soil's water holding capacity, specifically through measurement of a field-determined drained upper limit and crop lower limit.
- Characterisation of the soil with data for organic carbon, bulk density, and electric conductivity (to indicate subsoil salinity).
- Soil water and nitrogen contents measured to depth (typically 1.8 m) prior to planting, at flowering and after harvest.
- Crop emergence, flowering and maturity dates; plant numbers at establishment and harvest; crop yield (measured in hand-harvested small plots and machine-harvested strips); total biomass at flowering and harvest.
- Crop management information, including dates of planting and harvest; fertiliser application rates and dates; observations of damage from pests or disease.

Greater details on how to cost-effectively collect soil characterisation data have been published in the reference manual *Soil Matters* by Dalgliesh and Foale (1998).

Demands on providing evidence of APSIM's credibility have significantly declined in more recent years and there is now more ready acceptance of simulation by farmers in contrast to the heavy scepticism encountered earlier. It appears that our early demonstration of realism in simulations has reduced scepticism more generally in the farming community. Certainly, public expression of satisfaction with the capabilities and utility of APSIM by leading farmers and prominent agribusiness agronomists has helped carry APSIM over the initial credibility hurdle. This favourable reference has even extended beyond APSRU's primary mandate region, with farmer groups and agronomists elsewhere in Australia impressed by the market acceptance of APSIM in northeastern Australia and requesting trial applications for their region. However, our recent experience with a farmer group in southeastern Australia confirms past experience that it is always necessary to validate APSIM with new clients in new environments.

5.4. Simulation as a way of 'gaining experience'

> The model takes a lot of the gut feeling out of farming. Farmer quote from article by Brampton (1997).

In the highly risky farming environment of northern Australia it is difficult to assess the likelihood of desirable outcomes from any management decision—one would have to farm for many years to sufficiently experience the distribution of interacting seasons and cropping systems. Evaluation interviews with farmers have consistently identified APSIM simulation of the distribution of seasonal outcomes for any management option as a key benefit from engagement with the FARMSCAPE team. A common statement is that APSIM replaces one's 'gut feeling' where a decision is based mainly on intuition. McCown (2002b) draws on the metaphor of the ''business flight simulator'' to situate, in a much broader domain, the experience of farmers using APSIM to test alternative management options, and to gain expedient and risk-free experience.

Hochman et al. (2000) identified four types of applications in demand within the FARMSCAPE projects:

1. Benchmarking—where the performance of a past crop, in a given season and location, is compared with the simulated result in order to assess crop performance against its physiological and agronomic potential; benchmark simulations may assist in explaining actual crop performance or in highlighting deficiencies in the management of a crop. Simulations are run for the particular season of interest and entail exploration of detailed crop and soil performance—additional outputs that may help explain the yield are investigated by viewing their change on a daily basis.
2. Scenario exploration—where alternative management options are explored at a strategic level; options may include current and innovative management practices interacting with a range of environmental scenarios (different soil and climate variables). Simulations are run for the long-term historical climate record for the site of interest.
3. Tactical planning—where strategies being considered for the current or upcoming crop are evaluated based on the known status of the system prior to the season. Simulations are run using the long-term climate record for the site of interest but are reset every year to the soil conditions at the time of simulation.
4. Yield forecasting—where final yield probabilities are forecast at any time prior to or during a season. Simulations are run for the historical climate record but are reset for every year of the run to current crop, soil and climate data updated to the time of simulation.

The last three of these applications by farmers and their advisers provide simulation of yield outcomes for each year of the past climate record and for the nominated management practices. They provide comparative assessment of the expected yield, economic return and risk for alternative management decisions, and it is this quantitative analysis over a large sample of seasons which is highly valued by farm managers. Previously they made comparative decisions often with little past experience to draw upon to estimate likely outcomes.

Most farmers and advisers have preferred to view such simulations as simple histograms of yield and gross margin plotted against year of simulation rather than statistical distributions. This representation permits one's own past experience of seasons to be related to the simulation and it enables comparison of expected returns for alternative options in specific years as well as the likelihood of achieving a set target over a sequence of years. It allows each participant to set their own targeted outcome. Probability distributions [e.g. represented by cumulative distribution functions (CDF)] have not generally been well received by farmers or advisers.

Our earlier observation that the dryland cropping region of northeast Australia is a place 'most likely' to respond to and benefit from improved approaches to decision support for farmers is consistent with the view that a 'flight simulator' would be of most value where possible outcomes are highly variable. It is questionable whether similar benefits would be achieved in agricultural systems where climate variability is not a dominant driving variable, for example, in irrigated systems or in reliable rainfall environments.

5.5. Farmers are most interested in simulation when they are contemplating a change in practice

> Many interviewees became involved because they always want to learn more about farming and liked the intellectual challenge. (van Beek report, August 1998, p. 13.)

FARMSCAPE evaluation data suggest that conducting a virtual experiment with APSIM was clearly of most benefit to those farmers who were either contemplating changes to their cropping systems or who were concerned with finding ways of improving their management decisions. These farmers often nominated interest in contemplating change on entry to WifAD sessions and expounded on likely consequences of their WifAD simulations on exit (formal entry-exit surveys were conducted on most WifAD sessions). These farmers were already active in reflecting on their situation and found that simulation of possibilities served their planning needs. In contrast, farmers who were content with their current circumstance and management practices were less likely to enthusiastically seek simulations beyond the initial interactions. This was especially the case where simulations confirmed that their current practices were robust.

The attraction of a systems simulator to farmers contemplating change is that it allows them to explore their system in a manner akin to learning from experience (McCown, 2002b). However, a simulator also allows outcomes to be attributed to explainable causes, and the model's underlying crop physiology and soil physical or chemical relationships are demonstrated in the context of relevant issues about which farmers are interested to learn. Used in this mode, APSIM facilitates participative learning about farming system structure and function. The outcome of many of our WifAD sessions often did not include any clear decision on a course of action, but rather it added to farmers' learning about their system (both experientially and scientifically) and stimulated farmers to deliberate after the session was over on what this might mean for their pending management decisions.

5.6. Farm advisers are obvious candidates for delivering simulation as decision support

> Initially, most (farmers) would have liked to 'get their hands on' APSIM, either themselves or in small groups. However, there has been growing awareness of the level of sophisticated knowledge needed to get credible results. This led to a shift towards wanting to use trusted agronomists or consultants who knew the crops, the soils and the producers, and were able to drive the models. (van Beek report, August 1998, p. 7.)

To responsibly use a versatile simulator such as APSIM to mimic complex systems in ways that influence farmers' business actions, the user must have high level knowledge of APSIM's operations and science. Such requirements clearly limit the number of people qualified to use APSIM in this mode. However, an important finding from the FARMSCAPE experience is that advisers (government, agribusiness or private consultants) have an important role in leading 'what-if' discussions with farmers and in helping farmers interpret the outputs of APSIM simulations as they apply to their farms. The challenge, therefore, was to be able cost-effectively to transfer sufficient capability to these advisers to enable them to utilise APSIM in their business systems in a manner that captured the benefits from the FARMSCAPE approach. The current FARMSCAPE Training and Accreditation project is targeted at facilitating the sustainable delivery of the FARMSCAPE approach to farm advisers to support their clients' learning, planning and decision-making. As these trainees are unlikely to match the APSIM expertise of FARMSCAPE researchers, it is an explicit FARMSCAPE objective to assess the consequence of this trade-off on the satisfaction of the service providers and their clients.

At the time of writing the first 'class' is approaching the final stages of their training, a number of key researcher learnings include:

1. Both trainees and their employers reported high levels of satisfaction with the program.
2. Three of the four companies have started to use simulation in their consulting business.
3. Trainees were generally demonstrating high levels of competence in performing assessment tasks and involving clients in them.
4. Even with significant effort, not every agronomist has the ability to become a skillful simulator.
5. Some individuals were experiencing periodic difficulties meeting the demands of training in competition with urgent demands from their clients for their regular services. This affected the private sector agronomists much more than their public sector colleagues.
6. While the retention rate has been high, job mobility for agronomists and changing company ownership has proved to be a challenge for retaining the same trainees through a prolonged training program.

A subtle yet critical learning was that for training activities to compete for attention in a high-pressure commercial environment there is an ongoing need to nurture and reinforce the trainees' and their managers' early vision of a valuable new service to farmer clients.

5.7. Formal evaluation is an essential process

> Most farmer and business interviewees were keen to change the focus of the interviews, first from their farm and business practices towards their management processes, and then towards reflecting on possible roles of APSRU products in future management processes. (van Beek report, August 1998, p. 5.)

While science is judged traditionally in terms of tests of 'truth', as it moves toward application, usefulness becomes the primary test (Gibbons et al., 1994) and evaluation would seem to be unavoidable where there is to be accountability. Yet few agricultural research and development activities have encapsulated evaluation activities in order to assess their impact, i.e. initial baselines and quantitative and qualitative data on the processes leading to practice change and consequences (Bennett, 1975; Dart et al., 1998). Fewer still have actively and openly reflected on their performance and reported successes and failures. From as early as our pilot on-farm research activities we have attempted to document and reflect on our experiences in developing and delivering decision support for farmers. A significant investment in evaluation processes is regarded as an essential ingredient to FARMSCAPE activities.

It has been important for FARMSCAPE team members to document their interactions and query their fellow participants. The use of external evaluators has also been highly useful and is a cost-effective means of surveying stakeholder views. External evaluators are seen as being independent from the FARMSCAPE team and have been successful in drawing out the concerns and reflections of interviewees in some detail. Longitudinal studies, where a set of stakeholders was interviewed every 6–12 months, have provided important trends over time. For example, over 3 years of a FARMSCAPE engagement with several groups of farmers, involving monitoring and simulation, interviews in the first year were dominated by farmers' contributions on soil monitoring. By the third year, these same farmers' contributions were dominated by simulation matters. Unambiguous documentation established this pattern as a progression from concrete to more abstract representations of farming reality, which subsequent experience has affirmed as predictable. Feedback through formal evaluation has been instrumental in the development of soil coring tools for farmers, the design of the APSFront interface, the instigation of the "scientist in residence" activity and re-deployment of resources towards internet delivery systems.

Our evaluation activities over a 10-year period have also created the headache of an accumulation of reports and information that we were ill-prepared to process and naive in our capacity to utilise formally. Much of these data was qualitative by nature—the views and opinions of participants, observed reactions, expressed satisfaction or disquiet, statement of change in intent—although quantitative measures of economic benefit were also evident. While these data have certainly informed our planning and actions over the years, we have yet to fully analyse and utilise these data in publishing our insights and learnings from the FARMSCAPE experiences.

5.8. Learn from mistakes and conflicts

> Interviewees expressed concerns about the perceived cost of developing APSIM, and about a perceived lack of advanced extension and evaluation training within the 'frontline' FARMSCAPE team (van Beek report, August 1998, p. 11).

FARMSCAPE has been a 'Participatory Action Research' project, consisting of iterative cycles of action, reflection and re-design over a 10-year period. In its planning and implementation we have tried to inform future actions by what we learnt from our preceding actions. This includes the idea of learning from the effects of a small mistake with the test being that it never becomes a big one. While this paper has highlighted indicators of successful impact and learnings, our activities were littered with mistakes, failure and criticisms. We have also learned much and had our characters tempered from social conflict with what Biggs (1995) termed "contending coalitions of science and technology". It is an important characteristic of systems research to be frank about failure and criticism in order to learn from the experience. In this light, key mistakes and criticisms of the FARMSCAPE program over the years are nominated and briefly discussed below:

Internal conflict over intervention paradigms—from a team in 1993 unified by a 'new paradigm' of participative on-farm research, internal tensions developed to the point of fissure by 1995. The contentious issue was the appropriate role of simulation in researcher–farmer interactions. The debate was between those committed to addressing the research question of whether farmers could value simulation when used as a discussion-facilitating tool in WifAD sessions against others who argued that the 'old paradigm' of computer models should be restricted to being tools of scientists and be left behind in the office when scientists engage farmers in 'new paradigm' interactions. Elaboration of this debate can be found in Ridge and Cox (2001) and McCown et al. (2001). The paradigm conflict caused a schism that, informed by the recent phenomenon of 'multiple paradigm, multi-methodology', seems to have been philosophically unwarranted—see discussion on multi-methodological intervention in McCown (2002b).

External criticism from public extension officers—early in our pilot on-farm work it became evident that some public extension specialists were highly critical of our activities. A round of interviews with such critics by an independent consultant (van Beek report, April 1996, p. 14) recorded their expressed concerns as encompassing issues such as our lack of their recognition, the feeling that APSIM was an over-sophisticated product where simpler derivative tools could work, that we dealt with only the top farmers and thus our activities were irrelevant to most farmers, and the high cost of our interactions with so few farmers. Such criticisms were not universal, as a number of public extension officers were actively involved with the FARMSCAPE team at the time. Neither have they persisted, with the clear market demand and industry support for developing delivery systems answering much of the expressed concern. Our responses have been to redouble efforts to involve extension staff in activities, to progressively simplify the APSIM interface, and to construct a strategy for 'handover' to consultants.

Internal criticism from APSRU colleagues—the FARMSCAPE program clearly has been the largest research effort within APSRU's portfolio and it has the highest profile in APSRU's mandate region. Tensions emerged early within the life of APSRU as some saw the promotion of the FARMSCAPE projects as being competitive with APSRU and its other research projects. With FARMSCAPE projects being driven by CSIRO staff, the tensions also related to institutional rivalries in the formative stages of APSRU. Again this early tension has largely dissipated with the FARMSCAPE team clearly succeeding in attracting support within industry, and APSRU team members collectively accepting FARMSCAPE's mandate to progress the development of delivery systems for decision support.

Failure to deliver—over the past 10 years there have been examples of our failure to deliver on time on promises made to farmers and advisers. While such failings may not be uncommon in research projects, the consequence to relationships and reputation in the world of business is serious. Working in a participative mode is time-consuming, stressful, confronting, and at times frightening and demoralising (when activities do not work as expected). We soon discovered that the FARMSCAPE approach required new ways of research engagement that differed from our past researcher–funder relationships. Some insights include: frequent low level iterations of engagement are often preferred to infrequent detailed meetings; we needed to be proactive in the collaboration and communication; promised results have to be delivered on agreed dates, not a few days or weeks late; and one should not over-promise and under-deliver.

Naivety of social processes—"*APSRU does not treat farmers equally*" was a rare but serious accusation from a farmer participant in a FARMSCAPE activity. The quote related to arrangements for a meeting; specifically which farmer within an organised group should take responsibility for hosting the meeting. While this concern was proactively addressed at the time, it did highlight our need to become better students of the social structures and relationships within the local farming communities with whom we were engaging. Our reaction since has been to negotiate early in an engagement with a farmer group on who will be our principal contact and how arrangements will be made.

Hesitation in recognising and responding to the support needs of agribusiness—as the FARMSCAPE program shifted focus from working directly with farmers to transferring capability to agribusiness, we were initially naive about the realities of the conditions necessary for private firms to justify embracing our technology. Even agronomists enthused by APSIM struggled with the demands for using it both technically and operationally. It took some time to negotiate and act on ways of relieving these difficulties, as we were largely reactive rather than proactive in providing solutions. Improvements in APSIM's user interface (APSFront), writing the *Soil Matters* manual, creating an accessible database of soil characteristics, making available inexpensive automatic climate stations, facilitating access to long-term climate data, and providing at-call and on-ground support were all implemented over time to improve the technical application of APSIM within industry. However, it was only with the formation of the FARMSCAPE Training and Accreditation project that we acknowledged and sought solution to the operational difficulties faced by interested agronomists, the main issue being the availability of time to become expert with APSIM given their already heavy agronomic workloads. The training program therefore has placed emphasis on self-paced learning and on-the-job training exercises. Importantly, negotiations with senior managers of the four participating companies have allowed each of the FARMSCAPE trainees to be allocated 30% of their time to the training program. A key performance indicator of future success for commercial application of simulation will be the priority level given to time allocation to meet this commitment, versus priority for other agronomic services.

Deficiencies in APSIM capabilities—while APSIM addresses the major crops and cropping systems of relevance to the farming systems of northeast Australia, there are obviously deficiencies in its capabilities and performance (e.g. impacts of waterlogging, frost, pests). For continued interest in commercial APSIM applications we recognise that our model development and testing efforts have to correspond with industry demands.

Lack of publication—for a 10-year research experience, the FARMSCAPE portfolio of projects has provided relatively few publications. Our excuse has been our wholehearted commitment to demonstrating and evaluating impact amongst our industry stakeholders and time allocated for pursuit of scientific publication has been scant. However, FARMSCAPE projects are research endeavours and we recognise that publication and peer review are important components of research.

5.9. A systems approach needs a systems research team

> FARMSCAPE has involved people from all major domains in what increasingly became joint efforts, at least intellectually. In my view, the core significance of FARMSCAPE has been in these joint intellectual efforts. All parties believed that they contributed to the development of something of great potential value, namely a useful simulation model, which was acknowledged as being outside the reach of any single party. The interactions thus went far beyond the traditional exchanges of information. (van Beek report, August 1998, p. 15.)

The FARMSCAPE research team has been able to operate and succeed due to a concerted effort strongly supported by CSIRO, and by industry and government funding bodies. The project leadership had strengths in understanding and implementing the philosophical intent of systems research (McCown, 2001, 2002a, b), in aligning systems research with industry needs (Hochman et al., 2001) and in promoting and gaining support for our efforts (Carberry, 2001). Key contributions have also included the rigorous implementation of on-farm research, the specification and application of the APSIM model, the training and support for project participants, the exploration of new technologies such as the Internet and the design and implementation of evaluation strategies. Systems research needs a team of people committed to supporting common objectives.

6. Where to next?

Our research into developing and delivering decision support systems started in 1991, and in early 2002 we are nearing the end of the first round of training and accrediting commercial agronomists in the application of FARMSCAPE tools. Our immediate focus is to facilitate the agronomists from the four participating companies to complete this training program, and to support the application of these new skills and tools within their business systems. Their success is our primary goal and our evaluation of how system monitoring and simulation is perceived and adopted within agribusiness and their clientele will continue as a key learning objective.

In early 2002, we are also in serious negotiations with a consortium of agribusiness companies who wish to invest in a national delivery system for APSIM simulations targeted at farmer clients. This initiative was first mooted and is now being designed, promoted and will be financed and implemented by the agribusiness consortium. APSRU's role will be to provide and support the APSIM software and train accredited users. The commercial system being proposed is well aligned with the FARMSCAPE approach to decision support, with emphasis placed on the need for simulations to be contextualised to the requests and circumstances of individual farmers. If established, this commercial delivery system will be an important market test for the applicability of computerised decision support to industry.

While our operational focus is on facilitating development of delivery systems through commercial agronomic service providers, our research continues to focus on learning about the market for decision support and its viable delivery. In this research area two initiatives will take precedence—one will be to continue our efforts at assessing the internet as a delivery vehicle (Hargreaves et al., 2001), the other is a new initiative addressing a market barrier to wide adoption of decision support. As McCown (2002b) points out, a major challenge to the delivery of DSS is gaining the attention of farmers beyond 'Innovator'/'Early Adopter' types to those who comprise the majority. Accordingly, we have initiated research aimed at penetrating the 'Early Majority' market for improved risk management, by creating reference groups of satisfied adopters among the pragmatist category of farmers who are crucial to the diffusion process required for viable market volume. This new project is to be based on case studies built around farmer groups involving both innovative and pragmatist farmers, consultant agronomists and key researchers.

FARMSCAPE has developed into a successful approach to systems research, specifically in the exploration of a role for computerised decision support. Its focus has been on dryland farming systems of northeast Australia with participant interest concentrating on decisions which impact on the economics of alternative cropping options. There is now interest both within APSRU and from collaborating researchers to expand and replicate the FARMSCAPE approach in other regions, and to address a broader range of issues. Research projects implementing the FARMSCAPE approach have already commenced elsewhere in Australia as well as internationally. Collaborative projects have commenced to assess the role for APSIM in improving management practices in smallholder agriculture—Twomlow (2001) reported on a recent WifAD session successfully held with smallholder farmers in Zimbabwe. Expanding our systems view to incorporate natural resource management, weed management and agroforestry systems are all new project initiatives being undertaken by the FARMSCAPE team.

The Website (www.farmscape.cse.csiro.au) contains up-to-date information on past and current research activities of the FARMSCAPE team.

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