If interactive decision support systems are the answer, have we been asking the right questions?

Peter Stone[1] and Zvi Hochman[2]

[1]CSIRO Sustainable Ecosystems, Private Bag 5, PO Wembley, WA 6913, Australia. www.csiro.au Email peter.stone@csiro.au
[2]CSIRO Sustainable Ecosystems, Agricultural Production Systems Research Unit, PO Box 102, Toowoomba, Qld 4350, Australia www.apsru.gov.au/apsru/ Email zvi.hochman@csiro.au

Abstract
Over the last 30 years, significant resources have been devoted to the development of computer-based decision support systems (DSS), usually in the belief that they were capturing, assimilating and delivering information that could help farmers to better manage their farms. The accumulated evidence suggests that this belief was largely misguided - most DSS have 'failed' in the agricultural market place. Despite this, many scientists continue to develop and attempt to deploy DSS that are intended to help farmers make management decisions. Here we examine aspects of the 'success' or 'failure' of three DSS with the aim of drawing from the experience some guidelines that may help in the development and deployment of future DSS. We don't see DSS as a lost cause, provided that scientists learn hard-won lessons from their collective achievements and failures. These include recognizing: (1) the need for comprehensive marketing information to inform the process of DSS conception and delivery rather than just the more usual autopsy; (2) that there are almost invariably other, perhaps more effective, methods for acquiring and transmitting the knowledge embodied in a DSS; (3) that what appear to be technical and quantitative management 'problems' often involve social, qualitative and subjective processes and 'solutions' that DSS are not well-equipped to consider; (4) that DSS are usually best accepted when they seek to enhance rather than replace farmers' existing decision making processes, making those that help to understand 'how things work' generally better accepted than those that present 'optimized' solutions. Further lessons are examined.

Media summary
Computerised decision support systems – essential tools for farmers or scientific impedimenta? Currently, it's mainly the latter. We explore some options for change.

Key words
Computerised decision support systems, DSS, farmers

Introduction
The production and ongoing refinement of interactive, computer-based decision support systems (DSS) has drawn heavily on the financial and intellectual resources of the agronomic sciences for much of the last 30 years. Early activity tended to focus on developing models to improve the scientific understanding of complex crop production systems. Advances in this understanding were accompanied by more powerful and accessible computers and an escalating need to demonstrate the economic benefits of investment in agricultural research. Given these contemporaneous developments, it should not be surprising that scientists devoted an increasing proportion of their resources to developing and deploying computer-based tools as aids to farm management.

A cursory analysis of the success of DSS as tools for improved farm management would very strongly suggest that the latter phase of activity has been a failure, and that the ongoing levels of commitment to DSS shown by scientists have been unwarranted (Cox 1996). Despite many scientists' conviction that they should be useful to farmers, the use of DSS either by or for farmers remains very low (McCown 2002b; Stephens and Middleton 2002). The continued, though declining, development of DSS for use by farmers suggests either that a cursory analysis of the success of DSS does not do the technology justice or that a considerable number of agronomists are obstinately myopic.

Here we will evaluate the 'success' of DSS by examining their demonstrated capacity to add value to farm management decisions. Our intention is to determine whether continued investment in development of DSS for application to the practice of farming can be justified. Our investigation will follow five main lines of enquiry:

- What are performance indicators of successful acceptance of DSS by farmers?
- What are examples of successful or unsuccessful acceptance of DSS?
- Are there identifiable factors that distinguish or explain the varying acceptance of DSS?
- How likely is it that the knowledge gained from successful acceptance of DSS can be transferred to other situations?
- Does the accumulated evidence suggest that DSS have an important and defensible role in delivering information to farmers?

But first we'll define what we mean by DSS...

What are decision support systems?
In the broadest sense, decision support systems are any method by which information can be transmitted, shared or structured to help their users arrive at a decision. Decision trees, heuristics, rules of thumb, old wives' tales and proverbs are all forms of decision support. These have proved their worth to varying degrees over several millennia and are not the subject of this investigation.
Here we are interested in the more recent phenomenon of computer-based or interactive decision support systems (DSS) concerned with aspects of crop production. These DSS are usually based on an understanding derived from a statistical- and/or process-based analysis of factors affecting crop outcomes such as yield.

Some developers distinguish models (the mathematical representation of a system) from DSS (interfaces through which users access knowledge from a model). Others do not make this distinction, either conceptually or in practice, which may help to account for their varying degrees of acceptance by end-users (more of which later).

Here we will consider interactive DSS to be computer-based tools that seek to inform users of the likely consequences of crop management actions that are stipulated by the user.

What are performance indicators of successful acceptance of DSS by farmers?
For DSS, as in life, assessment of success comprises many elements, including value judgements, aspirations, the metrics used, and the ability to attribute credit to one of several participants working in the same field of endeavour. For these reasons we will avoid discussion of success in quantitative terms and concentrate on a qualitative evaluation of success. In a qualitative sense a DSS could be judged as successful if it is being used by a significant proportion of its target audience and its use has a beneficial impact.

In evaluating impacts we cannot avoid value judgements about whether these are beneficial. By definition, such assessments reveal more about the values of those making the assessment than about the reality of what is being assessed. Value judgements influence the motivation and processes for developing and deploying DSS as well as the process of evaluating them. Clearly, this doesn't provide a firm foundation for this analysis, but raises questions that include whether or not success should be judged by DSS impact on:

- Knowledge – is it important to have provided hitherto unforseen insights into how cropping systems function?
- Attitude – is it important to have affected scientists', land managers' or policy makers' attitudes to a given issue?
- Action - is it important to have indirectly or directly influenced the behaviour of cropping farmers?
- Production – is it important to have improved the tonnage, quality or value of crop production?
- Sustainability – is it important to have indirectly or directly enhanced the environmental resilience of cropping activity?
- Profit - is it important to have covered its costs of development and deployment through improved farm profitability?

Evidently, individuals will attempt to measure the success of DSS using criteria that mirror their own beliefs, opinions and goals. As a reflection of our audience, here we will attempt to evaluate the success of DSS using a range of these and other criteria, recognising that they to varying degrees impact on the capacity to add value to farm management decisions.

Consequently, we will now examine a very small sample of DSS to identify factors that lend themselves to 'success' or 'failure' by different criteria. By this means we hope to assist those who develop and deploy DSS to better match the design and application characteristics of their DSS with intended outcomes.

What are examples of successful or unsuccessful acceptance of DSS?
In addition to the problems of assessment outlined above, an impediment to the analysis of 'successful' or 'unsuccessful' acceptance of DSS is the simple lack of data available. Scientists are generally more interested in building DSS than establishing the practical impact or market credentials of their DSS. Consequently they are usually loathe to commit the resources required to gather anything other than anecdotal data (Walker 2002). Furthermore, they are not inclined to report failures (Matthews 2002), although there are notable exceptions (Hearn and Bange 2002; Hayman and Easdown 2002). As a consequence, this discussion extends the analysis methodology of McCown et al. (2002) and relies on the authors' reflection on case studies with which they are familiar, rather than a selection from the very large number of DSS that have been produced. This shouldn't matter, as our intention is not to catalogue different DSS, but to draw general lessons from the different experiences of the application of DSS. Furthermore, the great weight of evidence suggests that problems associated with implementation of DSS arise largely from concentrating too much on technologies and not enough on their users (Walker 2002). Here we will attempt to avoid extending that error of application into analysis!

The *Maize Calculator* (Reid et al. 1999) is an interactive DSS developed in response to New Zealand maize farmers' demand for methods for optimising fertiliser applications to maize crops. The DSS uses a combination of the PARJIB nutrient response model (Reid et al. 2002) and a modification (Wilson et al. 1995) of the Muchow et al. maize model (1990) to make fertiliser recommendations based on a maximised marginal financial return. The Maize Calculator was designed for direct use by farmers on their own personal computer and is exceptionally easy to use. It has modest data requirements, obliging users to select a hybrid, location and sowing time from drop-down lists and to input planting density, soil test data and the cost and price of fertiliser and grain, respectively. Historical weather data are supplied by the developers. The Maize Calculator was developed using data derived almost entirely from commercial crops and with an RMSD error of only 6% (0.7 t/ha) was widely accepted as credible by farmers. In its first year of release (1999), the Maize Calculator was used to inform crop management decisions for approximately 60% of the maize crop area in New Zealand (N Pyke pers. comm.), but within 3 years it had fallen into virtual disuse. Surely this constitutes a major failure?

Despite having been designed primarily to inform fertiliser application decisions – at farmers' express request - there is no evidence that the Maize Calculator influenced fertiliser application practices. Annual surveys of fertiliser use amongst maize farmers showed that there was no change in the rates of N, P or K applied to maize, despite the Calculator's consistent and universal recommendation that P & K applications be drastically reduced. As a fertiliser DSS the Maize Calculator was an abject and indisputable failure, even when supported by a widespread, intense and credible programme of on-farm demonstrations.

The Maize Calculator is also capable of informing decisions of selection of sowing time, hybrid and plant density, and was used in this capacity in conjunction with an active participatory action research and on-farm demonstration programme. Despite several years of intensive effort, the sowing time facility of the Calculator has had no discernible impact on farming practice (J Austin pers. comm.). The hybrid selection facility may have contributed to a trend towards the use of longer season hybrids, although this is perhaps more likely to have been promoted by the simultaneous release of better-adapted long-season varieties (Pioneer 2003a).

The plant density facility, on the other hand, supported a rapid industry-wide shift in attitudes and practice, despite being a non-core component of the DSS. Before the release of the Maize Calculator discussion of increased plant populations for the New Zealand grain maize industry was greeted with widespread and sustained hostility. A series of on-farm demonstrations, PAR and a high-profile extension campaign informed and supported by the use of the Maize Calculator resulted in a rapid shift in attitudes and practice. A survey conducted in the year following its release showed that while the majority of growers (55%) aimed to retain the standard 85-90,000 plants/ha, 25% sought crops with a population of 91-100,000 plants/ha and 10% aimed to achieve a final population of over 100,000 plants/ha (Shaw & Stone 2000). Within 3 years of its release, the industry-accepted standard for seeding rate had increased by over 15% from 88,000 to 105,000 seeds/ha (Pioneer 2003b). In this respect the Maize Calculator, supported by a programme of PAR, on-farm demonstration and extension, was a great success, and is expected to contribute an average one-step productivity increase of ca 7% (Stone et al. 2001). Notwithstanding this success, DSS sceptics could argue with some justification that it is not possible to ascribe this success story to the Maize Calculator itself, but to the programme of community-led research and extension that surrounded it.

Consequently the Maize Calculator has a chequered history and the status of its 'success' or 'failure' is arguable. We will attempt to draw some more general lessons from the Maize Calculator in the next section.

AspireNZ is an interactive DSS that is used by asparagus growers in countries as diverse as New Zealand, Mexico, Germany and the United States. It is based on the observation that the growth of asparagus spears and ferns is associated with an annual pattern of depletion and accumulation of root carbohydrate (Wilson et al. 2002). Deviations from the normal root carbohydrate concentration at a given time of year usually indicate sub-optimal crop performance, which AspireNZ helps to diagnose and resolve to increase the yield and profitability of asparagus crops. The DSS comprises three main elements: "(1) a simple method for assessing the carbohydrate status of roots; (2) information about how to interpret the results and use them to make management decisions and; (3) a database that retains information about each crop registered on the system…enabling users to retrospectively evaluate the effects of previous management decisions on crop performance" (Wilson et al.2002). The data requirements of AspireNZ are modest (root carbohydrate concentration and date are entered by the user) but tedious (frequent root sampling using >20 cores per sample). The DSS is available via subscription on the internet (www.aspirenz.com; www.aspireus.com), making international access and servicing simple. Like many DSS, the origins of AspireNZ lie in scientists' desire to extend their science based understandings to the practical world of farmers. AspireNZ is therefore a typical case of 'science push' (supply) rather than 'industry pull' (demand) for a DSS.

Despite being in many respects a 'typical' DSS, AspireNZ has circumvented many of the typical DSS problems of implementation. By acting as a 'fuel gauge' for the root carbohydrate 'fuel tank' AspireNZ enables farmers to assess whether extending the spear harvest into the more profitable tail of the season will unacceptably penalise the following year's crop. Demonstrations on 'standard practice' commercial crops have shown that a saleable yield increase of around 30% can be expected by extending harvest for 24 days beyond the standard 15 weeks, with no residual yield penalty (Wilson et al. 2002). In the first year of release (2000) AspireNZ was used by 15% of the New Zealand market, climbing to 30% of the crop area in 2002, and growing. Significantly, market 'turnover' is low with users currently maintaining their subscriptions, despite annual fees (D Wilson pers. comm.).

The success of AspireNZ in New Zealand – and its international renown amongst asparagus growers - has led its developers to pursue and be pursued for international deployment. Regionally specific versions of Aspire can now be found in a range of countries, and are being trialled in several more, where it is used in ways that the developers had not originally intended. In the USA, where it has been applied to ca 4% of the crop area in the first year of release, AspireUS has been used mainly to inform changes in irrigation practice. Farmers using AspireUS have drastically reduced the water applied to their crops. In Europe it is being used to inform decisions on disease management and to investigate and manage causes of long-term yield decline (D. Wilson pers. comm.). Typical subscription fees of ca US$2000 pa do not appear to have deterred interest in and use of AspireNZ and its international variants, because the potential benefits of using it are evident and potentially very large. It remains to be seen whether AspireNZ is able to avoid the decline in subscriptions that so often follows the use of successful DSS, as farmers believe that they have learned what the model will predict (Hayman and Easdown 2002; Hearn and Bange 2002; Sinclair and Seligman 1996; Stephens and Middleton 2002a).

The *FARMSCAPE* research and development team recognised in 1991 that DSSs were not succeeding in the agricultural market place. Rather than attempt to transform a simulator (APSIM; Keating et al. 1993) into a DSS they started with the question ‘can farmers value simulation as a tool in helping to manage their farming system?’ To this end researchers worked directly with farmers and their advisers, on individual farmers’ properties in Australia’s climatically variable northern-cropping region. The outcome of this effort was the FARMSCAPE approach to decision support. In this approach a versatile simulator is used to aid discussions between researchers, farmers and their advisers. Such discussions are designed to facilitate farmers’ planning and learning about tactical and strategic management of their own farms in a highly variable rainfall environment.

The FARMSCAPE team employed a Participatory Action Research approach to explore the marketplace for simulation tools. They found that once they were able to demonstrate the credibility of the simulator and their commitment to solving problems perceived by farmers, farmers became very keen to explore a wide range of management issues. The project demonstrated the effectiveness and value of simulation aided discussion sessions, as judged by participant farmers and their commercial advisers. An extensive evaluation program showed that farmers often attributed significant insights into their production system and changes to their management (and in some cases significant financial reward) to involvement in these sessions. By 1998, farmers’ demand for FARMSCAPE based tools and services exceeded the team’s capacity and mandate to deliver such services (Hochman et al. 2000, Carberry et al. 2002).

Researchers then turned their attention to ‘how to deliver FARMSCAPE tools and techniques in a cost-effective and commercially sustainable manner?’, and; ‘is the FARMSCAPE approach transferable to other cropping regions where climate is less variable and the flexibility of summer and winter cropping options does not apply?’. The first question was investigated by developing and providing an intensive training and accreditation program to a small number of agronomy consultants from both publicly funded institutions and private consulting companies. Of the accredited trainees one is now leading the development of Whopper Cropper; a DSS derivative APSIM product that targets the agronomist market. Two others in the private consulting sector are spending a significant proportion of their time conducting APSIM simulations for their farmer clients, for other agronomy consultants, and for R&D. Evaluation programs are showing that these consultants are achieving with their clients similar impacts to those reported by FARMSCAPE researchers. In one record of interview with a farmer who is the client of a consultant who uses an accredited consultant to do the simulations we found that while the farmer was not familiar with the words APSIM or FARMSCAPE, he altered his decision on time of sowing of Sorghum in response to discussion of the results of APSIM simulations with his consultant. He attributed a value of $500,000 to this one-off decision.

In seeking to explore the market in other Australian cropping regions the FARMSCAPE team developed a close collaboration with the Birchip Cropping Group; a farmer driven organisation with a membership of 500 family farms in the Victorian Wimmera and Mallee. The collaboration started in 2001 with sensibility and field testing of APSIM and by conducting a series of simulation aided what-if sessions. In 2002, with a degree of credibility achieved, this was supplemented with a monthly fax service ‘the Yield Prophet’ (YP) to all BCG members. YP provided updated forecasts of yield probabilities for 3 “locally representative” field sites. From the first issue of the 15th May and thereafter there were clear and increasingly more definite signals that 2002 was very likely to be a low yielding season. As it happened 2002 was the worst cropping season in the collective memory of BCG farmers. While few farmers had sufficient faith in the simulator at the start of the season to allow it to influence their practice that season, 2002 created a great deal of interest and qualified credibility for APSIM and YP (“we know it can predict crop failure in a drought but how will it go in a more normal year” was a commonly expressed sentiment).

In 2003 we continued to supply yield forecasting information at three demonstration sites through a large billboard visible from the roadside. We also suppled through regularly updated newsletters similar information to about 200 more farmers in two farmer groups in WA. The WA forecasts were based on four representative sites per group. The reports received contained yield probability information based on pre-season soil measurements, past management actions and simulated outcomes to date. Future outcomes were then simulated through hind casting the last 100 years of data from the nearest weather station and showing the results for all years against the results from analogue years corresponding to the most recent SOI phase (Stone et al. 1996). At various decision nodes reports contained alternative outcomes for impending decisions. For example, rates of N fertilizer, sowing times and cultivars in early reports, and top-dressing N fertiliser options as the crop approached the 6 leaf stage.

An innovative addition to these services in 2003 was the individual YP; a service offered to 29 fee paying BCG farmers who each received 9 paddock specific updates between May and November. As with the other YP paddocks data collected from these paddocks is being used to validate APSIM simulations 'in the real world' to continue the credibility building process and to inform commercially important decisions about the costs and benefits associated with precision in input data. A workshop was also held in October to obtain direct feedback from the farmer clients and to review the season. All farmers at the workshop indicated that they would participate again in 2004 and many expressed an interest in having multiple paddocks and crops other than wheat.

At the time of writing it appears that the number of YP subscribers for 2004 will be limited by the team's capacity to deliver rather than by client demand for the service. In order to cope with large numbers of reports and a wider geographical spread of clients, the team is developing a web interface to APSIM that will allow growers to request tailored reports for their paddocks. Farmers will enter paddock information like rainfall and agronomic information like time of sowing, species and variety sown while their consultants will enter soil information. A report can be automatically generated and emailed to farmers and their consultant showing expected yield outcomes under different scenarios.

Some observations on the three case studies

Functionally both the Maize Calculator and FARMSCAPE use mathematical models and integrate diverse management factors but while the Maize Calculator provides optimised recommendations for action, FARMSCAPE provides answers to "what-if" questions. Both AspireNZ and FARMSCAPE rely on measurements of the state of the production system and use algorithms that add value to these measurements.

A challenging observation to conventional wisdom is that the two more successful cases, AspireNZ and FARMSCAPE, were both conceived from a science push while the less successful Maize Calculator was designed in response to industry pull.

One observation common to all tree cases is that they produced unexpected applications. This is not surprising in the case of FARMSCAPE which started off without a pre-conceived application to explore the market for decision support in farm management. However the Maize Calculator was designed to optimise fertilizer usage but was most successful in changing plant populations, while AspireNZ expanded it repertoire to suite emerging markets.

Of the four promising niches McCown (2002) predicted for DSS, three are covered by our case studies. Both the Maize Calculator and AspireNZ are examples of DSS designed for use by farmers making decisions on structured tasks, though in the case of the Maize Calculator the task of optimising fertilizer requirements turned out to be complicated by the nutrient requirements of subsequent crops. FARMSCAPE is an example of a versatile simulator that has been used by researchers and consultants working with farmers as a tool to enhance farmer learning. It is also an example of a flexible simulator being used as a tool in farm consulting.

In identifying factors that contribute to success of DSS we should not expect that what works for a system designed as a tool for farmers making a highly structured decision will work for a system designed to enhance farmer learning or to be used as a consulting tool.

Are there identifiable factors that distinguish or explain the varying acceptance of DSS?

There is a growing literature concerning the problem of implementation of DSS in agriculture (Cox 1996; McCown et al. 2002; Stephens and Middleton 2002b). Much of it contains useful and sometimes counter-intuitive insights that should help developers and implementers to recognise, respond to and develop the conditions under which DSS are likely to be ‘accepted’. Here we’ll attempt to summarise the experience to date and will seek to add context to it by drawing on the examples in our case study, along with other examples.

- First and foremost, it is clear that most DSS are developed and released without much, if any, reference to the basic precepts of marketing. So it should not come as any surprise that the vast majority of DSS fail in the marketplace. It is somewhat bemusing that when marketing knowledge is applied to DSS it is usually as mortician rather than midwife.

Marketing as a discipline is devoted to gathering and deploying the intelligence required to help product developers and sellers to meet the needs of their customers whilst getting value in return. Marketing knowledge is therefore a pre-requisite for sustained acceptance of products (such as DSS) by users. Marketing comprises the range of activities that includes: “finding out what groups of potential customers (or markets) exist, what groups of customers you prefer to serve (target markets), what their needs are, what products or services you might develop to meet their needs, how the customers might prefer to use the products and services, what your competitors are doing, what pricing you should use and how you should distribute products and services to your target markets…[it also includes] ongoing promotions, which can include advertising, public relations, sales and customer service” (McNamara 1999). Documented examples of the application of this suite of activities to the development and deployment phases – as opposed to the coronial inquest phase - of DSS are very rare. In some cases that may be due to considerations of ‘commercial confidence’ (*e.g.* AspireNZ), but in most cases it is probably because they simply haven’t occurred.

Why have developers of DSS studiously denied themselves access to these skills and knowledge, so necessary for effectively transmitting an idea via a product to a receptive user? The evidence suggests that there are too many reasons to enumerate here, but amongst the most important are:

- Most DSS emanate from research activities and become DSS products by ‘managed accident’, rather than design. Acceptance by farmers is an interesting spin-off rather than a primary goal, so adequate (any?) resources are simply not devoted to marketing.
- DSS developers tend to work for government funded organisations, whose *raison d'être* and *modus operandi* do not reflect commercial or market dictates. Consequently, acceptance in the market place is not a significant arbiter of success. (Does the very low representation of the private sector in the DSS ‘industry’ tell us something about the market?)
- Most scientists delude themselves about their market knowledge. They assume that most farmers (the marketplace) are like those that they know. They fail to recognise that they actually tend to have most contact with niche rather than mainstream customers. With a discontinuous technology such as a DSS pragmatic farmers (i.e. the vast majority) need to be convinced of the value of a new technology before investing their time an effort in its evaluation. A well accepted view in IT marketing is that such pragmatists do not reference the innovative adopters that researchers tend to work with. The lack of referencing between these two groups of farmers creates a “chasm” in the traditional “bell shaped” diffusion curve (Moore 1991). This “chasm” may account for the failure of DSS adoption to diffuse from innovators through to early adopters, early majority, and finally to the late majority in the way that many agricultural technologies are adopted.
- Proficiency and preference lead many scientists (DSS developers) to concentrate on the technical rather than human elements of decision making. They are often either naïve about or dismissive of the expertise required to address the non-biophysical components of the farming-decision system.

It is clear that ignoring the necessity for some basic marketing – to inform the conception rather than burial process – would avoid some persistent and terminal problems in the implementation of DSS. For many DSS these are:

- The market simply does not want them. Farmers basically want an enhanced ability to solve, resolve or avoid problems and uncertainty. There are many ways of achieving this goal and, on the available evidence, DSS are generally amongst the least preferred. Many DSS should not be made because there is no demand for them.

- Even when DSS are desirable, they are usually developed and deployed in the face of overwhelming competition. There are a huge range of alternative methods for assisting with or arriving at decisions, most of which use long-established information and information networks. Breaking into and maintaining a presence in the decision-making market is very tough. Most DSS are not equipped to survive that competition.

The application of the basic precepts of marketing is a fundamental descriptor and determinant of successful acceptance of DSS in the market place. Many of the following specific factors that distinguish or explain the varying acceptance of DSS emanate from the varying extent of application of general marketing principles.

DSS that attempt to optimise outcomes by prescribing actions (making decisions) are not favoured by users. DSS should instead seek to provide information to users that they can then apply using their favoured decision making processes (McCown 2002b). This is important for two main reasons.

First, problems that require the assistance of a DSS are often by definition complex. This means that they occur in the context of interacting and overlapping factors, and against a background of multiple objectives (Stephens 2002), some of which relate directly to the problem but others which relate indirectly to other aspects of people's work and life (Goodwin and Wright 1998). DSS cannot hope to encapsulate the cognitive 'mess' (Ackoff 1981) and inertia (Goodwin and Wright 1998) that this generates – and would-be DSS users know it. DSS developers should acknowledge this and not attempt to make decisions on behalf of users, but provide them with information that they can use to inform their own decision making processes.

Second, experienced managers in any domain place a high value on their decision making processes and good judgement, and in farmers this outlook is reinforced by a self image based on values of freedom of choice and autonomy (McCown 2002b). Consequently, DSS that seek to replace rather than complement individuals' decision making processes are likely to be seen as either redundant or a threat. That models 'teach farmers how to suck eggs' is a consistent refrain amongst would-be users.

These phenomena were implicated in the failure of the Maize Calculator to influence the fertiliser, sowing time or hybrid choices of farmers. Demonstrating to farmers that these factors interacted in ways that were difficult for them to quantify largely reinforced their belief that good judgement rather than the 'precision' of an optimised modelled 'solution' was required to deal with this uncertainty. Many other DSS have failed to excite or maintain user interest for similar reasons, including SIRATAC (Hearn and Bange 2002) and Wheatman (Hayman and Easdown 2002).

These phenomena also help to explain the attractiveness of AspireNZ. By interpreting information on one factor (root carbohydrate concentration) with respect to an expected norm, AspireNZ leaves plenty of 'management space' for farmers to exercise their valued judgement.

Consequently, 'expert systems' or DSS that seek to become comprehensive by aggregating the components of decision-making actually exclude users from the decision-making process, and are not attractive. While a whole of system approach may be necessary for scientists, users prefer to use DSS to address individual operational issues(McCown 2002a). This enables them to participate fully in the decision making process and to interpret DSS-derived information to fit their unique biophysical, economic and social situations.

Again, this helps to explain some of the failings of the Maize Calculator, as well as those of Calex-cotton (Plant 1997), GrassGro (Donnelly et al.2002) and CottonLOGIC (Hearn and Bange 2002). It is noteworthy that models that are capable of analysing extremely complex interactions in cropping systems (such as APSIM) are now primarily employed in the marketplace for analysis of relatively constrained issues, such as tactical application of nitrogen in response to crop water availability (Carberry et al.2002). The attractiveness of AspireNZ may emanate from its ability to use root carbohydrate concentration as an integrator of system function. This allows it to simultaneously and comprehensively address outcomes whilst focussing on simple and individual operational issues.

Furthermore, excessive aggregation of problem-solving factors and processes: (i) hides the process of information generation from the user which reduces their ability to verify its results (“if I can’t examine ‘thought process’, how can I trust the answer” and (ii) usually multiplies the inputs required to drive the DSS, making it both more onerous and confusing to use.

Interestingly, AspireNZ is in some respects a ‘black box’, but it seems likely that, by providing a simple interpretation of two simple inputs, it has overcome both shortcomings (i) and (ii). While APSIM is not a ‘black box’ and can provide users with a detailed breakdown of the process by which it arrives at its final ‘answer’ its high requirement for input data (or parameterisation) reduces its attractiveness in the market place and even amongst some scientists.

DSS have most impact on decisions when there is enough rigidity of problem structure to enable the problem to be defined (Keen and Scott-Morton 1978). The complexity, instability and uncertainty that farmers grapple with cannot be reduced or removed by applying specialised knowledge to an ill-defined task (Schon 1983). Only when there is adequate problem definition is it possible to design structured approaches to that problem, which could include solution (remedy), resolution (collapsing into more manageable components) or dissolution (avoidance). Clearly, starting with a structured answer (model or DSS) and seeking a question is antithetical to defining a problem and formulating the most appropriate response, yet this is how most DSS appear to be developed.

In many instances, problem definition is not as obvious as it might first appear. Farmers requested and paid for the Maize Calculator to be constructed because they wanted a method for better matching fertiliser supply with nutrient demand in their maize crops. Even though it was designed to directly address this issue it failed to have any impact on farmer practice partly because farmers application of fertiliser to crops was influenced by the perceived nutrient requirements of subsequent crops or pastures. While farmers knew this when specifying the functionality required of the Maize Calculator, it did not become ‘important’ until they were presented with precise recommendations for fertiliser application. Once these became mixed with ‘soft’ notions of the nutrients available for and required by subsequent enterprises, the value of precise recommendations for maize crops evaporated. Had we better defined the real problem, it is unlikely that we would have sought to employ the Maize Calculator as a DSS for fertiliser application.

On the other hand, in most instances the biggest problems facing farmers are easily defined. Farming is a business based largely on trade-offs between risks and gains that emanate from actions taken in response to uncertainty about the future. Weather and commodity markets are major and multiplicative determinants of farm business resilience and health, and each is both uncertain and beyond the influence of individual farmers. Farmers’ ‘imprecise’ or ‘non-optimal’ decision-making behaviour is a learned, highly rational and almost universal response to these uncertainties that affect their livelihoods. A DSS’ ability to iteratively, incrementally and precisely analyse and enumerate the outcomes arising from various combinations of uncertain events does nothing at all to reduce the uncertainty of those events. Consequently, it shouldn’t be surprising that DSS have generally had little impact on management responses to those events. Put bluntly, DSS are frequently the right answer to the wrong question. Farmers’ main problem is not knowing how to respond to the future. It is knowing what the future will be. The small rock of precision that many DSS present in the sea of climatic and market uncertainty is perhaps more likely to promote shipwreck than succour to its survivors.

Most problems in agriculture have a large solution space, which means that there is a wide range of actions that might be recommended to deal with them. At the most basic level, for example, a given profit target can be reached using a wide range of enterprises and within each enterprise a wide range of specific management alternatives such as sowing time, fertiliser and variety. The size of the solution space and the information that can be brought to bear within it are naturally restricted by the rigid or at best semi-rigid structures imposed by use of computers, which cannot act laterally or usually with great flexibility. Consequently, use of computers for decision support can reduce rather than multiply the number of tools and approaches brought to bear on a question, making users less flexible and effective (Klein 1980). Paradoxically, then, while a highly defined problem is a pre-requisite for the successful development and deployment of DSS (5, above), this very need militates against them being singularly useful in a farming system context, where getting most things reasonably right is more important than getting some things exactly right (Malcolm 1994; Hayman & Easdown 2002).

Farmers will seek to benefit from DSS with the minimum possible formal use (McCown 2002b). This shouldn't come as a surprise given that DSS are usually 'just tools' to all but their developers. A successful design and implementation strategy for a DSS may therefore revolve around helping users to acquire skills without the requirement that they use the DSS to implement those skills (McCown 2002b). Given this, developers need to assess the extent to which a DSS is best used (or most likely to be used) for a discrete-use 'education' role or for ongoing decision support. This should inform plans for DSS design and deployment, including the resources devoted to DSS development and support.

The Maize Calculator conformed to a common pattern of DSS usage in that it helped farmers to acquire the knowledge required to select more appropriate planting densities and was not then required to implement that knowledge, so fell into disuse. Similar phenomena have occurred for a wide range of other DSS (Wheatman, SIRATAC). It remains to be seen whether the currently high rates of ongoing use of AspireNZ continue, once farmers 'get a feel' for the implications of varying root carbohydrate levels. The developers of AspireNZ are seeking to avoid this persistent 'problem' of DSS by continually adding functionality to the system in response to marketing-derived intelligence (D Wilson pers. comm.).

Similarly, DSS that address a specific challenge or uncertainty are likely to be referred to only when that challenge is confronted and, usually, first confronted (McCown 2002b). Once uncertainty has been reduced the DSS has served its purpose and becomes redundant. Given this, would-be DSS developers need to assess the extent to which their proposed DSS fit the 'specific learning' category to adjust their expectations of duration of use accordingly.

Furthermore, given 7 & 8 (above), it's entirely possible that where the acquisition of skills does not involve iterative or complex computing tasks, teaching tools other than DSS may be more appropriate. In fact, even where the acquisition of skills could involve iterative or complex computing tasks there is often no justification for assuming that farmers need to be directly exposed to a DSS. Those involved in providing advice to farmers often develop methods for communicating the lessons derived from models that are far more effective than use of the models themselves (Hayman 2000).

While the Maize Calculator was used to help understand and generalise - in space and time - uncertainty about the consequences of increased plant populations, this probably could have been achieved by relying on traditional extension techniques supported by on-farm demonstrations. The extent to which use of the Maize Calculator assisted adoption of higher plant populations is highly contestable. However, had its developers known that (i) it would be useful only for this purpose and (ii) would achieve this purpose with minimal use, they would probably not have developed the Maize Calculator as a DSS intended for farmer use.

Farmers are more likely to seek to use DSS through intermediaries than by direct use – at least at present (McCown 2002b). In developed countries such as Australia, most farmers are in the 42-52 age group (DPL 2003) and are less likely turn on a computer - let alone turn to one to analyse problems – than younger people. It is likely that the cohort of children who 'grew up with computers' will be less likely to rely on intermediaries and more likely to consider directly using DSS than their parents. Given the large number of other impediments to the use of DSS by farmers, however, it would not be wise for scientists to rely on this trend alone to solve their 'deployment problem'.

Some computer use figures may help to illustrate the scale of the 'computer' aspect of the deployment problem, and provide clues as to its likely reduction over time. In developed countries such as Australia computer ownership on farms is rising rapidly (over 10% per annum) and was almost 60% in 2000 (ABS 2003). If this trend has continued and 100% of farmers now own a computer, fewer than 40% use them for work purposes because approximately 25% of adults with a access to a computer do not use them. Amongst those using a computer only 50% use them for work purposes.

Having said that, these 'average' computer use figures obscure some of the positive computer use trends that are likely to emerge. Computer ownership is concentrated in the smaller number of large farms (estimated value of operation; EVAO >$1m), which are approximately twice as likely (90 cf. 50%) to use a computer as the large number of smaller farms (EVAO <$50,000). As farm size continues to increase computers are likely to become more important. Similarly, computer use will rise as the current cohort of farmers (most of whom are high school educated and 42-52 years old) is replaced by a younger and more tertiary educated cohort of farmers. Computer use by adults declines by about 1.5% per year of age from a maximum of 90% for 20 year olds. Tertiary educated farmers (currently 12% of the total) are twice as likely to use a computer as those with a high school level of education.

Consequently, computer ownership and usage figures suggest that in developed countries the number of potential users of DSS will rise slowly from a modest base. In less developed countries (LDC) the number of online computers is about 1% of the population, compared with almost 60% for developed countries such as USA, UK and Australia (CIA 2003). For reasons of availability alone, DSS are unlikely to be an effective means of influencing farm management in LDC.

Remote deployment of DSS doesn't usually work (McCown 2002b), possibly because the relationship between scientist and farmer is important. This is understandable when a DSS is seeking credibility in the market place, because a scientist (particularly one involved in DSS development) is often uniquely qualified to act as an advocate or sales representative. Understandably, potential users would 'rather speak to the organ grinder than the monkey', at least while they gain confidence in a DSS. The fact that this situation frequently persists well beyond the credibility building phase suggests that other forces are at work. Some DSS are simply not easy or enjoyable to use, making unassisted use unattractive. It is also possible that in many cases DSS are a 'Trojan horse', providing a focal point and forum for communication between farmers and scientists rather than the main basis for the relationship. This is a legitimate use of DSS that can be valuable as demonstrated by FARMSCAPE (Carberry et al. 2002).

AspireNZ again appears to go against the trend. It has been designed for remote use and is deployed solely via the internet. It certainly relies on a relationship between farmers and scientists in order to garner credibility but once this phase has passed it is used by farmers individually and unassisted. This is probably not surprising given that it is exceptionally easy to use, addresses simple and individual operational issues and relies on only one measured input. Relationships between farmers and scientists add little to its utility.

The most valuable uses for DSS are not always apparent to their developers, and the success of a DSS can sometimes be constrained by scientists' belief in their value. For example, one of the world's largest food processors uses a crop DSS to reduce the costs associated with field staff, to exert greater uniformity of 'control' over their growers and to demonstrate a point of difference with competitors. For them the DSS has value as a liaison and promotional device rather than a technical tool. This contrasts markedly with one of their competitors who has used the same core DSS to significantly change aspects of crop agronomy – but who didn't want their growers to know that a computer DSS was involved!

Similarly, crop scheduling DSS (used to reduce process crop by-pass) are valued by processors as much for their relationship management value [farmers do not like to have their crops by-passed for harvest, even though they are paid fully for them] as for their direct economic benefits (increasing the efficiency of harvesting and processing and the quality of end-product). The use of reliable scheduling DSS enables processors to maintain cordial relationships with their growers and this provides them with a significant comparative advantage – loyalty that reduces the annual transaction cost of finding suitable growers and paddocks.

Scientists' generally technically-oriented view of the world frequently impairs their ability to sympathise with businesses for which technical considerations are important but do not have priority. Discussing the possible role of DSS in business – and accepting this as a valid use – can help scientists to better tailor their 'products' for the market.

How likely is it that the knowledge gained from the successful acceptance of DSS can be transferred to other situations?

The great weight of evidence suggests that the factors leading to 'success' or 'failure' of DSS are generic, and that the lessons learned from one or other DSS can - and should - be applied when considering developing or deploying another. We believe that they are generic because the problem of DSS is not primarily software or DSS based. Making 'better' software will not overcome the problem of implementation. Recognising that DSS are accepted by farmers under only a narrow range of conditions should help to avoid the problem of implementation, by encouraging scientists to take a more appropriate route for making decision-related information accessible to farmers.

We believe that the problem of DSS is generic because it is user based. This certainly does not imply that there is a problem with the (non-) users of DSS. Rather, the 'problem' is that DSS continue to be developed for farmers who for understandable and understood reasons do not derive sustained value from using them. The experiments have been plentiful. An extremely wide range of crops, management issues, environments and computer interfaces have been trialled with farmers but the results of 'acceptance' (if not impact) are remarkably consistent. We should be far less surprised by evidence suggesting success or failure of DSS than by our collective inability to have learned from it. While the knowledge derived from DSS can be of immense value, the tools themselves are not generally sought by farmers or their advisors. Prospective developers of DSS should seriously consider whether a DSS is the most effective medium for delivering a farm management message.

Does the accumulated evidence suggest that DSS have an important and defensible role in delivering information to farmers?
Despite the pervasive negative tenor of much of the previous discussion, we believe that DSS can play an important role in delivering information to farmers. The evidence suggests that the roles will be fewer, more constrained and shorter-lived than many DSS developers might have hoped. That needn't make DSS any less useful - just less used. Recognising and responding to the more limited parameters within which DSS are likely to be effective can only make those that are produced more useful. DSS are most likely to be useful for delivering information to farmers if they:

- provide information with evident, defined, high and capturable value;
- are demonstrably the best and preferably the only method for imparting that information;
- provide information for farmers to use in their own decision making processes, rather than providing them with an explicit answer;
- address discrete operational matters rather than comprehensive or whole-system issues;
- address issues for which outcomes do not rely on responses to uncertain events (eg. weather, markets);
- possess transparent logic, if not computational processes;
- are used to acquire rather than implement new skills; and
- require as little direct use as possible.

Incorporating the 'success factors' suggested above into DSS may require a change in attitude by many DSS developers. We need to pay more attention to distinguishing the levels of complexity at which crops can be modelled from those at which they can be managed. The evidence strongly suggests that the most effective DSS are those that avoid ostentatious displays of scientific knowledge and are simply and elegantly designed to meet a tight specification. DSS will more consistently achieve impact on farms when they overtly seek to perfect a supporting role rather than attempt to be producer, director and star of the show. The farmer, after all, owns the stage.

References:

Ackoff RL (1981). The art and science of mess management. Interfaces 11, 20-26.

Australian Bureau of Statistics (2003). Farm use of information technology. http://www.abs.gov.au/Ausstats/abs@.nsf/Lookup/557B082B122CE9ECCA256CAE00163434

Carberry PS, Hochman Z, McCown RL, Dalgliesh NP, Foale MA, Poulton PL, Hargreaves JNG, Hargreaves DMG, Cawthray S, Hillcoat N and Robertson MJ (2002). The FARMSCAPE approach to decision support: farmers', advisers', researchers' monitoring, simulation, communication and performance evaluation. Agricultural Systems 74, 141-177.

CIA (2003). World Factbook. http://www.cia.gov/cia/publications/factbook/index.html

Cox PG (1996). Some issues in the design of agricultural decision support systems. Agricultural Systems 52, 355-381.

Donnelly JR, Freer M, Moore AD, Simpson RJ, Salmon E, Dove H and Bolger TP (2002). Evolution of the GRAZPLAN decision support tools and adoption by the grazing industry in temperate Australia. Agricultural Systems 74, 115-139.

Goodwin P and Wright G (1998). Decision Analysis for Management Judgment, Second Edition (Wiley, Chichester).

Hayman P (2000). Communicating probabilities to farmers: piecharts and chocolate wheels. In 'A manual of tools for participatory R&D in dryland cropping areas. (Ed. RJ Petherham). RIRDC Publication No. 00/. http://www.rirdc.gov.au/reports/HCC/00-132.pdf

Hayman PT and Easdown WJ (2002). An ecology of a DSS: reflections on managing wheat crops in the northeastern Australian grains region with WHEATMAN. Agricultural Systems 74, 57-77.

Hearn AB and Bange MP (2002). SIRATAC and CottonLOGIC: persevering with DSSs in the Australian cotton industry. Agricultural Systems 74, 27-56.

Hochman, Z., Carberry, P.S., McCown, R.L., Dalgliesh, N.P., Foale, M.A. and Brennan, L.E. 2002. APSIM in the Marketplace: a Tale of Kitchen Tables, Boardrooms and Courtrooms. Acta Horticulturae 566, 21-33.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K.L, Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M., and Smith, C.J. (2003). An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267-288.

Keen PGW and Scott Morton MS (1978). Decision support systems: an organizational perspective. (Addison Wesley, Readings MA.)

Klein GA (1980). Automated aids for the proficient decision maker. IEEE Proceedings 1980 (New York) pp 301-4.

Malcolm LR (1994). Managing Farm Risk: There may be less to it than is made of it. In 'Risk Management in Australian Agriculture' University of New England Armidale pp. 75-90.

Matthews R (2002). Introduction. In 'Crop-Soil Simulation Models: Applications In Developing Countries'. (Eds. RB Matthews and W Stephens) pp 1-5. (CABI, Wallingford UK).

McCown RL (2002a). Locating agricultural decision support systems in the troubled past and socio-technical complexity of 'models for management'. Agricultural Systems 74, 11-25.

McCown RL (2002b). Changing systems for supporting farmers' decisions: problems, paradigms, and prospects. Agricultural Systems 74, 179-220.

McCown RL, Hochman Z and Carberry PS (2002). Probing the enigma of the decision support system for farmers: learning from experience and from theory. Agricultural Systems 74, 1-10.

McNamara C (1999). Marketing basics. (http://www.managementhelp.org/mrktng/basics/basics.htm)

Moore, G.A. (1991). Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers. Harper, New York

Muchow RC, Sinclair TR and Bennett JM (1990). Temperature and solar radiation effects on potential maize yield across locations. Agronomy Journal 82: 338-343.

Parliament of Australia (2001) Bills Digest No. 8 2000-01, Retirement Assistance for Farmers Scheme Extension Bill 2000. http://www.aph.gov.au/library/pubs/bd/2000-01/01BD008.htm

Pioneer (2003a). Maize for grain hybrid performance and positioning information for Spring 2003. Pioneer Hi-Bred International Inc. http://www.pioneer.co.nz/Grain%20Weigh%20Wagon/WeighWagonFrameset.htm.

Pioneer (2003b). Planting populations for maize in New Zealand. Pioneer Hi-Bred International Inc. http://www.genetic.co.nz/pdf%20files/maize%20pdfs/341.pdf

Plant RE (1997). Implementation of cotton crop management expert systems: lessons from 10 years of experience. AI applications 11, 33-39.

Reid JB, Stone PJ, Pearson AJ and Wilson DR (1999). Yield response to nutrient supply across a wide range of conditions: 2. Analysis of maize yields. Field Crops Research 77, 173-189.

Reid JB, Stone PJ, Pearson AJ, Cloughley C and Wilson DR (1999). The Maize Calculator - a simple system for predicting fertiliser nitrogen requirements of maize. Agronomy New Zealand 29, 73-74.

Schon DA (1983). How professionals think in action. (Basic Books, New York.)

Shaw SR and Stone PJ (2000). A survey of plant populations and their variability in commercial maize crops. Crop & Food Research Report No. 530. (Crop & Food Research, Canterbury, New Zealand).

Stephens W (2002). Decision theory and decision support systems. In ‘Crop-Soil Simulation Models: Applications In Developing Countries’. (Eds. RB Matthews and W Stephens) pp 95-103. (CABI, Wallingford UK).

Stephens W and Middleton T (2002b). Why has the uptake of decision support systems been so poor? In ‘Crop-Soil Simulation Models: Applications In Developing Countries’. (Eds. RB Matthews and W Stephens) pp 129-147. (CABI, Wallingford UK).

Stone PJ, Shaw SJ, Pearson AJ, Sorensen IB and Rogers BT. (2001). Effect of row spacing and plant population on maize yield and quality. Crop & Food Research Report No. 527. (Crop & Food Research, Canterbury, New Zealand).

Stone RC, Hammer GL and Marcussen T. (1996) Prediction of global rainfall probabilities using phases of the Southern Oscillation Index. Nature 384, 252-255.

Walker DH (2002). Decision support, learning and rural resource management. Agricultural Systems 73, 113-127.

Wilson DR, Cloughley CG and Sinton SM. 2002. AspireNZ: A decision support system for managing root carbohydrate in asparagus. Acta Horticulturae 589, 51-58.

Wilson DR, Muchow RC, Murgatroyd CJ (1995). Model analysis of temperature and solar radiation limitations to maize potential productivity in a cool climate. Field Crops Research 43, 1-18.