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Re-inventing model-based decision support with Australian dryland farmers. 2. Pragmatic provision of soil information for paddock-specific simulation and farmer decision making

N. P. Dalgliesh[A,C], *M. A. Foale*[B], *and R. L. McCown*[A]

[A]Agricultural Production Systems Research Unit (APSRU), CSIRO Sustainable Ecosystems, 203 Tor Street (PO BOX 102), Toowoomba, Qld 4350, Australia.
[B]Agricultural Production Systems Research Unit (APSRU), CSIRO Sustainable Ecosystems, 306 Carmody Road, St Lucia, Qld 4067, Australia.
[C]Corresponding author. Email: Neal.Dalgliesh@csiro.au

Abstract. Economic and climatic pressures are forcing many Australian dryland farmers to reassess their management of soil resources and climatic risk. FARMSCAPE intervention has offered enhanced soil characterisation and monitoring as a contribution to soil water and nitrogen inventory, and simulation as a contribution to interpretation of locally measured environmental data in stochastic production terms. This paper relates the journey taken by the farmers, their consultants, and the researchers as they worked together to assess the value to farming and consulting practice of these scientific tools and techniques.

Ten years after FARMSCAPE interactions commenced, a sample of participant farmers and consultants was interviewed to evaluate effects on thinking and practice. Understandings and concepts gained in FARMSCAPE continued to guide thinking and action. Early simulations in response to 'what if. . .?' enquiries of strategic importance, such as crop sequencing and rotation choice, were still referred to as learnings of continuing value. However, techniques and practices varied markedly between individuals and organisations. Monitoring of soil resources varied from continued use of the relatively complex tools and techniques provided by the researchers through to the use of much-simplified techniques that provided adequate information to satisfy the conceptual models. Methods for interpreting soil water ranged from use of the simulator, APSIM, to simple water-use efficiency 'rules of thumb'.

Additional keywords: soil characterisation, monitoring, participation, evaluation.

Introduction

Productivity of the subtropical cropping region of Australia relies heavily on the high water-holding capacity of the predominantly heavy clay soils (Fig. 1) (Isbell 1996; Dalgliesh and Foale 1998). In this highly variable summer-dominant rainfall environment, the capacity to store a large proportion of rainfall for subsequent crop use has enabled both summer and winter cropping industries to flourish. Conventional practice has been to reduce the risk of crop failure by accumulating water in the soil profile during a fallow period of 6–18 months to reduce dependence on in-crop rainfall, during which time substantial mineralisation of nitrogen also occurs. More recently, rising costs of production, rising land values, and exposure to world parity commodity pricing have increased pressure on farmers to adopt more intensive cropping systems. This has meant a further trend away from mixed crop/livestock enterprises towards specialised, high-value crops (especially cotton), greater use of N fertiliser, more opportunistic crops, and shorter fallows.

Such pressures raise premiums for better techniques for assessing and responding to the states of soil water and nitrogen. Gone are the days when a wheat crop was sown if it rained enough that a screwdriver could be readily pushed into the soil to its hilt, undeterred by risk of crop failure. Inputs were low because native soil fertility was high, and a failed crop was a forage windfall for the complementary grazing enterprise. In contrast, in today's economy the strategy of increasing numbers of farmers is to avoid planting when the risk is too high and to increase fertiliser inputs when good conditions are expected. The practical question for systems research concerns what sort of information systems might better support these types of risky decisions.

The primary aim of FARMSCAPE was to provide a means for farmers to assess climatic risks and opportunities in such decision situations. On offer was, first, an analytical framework for thinking about this challenge, which combined 3 types of knowledge: (*1*) knowledge of the status of soil water at important decision times; (*2*) simulation of the effect of existing stored soil water status on crop performance; (*3*) probabilistic yield

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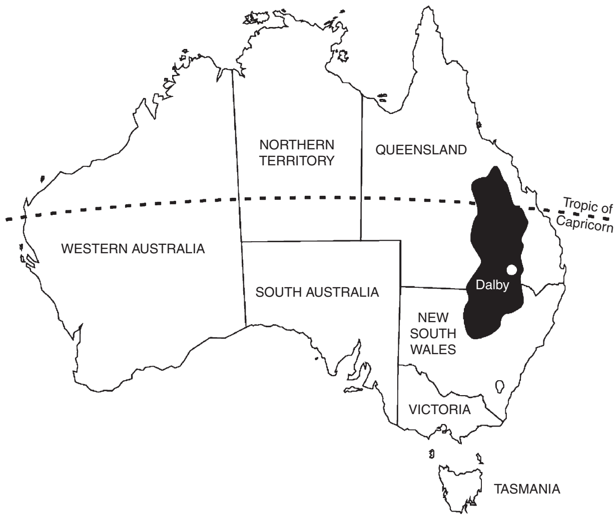

Fig. 1. Australia's northern cropping region runs from the Central Highlands of Queensland to central New South Wales.

expectations based on simulations of soil water (and N) supply as determined by local soil characteristics, initial stored water and N, local daily rainfall history, and a current climate forecast based on the Southern Oscillation Index (SOI). Second, we also offered a partnership with farmers and their advisers in testing the feasibility of this approach in which we provided the simulator, access to the required weather data, and capability for practical acquisition of soil data.

But we encountered a serious impediment to implementation of the feasibility testing. We could not find any farmers who were sufficiently interested in the simulation tool to participate in research on its evaluation. When farmers were presented with our proposal of a collaboration that entailed (*a*) characterisation of the water storage characteristics of their soils and monitoring of water content in relation to weather and management actions and (*b*) simulation of consequences for crops, there was enthusiasm only for the former (Carberry *et al*. 2002; McCown *et al*. 2009, this issue). Consequently we deferred the simulation activity but proceeded to collect the soil data that would enable site-specific simulations if/when farmers became more receptive to the idea.

Assessing soil water and nitrogen at paddock scale

On-farm research with farmers and their advisers commenced in 1992 with 3 groups of broadacre cropping farmers in southern and central Queensland (Cox *et al*. 1993; Foale *et al*. 1993, 2004; Carberry *et al*. 2002; Hochman *et al*. 2002). This activity combined collaborative soil sampling in farmer-nominated paddocks, generation and manipulation of the data by the scientists, and meetings with farmers and advisers to discuss the data, its meaning, enhanced by appropriate 'theory', and possible management implications.

Appropriate soil measurements

An early scientific challenge was to provide a means of characterising and monitoring soils, which was an acceptable compromise between what soil scientists do and what might be practically feasible in a farming context. The early tradition of applied agricultural soil physics considered soil water dynamics as a steady-state equilibrium of water in a relevant soil zone, e.g. the crop rooting zone. The state of this zone was expressed as the amount of plant-available water, the agronomically salient term in the so-called water balance equation, along with rainfall, runoff, surface evaporation, extraction by plants, and drainage beneath the rooting zone (Saxton *et al*. 1986). Later developments in soil physics resulted in a shift from this *water budget* to a flux theory of soil water change, in which water moves along gradients of energy potential and is rarely at equilibrium (Ross 1990). For the purpose of crop modelling, however, there are significant practical advantages to the theoretically outdated water balance model (Ritchie 1981). In brief, it is computationally more efficient, variables to specify the model can be measured more simply and cheaply, and the system is more readily conceptualised by farmers, advisers, and agricultural scientists. And fortunately, when the main interest is in supply of water to crops, the accuracy compares favourably with the flux model (Verburg 1996).

Procedures for determination of particular soil properties and states are described in the Accessory Publication 'Procedures for determination of soil properties and states relevant to crop simulation and farmer crop management decision making' which is available on the journal's website. These include plant-available water capacity (PAWC) as the difference between drained upper limit (DUL), or field capacity and crop lower limit (CLL), plant-available water status (PAW), and bulk density (BD). Strategies and techniques for sampling both soil water and nitrogen are also described.

It quickly became clear that farmers had an active interest in the soil sampling, seeing it as a rare opportunity to learn about both the observable and the analytical attributes of their soils as well as implications for actions and production. This started with the individual farmer but quickly extended to production and environmentally focused farmer groups interested in promoting the benefits of soil coring to resource understanding, and eventually led to the development of the structured soil training activities discussed later in this paper.

> 'It was just interesting what the soil was like at depth . . . to have the soil laid out in front of you and actually feel it and look at it and see how it changed with depth . . . and see how the roots were going down through it and just the picture you've got of your asset I suppose. Then to be told what its potential should be . . . was quite a watershed. To see how deep the soil was and to see that there were no constraints and the roots should be able to go down in our country as far as they wanted and then to look at what its yield potential was and what we were growing and saying I should be actually growing twice as much as I am now.'

Interpreting soil information in farmer group meetings

Representation of analysis results coupled with new concepts

To most farmers and some advisers we were introducing a radically different way of thinking about crop water supply, and clear meanings were needed at two levels; the first concerned quantifying water in the soil that the crop could reach, and the second concerned relating this water to crop growth, development, and yield using a simulation model.

Soil water was represented as in Fig. 2. This shows volumetric soil water plotted against soil depth. Also shown are the upper and lower limits of storage for wheat with any constraints to root growth and water extraction (caused through physical impedance or chemical toxicity) inherently reflected in the field measure of crop lower limit. This defines the size of a 'bucket' of available water and provides a reference for determining fraction fullness of this 'bucket', based on a PAW measurement. The calculated 'bucket' *capacity*, proportional to the area between DUL and CLL, is converted to rainfall-equivalence, which in Fig. 3 is 197 mm. The actual stored water *amount* (PAW), calculated from the difference between measured and CLL, is 132 mm, 66% of capacity. Also shown is the line for an even drier PAW scenario of 66 mm, 33% of capacity.

This representation of soil water available to a crop is considerably more analytical than concepts held by farmers and consultants, radically so for many. The notion of 'storage' varied greatly among participants. The prevalent approach in the broad farming community was an intuitive judgement of the water status based on recent rainfall and the observer's experience with the particular soil. However, most of the farmers participating in FARMSCAPE had a more sophisticated concept of storage. Refereeing to this 'elite' sector, an interviewee recalled that at the time when the project started.

> 'We did have a good idea of full and ½ full profiles and generally speaking that a full profile is going to be better for you. We all knew that.'

This 'profile' concept was supported by technology, in the form of the 'push probe'. This is a 1-m long steel rod with a tapered cone tip that is pushed into the soil to gauge the depth of soft, i.e. *wet*, soil (Fawcett 1969; Dalgliesh and Foale 1998). Many participating farmers readily came to value the 'bucket' of Fig. 2 as enhancing their understanding of the profile. The

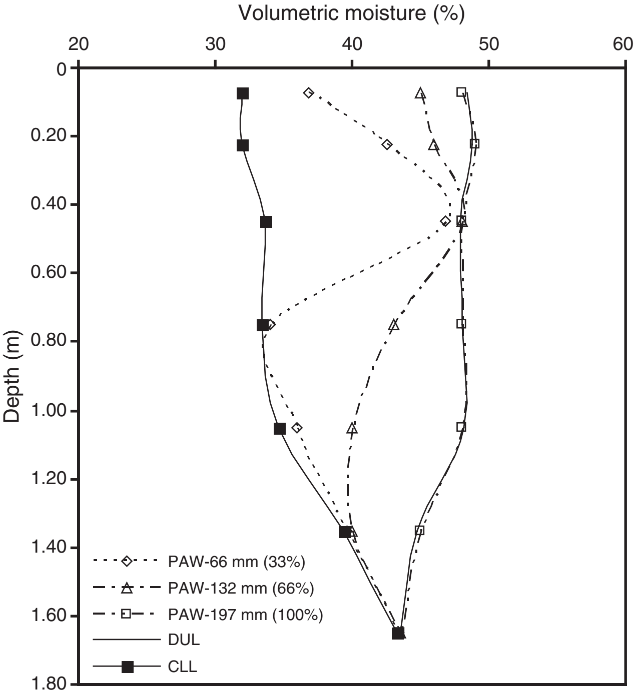

Fig. 2. Pre-planting soil water profile referenced to DUL and CLL, providing visual representation of relative fullness of the 'bucket'. The profile contained 132 mm PAW (66% capacity) (data from a Grey Vertosol paddock near Dalby, Queensland, sampled before planting a wheat crop).

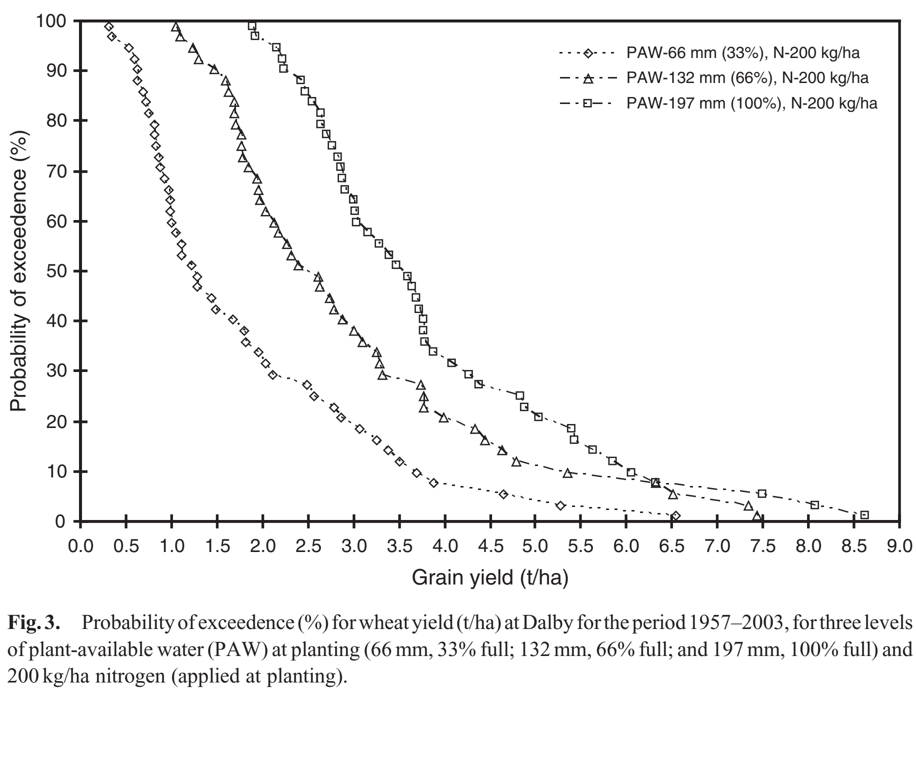

Fig. 3. Probability of exceedence (%) for wheat yield (t/ha) at Dalby for the period 1957–2003, for three levels of plant-available water (PAW) at planting (66 mm, 33% full; 132 mm, 66% full; and 197 mm, 100% full) and 200 kg/ha nitrogen (applied at planting).

'bucket' characteristics of CLL and DUL provided meaning to the soil water measured: the measured amount of PAW can be referenced to the PAWC for that soil; soils differ greatly in retention characteristics at both the wet and dry limits; and the lower limit of extraction varies predictably with crop species. This representation was the starting point for discussion of soil water dynamics as a *budget*, the key to calculation of the implications of storage in planning and decision making in a risky climate.

Simulation to make meaning of stored soil water

The key to interpretation of monitored soil water and nitrogen in FARMSCAPE and its commercial implementation later in Yield Prophet® (www.yieldprophet.com.au; Hunt *et al*. 2006; Hochman *et al*. 2007, 2009, this issue), is the Agricultural Production Systems sIMulator (APSIM) (Keating *et al*. 2003; Carberry *et al*. 2009, this issue). This can compute the production outcome for a decision situation, given weather data and initial soil water (and nitrogen) states. In farmer meetings, simulations enabled 'answering' the question of what if we had had this soil water and nitrogen situation last year (or any other year in the weather record), or if we had taken some other action, this year, how often could we expect a better or worse outcome? Likely implications of soil conditions for the coming season can be discussed aided by the statistical distribution of events in previous seasons simulated using historical daily rainfall data.

For example, simulations were run using APSIM to predict the production of wheat for the site represented in Fig. 2, for each of 46 years (1957–2003), using current crop management practices such as variety, sowing date, seeding density, and soil moisture (132 mm) and soil nitrate nitrogen (200 kg N/ha) measured before sowing. This provides a probability distribution of yields for the pending season shown in Fig. 3. Also shown are distributions for yield for scenarios with a full soil water store at planting and for a store only one-third full.

The simulation analysis (Fig. 3) demonstrates the importance of the amount of stored plant-available soil water (PAW) to farmers' planning in this cropping environment with high variability of growing-season rainfall. With a full initial profile (197 mm PAW) there is a 90% chance of achieving a yield of at least 2.4 t/ha, whereas with 132 and 66 mm PAW the 90% expectations are only 1.5 t/ha and 0.7 t/ha respectively.

These analyses combined the 'bucket' representation that farmers readily embraced for their analytical thinking about their system with the computer-based activity that they had rejected at the outset of the project. Increased appreciation for the latter for making sense of their farming experiences came about by two avenues. One was through learning how the simulator works (at an appropriate level, e.g. the soil water budget) and finding the concepts helpful in understanding their production system. The second was to experience a satisfying correspondence between simulated outcomes and known real outcomes, the key often being a local characterisation of soil properties related to water holding (Carberry *et al*. 2009, this issue).

> 'I think until you understand your soil and you do the monitoring, people aren't going to believe simulation results. We did some simulations the other day with a group and showed them what their yield potential should be and they just said they didn't believe the results. They said, it's just a computer model, basically. But they hadn't seen the soil and done the measurements. They didn't know what their soil held when it was full; they didn't understand lower limits for different crops and that sort of stuff.'

Soil data management

As FARMSCAPE developed, the project team increasingly worked with farmer groups that were more geographically dispersed and whose members were farming on a wider range of soil types. It became apparent that there was a need for a database for 'bucket' characteristics of major soils and software for organising and viewing soil monitoring. The software database APSoil was developed to serve both these needs (Dalgliesh and Foale 1998).

APSoil has developed into a national database of soil water characteristics (Dalgliesh *et al*. 2006) and is integrated and utilised as the soil library in current versions of the APSIM model. A stand-alone version is also available for download from www.apsim.info, or online through the Australian Soil Resource Information System (ASRIS) (Johnston *et al*. 2003; McKenzie *et al*. 2005) website at www.asris.csiro.au/index_ie.html. The data may also be viewed spatially using Google Earth (http://earth.google.com), with individual site characterisation information able to be downloaded for use. The Google Earth data file (*.kml) is available for download from both the ASRIS and APSRU websites.

Unexpected consequences of farmer enthusiasm for soil measurements

The experience of being able to explore their soil prompted even some of the most successful farmers to acknowledge that they knew very little about their soil and that this needed to change. Significant numbers, either individually or in consortia, purchased or fabricated soil sampling equipment and acquired equipment for drying and weighing soil samples.

> 'We'll hook the tractor up to the soil sampler and sample all 3 farms at once. For a summer crop we'll probably core at the end of August, early September and then we'll throw the results into APSoil and the results will tell us whether we should skip row or solid plant.'

The degree of enthusiasm for soil measurements among farmers that eventuated was not anticipated. Some on our team had some sympathy with critics that argued that these soil monitoring techniques were excessively elaborate for practical farm management. But the surprising response of farmers to the opportunity to invest more in soil information and in just 'looking' more closely and deeper in the profile prompted two key classes of stakeholders, i.e. commercial consultants and industry-funded R&D funders, to take significant actions.

Soil training workshops

The enthusiasm of farmers for soil coring and determination of water and nitrate profiles led to R&D funders offering to support extension of these activities to larger numbers of farmers in a way that reduced per capita costs. This led to one-day workshops for farmers and consultants. Provision of such workshops assumed a life of its own and constitutes a complex story that will be reported elsewhere. It suffices here to observe that the motivation for workshops stemmed from farmers' enthusiasm for on-farm coring and measurement activity in which they were obtaining better understanding of their soils and getting information they found useful in decision making. Guided by this, early workshops featured training of farmers in soil sampling and quantitative measurement of water content. But as became clear over time, and is discussed later in this paper, this emphasis was misguided. Both workshops and on-farm soil monitoring activities evolved away from a focus on measurement.

Commercialisation of FARMSCAPE technologies in farm consulting services

Consultants' recognition of business opportunity

The involvement of consultants from the very first FARMSCAPE farmer group meetings enabled direct interaction with researchers on issues of importance to their practice and exposure to technologies which provided the opportunity to better understand the farming systems in which they worked. This new understanding was seen as a commercial opportunity to increase individual company competitiveness and to provide a more informed service to their clients. Companies involved in the project responded by investing in soil sampling equipment, training, and the provision of advice informed through simulation. Over time, other companies became involved, buying equipment and increasing demand for access to simulation. While consultants were developing the skills and equipment needed to better service their clients, the farmers were also developing a better understanding of soil water management, which increased the pressure on their consultants to provide the appropriate services.

> 'I have stopped using one company for soil testing for fertiliser because they never had a probe to spear down a metre or 1.2 or whatever and pull a core out. They just used to do a little hand thing. I use another company.'

FARMSCAPE training and accreditation program offered by APSRU

Responding to farmer enthusiasm for FARMSCAPE technologies, consultant firms were motivated to invest in training of their people to deliver a service that could be seen as best practice. The FARMSCAPE Training and Accreditation program (Dalgliesh 1999; Carberry *et al*. 2002; Hochman *et al*. 2002) was designed to deliver the required training, as well as providing a means of assessing the potential for agribusiness to deliver FARMSCAPE technologies into the market place. While the action-learning course, which ran from 1999 to 2002, was supported through industry R&D funding, substantial fees were also charged for participation. Nine consultants and advisors commenced the training (7 commercial agronomists, 2 government advisors), with 3 achieving level 1 accreditation and another 4 achieving both level 1 and 2. A significant component of level 1 training focused on advanced technical training in soil water management, in particular soil characterisation and monitoring. Level 2 focused on the science underpinning crop modelling, the application of models, and interpretation of simulation output. While successful in its aim of training a small number of consultants in the FARMSCAPE technologies, the training and accreditation mode of delivery was not considered a cost-effective utilisation of researcher time and the decision was made to explore other delivery mechanisms, which included the commercialisation of APSIM and the use of web-based delivery systems. Commercial arrangements entered into with the Birchip Cropping Group resulted in the development and delivery of the web-based decision support product, Yield Prophet®.

What have we learned about pragmatic provision of soil information for paddock-specific simulation and farmer decision making without simulations?

In the normal course of research funding cycles, FARMSCAPE moved on to work with new farmers in new regions, which meant discontinued interaction with the original participants. These included participants with whom we had the most active and sustained interactions regarding soil matters and risk analysis using simulation and the most enthusiastic adoption of and significant investment in our soil monitoring techniques. It later became apparent that it would be valuable to know what transpired following the project's departure with regard to the thinking and behaviour of these proponents who had been introduced to the FARMSCAPE approach about 10 years earlier.

Farmers' reflections and perceptions of FARMSCAPE impact 10 years on

The evaluation strategy was to study a set of cases of farmers and advisers, most of whom were, formerly, the most committed to our interventions. Of the 14 farmers interviewed, 12 had had no significant contact with the project researchers for 6–8 years. The other 2 had never had direct contact with researchers but were involved in monitoring and simulation activities initiated by their consultant who was, formerly, closely involved. In keeping with their preferences, 5 farmers were interviewed individually, and 9 others with their local farmer groups (3 groups). All farmers interviewed managed broad-scale cropping operations, with 12 of the 14 growing dryland cotton as a component of their system. Of the 3 consultancy firms represented, individuals from two were interviewed in company groups. The absence of any public sector advisers reflected the demise of this mode of advising in the public sector by this time.

The question sets for farmers and consultants were designed to fit their differing perspectives. Both sets focussed around the themes of soil water monitoring and characterisation, nitrogen monitoring and management, and the place of simulation modelling in relation to soil information. Although the main aim was to learn about the post-FARMSCAPE period, the opportunity was taken to capture the earlier experiences and retrospective interpretations of these at the time when interviewees encountered our interventions. They were also requested to do this against what they considered 'traditional' thinking and practice.

The fact that the interviews were structured did not preclude spontaneous contributions or relevant unplanned questions. Sessions lasted 1–2 h, and by permission of the interviewees, all interviews were recorded, and later transcribed for analysis.

Changes in attention to soil information driven by changes in farming environment

Farmers explained the positive response to FARMSCAPE interventions in the early 1990s as suiting the changes that were taking place in their farming environment. In response to sustained trends in land and commodity prices, most farms had converted from mixed crop–livestock farming to specialised crop production. On most farms, increase in intensity of land use was reflected in reduction of fallow lengths and a shift to more opportunistic grain cropping. These structural changes coincided in the 1990s with below-average rainfalls and low grain prices. There was intense interest in dryland cotton, which promised high returns but entailed high costs and risks, the latter due in part to farmers' inexperience with this crop. There was new attention by some farmers and advisers to improving efficiency of resource use, particularly of soil water and nitrogen. This period was also a time of continuing change in local farming systems, with increasing adoption of zero-tillage and stubble retention.

> 'We wouldn't be here if we didn't change. Back then it was all long fallows. You had a long fallow, you planted and you grew a crop. You didn't worry too much. But now you push the system more. You've got short fallows and you've got to get it right.'

Reflections on farmers' experience with FARMSCAPE interventions

The picture provided by interviewees of traditional attitudes and behaviour came partly from personal histories and partly from observation of contemporary farmers who have resisted change.

> 'FARMSCAPE came at about the time we were starting to just use a hand probe. Prior to that, we just had no feeling for water. We didn't even think that much about it or even understand it. Our soil monitoring was the traditional surface soil tests for nitrogen and other elements.'

> 'There are still farmers around here that have had some rain and don't even put a probe into their soil and think, 'I've had enough rain I'm going to plant'. They haven't a clue what moisture they have in their soil and there are still a lot of farmers around that are like that – the older farmers, the older style. All they're concerned about is getting enough moisture in the seed zone to establish a crop.'

It became clear from interviewees' stories that when FARMSCAPE started, some farmers were already on a course of changed thinking about the soil water constraint and changed ways of assessing it.

> 'We did have a good idea of full and $\frac{1}{2}$ full profiles and generally speaking that a full profile is going to be better for you. We all knew that. Then after that, we realised the need to determine what your soil moisture holding capacities are and that's where it all started from.'

> 'Before you people started with us, our way of assessing what we had was our steel probe. We pushed it into the ground and we went on gut feeling, how easy it was to push and how it sounded when it came out.'

People recalled their early impressions of soil coring as an opportunity to see and feel the whole soil profile that had long been a mystery. They welcomed new ways to think about resources, e.g. the soil as a 'bucket', and new related practices for assessing capacity for supporting production.

> 'I think what we went through in the early nineties has really stayed. I think all that information has been so valuable, and I just keep thinking to regard the soil as a bucket. I go out and take cores at decision time through the year, you know when we're fertilising, going to take our soil samples for nitrogen testing and at the same time looking at moisture levels. That then helps to start formulating what crops are going to do and how much nitrogen is needed.'

The value of soil water information was enhanced by simulation through 'translating' millimetres of available soil water to kilograms of yield and for enabling a paddock-specific risk analysis.

> 'Ten years ago we didn't have a strong appreciation of water use efficiency, as in 'millimetres means this much yield'. There is no point knowing how much water you've got in your profile if you don't know what it means to your risk profile or your cropping potential if you like. Knowing the soil water level is one thing, but knowing what it means in terms of future yield is another thing. [ ] That's just where APSIM and other crop models came in.'

For the simulator to provide these functions it had to be credible. Farmers recalled various tests of the models against measured farmer yields in collaborative trials and against farmers' yield records that provided their confidence in this tool.

> Farmer: 'We've got away from thinking, well, maybe the model is wrong. I just sort of realised, we're saying well the model is the bench mark and we're assuming it's right now.'

> Interviewer: 'What has changed?'
> Farmer: 'When you see that new bit of technology, you are pretty sceptical to start with aren't you? I think there were some issues with it in the early days too that were fixed. A lot of it had to do with soil characterisations and understanding your water as much as the model itself.'

Farmers credited FARMSCAPE with contributing to their knowledge about their soils in general and, in particular, to more adequate and timely information about the availability of water, their most limiting resource. One farmer summed up the contribution as helping farmers to be more 'professional' in their dealing with climatic constraints. They had come to realise that they were in the business of 'farming water', and a critical component of success was improved resource information.

A frequently cited experience was the discovery of large quantities of subsoil nitrate that had accumulated following successive fertilised crops but that had been missed by routine surface soil samples analysed for nutrients.

> 'Six or 7 years ago you blokes showed that we had 300 kg and 400 kg of nitrogen below 30 cm, which is what you call the 'Eureka' factor of the whole exercise. All our old soil testing had been shallow, but we've been building N up [at depth] through leaching. As the crop gets bigger, the roots eventually get down to that bulge. We've actually brought that bulge back nearly into a straight line. We had a paddock containing 450 units of N. You're probably looking at a cost saving for 200 kg of N. That's the biggest shock we had.'

For this farmer, the discovery of the nitrogen bulge caused him to reduce nitrogen application for a time to a maximum of 40 kg/ha from his previous standard of 80–140 kg/ha. This resulted in both a substantial financial saving and a potential environmental benefit of reduced leaching of deep nitrate from the profile.

> 'By being able to monitor, we knew we had plenty of N and we knew where it was and we were able to plant a cotton crop with confidence of getting a good yield without significantly more nitrogen. That was probably saving us a bag of urea to the acre [100 kg/ha]. Traditionally you just went out and put a heap on for your cotton. You just did it. People still do it. By monitoring it we knew we didn't have to.'

Evolution in practice since FARMSCAPE

Finessing planting decisions. It became clear from the interviews that planting judgements had progressed beyond interpreting soil water supply as semiquantitative adequacy of soil conditions to establish a crop to quantitative adequacy for producing a profitable crop.

> 'This gets you into this risk analysis, and we say the worst thing you can do is grow a failed crop, because not only do you lose money on that crop but you then upset the next one. What farmers need to know is at what point do they actually make a profitable crop in terms of millimetres of water? That's the added dimension to making a risk analysis or a risk decision on whether we do or we don't plant. Out here it's often been the case that farmers' biggest constraint, as they would see it, is planting rain, planting events. Now there's better appreciation that you're better off letting a lot of planting events go if you don't have sufficient soil moisture to give you a high probability of growing a viable crop. So that's totally different.'

> 'Not planting crops has probably been some of the best decisions that this technology has given us. [ ] We've never ever regretted not planting the paddock.'

> 'We've been willing to walk away from planting our crop. I think even at the moment we went into this season on limited moisture in a lot of paddocks and we made a decision not to plant a summer crop on the first rain. We just said 'hey, it's too risky'. There's 30 cm of moisture. The neighbours next door were out putting on fertiliser and ploughing fence to fence ready to go. We said forget it. We're not going to plant until we've got at least 60–70 cm on it to go into sorghum and more for cotton. It was nice to be able to make a decision like that and walk away in confidence that you know that it's been calculated.'

Interviews revealed that some farmers finessed planting decision making based on soil water even further.

> 'We're getting water-saving options like skip row cropping. These are things we can look at now with a lot less than desirable soil water levels and still be fairly well assured at the other end of having a crop, which is an important thing. We've got to get a crop. [With skip row] we might be losing some yield potential, but if we improve the security that's good. So, if we looked at a profile and it's not real full, the seasonal outlook is not real fantastic, we've still got a planting opportunity.'

Finessing soil monitoring: the trade-off between accuracy and costs. Most interviewees revealed that, although their FARMSCAPE-facilitated views about soil water had not changed, their level of investment in getting soil water information had. These changes were aimed at economies, mainly in time and labour. Economies reported were (*1*) reduced total depth of sampling, (*2*) reduced number of soil layers sampled, (*3*) reducing spatial intensity together with stratifying for soil types, (*4*) replacing drying and weighing of soil to measure water content with estimation by squeezing in the hand, and (*5*) reduced frequency of coring by substituting calibrated push probing and water and N budgeting. A consultant best articulated the underlying rationale for the inevitable losses associated with such cost-cutting changes:

> 'We've been doing this because it's very quick. [ ] We've found over time that knowing the soils at the start and knowing their upper and lower limits we can make some pretty good decisions quickly using cruder approximations of water actually there, at any point in time. You need a high degree of accuracy in the *decision* not a high degree of accuracy in *measurements*.'

One of the prevalent changes was substitution of 'squeezing in the hand' for gravimetric soil water measurement on core samples.

> Farmer: 'I did a bit of measuring of it there a while back. Now it's just a matter of look and feel.'
>
> Interviewer: 'Why did you change to touch and feel?'
>
> Farmer: 'Just effort. It is a lot of work to get a good meaningful result by the time you've taken a core and split it up, dry it and weigh it and all that. I started with

[gravimetric measurement] and later just estimated squeezing the soil where it was wet.'

Another approach that evolved was substitution of the push probe for coring, but with a new skill in interpreting results as a result of the FARMSCAPE coring experience, i.e. calibrating the subjective probe estimate against profiles of gravimetric measurements. A consultant, who is also a farmer, described his experience:

'We've done a bit of a circle, really. Before FARMSCAPE we used to say 'we've got a foot or a couple of feet of water.' With FARMSCAPE we cored and went and measured that through drying and that sort of thing. Now we sort of know what a foot and 2 feet is in millimetres of water. Before you didn't know what it was.'

Three farmers mentioned occasional use of a third 'simplification' of soil water monitoring, i.e. the use of the simplified soil water balance model, HowWet (Dimes *et al*. 1996). This easy-to-use computer program simulates soil water for fallows without vegetation from daily rainfall, given initial PAW and PAWC.

Although the prevalent trend has been simplification to save costs, special reasons sometimes arise for farmers to acquire soil information with a high degree of precision (and cost).

'Now and then I tend to get more of a volumetric water measurement if you like, with the weighing of the soil and drying it out and that sort of thing...it's [the crop] grown under contract for a company in Melbourne. They want to know how much starting soil water I've got because they're interested in the crop potential. That is tied into their production.'

Evolution of farmers' use of simulation

The basic premise underpinning FARMSCAPE was that risk-taking dryland farmers would benefit from knowing the odds for relevant weather-influenced outcomes, and (*a*) that paddock simulation could provide this knowledge for relevant decision options and (*b*) characteristics of the specific soil and the amount of soil water at planting were needed to achieve this. In interviews, farmers' stories frequently confirmed the value of simulation in this role, but it was also clear that farmers were discriminating about when simulation was valuable and when it wasn't worth pursuing.

Being able to add value to soil resource information through simulation was seen by some as a low cost/low risk means of challenging 'status quo' thinking, exploring new options, and comparing the 'riskiness' of particular courses of action. For one group, yield simulations challenged expected yields and led to a major re-think of the yield potential in the district. Using local soil and climate information, the model predicted substantially higher summer crop yields than were being achieved. The crucial question for participating farmers, therefore, was whether the simulated yields were unrealistically high or whether farmers were under-achieving. Many of the farmers took up the challenge, accepting that there was scope to 'lift their game' by modifying the farming system, improving operations, and changing inputs.

'[ ] when we first started the modelling, the big stand-out thing was that our yields were about half what the model said were possible and so everybody was asking why. People took different messages out of that. Some went and bought fancy planters and some went and put heaps of nitrogen on and some put more seeds-to-the-metre on. There were lots of responses based on one little piece of information which said that you guys are only growing half of what the potential is. That was a big influence on the farmer group as a whole. [ ] I think it's all been for the better. You're talking about guys that planted sorghum with a scarifier [tyned tillage implement]. They put a few press wheels on it. It's been a big leap forward I think in the last 5 years. Guys are running around with 8-row planters, disc openers and getting every seed up and getting on top of their population, shield spraying and getting the weeds down.'

One of the farmers who took up the challenge presented by the higher than expected yield predictions, invested in precision planting equipment and set a target yield for sorghum in the following season based on soil PAWC and available soil water at planting. Yields of 4 t/ha were achieved in that and in the subsequent summer season, well above the 2.5 t/ha previously judged by the farmer group to be the maximum feasible.

A farmer in another district was seriously challenged by the results of custom simulations to reconsider his production expectations.

'We were just doing things wrong when we started looking at it. We were focussed on risky rainfall but found that soil was actually more important than climate in our area, with our soil type. We then went on to figure out if our soils were potentially this good; we were under-shooting. If you're going to go and throw that much fertiliser on to grow the perfect wheat crop that you can grow using the model, then you had to have a few other things right such as disease [management] and whatever else. One thing leads to another, and ends up with you trying to build a rotation. Then we've done those simulations with our soil type, looking at our climate and topography, and we build the system we've got now which is 4 crops in 4 years.'

'I've changed my yield expectations. I've changed my rotation. I've changed my fertiliser strategies. I've changed my seeding strategies. I've changed my row configurations. My inputs have gone up. The profits have gone up. The gross margin per hectare has increased.'

Other farmers recalled things they had learned concerning new strategic possibilities by being able to try them out with the computer 'on the spot'.

'Once you've done the simulations you can sort of think of the runs and how they might be applied. We did a lot of that work back in the '92–'93 drought, and I distinctly remember the model runs we did on a sorghum planting in September with, I think, 40 cm of moisture versus a sorghum planting in December. I still remember those runs and how the December one came out better simply because of the chance to store more moisture in a fallow period. That comes back to you. You remember those ones. I think that's what it's all about. It's just getting the confidence to make a decision or the information to make a decision and the confidence then to act on it.'

Significantly, and without contradicting the general experience of benefit to their strategic thinking about their management, farmers had come to recognise a class of decisions as not, or no longer, warranting simulations, but rather could be dealt with using the rule of thumb, water-use efficiency (WUE). This was of some surprise to the researcher-interviewers who had been involved with several of these same farmer-interviewees some 10 years earlier in on-farm action research in which they came to value simulation in such decisions, e.g. species or cultivar choice, fertiliser application rates, planting times, and whether to plant in the current season or defer until the next possible opportunity in anticipation of improved soil water levels. But it was clear that with time and experience, farmers had developed their own short-cut guides to practice, often enabled by new insights provided by the simulations.

Farmer: 'From experience we can put some numbers on it and even predict some of the outcomes in the normal type seasons. We all know the 'rules of thumb' about planting dates for wheat or sorghum. Yields will decline after a certain date and we know the effect of more starting moisture. We can sort of generally know and predict the outcome. But there is still a place for simulation when you've got a planting date out of the ordinary. This season will be a classic I suppose. Sorghum versus corn at the end of December when it finally rains or something like that. Moisture is this, SOI is that. Just when you get out of the normal system there's still a place for it.'

Interviewer: 'I get the impression from what you're saying that monitoring is the routine part of your process these days? Simulation is something you would do strategically if there is an issue that comes up that needs a little bit of further investigation.'

Farmer: 'That's fair comment. The thing is, at the beginning of the season we never know exactly how it's going to rain. If you did, maybe simulating everything every time would give you a benefit that would be worthwhile. Because we're dealing with a lot of unknowns, all we have are scenarios [best bets] from past years. What are the best options for different soil water profiles? We've seen that on the model and we've even had the practical experience with it. We've seen the scenarios for a wide range of soil storage and for different types of seasons. We are looking at them in a different way but we've had the experience. I don't think you need to go back and do all of that every year. You tend to remember most of those main important things. It's more important than seasonal outlook by a mile on our soils because our soils are so good.'

In contrast to when FARMSCAPE began, farmers' attitudes that were revealed in the interviews were not antagonistic towards modelling and simulation. But in contrast to the often uncritical enthusiasm common 3 or 4 years into the project, after 10 years, farmers were maturely critical and discriminating in their judgements about the value of simulation for management. In FARMSCAPE they had come to highly appreciate the two things that simulation could do for them. One was the 'translation' of soil water to crop development and yield. The second was the interpretation of the effect of their current soil water status on the climatic risk to their yields. But it was clear that farmers had pragmatically adapted in ways that reduced need for access to simulation without losing these two important enhancements to soil water information. For the first, they substituted a simple water-use-to-yield coefficient (WUE). For the second, they eliminated the need for repeated simulations by substituting a rule of thumb based on a 'best bet' judgement, often facilitated by probabilities from earlier simulation analyses. However, for farmers with these histories, the logical response when faced with a significant *novel* situation—an 'out of the ordinary' decision—was to seek out an opportunity to simulate it.

Consultants' evaluation of FARMSCAPE interventions 10 years on

As farmers have learnt more about their soils over the last decade and modified monitoring techniques to better fit their information requirements, so too have advisers changed their methods and the type of information provided to clients. Interviews revealed that changes in consultants' practices were responses to: (*1*) demand from farmers for FARMSCAPE-like services, (*2*) a firm's judgement that marketing FARMSCAPE technologies offered a business opportunity, (*3*) belief that FARMSCAPE thinking and technologies (or surrogates) could enhance a firm's capability to advise farmers. To differing degrees, responses '*1*' and '*3*' applied to all three firms. Only one of the three responded as per '*2*' and marketed both soil monitoring and simulation to their clients. But new providers of a soil monitoring service came to include many of the consultants' firms in the region.

> 'We see nearly every company now running around with corers on their utes [pickup vehicles]. There wouldn't be one company . . . here that does not have a deep soil corer when they're going out doing their soil tests.'

Another indicator of this latter change is the number of soil coring rigs available; one of the larger manufacturers has built more than 40 in the past 10 years, mostly for use in the northern cropping region (R. Milne, Milne Industries, pers. comm.).

Over time, advisers have modified monitoring technology to suit the economic constraints of their business and their clients' changing requirements and expectations. Of the three original agri-business companies involved in the early FARMSCAPE project, at the time of the interviews, Co. 1 continued to provide a full range of FARMSCAPE-based services, from characterisation of PAWC to detailed water and nitrogen monitoring, although this is generally only done in anticipation of simulation activity where data for the full rooting zone were required. In cases where the farmer required information for more general seasonal decision making, the company provided feedback on depth of wet soil through observation of the soil core, either as a special water-monitoring exercise or as ancillary information in sampling for nutrient analysis. Approximately 30% of its clients sought information on soil water status in this way. In some cases, farmers used this information to calibrate their use of the push probe. Monitoring of nitrate nitrogen was requested by ~80% of its clients. Not all clients requested monitoring in every year, some preferring to undertake a check sampling for nitrate nitrogen every 2–3 years and rely on a budgeting approach for the intervening years. Sampling was routinely undertaken to 0.90 m and at times to 1.20 m when deep soil moisture was considered an issue. A major change for this company was the move to increase the number of sampling layers, from 2 (0–0.10 and 0.10–0.90 m) to a 3-layer configuration (0–0.10, 0.10–0.60 and 0.60–0.90 m). This change was considered necessary to better describe the depth of any nitrogen bulge and assess its likely availability for crop uptake.

Agronomists from Company 2 indicated that they had reduced their routine soil water monitoring activities as they considered that it was uneconomic to undertake FARMSCAPE-style soil monitoring on a large scale.

> ‘We used to do coring until the coring rig conveniently got broken and wasn’t repaired in order to stop growers ringing us to come and do their soil tests, which we couldn’t afford to do. What we’re actually doing now is getting a grower to inform us of his rainfall every time it falls and have a HowWet file on every grower with all his rainfall. At any point in time depending on the stage of the fallow, whether it’s just come out of crop or it’s been in fallow for 6 months, we can put in another rainfall event and come up with an estimate of his current soil profile moisture. The old hand push probe is useful for any field confirmation. We have calibrated the push probe against the monitoring we’ve already done in the past, and we know what most soil types hold [PAWC]. So then it is only a matter of working out a percentage of stored water, which we can do, and we’ll compare that against ‘HowWet?’ just based on rainfall. The results have been pretty good. . . . We can . . . get the farmer’s rainfall records over the phone and put then into our computer and we’ve got a reasonable estimate (of available water) without even walking out of the office. It’s good when you consider that we’re dealing with about 50 or 60 clients who could have 10 or 15 paddocks each . . . so when you get a rainfall event you want to make a decision. Without our increased understanding of soil water we couldn’t shortcut the system to arrive at that decision making point as quick as we can.’

The Company 3 agronomist, who was a sole operator, made a series of changes over time in his approach to soil monitoring, progressing from use of a push probe, to hand coring and subsequently to hydraulic coring.

> ‘I suppose the push probe just wasn’t accurate enough really. I can still remember going over to a neighbouring farm where you demonstrated the hand core. That’s how we did it for a start. . . .it’s just gone from there. . . .when we started going down to 1.5 to 1.8 metres, just seeing what the nutrients were doing, that was ground breaking work I think.’

After several years, however, he made the strategic decision to contract out his clients’ routine soil monitoring and concentrate on analysis of results and on strategic planning.

Consultancy firms differed in the ways in which they valued and used simulation. Co. 1 used the simulator as a decision support tool directly to provide guidance to farmers on particular issues relating to their cropping system. In this situation, the model was run using local soil and climate information and the results presented to the farmer for discussion. This required the provision of a comprehensive soil monitoring and simulation service to their clients. The company promoted the service through district farmer groups, characterising and monitoring soils on an individual farm, and running simulation scenarios of interest to the group. Further activity after the initial promotional work was generally undertaken with individual farmers.

> ‘I think when you go to a new grower group, you stick a soil characterisation pond in and it becomes a focal point of the grower group. You show them what you get out of it and you run some scenarios and they see what it can do, and I think then you’ll get interest. Again you’ll probably get an 80/20 curve within that group. Even if you get 1 or 2 guys that are interested, at least the rest of them know about it, and I think all the time they’re going to be looking over the fence. They’ll probably want to know, is the information or the decision making being enhanced, and are those guys making more money? They only have to pull off the odd extra crop in a difficult year.’

This particular company indicated that ~10% of its clients continued to use simulation in their business, although there has been some turn-over of individual users. Their explanation for this turnover reflects the comments of farmers who suggested that once understanding of a particular issue has been gained there was no need to undertake further simulation until another issue arose.

Instead of training all of their consulting staff in the use of APSIM, this company has developed a centralised desk that provides a simulation service to their advisers and clients across the entire northern cropping region.

Company 2 used simulation very differently. It considered the model to be of more value in increasing the knowledge of their own staff than as a tool for direct use with individual farmers. Once the consultant, in collaboration with a small group of key clients, had explored a particular issue, they extrapolated the findings to other farms using soil and weather analogies. In this way, simulation results, while not specific to an individual farm, became an integral component of the overall advice being offered.

> ‘The confidence in what we’re promoting comes partly from the value of running the simulations. You do a lot of good work and simulations on their farm, and that gives you confidence then to go and promote what you’re learning in a generic fashion to the rest of your clients. If you didn’t have that behind you, you wouldn’t be quite so confident in your recommendations, and that’s the thing that makes your clients interested I think.’

It came as something of a surprise to learn that all consultants saw simulation as a valuable means for generating new ‘rules of thumb' through systematically exploring an issue. For example, two companies were using this approach to improve their WUE rules. While it was relevant to know available soil water at planting, both recognised that the information was most valuable when it was used to calculate yield potential and risk. This led to the analysis of water-use efficiency and the development of production risk profiles for a range of soil water starting conditions, seasonal outlooks, and soil types. One company developed water use 'rules of thumb' for various stages of crop development (e.g. emergence to anthesis, anthesis to physiological maturity), which enabled their advisers to make informed decisions on crop potential when presented with soil monitoring information.

> 'That's where we use APSIM and other forms of crop models to develop freehand ways of calculating in terms of water-use efficiency, what millimetres of water will it take to convert it [available water] to a particular yield. Now we've got all that down in a series of best bet rules if you like, so we don't have to re-assess that every time we want to make a decision. We've already calculated that. There's the cut off, don't go below that.'

While the major goal of consultants is to optimise production and reduce the risk of crop failure for their clients, another is to ensure that they manage internal company risk appropriately through the provision of the best advice using well trained and informed staff. Thus APSIM simulation was seen as providing the means to quickly develop understanding of the crops and cropping systems in use, understandings that could take several years to develop under normal circumstances.

> 'It all comes back to minimising our risk and our clients' risk, and by trying now to delve deeper into the model and ascertain how these crops grow and the mechanisms and the requirements to get to each particular (crop) stage. That's the sort of information we're after now. So it's driving us as well.'

Discussion and conclusions

The farmer groups that participated in FARMSCAPE contained mostly 'elite' farmers who, as an insightful consultant put it, 'were leaders in application of the latest agronomy who now find themselves *up against the environment*'. Just what they were up against and how they might do things differently became the focus of the FARMSCAPE engagements. When the FARMSCAPE project concluded in the Northern Region, participating researchers felt that they were leaving behind groups of farmers who were committed to a new way of thinking about the soil they farmed and to new ways of obtaining soil information to guide tactical and strategic planning.

Much of this paper concerns an evaluation of this perception of positive impact, an evaluation a decade later. The evaluation needs to be seen as a set of case studies of participants' experiences. The cases were selected as those in which farmers and consultants had been, a decade earlier, enthusiastic adopters of the soil monitoring and simulation approaches offered in FARMSCAPE intervention. Although an evaluation might be expected to provide an *extensive* picture of rates of adoption, the objective of this evaluation was *intensive*: to gain insight regarding the sustained 'goodness of fit' of the technology to the practice of those farmers where it fit best during the technology development phase. Insight was provided by knowledge of what participants *did*, enriched by their experiences and explanations.

The case interviews revealed a surprising diversity and magnitude of changes in technical practices. But, significantly, farmers and consultants had retained their 'new' perspective and mental models regarding soil resources acquired a decade earlier. How should the changes over time to simpler techniques be interpreted? Superficially, at least, technology that was unequivocally adopted was later 'unadopted'. But modern literature on technology adoption tends to treat this sort of behaviour as integral to the adoption processes of empowered and creative managers (Douthwaite *et al*. 2003).

When farmers encountered the FARMSCAPE project they were assessing soil water status more or less intuitively and simply. Some assessed water supply by a judgement based on recent rainfall and experience with the particular soil. Others gauged the depth of soft soil with a screwdriver or the purpose-made push probe. In evaluation interviews, farmers and consultants gave two reasons for their interest in the soil water assessment approach offered by FARMSCAPE. The first was gain in reliability by moving away from the subjectivity of the probe technique.

> 'With the hand probe, people believed what they wanted to really. If they wanted to plant they would push a bit harder. You just wonder how accurate it was.'

The second reason given was the potential value of the new types of information, e.g. the PAWC as characteristic of a particular soil, the amount of PAW, and PAW relative to the PAWC. Although these added complexity and cost, initially at least, this was acceptable to many. But with experience, this changed, and these pragmatic managers substituted much simpler techniques with much lower costs. But crucially, this *new* simplicity was not a return to the *former* simplicity. This pattern of behaviour may be an example of the phenomenon Judge Oliver Wendell Holmes had in mind when he said, 'I would not give a fig for the simplicity this side of complexity, but I would give my life for the simplicity on the other side of complexity' (Hayman 2004).

It may be hard to do better than the best simple 'rules of thumb' in the still-unavoidable ignorance of pending in-crop rainfall, especially without a readily accessible simulation service for tactical decision support, such as Yield Prophet®. But in the case of soil information for farming, this might slight the possibility that practices that can be characterised as 'near-side' simplicity, complexity, and 'far-side' simplicity are all to be preferred for respective stages in the evolution of farming systems. In the former mixed crop–livestock farming system of this region, there was little pay-off for more than simple assessments of planting conditions because pressure on land allowed long fallows and the buffering of returns from cropping by the livestock enterprise. From these interviews, it is apparent that in the intensive cropping systems that have since evolved, there can obviously be large pay-offs for knowing the soil water status. Farmers were willing to change their mental models about soil water and adopt new techniques to achieve its conceptually meaningful assessment. But they have been inventive in achieving a new efficient simplicity in techniques without sacrificing the new conceptual meaningfulness. Although FARMSCAPE intervention was effective in using analytical complexity to facilitate farmers seeing their soils differently, only the farmers and consultants were able to simplify the techniques so they better suit their practice situations. This is the historical legacy of the division of labour in participatory action research. Complex analytical concepts and thinking may be necessary to get from the old simplicity to a new, superior simplicity. The elegance of this latter simplicity, so coveted by Holmes, seems to be due to the conceptual insight.

> 'I've sort of got my own classification I suppose for most of the soils and I've just got a rough number about the number of millimetres of water those soils hold and the amount available for different crops. I've never gone to the extent of drying down and weighing any of the samples because I've simply got too many and it's too time-consuming. I haven't had time to get to that level but I've tried to sort of get to the stage where I can identify the cores when I take them, look at the moisture movements through the core and just be able to put a number on it and saying this is somewhere around 60% or something. You know if it's in the Kupunn country with 290 mm available [PAWC] for cotton this might have 200 available you know. I try to roughly put a number on it without getting too scientific and too hung up on it. What I am noticing more and more is not only looking at the numbers but at the actual condition of the structure of the soil through the profile.'

But from the interviews it was clear that in some cases, much of the complexity of the FARMSCAPE approach to acquiring and using soil information in decision making was retained. This divergence forms the basis of two contrasting consulting strategies to support such decision making. One largely adopts the FARMSCAPE approach in using soil monitoring techniques and simulation. This approach was the basis for the FARMSCAPE Training and Accreditation program and delivery of services by participating agribusiness firms. The other strategy transforms the FARMSCAPE approach by greatly simplifying soil monitoring and using simple 'rules of thumb' to replace simulation in tactical decision making. Both approaches have persisted to the present. An ongoing research objective is to be students of these implementations of contrasting value propositions for implementing a shared set of concepts.

Our original choice of the static water budget model over a dynamic soil flux model favoured in analytical soil physics proved to be a good decision both with regard to the objectives for customised simulations and enhancement of farmers' soil concepts and monitoring practices. Characterisation of soils in terms of upper and lower limits of storage has proved to be a practical field technique for an extensive network of sites as well as enabling adequate simulations for a wide range of soils. Farmers readily adopted the concept of a 'bucket' whose size is determined by both soil and crop attributes. Such a response could not be expected with a flux model.

Footnote

In the years post-2002 the technologies and techniques described in this paper have continued to develop. Precision Agriculture (PA) (Cook and Bramley 1998) has moved into the main stream of agricultural production with zonal management utilising global positioning systems (GPS), yield mapping, and tools including Electromagnetic Induction (EM) (Corwin and Lesch 2003) now a reality and readily available to producers. This has resulted in the ability to identify management zones based on productive capacity (often caused by differences in soil water-holding capacity or in degree of subsoil constraints), enabling a much more focused approach to monitoring of soil resources using either conventional coring methodologies or tools such as EM (Huth and Poulton 2007).

The training of agricultural practitioners in the characterisation and monitoring of soils and the use of the information in management has continued to expand. Soil training and characterisation programs are now in place, in collaboration with local government agencies and agri-business companies, in most major cropping regions of Australia, with a resultant increase in knowledge and skills within the agricultural community. Soil characterisation has been and is being undertaken by several public and private organisations and information for over 500 soils nationally is now available in the public domain. This has allowed decision support tools such as Yield Prophet® to be used successfully around the country.

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