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Re-inventing model-based decision support with Australian dryland farmers. 4. Yield Prophet® helps farmers monitor and manage crops in a variable climate

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Abstract. In Australia, a land subject to high annual variation in grain yields, farmers find it challenging to adjust crop production inputs to yield prospects. Scientists have responded to this problem by developing Decision Support Systems, yet the scientists' enthusiasm for developing these tools has not been reciprocated by farm managers or their advisers, who mostly continue to avoid their use.

Preceding papers in this series described the FARMSCAPE intervention: a new paradigm for decision support that had significant effects on farmers and their advisers. These effects were achieved in large measure because of the intensive effort which scientists invested in engaging with their clients. However, such intensive effort is time consuming and economically unsustainable and there remained a need for a more cost-effective tool. In this paper, we report on the evolution, structure, and performance of Yield Prophet®: an internet service designed to move on from the FARMSCAPE model to a less intensive, yet high quality, service to reduce farmer uncertainty about yield prospects and the potential effects of alternative management practices on crop production and income.

Compared with conventional Decision Support Systems, Yield Prophet offers flexibility in problem definition and allows farmers to more realistically specify the problems in their fields. Yield Prophet also uniquely provides a means for virtual monitoring of the progress of a crop throughout the season. This is particularly important for in-season decision support and for frequent reviewing, in real time, of the consequences of past decisions and past events on likely future outcomes.

The Yield Prophet approach to decision support is consistent with two important, but often ignored, lessons from decision science: that managers make their decisions by satisficing rather than optimising and that managers' fluid approach to decision making requires ongoing monitoring of the consequences of past decisions.

Additional keywords: DSS, APSIM, climate risk, risk management, wheat, barley.

Introduction

Australia's dryland farmers face an extremely variable climate (Nicholls *et al*. 1997) and consequently, extreme variation in potential and actual grain production (National Land & Water Resources Audit 2001). Such climatic uncertainty diminishes a farm manager's capacity to plan for any given season. Consequently, the challenge faced by farm managers is to flexibly adjust their level of investment in crop production inputs in order to avoid either over-investing in crops with poor yield prospects or under-investing in crops with good yield prospects.

The major management choices available to Australian grain growers may be summarised as follows:

- Crop or fallow: if a poor season is expected, one response is not to sow a crop and to preserve winter rainfall as stored soil water for the next crop.
- Crop choice: some crops are more profitable in a good season but more prone to failure in a dry season.
- Time of planting and variety choice: early planting in the autumn allows for a longer growing season but increases the risk of frost damage to the flowering crop. Faster maturing varieties can be used to compensate for a later than optimal planting opportunity.
- Variable levels of inputs: inputs (e.g. nitrogenous fertiliser, selective herbicides and fungicides) can be adjusted to suit the seasonal conditions. Conservative inputs early in the season

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can be compensated for later in the season if prospects improve (e.g. by applying nitrogenous fertiliser to a growing crop, a practice referred to as topdressing).

Because seasonal outcomes are uncertain, these management variables cannot be applied with confidence, and decisions are risky. A ‘flexible’ risk management strategy sees each cropping situation as unique and management as problem solving using available information. A flexible strategy may be analysed as: (*1*) knowledge of the current system status (e.g. available soil water), (*2*) a means of interpreting this in terms of likely production, and (*3*) a forecast of seasonal climate prospects.

Australian agricultural research has confronted this challenge with the aid of simulation modelling (Christian *et al*. 1978; Littleboy *et al*. 1992; Hearn 1994; McCown *et al*. 1996) and later with Decision Support Systems (Hearn *et al*. 1985; Woodruff 1992; Dimes *et al*. 1996; Donnelly *et al*. 1997). As with parallel efforts around the world, the effect on farm decision making has been disappointing (McCown 2002*a*, 2002*b*; McCown *et al*. 2002, 2006; Hayman 2004; Stone and Hochman 2004).

In the FARMSCAPE program, scientists explored whether farmers, supported by researchers and advisers, could benefit from simulation as an aid to risk management. The following 3 science-initiated technologies were explored to assist farmers in their flexible management of cropping systems:

(*i*) soil coring tools that allow farmers to generate data, to appropriate depth, on the physical and chemical characteristics of their farms’ main soil types, and on the soil water and nutrient status at key decision points in the season (Dalgliesh and Foale 1998; Dalgliesh *et al*. 2009, this issue);
(*ii*) systems simulation using the APSIM model (McCown *et al*. 1996; Keating *et al*. 2003) that utilises locally relevant information on soil characteristics and its current status, and on the seasonal climate outlook, combined with historical climate records, to simulate probability outcomes for intended management actions relevant to an individual farmer’s actual crop; and
(*iii*) seasonal climate forecasting tools that can provide significant skill in determining the probabilities of rainfall and temperature for the upcoming 3-month period (e.g. the phase system of the Southern Oscillation Index (SOI); Stone and Auliciems 1992; Stone *et al*. 1996).

The achievements of FARMSCAPE and the high level of engagement used were consistent with the first aim of the FARMSCAPE program, which was to learn how to intervene effectively in farm management practice using complex biophysical models of croplands, specified with local soil, climate, and management data (Carberry *et al*. 2002). The second aim of the FARMSCAPE program was to learn how to construct a science-based risk management service that would be valuable to farmers and be delivered cost effectively. The preceding papers in the current series (Carberry *et al*. 2009; Dalgliesh *et al*. 2009; McCown *et al*. 2009; all this issue) primarily explored important aspects of the first aim. The evaluation data that provided evidence of effects from the first stage of FARMSCAPE also indicated a need for a modified approach that entailed delivering a comparable service without the high transaction costs associated with frequent direct farmer–scientist engagements. Thus, the remaining challenge was to meet the second aim of the FARMSCAPE project, which was to deliver benefits, similar to those previously achieved by intensive engagement with small groups of local farmers, to a large number of farmers by extending both the geographical reach and the scope of issues covered, in a cost-effective and commercially sustainable manner.

In this paper, we report on the evolutionary development of a new tool and support network—Yield Prophet® (YP)—that was designed to combine the 3 FARMSCAPE tools to provide cost-effective decision support to farm managers engaged in extensive cropping. It is the story of collaboration between the government sector CSIRO/APSRU (the FARMSCAPE team) and the Birchip Cropping Group (BCG, a non-government, not-for-profit farmer-based research and extension organisation) to implement model-based decision support to Australian farmers. The collaboration started with an invitation from BCG to the FARMSCAPE team to simulate their cropping systems’ field experiments and, over several years, evolved into the development of an innovative internet service for monitoring and simulating crop paddocks. The motivation of both groups was to reduce farmer uncertainty about their crop management environment and to enable them to assess the possible effects of alternative management practices. The evolution of YP was guided by an action research approach typified by iterative cycles of: plan→action→observation→reflection→modified plan. Thus, the work was conducted in a sequence of distinct cycles of action, observation, and reflection leading to new action in a subsequent learning cycle (Zuber-Skerritt 1993). The systems thinking that evolved through our FARMSCAPE experience (McCown *et al*. 2009, this issue) and our reading on managerial risk taking provided the theoretical framework for this investigation.

Collaboration between the FARMSCAPE team and BCG

In seeking to explore the market demand for the climate variability management support tools, the FARMSCAPE team developed a close collaboration with BCG, a farmer-driven organisation with a membership of 500 family farms centred at Birchip (35.98°S, 142.92°E; elevation 102 m) in the Victorian Wimmera and Mallee (www.bcg.org.au). The collaboration started in 2001 when BCG became interested in exploring the use of simulation as a tool to extrapolate the results of their farming systems’ field experiments to real-life farms in a wider range of seasonal conditions and to other locations and soil types. In addition to an interest in the project proposed by BCG, the FARMSCAPE team was keen to explore with BCG ways of delivering the potential benefit of their tools to a larger number of farmers in a commercially sustainable manner.

In order to obtain the minimum data requirements for cropping systems simulation, the soil plant-available water capacity (PAWC) of the BCG systems’ field experiment site was determined using the methods of Dalgliesh and Foale (1998). To aid communication of the concept of different soils having the ability to hold different amounts of water (measured in millimetres), the data were presented to BCG members using a ‘bucket’ metaphor (Dalgliesh *et al*. 2009). Using the PAWC data, along with local meteorological data, we presented APSIM simulations of wheat yields to a meeting of BCG farmers to obtain feedback on whether the simulated results seemed realistic. BCG farmers found the simulation reasonably credible and the meeting was followed by a series of simulation-aided ‘what-if’ management scenario evaluation sessions (most of these ‘meetings’ were conducted online *via* Microsoft NetMeeting to bridge the distance between Toowoomba and Birchip; see Hargreaves and Hochman 2004).

In March 2002, a simulation-aided ‘what-if’ session was held to explore the importance of pre-season soil water content and soil nitrogen levels on potential grain yield outcomes. These simulations were based on measurements from soil samples taken to 1-m depth on the farm of one of the BCG members. The measurements indicated that there was nil plant-available soil water at the time of sampling. The simulations presented at the meeting indicated that the lack of stored moisture had severely limited the likelihood of obtaining an above-average yield in the coming season. A discussion at the conclusion of the meeting led to a request by BCG for the FARMSCAPE team to keep updating the seasonal outlook for grain yields on a monthly basis throughout the 2002 season.

The inception and development of Yield Prophet

In May 2002, BCG initiated a monthly FAX service that was provided to all BCG members. This initiative was called the ‘Yield Prophet’. It provided updated forecasts of yield probabilities for 3 locally representative sites on which BCG were planning to hold their annual field days. The FAXed reports contained probability-based yield forecasts. Figure 1 is used to illustrate how this information was derived from 3 components of measurement and calculation:

(*1*) the Past: measurement of pre-season soil water and soil nitrogen status, plus an up-to-date record of past management actions relevant to the current season (crop, variety, sowing date, fertiliser rate, etc.);

(*2*) the Present: simulation is used to calculate changes in stored soil water and nitrogen, crop development, and crop growth, from the time of measurement up until ‘today’ (when the report is generated), using the information from (*1*) and the observed daily weather data for the period between the pre-sowing soil sampling date and the present time; and

(*3*) the Future: simulation of crop growth and yield from tomorrow until maturity is derived by using the last 100 years of data from the nearest weather station to calculate 100 different outcomes.

The results for all years were presented in probabilistic terms (e.g. a 1 in 5 chance of yield being below 0.3 t/ha at the Birchip site). In July 2002, when the SOI phase was consistently negative, YP presented the results from the relevant analogue years corresponding to this SOI phase alongside results from the last 100 years.

From the first FAXed YP issue on 15 May onward, there were clear and increasingly more emphatic likelihoods that 2002 would be a low-yielding season. As it happened, 2002 was the worst cropping season in the collective memory of BCG farmers. It was not surprising that, at the start of the season, few farmers had sufficient faith in the simulator to allow it to influence their management during the season. However, YP’s consistent monthly message of low yield prospects throughout 2002 created interest among the BCG members who invited the scientists to explain and defend these forecasts at meetings, in the annual BCG Expo event, and at the Birchip research update field day. This provided the scientists with an opportunity to discuss with farmers their ideas about the value of soil and crop monitoring, the way simulation can be used for ‘virtual monitoring’ to explore the current status of the soil resources, and to use APSIM with long-term local climate data to explore possible outcomes for the rest of the season and answer

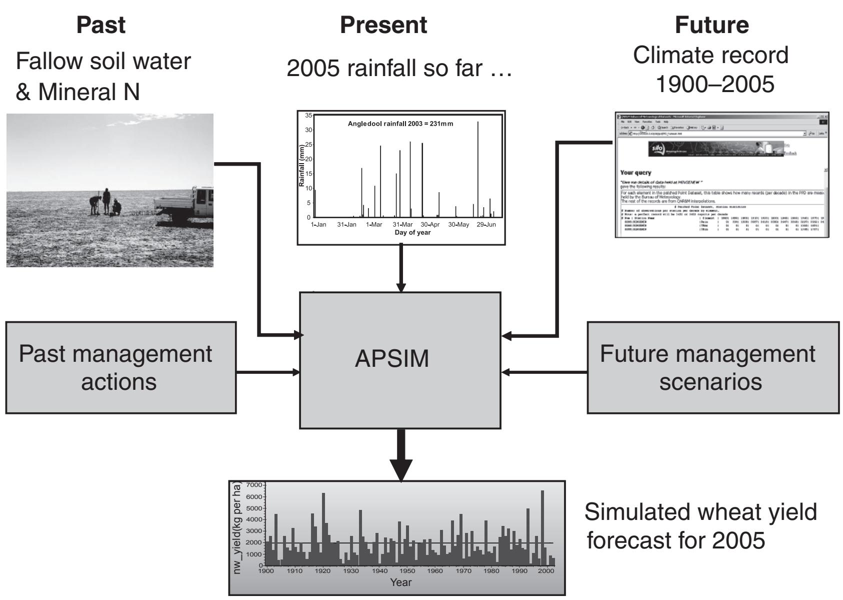

Fig. 1. Schematic representation of the process of in-season crop yield forecasting.

questions such as 'what would happen if we had 25 mm of rainfall next week?'. The experience of the 2002 season created a great deal of interest and a measure of credibility for APSIM and YP among BCG's members.

Independent evaluation of interactions between researchers and BCG members in 2002 showed that significant learning had taken place among farmers and advisers. Many were surprised that stored soil water after a fallow, the cornerstone of cropping in the subtropics (Dalgliesh *et al*. 2009, this issue), can, in some seasons, be of critical importance in the temperate southern cropping zone. Some were aware that such information could be used to adjust crop choice and fertiliser inputs. Many gained new appreciation of differences in PAWC between soil types, and the depth of crops' rooting zones.

> '*I had no idea of* '*the bucket*' *before. Now I will adjust fertiliser. I did not listen that we did not have enough in the bucket to grow canola; I planted anyway and lost*' (Farmer, Victoria 2003).

Several farmers indicated that they would take more notice of YP in future:

> '*After this year I will take notice of it (YP). In June/July it was forecasting zero-yield. We thought* '*oh yeah*' *but it was right*. . . . *We said* '*You have got to allow for this or that, e.g. rainfall during growth*'. *They put some [additional] rain in, but still it gave almost no yield*' (Farmer, Victoria 2003).

> '*We will be reluctant to sow a crop without stored moisture. As a result of APSIM, I am a bit wary of next year*'*s potential. If there is no subsoil [water] I will not plant. I cannot afford the loss of inputs, but I can survive a year with no crops*' (Farmer, Victoria 2003).

Encouraged by the 2002 experience the YP team decided to continue supplying yield forecasting information in 2003 through regular FAXes to the BCG membership. Large billboards visible from the roadside were erected at 3 demonstration sites providing a visual and regular update of simulated soil water status, seasonal rainfall forecast, and forecast yields, using a graphic format inspired by the nationally familiar roadside fire danger indicators. The YP team also supplied similar information to ~200 more farmers in 2 farmer groups in the northern wheatbelt of Western Australia (WA), through regularly updated newsletters. The WA forecasts were based on 4 representative sites per group. Reports, produced in anticipation of various agronomic decision points, contained alternative outcomes for impending decisions, e.g. rates of nitrogen fertiliser, sowing times, and cultivars in pre-season reports, and top-dressing nitrogen fertiliser options as crops approached the 6-leaf stage. Further 'what-if' questions were addressed in regular meetings among scientists, agronomic advisers, and farmer members of these groups.

An innovative addition to these services was the 'individual' YP; a service offered to 29 fee-paying BCG farmers who each received 9 paddock-specific updates between May and November 2003. As with the other YP paddocks, data were generated from these farmers' specific paddocks to obtain soil characterisation parameters for a range of local soil types, to obtain soil water data before, during, and after the crop, and to obtain a range of agronomic data including grain yield. On-farm daily rainfall data were collated from all paddocks for each of the 9 updates. Other meteorological data were obtained from the nearest Bureau of Meteorology climate station (Jeffrey *et al*. 2001; www.nrw.qld.gov.au/silo/).

Generating soil characterisation data was particularly important in 2003, as at the time there were only 3 characterised soils in the entire area covered by Yield Prophet. Consequently, during the season and until after harvest when we collated the soil characterisation data, the team had to rely on estimates. Soil water and crop yield data generated from YP paddocks were used to validate APSIM simulations 'in the real world' in order to continue the credibility-building process. In addition, these data informed the YP team about important decisions regarding the costs and benefits associated with the effort required to achieve adequate precision in input data (see Carberry *et al*. 2009, this issue, for a wider treatment of this issue). The initial comparison of observed yields against simulated yields, using the estimated soil characterisation, was rather poor (accounting for 42% of the variability in observed yields). However, when the estimated soil characterisation data were replaced by measured data (which were not available at the start of the season), simulated yield accounted for over 70% of the variability in observed yield, which ranged from 1.3 to 4.7 t/ha. Using measured soil characterisations also resulted in simulated soil water during the season accounting for over 75% of the variation in total soil water to 1-m depth, which ranged in value from 130 mm to 451 mm (data not presented).

We held a workshop in October to obtain direct feedback from the farmer clients and their agronomic consultant, to provide farmers with hands-on training in interpreting the probability-based yield forecast outputs, and to review the season. An important finding regarding the individual YP was that the farmers' agronomic consultant found the reports to be a valuable tool in his ability to discuss risk management with his clients. This emphasised both the potential value of the product to consultants and the importance of involving consultants in the YP network to ensure that farmers derive full value from the reports.

Farmers' positive responses to the 2002 and 2003 experiences, and the validation results, convinced both the FARMSCAPE and BCG teams that there were good prospects for developing a market for a fee-for-service product. The idea for an on-line subscription service based on the Yield Prophet system was a response to the high level of stress placed on the BCG team in collecting data from the farmers and on the FARMSCAPE team in manually generating the customised simulations. If the number of people receiving such a service were to grow, an automated system would need to be developed that would alleviate the need to collect data and to manually generate customised reports. The YP team recognised from the outset that the capacity to deliver such a service nationally would present significant challenges. If the YP service were to be economically sustainable, it would need to arrive at commercially attractive cost and price structures and to gradually attract a large number of fee-paying subscribers. The YP team decided that in order to cope with larger numbers of reports and a wider geographical spread of clients, it was necessary to develop a web interface to APSIM that would allow subscribing farmers and/or their advisers to request reports specific to their own paddocks.

Yield Prophet Online: design

Technically, the challenge in providing YP Online (www.yieldprophet.com.au) was to automate the scientists' job of generating APSIM reports, while still providing untrained users (farmers and their consultants) with the ability to specify their 'what-if' enquiries and to generate reports anytime, anywhere, and as quickly as possible. This rapid return time is necessary to allow users to follow up one enquiry with another in a single session. Figure 2 schematically summarises the solution that was implemented.

Users, represented in Fig. 2 as farmers, consultants, and administrators, gain access to the YP website from their personal computers *via* their internet service provider (ISP). While logged onto the website, users first need to provide data about their paddock. This includes selecting the correct soil type, nominating the nearest meteorological station, updating their farm rainfall record, entering initial soil water and soil nitrogen data, etc. (see Dalgliesh *et al*. 2009, this issue, for details on obtaining and managing the requisite soil data). These data are entered in a database such that users only need to provide this information once. This initial setting up of the paddock is a critical step that usually involved the consultant and sometimes the user support team.

Users have different access classifications: farmers can only generate and view their own reports; consultants can generate and view the reports of all farmers who nominate them as their consultant; while administrators can generate and view reports for any users. A fourth category (not shown in Fig. 2), called 'visitor', is available to non-subscribers and allows access to the user interface and to reports generated for the BCG trial sites, but does not allow visitors to save changes or to generate reports.

Once the paddock has been set up, users can start to request reports. These require the user to set up one or more management scenarios and request the appropriate report. Most of the options required are selected through drop-down menus, with dates nominated on a pop-up calendar and numbers (e.g. fertiliser N in kg/ha = 25) entered *via* the keyboard. To keep the reporting simple yet flexible, users can select from a range of different report types. At the time of writing, the report options included: (*1*) crop report (showing the current status of crop and soil variables as well as climate and crop outlooks for the next 3 months, evolved from the merging in 2006 of the original Agronomic and Climate reports); (*2*) sowing date by variety report; (*3*) nitrogen comparison report; (*4*) nitrogen profit report; (*5*) irrigation comparison report; (*6*) irrigation profit report; (*7*) fallow monitoring report; (*8*) stubble monitoring report.

Once a report is requested, the data input by the user is translated into a set of instructions for running APSIM simulations on an updated 100-year meteorological data file from a national database of long-term climate stations (www.nrw.qld.gov.au/silo/). These instructions are sent to the report generator. The simulations are then queued for running on a dedicated cluster of computers with multiple processors to allow multiple simulations to be processed in parallel. Simulation outputs are then represented in graphic and tabular form to suit the report template. A report is posted back to the website and an email is sent to the address of the person who generated the request to alert them that the report is available for viewing, printing, or downloading. All data and files are centrally stored for future reference. The whole process, from when the user requests a report, to the user being able to view the new report as well as any previously generated reports *via* the YP website, is fully automated and usually takes 5–10 min.

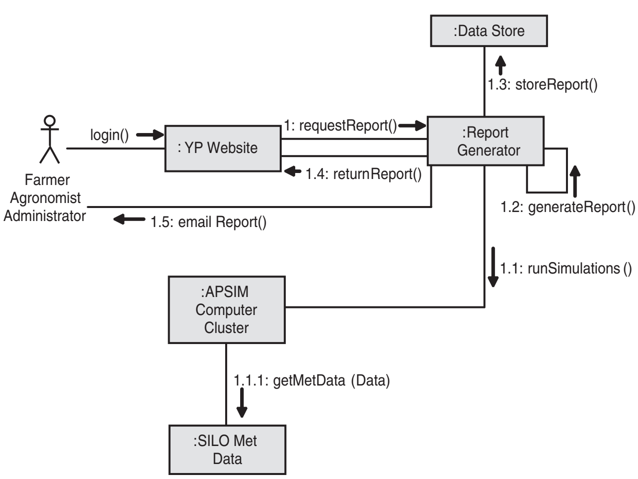

Fig. 2. UML Collaboration diagram depicting the processes involved in a Yield Prophet Online simulation.

Supporting Yield Prophet Online

It was clear from the outset that encouraging farmers and their advisers to use YP Online would require a substantial support network that would include:

- a field monitoring component responsible for ensuring that subscribers have good input data especially with regard to soil variables;
- a user interface design, monitoring, and maintenance component responsible for functioning of the YP Online web interface;
- a scientific support component to ensure quality of simulation and continued innovation;
- a communication component for ensuring that clients understand the simulation outputs and have an opportunity to discuss with their consultants the meaning and implications of YP Online reports for management of the paddock; and
- a business plan for ensuring the viability of the enterprise, marketing, user support, and relationships with consultants.

Leadership and resourcing of each of these components were shared between BCG and the FARMSCAPE team. BCG employs a full-time coordinator for Yield Prophet® who represents its human face and first point of call for inquiries and support. BCG also contracts part-time an experienced agronomist consultant and a web programmer. Their resources come from subscriptions, sponsorship, and industry Research and Development grants. Likewise, CSIRO contributes scientific and technical staff time to the Yield Prophet® endeavour (in the order of 1 person-equivalent per annum), funded from core and industry funds.

Field monitoring

Field monitoring is necessary in order to provide reliable, cost-effective, paddock-specific input data for simulations. It consists of an agreed protocol for sampling soils to determine pre-season soil water and soil nitrate status, and for soil characterisation to determine PAWC, soil organic matter, soil pH, and other indicators of soil chemical constraints such as soil electrical conductivity, chloride concentration, and sodicity. These activities are paid for by the farmer and are mostly executed by the farmer's consultant and/or a local soil sampling and analysis service provider. Farmers or their consultants are responsible for recording and entering their own on-farm rainfall data. Farmers or their consultants are also responsible for correctly describing management activities such as sowing date, crop, variety, fertiliser rates, and dates of fertiliser applications. Farmers and consultants are also encouraged to make in-field observations (e.g. crop growth stages) in order to compare those with simulated outcomes and report any discrepancies to the user support team.

Increasing soil sampling expertise and available databases in soil characterisation are critical requirements for YP Online. Fortunately, these demands coincide with the objectives of a series of Australia-wide 'Monitoring and Managing Soil Water' workshops that aim to provide farmers and consultants with a background understanding of soil water and its management (Dalgliesh *et al*. 2009, this issue). The grains industry Research and Development program supports these workshops because they see increasing farmer knowledge of soil water as a benefit to the industry.

The user interface

The user support team is responsible for the design, implementation, monitoring functions, and maintenance of the internet-based user interface to the APSIM simulator. This team designed the user interface (input screens, output reports) and implemented the design and its subsequent upgrades. Practical challenges include the need to work within the limitations imposed by the internet access of most clients, occurring through narrow bandwidth, which can result in long delays in loading web pages. Another challenge has been the need to minimise down-time that may be caused by failure at any stage in the process described in Fig. 2.

BCG owns, resources, and operates the Yield Prophet® website and its associated reports (Fig. 2). It funds this mainly from subscription revenues. The FARMSCAPE team maintains and supports the APSIM computer cluster, the report generator, and the communication infrastructure with the web interface (Fig. 2).

Science and quality assurance

Quality assurance relies significantly on farmer queries and consultant's questioning regarding the validity of simulations. Such queries are important triggers for closer inspection of simulation results as well as input data, and occasionally lead to identification of programming or data entry errors. Both BCG and CSIRO scientists take responsibility for monitoring input data and results of simulations performed in selected sites and attempt to ensure that YP Online is producing realistic yield projections and status reports. Some new elements of YP Online, such as the introduction of irrigation reports and new crops, were first tried off-line for a season before their introduction to all subscribers. One of many challenges to ensuring the scientific rigour of simulations while meeting the real-world demands of farm managers arose from the rapid rate of growth of YP and the demand this created for making new cultivars available in YP without access to the necessary supporting data required to parameterise their phenology. On several occasions, the quality assurance process has led to decisions to undertake further field measurements. At the end of each season, data on simulated *v.* harvested yields were analysed and reported at grains industry communication events.

Communication of simulation results

The user support team, led by BCG's Yield Prophet® coordinator, liaises among users, consultants, and the user interface team. They are the farmers' and consultants' first point of contact, providing them with their account details, 'getting started', and user help instructions. The user support team reports back to the user interface team on users' problems and users' suggestions for improving the interface. While farmers may require and receive help in correctly understanding the graphic representations of simulation results, it is not the role of the user support team to provide any managerial or agronomic advice to farmers.

Interpretation of simulation results is the responsibility of farmers and their consultants. Consultants are encouraged to stimulate farmer clients to ask YP Online a range of 'what-if' questions, to help farmers interpret the results and to discuss the implications of simulation results for management decisions. Alternatively, some consultants choose to conduct the simulations on their farmers' behalf and then use the reports as a focus for discussions with their clients (including non-subscribers).

The business plan

The overall business plan was guided by an agreement between APSRU and BCG, whereby BCG was allocated rights for commercialisation of APSIM. Conceiving, resourcing, and implementing the business plan are the responsibility of BCG. The business team is responsible for developing a sound business model that will lead to a financially sustainable delivery of the service, this includes:

- promoting YP Online;
- pricing subscription fees;
- signing up and billing subscribers;
- committing resources to be invested in the product;
- ensuring customer satisfaction; and
- managing relationships with farmers and consultants as well as with other risk-management product providers in the marketplace.

As at the time of publication, BCG had developed a business plan that targets Yield Prophet® delivery *via* a commercialisation path which:

- focusses on the top 20% of growers in Australia (~6000 farmers);

- works closely with APSRU to ensure ongoing access to the underlying APSIM software technology; and
- implements a marketing model based on accredited consultants supplying services to farmers.

To date, efforts in Yield Prophet® development and delivery have established the feasibility and market demand for this service. The business model aims at establishing a sustainable commercial service and, as such, BCG are exploring options for resourcing its progression.

Yield Prophet Online in action in 2004

Recognising that YP Online was an untested system with many potential pitfalls, the YP team decided on a cautious growth strategy in 2004. YP Online started with 50 subscribers nationally including 20 re-subscribers from 2003, and several new subscribers from Victoria, New South Wales (NSW), South Australia (SA), and Western Australia (WA). Once some technical problems arising from user inexperience with the internet or from problems with firewalls blocking access to the site were overcome, subscribers were generally able to specify their own paddock-specific management variables online without difficulty, and most experimented with 'what-if' scenarios whenever and as often as they wished. In excess of 1200 reports were generated in the first season. The pattern of usage for wheat crops was steady throughout the season, with a peak experienced in September around the time when nitrogen fertiliser topdressing decisions were due to be made.

In many of the farms in the southern cropping region of Australia, nitrogen fertiliser topdressing was a difficult decision in 2004. Still recovering from the 2002 drought, many farmers were conservative in their initial fertiliser application rates. This low initial application essentially allowed these farmers to postpone their nitrogen fertiliser decisions until late August or early September, when they had the option of topdressing additional nitrogen fertiliser. While each paddock was different, Fig. 3 shows a Nitrogen Comparison Report generated by one Victorian farmer on 24 August comparing the probabilities of yield and protein outcomes for 3 topdressing scenarios: (*i*) no fertiliser, (*ii*) 25 kg N/ha, and (*iii*) 50 kg N/ha. At that time, crops were looking good and showed no symptoms of water stress. However, YP Agronomic Reports were showing that there was very little plant-available water as crops were about to enter the spring period of high evaporative demand. Figure 3 shows that the likelihood of getting a good yield return from topdressing N was not high when probabilities were considered using simulated outcomes over the last 100 years, and that if only the analogue years, with a consistently negative SOI phase in August, were considered, the odds were even poorer. The farmer decided not to topdress that season. With a final yield of 1.4 t/ha and 10.5% protein, this decision was vindicated. When asked in December to reflect on his YP experience, this farmer replied:

> '*So in retrospect how useful was it? In terms of the big picture, it was good and that seems to be determined nearly entirely by starting stored moisture. It stopped me from adding extra N when it rained in August/September.*' (Farmer, Victoria 2004).

A contrasting situation existed for YP subscribers in northern NSW where many farmers had near-full soil profiles at sowing. Figure 4 shows a Nitrogen Comparison Report for wheat, generated by one northern NSW farmer on 2 September, in which he considered 0, 50, and 100 kg N/ha topdressing options. In this case the odds were more favourable and, with the SOI having moved on to a near-zero phase, analogue years were not significantly different from the 100-year outlook. Despite topdressing being an uncommon practice in this region, this farmer, with the support of his consultant, decided to topdress his paddock with 50 kg N/ha (an option that was shown to be stochastically dominant to 0 kg/ha). He also tested the YP simulation by trying a strip across the paddock with 100 kg N/ha (which was shown to have about a 70% chance of out-yielding 50 kg N/ha). When asked in December to reflect on his YP experience this farmer replied:

> '*The trial strip confirmed the results of a nitrogen comparison report that this application would be economically viable although at the time I had significant doubts.*' (Farmer, NSW 2004).

This farmer also calculated that for an approximate yield increase of 1.0 t/ha, a farm-gate price of 140 AUD/t for an outlay of 56 AUD/ha, the profit from the additional 50 kg N/ha was 84 AUD/ha.

Based on the experience of 2004, the YP team decided that it was necessary to continue on a path of gradual growth, to register the Yield Prophet® trade mark, to increase the number of crops and the scope of reports that can be generated, and to increase the investment in soil characterisation.

Yield Prophet Online in 2005–07

The recognition that an expansion of soil characterisation activity was required to improve both the geographic scope of YP use and the accuracy of simulation, resulted in an increased national investment in soil characterisation. This activity was supported by the 'Training growers to manage soil water' project (Dalgliesh *et al*. 2006) that provided training in soil water monitoring and management and encouraged consultants and farmers to join with researchers in the generation of soil information of importance to regional agriculture. While the APSoil database (Dalgliesh and Foale 1998) was used to store soil data for several years, this activity provided the catalyst to increase its geographic spread and to improve public access to the data.

From a single-page report in 2002 and 2003, YP has expanded the information that it provides to 8 report types. This proliferation has been mostly driven by subscriber feedback but also by the YP team's appreciation of the need to keep using YP as a vehicle for stimulating innovative farmers.

Potential barriers to adoption of Yield Prophet

Reflection on the 2003 and 2004 seasons led the YP team to recognise several potential barriers to YP Online becoming a useful and sustainable decision support network. We identified several potentially critical barriers to success.

The first issue identified was that farmers and advisers will not use YP as a management tool until they develop trust in its ability

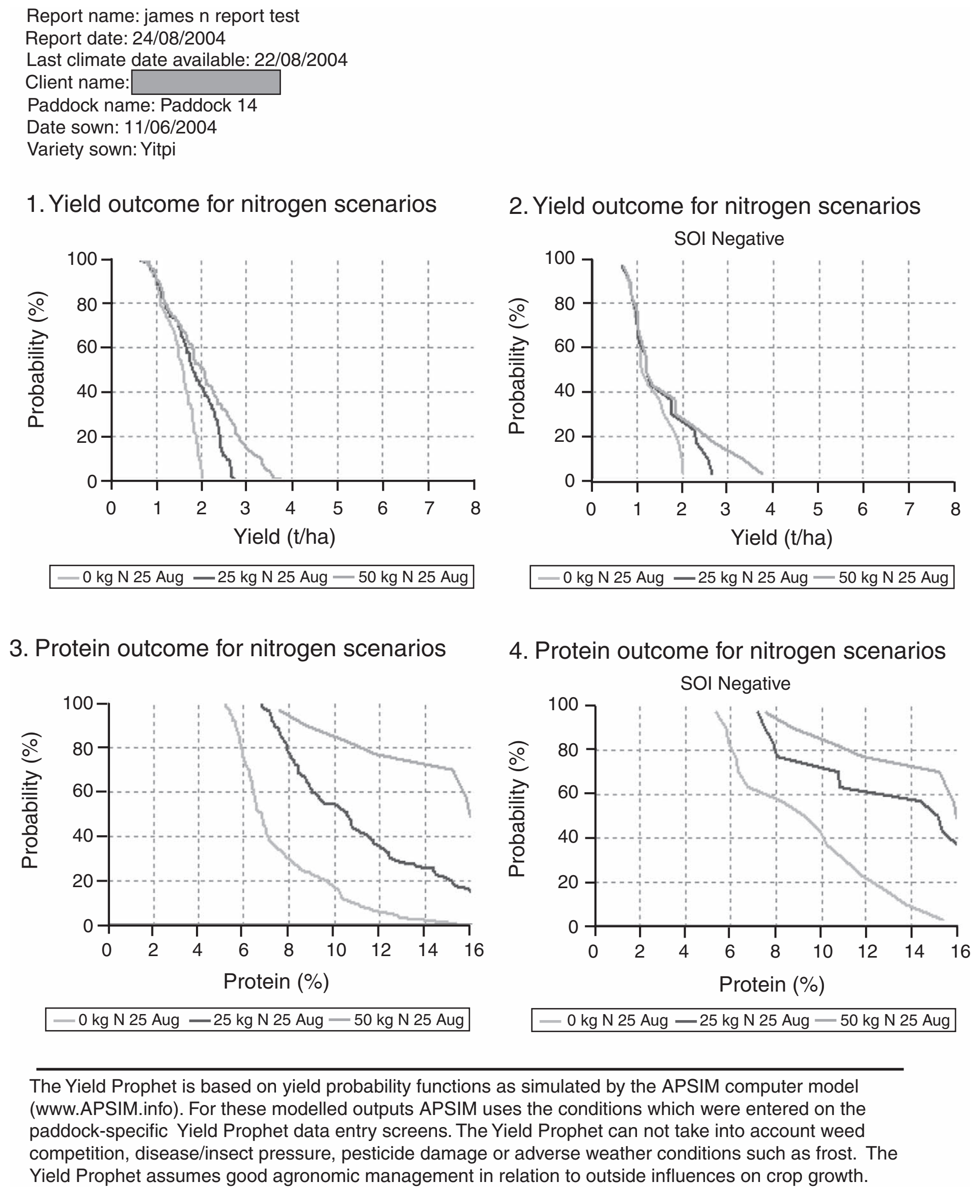

Fig. 3. A Nitrogen Comparison Report generated by a Victorian farmer considering topdressing in August 2004. Graphs 1 and 3 relate to all years; graphs 2 and 4 relate to years with the current SOI phase.

to accurately simulate crop yields in their paddocks. As noted by Carberry *et al*. (2009, this issue) the fundamental scepticism of farmers concerning the ability of a theory-based simulator to mimic their reality makes farmers harsh judges of simulator performance.

> '*I am going to talk in bags per acre. Our yield came in at about 16 [3.2 t/ha] and they were predicting about 20 [4.0 t/ha] so they overestimated and that sort of thing and that is probably my biggest concern with the Yield Profit is that it can't predict a hot day at the end of the season that is going to stitch you up.*' (Farmer, Victoria 2004).

This quote indicated that a simulation error of 0.8 t/ha was not acceptable to this farmer. From numerous discussions on this subject, we formed an impression that errors of up to 0.5 t/ha were tolerable to many farmers and agronomic consultants.

The second issue relates to the cost of obtaining useful input data. This issue is related to the credibility of simulation issue in that simulation accuracy was demonstrated by Carberry *et al*. (2009, this issue) to be dependent on access to specific local data. Similarly, the YP validation results obtained in 2003 emphasised the importance of soil characterisation to yield prediction. Farmer interviews indicated that some valued the soil characterisation information provided and developed a new appreciation of the importance of stored water where previously the wide perception in this region had been that crops grew predominantly on in-season rainfall. Unfortunately, the improved simulation accuracy and farmer learning associated with soil characterisation come

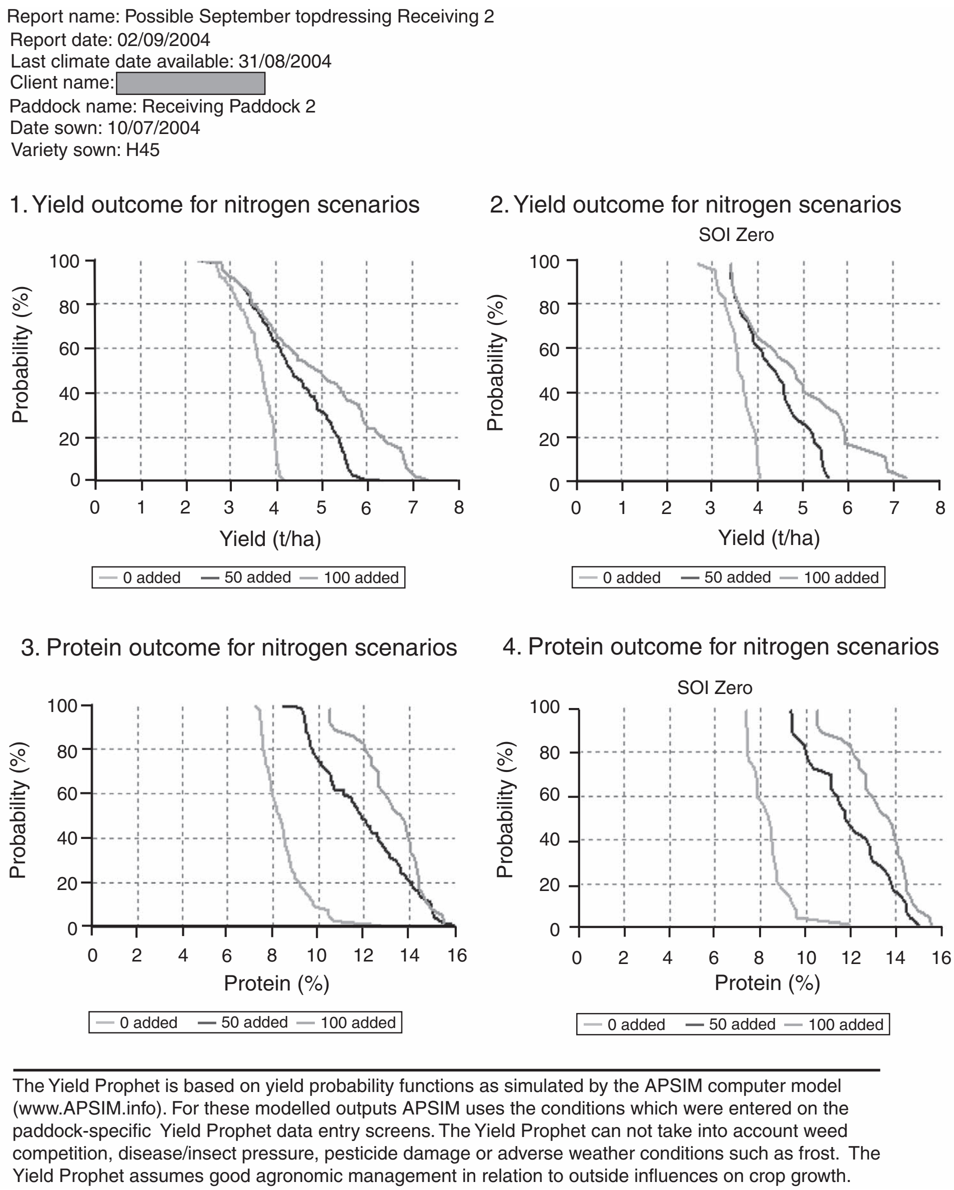

Fig. 4. A Nitrogen Comparison Report generated by a northern NSW farmer considering topdressing in early September 2004. Graphs 1 and 3 relate to all years; graphs 2 and 4 relate to years with the current SOI phase.

with an associated cost of being a slow and labour-intensive process. It was recognised that the high cost associated with soil characterisation could provide an obstacle to the wider adoption of YP.

The third issue was the need to have farmers and advisers understand the information that is represented in Yield Prophet Reports so that they can interpret such reports and critically assess their implication for management action.

> '. . .*it takes your head a long time to get around probabilities if you've never done any work with them. As far as selling it to people, I think we've got a little bit of way to go as far as that goes. You can see it being quite valuable and a lot of the discussion with the group in Birchip is what relevance it's going to have and when you're best to use it, whether you can take it right back to crop planning stages and that sort of thing. Because it would be pretty valuable then, the problem is your probabilities are so wide when you're nine months out*'. (Farmer, Victoria 2004).

Here the challenge was both to represent science-based and, more particularly, probabilistic, information as comprehensively and as simply as possible and to provide opportunities for YP subscribers to learn how to interpret such representations.

Performance of Yield Prophet Online in relation to potential barriers

Partial validation of Yield Prophet simulation results

At the conclusion of each season, crop yields were simulated using the original data entered for all the YP paddocks, for which farmers had provided the Yield Prophet team with their grain yield results. The results of a comparison of observed and predicted yield of hundreds of crops over 5 seasons from 2003 to 2007 are reported elsewhere (Carberry *et al*. 2009, this issue; Hochman *et al*. 2009). However, it is important to note that while the results were close to those obtained in field experiments managed by scientists, about half of the predicted results differed from the measured results by more than 0.5 t/ha.

Cost of obtaining useful input data

The relevant data are meteorological data, soil characterisation data, pre-season soil water and soil nitrogen data, and crop management data.

Meteorological data

The presence of a relatively intensive network of meteorological stations in the Australian grains region and access to up-to-date long-term data from the nearest recording station through the national database are critical success factors for YP. All that is required of the user is to update their on-farm rainfall records. This is a relatively simple requirement as most farmers are already in the habit of keeping such a record. For those users who prefer not to enter their own rainfall data, YP provides the option of using rainfall from the nearest recording station. Only a small minority of users choose this option.

Soil characterisation data

At the time of writing, soil data for over 500 Australian soils were available (*a*) as a data layer within the Australian Soil Resource Information System (Johnston *et al*. 2003; www.asris.csiro.au), which enables location of individual sites nationally and the downloading of the data for that site; and (*b*) through the web product Google Earth (http://earth.google.com), which provides a similar service to ASRIS in that sites are located spatially and the data may be extracted for use in simulation. The Google Earth data file required to gain access to these data is available though the ASRIS websites. The availability of such data has been a prerequisite to expanding the geographical reach of YP and further expansion is likely to require more soils to be characterised. A further requirement is for agronomic consultants to be able to match specific paddock soils to the best matched soil in the database. Some research and extension may be required to ensure that such skills are readily available among these consultants.

Pre-season soil water and nitrogen data

Pre-season soil water and soil nitrogen data are obtained by deep coring of at least 5 samples per paddock to a depth of at least 1.0 m and sending samples off for analysis by commercial laboratories. This is usually organised by the consultant who also enters the data into YP.

The farmer or the consultant also enters crop management data into YP.

Investigating the online use of Yield Prophet

In 2005 there were 356 registered Yield Prophet® paddocks Australia-wide, directly involving a networked community of 236 growers supported by 38 agronomic consultants and involving 19 organised grower groups and 5 State Government funded researchers. The number of reports generated exceeded 6800, with peak usage of >2000 reports per month in August and September. In 2006, the number of registered paddocks increased to 550, and despite the limited management options due to the widespread drought, more than 8300 reports were generated (an average of 15 reports per paddock). Subscription numbers held steady in 2007 (Table 1) despite the dire financial circumstances of most grain growers following the severe drought of 2006 and several consecutive poor seasons in much of the Australian grain belt .

The use of different YP report types, expressed in relative terms to remove the effect of the growing number of reports generated in successive years, shows a consistent pattern (Fig. 5). About two-thirds of the reports produced each year were Crop Reports (in 2005 this included Agronomic and Climate Reports, which were superseded by the Crop Report but remained in use during 2005). Nitrogen Comparison Reports accounted for ~18% of the total. Nitrogen Profit Reports and Sowing by Variety Reports each accounted for 5–7% of reports, while the sum of other reports was less than 5% of the total.

Discussion

Providing farmers with access to APSIM through the Internet was a significant technical achievement. Consultants played a key role, in setting up and running the initial reports for farmers and in discussions with their clients. They largely substituted the role of researchers in the earlier phase of FARMSCAPE by reducing the entry barrier to farmers' benefiting from simulation and by stimulating farmers to discuss and respond to the results of simulations. Based on past evidence of the failure of many traditional DSS to influence farm management, we considered it necessary also to provide an environment that

Table 1. The growth of Yield Prophet's subscriptions and usage from 2002 to 07

	2002	2003	2004	2005	2006	2007
Subscribed fields	5	29	50	356	550	558
Consultants	1	1	3	37	37	50
State govt. researchers	0	0	2	5	8	21
Reports produced	7	260	1200	6800	8300	9200

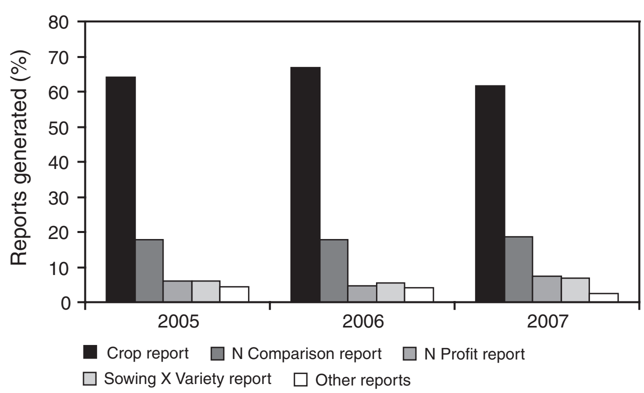

Fig. 5. Relative frequency of use of different report types from 2005 to 2007.

would support farmers' capacity to manage risk. This support had two components: (*1*) virtual monitoring, and (*2*) virtual experience. Virtual monitoring provided farm managers with updated information on the status of soil resources and the current level of crop water and nitrogen stress levels as well as the updated prospects for rainfall and grain yield given current management settings. The virtual experience component enables participants to learn by 'virtual' experimentation with immediate feedback including unambiguous 'virtual' consequences of their virtual actions (Senge 1990; McCown *et al*. 2009).

Our approach to providing support for farmers in risky situations was guided by our learning through the action research cycles outlined above. However, as we learned by doing we were also influenced by our reading about management and decision making. We were influenced by a descriptive study of the decision process of 656 executives (Shapira 1997), which found that, contrary to the assumption of statistical decision theory that decisions are taken at the moment of choice, managers treat risk taking as a continuous process in which they apply their skills and exert control.

> '*Dealing with risk taking is therefore a prolonged process, starting with the collection of lots of information and continuing through modification of estimates and active working on the problem*.' (Shapira 1997, p. 78).

Research on *naturalistic decision making* frames management decisions in a dynamic, real-time context wherein decisions are made by directing and maintaining the continuous flow of behaviour towards a set of goals rather than as a set of discrete episodes that involve choice dilemmas (Brehmer 1990). Reasoning and acting are interleaved. 'Instead of analysing all facets of a situation, making a decision, and then acting, it appears that in complex realistic situations people think a little, act a little and then evaluate the outcomes and think and act some more.' (Orasanu and Connolly 1993).

We used this conceptual framework of managers' decision making processes to guide our thinking about how effective support might be provided to farm managers. One clear conclusion was that support must be provided beyond a single moment of choice (e.g. pre-sowing) and should enable ongoing information collection and monitoring of the consequences of decisions taken until the outcome is determined (e.g. at harvest).

Yield Prophet is not a typical DSS

It is instructive to reflect on the difference between Yield Prophet and a traditional DSS that incorporates a system simulator. Typically, scientists design such a DSS, with varying degrees of user consultation, with an expectation that either a manager or a consultant will use it. By contrast, the idea of YP emerged from collaboration between the FARMSCAPE and BCG groups, with each group appreciating the contributions that the other could make and working together to explore the potential of a new management and monitoring tool. YP emerged from an action research program that included ongoing evaluation of participants' experiences in using YP and formal and informal reflections that led to modified plans to guide and shape the product.

Typically, DSS products are either distributed as CDs or made available for downloading from a website. They are then available for instant use when needed, but the decision points are pre-set by the DSS developers at pre-determined times or events. Yield Prophet was similarly available for instant use (online) when needed, but users defined the decision points. YP reports were often a focus for discussions between managers and consultants, with scientists sometimes asked to discuss unexpected results.

Traditional DSS are designed to compare (and to select an optimised recommendation from) a range of standard solutions for a limited number of pre-defined problems. They are specified for a limited range of environments that do not quite match the almost infinite number of individual farmer's situations (e.g. a cropping region may be represented by 5 soil types and 6 historic weather stations). In contrast, YP allows the users to specify their paddocks' particular soil type, weather conditions, and management variables. While problem configuration in YP is limited by the range of available report types, a wide range of scenarios can be flexibly specified for each YP report (e.g. the nitrogen report allows users to specify any combination of rates and dates of fertiliser applications and there are more than 70 wheat varieties from which to choose).

In stark contrast to traditional DSS, Yield Prophet provides users with a means for virtual monitoring of the consequences (for crop and soil status) of past weather and past management decisions as the season progresses. Yield Prophet enables users to delay or revisit previous management decisions such as application of nitrogenous fertilisers.

Yield Prophet in practice

The performances of the barley and wheat modules were quite satisfactory when compared with other published validations of these crop yield models (Wang *et al*. 2003; Manschadi *et al*. 2006). These results form part of the dataset of Carberry *et al*. (2009, this issue) and support their conclusions with regards to feasibility of achieving valid on-farm simulation results. However, feedback from some subscribers indicates that discrepancies between observed and predicted yield that exceeded 0.5 t/ha reduced their confidence in use of the model for decision support. From this perspective, the performance of YP requires improvement (Hochman *et al*. 2009). It remains subject to conjecture as to whether such improvements can be achieved by improving APSIM or by designing more rigorous yet cost-effective procedures to characterise and monitor soils. We plan to pursue both of these aspects.

The introduction of YP has taken place against the background of a series of dry seasons (2002–07), which have caused widespread hardship for Australian crop producers. While some subscribers reported that YP supported their management of this situation by reducing inputs, there have not been many opportunities to demonstrate the positive windfalls that can be generated by increasing inputs in response to improved prospects for realising a high yield. The case study of the NSW farmer in 2004 (Fig. 4) illustrates the potential for such gains. Against this background, the YP subscription numbers are significant. Yet they are insufficient financially to sustain YP on the basis of subscription fees alone.

Yield Prophet use patterns show that managers value virtual monitoring

An interesting development since 2005 has been the high popularity and expanding scope of the Crop Report. It accounted for 62–67% of all reports generated in 2005–07 and was by far the most popular report type generated by subscribers. Figure 6 shows page 3 of a 5-page Crop Report produced for a Field Day site in South Australia. It illustrates the kind of information that is provided in the crop report. The crop report deviates from classical decision support in that it does not support any future alternative 'what if' scenarios, but reports on the progress and potential outcomes of the crop because of past management decisions, past climatic conditions, and projected future seasons. Rather than supporting a forthcoming decision, the crop report is effectively a tool for virtual monitoring of the crop, based on past decisions and circumstances.

In summary, YP has advantages over conventional DSS in that solutions to problems can be flexibly configured and locally situated. This is particularly important for in-season decision support and for frequent reviewing of the consequences of past decisions and past events on the likely future outcomes by providing a means for virtual monitoring of the progress of a crop throughout the season. Thus, YP's approach to decision support is consistent both with Simon's observations that managers make their decisions by satisficing rather than optimising (Simon 1955), and with Shapira's observations about managers' fluid approach to decision making, which requires ongoing monitoring of the consequences of past decisions (Shapira 1997).

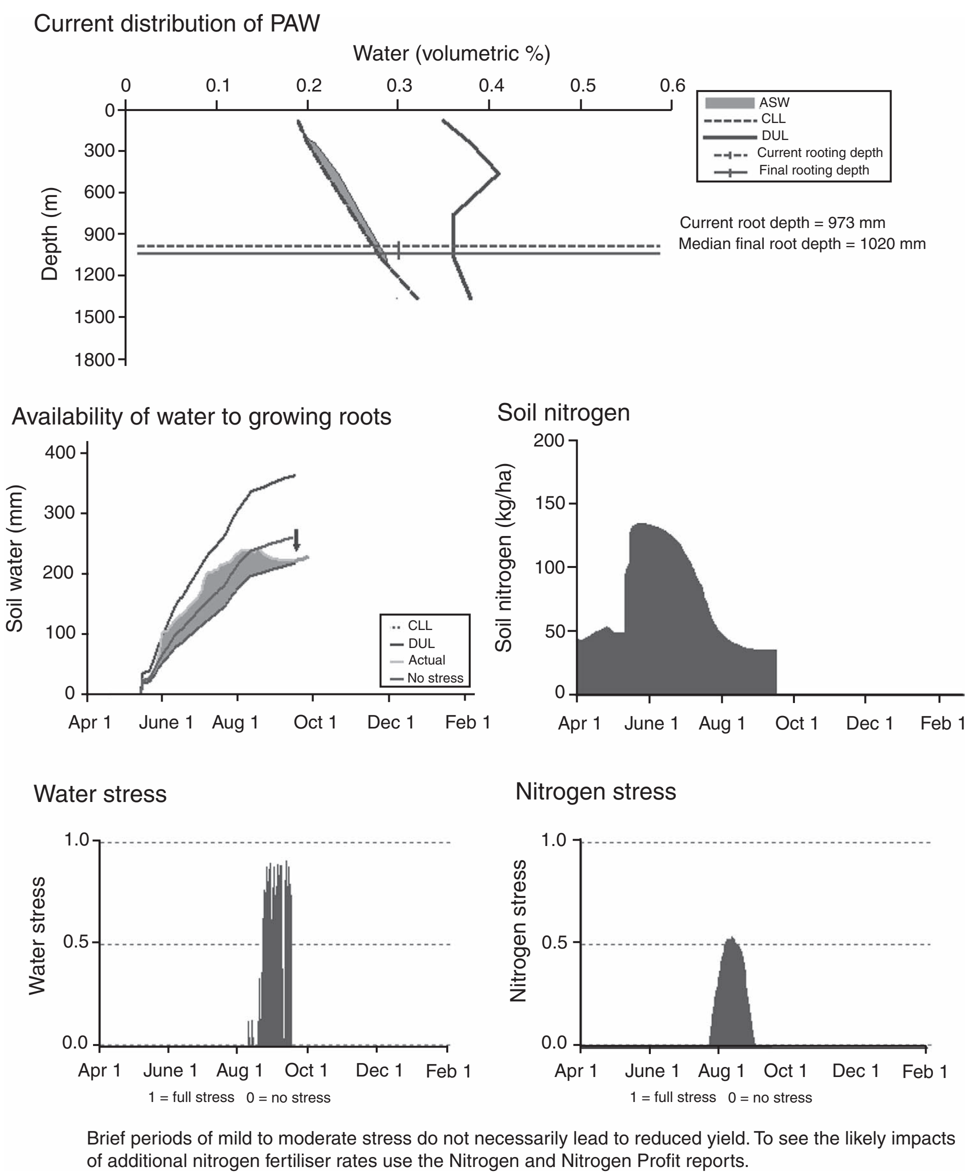

Fig. 6. Page 3 from a Crop Report generated for the Hart Field Day Site on 18 Sept. 2007.

Conclusions

Yield Prophet is a case study of action research methodology used to deliver decision support to Australian farm managers. From the outset, the project was guided by insights gained from reflection on the past failures of the traditional DSS and by the lessons learned from the experience gained in developing the FARMSCAPE approach to supporting farmers' learning and decision making. The challenge was to adapt this approach to make it accessible to a large number of farm managers.

While moving away from an intensive engagement between scientists and farmers and their advisers to focus on a more commercially sustainable model of engagement using YP, we avoided several shortcomings of the traditional DSS approach. This was achieved by: (*1*) providing a tool that can be flexibly specified to a particular management situation; (*2*) situating YP in a supported network of farmers, consultants, and scientists; (*3*) providing users with flexibility in problem description; and (*4*) providing a tool that can be used for post-decisional monitoring.

The popularity of the Crop Report with its focus on ongoing virtual monitoring was roughly double that of the combined number of other reports with their focus on making a specific decision. This observation provides quantitative evidence that farm managers' thinking about risk is strongly linked to the possibility of continuing to have an influence on the outcome of risky decisions (through other compensatory actions) well past the 'decision point'.

After 4 years of development and implementation, YP is a technically robust and comprehensive system that provides users with a credible science-based tool for virtual monitoring of soils and crops and for supporting tactical crop management in a risky, climatically variable, environment. At the time of writing, Yield Prophet was not financially sustainable on the basis of fees alone. It remains to be seen if viability can be achieved and what will be required to realise this ultimate goal.

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