SIP09 Precision Agriculture Initiative

Summary
This project has contributed to the GRDC initiative on precision agriculture (PA) by providing understanding of how climate variability and soil properties interact to cause spatial yield variability, and why yields vary spatially between seasons. The ability of electromagnetic (EM) surveys to predict yield has also been investigated, and two prototype decision support tools for rapid mapping of spatial and temporal yield variability have been developed. One produces simulated yield maps from satellite images, and requires no measurement of field data, the other uses EM surveys and their relationship with plant available water. These tools will provide growers with information on the cost of yield variability across their property.

Report Disclaimer
Conclusions

The major conclusions of this project can be summarised as:

Due to poor seasonal conditions, no response to nitrogen (N) was found in any of the paddock zones for trials done in 2004 and 2005. However, crop modelling suggested there was an N response in long term yields for all zones. The difficulty in predicting the optimal long term N response function is a major challenge for more efficient nutrient use.

Strong temporal correlations (although not 1:1 due to seasonal shifts) were found for EMI sensors, but not for radiometrics. This stability in spatial structure across seasons supports the use of a single time collection of electromagnetic induction (EMI) data for identifying the spatial paddock features important for paddock zoning.

Spatial linear modelling with the 1996, 1998, and 2005 yield maps found that only EM38h, EM38v and gamma-ray total count significantly correlated with yield in all three seasons. However, the coefficients of determination ($R^2$) were generally low (6%, 14% and 4% for 1996, 1998 and 2005, respectively). It is concluded that significant but weak associations existed between crop yield and these geophysics explanatory variables, but are not likely to have much predictive value in this case.

Calibrated terrain information, collected from a differential GPS, may prove as useful in defining zones as more complex geophysical sensors.

Simulated yield mapping provides a cost-effective tool that can fast-track economic analysis of the potential benefits from managing crop spatial and temporal variability. The technique requires no field sampling, which means there is a considerable saving in effort and cost that makes it more suitable than other options for application across an entire grower’s property or catchment.

Simulated yield mapping provides a major advance in mapping techniques, as it develops an individual relationship between the remotely sensed data and crop yield for each paddock. This is generally considered a prerequisite if good correlations between remotely sensed data and biophysical parameters are to be developed.

A linear negative relationship was found between grain yield and both plant available water capacity (PAWC) and permanent wilting point (PWP) across the management zones during four seasons (1996, 1998, 2004, 2005). Depending on the season, 59-95% of the observed variation in grain yield could be explained by variation in PWP. Unlike other studies, it has been
concluded from theoretical considerations that using any single soil hydraulic property, such as PAWC, field capacity (FC) or PWP, is inadequate for defining paddock zones. Rather, management of spatial and temporal yield variability needs to take a more sophisticated approach of using both FC and PWP in relation to the distribution and magnitude of rainfall events.

Soil salinity, exchangeable sodium percentage (ESP), and boron were all significantly higher in the low yielding zones compared to the medium and high yielding zones, especially in the subsoil. It therefore seems likely that yields are reduced by variation in soil hydraulic properties (PWP in dry seasons and FC in wet seasons) in the upper soil layers and reduced at depth by other chemical-physical constraints.

Crop models are increasingly being used by growers as decision support tools. However, these models are too complex to map paddock scale spatial variation in yield. A simpler model has been developed based on the relationship between EMI data and effective soil-water available for production. The model showed good similarity in spatial patterns compared with the actual yield maps.

**Recommendations**

It is clear from this study that managing spatial and temporal variability offers growers considerable potential to improve their gross margins and reduces the detrimental impact of farming on the environment. However, it is also clear that the interaction between a complex suite of soil properties and a highly variable climate results in a spatial and temporal yield variability that is problematic to predict. For this reason, the first recommendation from this work is that a greater focus for precision agriculture needs to be on the development of management decisions that are based on the spatial measurements of soil properties that are known to have a sound theoretical basis for controlling yields.

A key theoretical basis for yield variability in the majority of grain growing regions in Australia is the quantity of plant available water. In seasons with predominantly light rainfall events, the plant available water is principally controlled by variability in soil PWP while in seasons with more intense rainfall, it can be controlled more by variation in the PAWC. It is therefore recommended that climatic variability should be analysed in relation to which of these soil parameters is principally influencing yield. Since the location of high yielding regions will be very different depending which of these soil properties is most important in a season, this approach will begin to enable a robust understanding of paddock variability.

In the absence of reliable climate forecasting tools, stochastic analysis provides the best option for predicting likely seasonal conditions. It is recommended that new relationships are investigated to see whether a PWP or PAWC controlled season can be predicted from early season trends, such as the date of sowing.

If soil texture is relatively uniform across a paddock, yields may also be expected to be more uniform. If this is not the case, it is recommended that other yield controlling factors are investigated, such as variation in soil depth.

Ultimately any precision agriculture tool will require validation against true yield variability. It is therefore recommended that growers collect as much yield data as possible for future inclusion into development of spatial management practices. It may be useful for GRDC to host a web site where growers can register any paddocks that have been yield mapped. Commercial development of other yield mapping tools such as simulated yield mapping should be considered.

For many years considerable financial resources have been available for the development of robust crop models. However, it is now acutely obvious that the usefulness of these models is constrained by the difficulty in obtaining accurate input data, at a spatial density required for new paddock management practices. It is therefore recommended that investment in the development of cost effective techniques for the intense spatial measurement of important crop model parameters is vital for widespread adoption of PA in Australia.

**Outcomes**

**Economic outcomes**

Despite previous studies demonstrating significant financial benefits from PA through improved fertiliser management and other management decisions, the adoption of PA in Australia is still low. This is largely attributed to the cost of PA equipment and the perceived cost versus benefit, although setting up equipment, matching and understanding data sets, and collecting and collating data are also considered substantial barriers (GRDC Survey 2004). The economic outcomes from this project flow from new tools and understanding that will help to increase grower confidence in PA and thus improve the rate of
Two prototype tools for mapping spatial and temporal yield variation have been developed through this project. The methodologies used in both of these tools are a paradigm shift from current data analysis techniques, and are focused on the need for low cost and minimal data collection. The tools offer growers and land managers rapid and cost-effective techniques for initial estimation of sub-paddock yield variability. As such, they may help to overcome constraints to the adoption of PA due to the cost and complication of data collection, and provide an affordable entry level option for evaluating yield variability. They will also provide growers with the information necessary to evaluate the financial benefits of alternative PA management options, and to carry out on-farm testing of the benefits derived from the variable rate application of agronomic inputs.

The project has also developed greater understanding of the processes that control yield variability, and in particular the dynamic nature of yield maps. The economic outcome from this knowledge results from the development of management practices that are able to better respond to yield variability. The research demonstrates that paddock zoning should be based on sound theory for the interactions between key soil parameters and climate variables, rather than on the correlation with short term yield data.

Environmental outcomes
The environmental outcomes from this project are as a result of providing tools that increase the adoption of PA. The underlying philosophy for PA is the application of inputs at the right amount, at the right place, and at the right time. Successful achievement of this will result in reduced off-site contamination and a lower carbon footprint.

Social outcomes
The social outcomes from this project are a result of providing growers with tools that provide decision support and thus easier management and enabling profitable farming and a thriving rural community.

Achievements/Benefits
It is estimated that only 3% of Australian grain growers are using some form of PA technology. This is despite previous studies demonstrating significant financial benefits from PA through improved fertiliser management and other management decisions. If a significant acceleration in the adoption of PA is to be achieved, it is important to be able to offer growers, at an acceptable cost, information they can use to make more informed decisions about the adoption of spatial crop management for their property. This report covers the work undertaken by the Department of Primary Industries (DPI) Victoria from 2003-2008 as part of the GRDC Strategic Initiative on PA (SIP09). This work was carried out on a paddock near Birchip (Paddock 17), in the Victorian Mallee which was used for a multifaceted research approach to deliver new knowledge in the output areas identified by GRDC of:

‘New techniques to rapidly assess and map soil characteristics and other sources of within paddock variability’.
‘Improved and quantified understanding of how variation in landscape characteristics affects crop performance’.
‘Decision support systems to help growers make informed management choices from PA data’.

An important issue throughout the project has been the poor climatic conditions in south east (SE) Australia, which at the site resulted in the growing season rainfall for 2004, 2005, 2006 and 2007 being 33%, 19%, 62%, and 31% lower than the long term growing season average. Under this situation, the research results are skewed towards drought conditions. Despite the poor seasonal conditions, the emphasis in this project on developing better knowledge and new analysis techniques has meant that the planned outputs have been achieved, and new knowledge has been gained in the three areas identified by GRDC.

New techniques to rapidly assess and map soil characteristics and other sources of within paddock variability.
It is generally accepted that soil and terrain differences are the principal causes of spatial yield variability. Geophysical sensors and GPS technology provide the opportunity to cost effectively collect such data at a high spatial density. Hence the considerable research interest in developing robust relationships between yield variability and easily obtained metrics such as EMI or gamma radiometrics. Several surveys of Paddock 17 showed strong temporal correlations (although not 1:1 due to seasonal shifts) between EMI sensors, although this was not the case for the radiometrics. This stability in spatial structure across seasons supports the use of a single time collection of EMI data for identification of spatial features important for paddock zoning. Spatial linear modelling with the 1996, 1998, and 2005 yield maps found that only EM38h, EM38v and gamma-ray total count significantly correlated with yield in all three seasons. The regression coefficients were similar for each year, although the intercepts were different, suggesting that a single relationship may be possible that can be adjusted up or down to account for seasonal differences. The coefficients of determination ($R^2$) were generally low, and the average 95%
credible interval was 0.8t/ha. It was therefore concluded that significant but weak associations were found between crop yield and some geophysical explanatory variables, although in these circumstances they are unlikely to have much predictive value. However, these tools may be better suited to the rapid measurement of the soil hydraulic properties that control yield, and are the input parameters for crop models. This work has been reported in the journal paper ‘Advances in precision agriculture in south-eastern Australia, Part II: Spatio-temporal prediction of crop yield using terrain derivatives and proximally sensed data’ (Robinson et al., in press).

In an alternative approach to developing new techniques to rapidly assess and map sources of within paddock variability, satellite data and agricultural statistics, in the form of historical paddock yield records, have been used to obtain the relationship between spectral reflectance indices and yield variability. This technique does not require field sampling and therefore provides a considerable saving in effort and cost, placing the technique in the realms of commercial feasibility. An individual relationship is developed for each paddock and can therefore account for differences in conversion of biomass, measured by Normalised Difference Vegetation Index (NDVI), into final yield. This is important because it has generally been found that good correlation between remotely sensed data and biophysical parameters only seems to work for single or localised paddocks as a result of underlying geological or terrain differences. The accuracy of this technique has been tested for cereal yields in Paddock 17. The results show that the map of simulated yield (mean of six seasons) had 63% and 78% of the paddock area with an error of less than 20% and less than 40%, respectively, compared to the measured yield (mean of four seasons). These results are comparable to other approaches, such as the prediction of the spatial yield distribution of sorghum in a northern New South Wales (NSW) paddock using the APSIM crop model (Brennan et al. 2007). The simulated yield mapping technique was used to map a 1,348 hectare (ha) property consisting of 12 paddocks. A simple economic analysis comparing uniform versus variable rate N fertiliser, demonstrated that the benefits of using variable rate technology (VRT) differed considerably between paddocks, depending on the degree of spatial yield variability. The simulated yield mapping approach offers growers and land managers a rapid and cost-effective tool for initial estimation of sub-paddock yield variability. Such maps could provide growers with the information necessary to evaluate the financial benefits of alternative PA management options, and to carry out on-farm testing of the benefits derived from the variable rate application of agronomic inputs. This work has been reported in the journal paper ‘Advances in precision agriculture in south-eastern Australia, Part I: Methodology for the combined use of historical paddock yields and Normalised Difference Vegetation Index to simulate spatial variation in cereal yields’ (Fisher et al., in press).

Improved and quantified understanding of how variation in landscape characteristics affects crop performance:

Soil water availability is the major limitation to grain yields throughout the Mediterranean dryland cropping regions of southern Australia. Therefore, understanding the spatial distribution of soil hydraulic properties and their interaction with the size and frequency of rainfall events is paramount for predicting yield variability. Across the 90ha southern half of Paddock 17, 50 soil sampling locations that adequately represented the previously defined six management zones, were established. A positive linear relationship was found between clay content and both FC and PWP. The diverging nature of these two relationships with increasing clay content meant that there was also a positive linear relationship between PAWC and clay content. Across the paddock, there was a linear negative relationship between PAWC and the grain yield in each management zone. This suggests that PAWC was not the limiting factor in terms of yield variability. These results are in contrast to a sandy soil in Western Australia (WA) (Wong and Asseng 2006). A theoretical consideration of soil hydraulic properties suggests that spatial differences in the value of PAWC will only be the direct cause of crop yield variability when the soil water content in part or all of the paddock reaches FC and subsequently falls again to levels that result in crop stress. If soil water content does not reach FC, which has been the common situation in recent seasons in north western Victoria (VIC) then theory would suggest that the spatial variation in PWP should be a better predictor of yield variability. Soils that have a low PWP tend to be sandier in texture and do not have a high PAWC. Across the management zones, there was a linear negative relationship between PWP and grain yield during four seasons (1996, 1998, 2004, 2005). Depending on the season, 59-95% of the observed variation in grain yield can be explained by variation in PWP. Therefore, consideration of the spatial variability in FC and PWP provides a logical explanation for zones that may flip-flop between being high and low yielding, depending on the rainfall distribution. Rapid methods for predicting the spatial distribution of these soil hydraulic properties, and use of an appropriate crop model with good soil hydrology algorithms, is likely to provide the best solution for explaining spatial variability in yields. This work has been reported in the journal paper ‘Advances in precision agriculture in south-eastern Australia, Part IV: Spatial variability of plant available water capacity of soil across site-specific management zones’ (Rab et al., in press).

To improve knowledge of how yield controlling processes interact with the climate to cause spatial yield variability, crop performance was monitored in detail at 40 reference points located across the southern 90ha of Paddock 17 to represent the...
six management zones. As well as differences in the soil hydraulic properties between the different management zones, significant differences were found in other potential chemical-physical constraints to crop growth. Soil salinity electrical conductivity (EC), exchangeable sodium percentage (ESP) and calcium chloride (CaCl₂) extractable boron (B) were all significantly higher in the low yielding zones compared to the medium and high yielding zones, especially in the subsoil. These chemical-physical constraints did not appear to affect the rooting depth of barley which was not significantly different between zones in 2005 and 2007. However, lentil roots in 2006 were found to be significantly shallower in the low yielding zone. There was also greater total volumetric water in the soil profile (0-120cm) for the low yield zone than the medium and high yielding zones at both anthesis and grain maturity in all three years. These differences in stored water closely reflect the changes in chemical-physical constraints of EC, ESP, and B. Therefore, the plant available water in the low yielding zones is likely to be reduced in the upper layers by greater PWP values, and reduced at depth by other chemical-physical constraints. This work has been reported in the journal paper ‘Advances in precision agriculture in south-eastern Australia, Part III: Interactions between soil properties and water availability help explain spatial variability of crop production’ (Armstrong et al., in press).

Decision support systems to help growers make informed management choices from PA data:

The high cost of fertiliser means there are potentially large economic gains to be made if inputs and crop growth can be better matched to the plant available water. However, for zone management to be useful, responses to nutrient inputs need to be reliably estimated before making management decisions. The robustness of the yield zones defined for Paddock 17 have been explored by using long term weather conditions and APSIM simulation modelling for wheat and barley using four fertiliser rates and three sowing times. In contrast to the zoning carried out using data from recent seasons, the zone with the highest long term yield in both wheat and barley was the low variable zone. However, at the highest fertiliser rate the median long term yield was almost the same in all four yield zones for the wheat, although in the barley, the low variable zone had higher median yields, even at the highest fertiliser rate. The better performance of the low variable zone may be attributable to having the largest PAWC of the four zones. In the other three zones, long term median yields, at the same fertiliser rate and sowing time, were very similar, although the high stable zone tended to have the next highest yields. The long term results also showed that in contrast to the fertiliser trials in 2004 and 2005, there was a long term positive median yield response to increasing fertiliser rate in most of the yield zones. The next step required in this analysis is to calculate the economic value of these fertiliser responses, as greater fertiliser inputs may increase yields but are quite possibly unprofitable. This work has been reported in the journal paper ‘Advances in precision agriculture in south-eastern Australia, Part V: The effect of seasonal conditions on wheat and barley yield response to applied nitrogen across management zones within a paddock’ (Anwar et al., in press).

Although applying a process based crop model is helpful for understanding the causes that drive crop variability, one limitation of such models is their requirement for large amounts of input data. In contrast, crop models that can be easily applied at a high level of spatial resolution are likely to become increasingly important as decision support tools. As an alternative approach, a transpiration-based potential yield model with lesser data needs has been applied in a spatial context. The approach has assumed that transpiration efficiency is constant and that soil evaporation varies spatially as a function of clay content. The parameters necessary for the model, crop lower limit, sowing soil water content, and soil evaporation, were all obtained through correlation with an EMI survey at either sowing or harvest. The model performed quite well despite not being calibrated on yield data. Despite low Coefficient of Determination against observed yield maps, the absolute errors were comparable to more complex simulation models.

Other research

The adoption of PA in Australia is still low. This reflects the complex nature of spatial and temporal crop variability, but also the limited amount of research in this emerging discipline. Many key research and development (R&D) needs have emerged during the course of this project and are summarised as:

Cost effectively mapping yield variability:
No technique currently exists for cost-effectively mapping crop variability over large areas such as an entire property or catchment. Simulated yield mapping provides a potential tool to fill this gap and significantly increase the adoption of PA. Before wide-scale adoption or commercialisation of the process can take place, further R&D is required to validate the technique for a wider range of soil types over different agro-ecological zones, and to improve the precision by understanding where and why the model over- or under-predicts true yield.
Understanding N response to increase gross margins:
The temporal variation in fertiliser response curves makes spatial management of N complex for growers to manage. In the absence of accurate seasonal forecasting tools, a probabilistic modelling approach to N response in management zones is the best option. One potential research opportunity is the economic analysis of N response functions in management zones as a function of the sowing date, and to provide this as a tool for growers. This approach would probably result in less fertiliser application and less need for spatially variable application with later sowing dates.

Cost effective collection of model input data:
A clear research need that has emerged is the ability to rapidly obtain the spatial distribution of the parameters required for more dynamic paddock mapping based on crop modelling. A research opportunity exists to use geophysical sensors to cost-effectively map the soil hydraulic properties and soil water profile required for crop modelling. Initial investigation of this concept has been undertaken through the GRDC rapid soil testing initiative that is nearing completion but greater R&D is required.

A different and relatively new approach for obtaining the spatial distribution of soil hydraulic parameters is to derive them from inverse modelling of existing yield maps. This research opportunity could potentially provide a very cost effective mechanism for obtaining the data required for the spatial application of crop modelling.

Understanding the relative importance of topsoil versus subsoil on spatial yield variability:
It seems likely that yield variability is the result of a) changes in soil texture affecting the hydraulic properties in the upper soil layers, and b) the existence of other chemical-physical constraints at depth. Before yield variability can be better predicted, there is a need for fundamental research to identify whether these shallow or deep effects are more important in controlling spatial variability.

Development of simple spatial yield models:
Crop models are increasingly being used by growers as decision support tools, however without new methods for estimating the spatial variability in soil properties, these models are too complex to model paddock-scale spatial variability. A simpler yield model has been developed based on the relationship between EM data and effective soil-water available for production. The low cost of this technique warrants further R&D.

Additional information
A total of over 30 publications were produced using data from this project including five refereed journal papers, five conference papers, six symposium papers and many newsletters and magazines articles (attached).