Australian Centre for Precision Agriculture

The University of Sydney

The Australian Centre for Precision Agriculture Symposium on Precision Agriculture Research in Australasia

Proceeding of the 1999 Symposium

Universitas Sidneiensis

Programme of Presentation

Rice yield mapping.
Brendan Williams, The University of Melbourne.

Precision Agriculture: A farm Management Philosophy
Some Definitions

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Alex McBratney, Alex McBratney, The Australian Centre for Precision Agriculture, The University of Sydney

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Welcome

Alexander McBratney, The Australian Centre for Precision Agriculture, The University of Sydney

On behalf of the Australian Centre for Precision Agriculture (ACPA), the University of Sydney and the Australian precision agriculture community, we'd like to welcome you to our 3rd Annual Symposium. We'd particularly like to welcome those who are making their first visit to this annual symposium which hosts participants from a broad cross section of agricultural industries. The day is attended by growers, representatives of agri-businesses and information technology companies, research providers, researchers and educators.

It is pleasing to note that Precision Agriculture (PA) continues to pick up momentum. Overseas there have been many developments in the past year including the legislation of PA research funding policy in the USA, the announcement of the first commercial protein sensor from the USA, on-the-go nitrogen requirement sensing and fertiliser application from Europe, a large research conference in Denmark and the publication of the first scientific journal devoted to precision agriculture research.

In Australia yield monitoring has increased and a greater understanding is being brought to bear on the management potential of the gathered information. The application of fertiliser at variable rates within paddocks is moving through the research phase as a result. In parallel, new companies have sprung up, PA stands star at field days, the rural Research & Development Corporations are committing to increased research, the GRDC has called for a scoping study on potential benefits of PA, but there is still no real government policy.

For all those here today, the commitment of the Australian government to a long-term Precision Agriculture research program should be seen as a high priority. We all need to work towards showcasing the potential benefits of PA to the economic and environmental well-being of agricultural production. These need to be revealed to the agricultural and wider rural and urban communities.

We do hope you enjoy to-day's activities. Hopefully you'll take home a good idea of recent developments and a representative cross section of the best things that are happening in Australia.

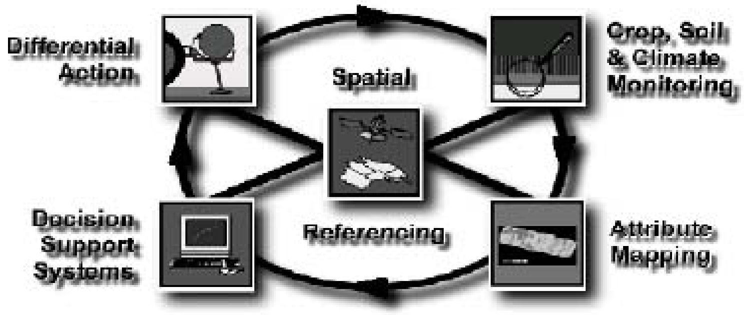
Staff & Students

The Australian Centre for Precision Agriculture, The University of Sydney

Precision Agriculture

A Farm Management Philosophy

The Components.......



Some Definitions of PA.......

US Agricultural Research, Extension & Education Reauthorisation Act (1997)

An integrated information- and production-based farming system that is designed to increase long-term, site specific and whole farm production efficiencies, productivity, and profitability while minimizing unintended impacts on wildlife and the environment.

US National Research Council (1997)

Precision agriculture is a management strategy that uses information technology to bring data from multiple sources to bear on decisions associated with crop production.

Reconciling Continuous Soil Variation & Crop Yield - Whelan (1998)

The observation, impact asessment and timely directed response to fine-scale variation in causative components of an agricultural production process.

A Wander in Precision Agriculture Paddocks

Alex. McBratney, The Australian Centre for Precision Agriculture, The University of Sydney

"It's not the technology that counts - it's how you use it"

In my introductory talk, which by necessity, (and perhaps unlike Precision Agriculture), covers a lot of country without considering it carefully and pretty fast, I shall,

a) Give a quick review of what people consider Precision Agriculture to be (see definitions on previous page) as a framework for discussion and particularly for the benefit of new attendees.
b) Compare the original American model for PA management with the currently developing Australian/European management-zone approach.
c) Make a brief statement about Precision Agriculture in Australia. The principal industries for adoption would seem to be (in alphabetical order) cotton, grains, sugar and viticulture.
d) Briefly describe some of the research projects and other activities of the Australian Centre for Precision Agriculture (outlined later in this document).
e) Discuss some implementation and adoption statstics for PA in the US and boldly extrapolate them to Australia.
f) Discuss barriers to development and adoption such as:-culture of potential users, property size, hype versus success stories, market imperfections, technical expertise, data costs, and, of course, knowledge gaps. data costs, and, of course, knowledge gaps.
g) Briefly discuss the `GMO issue' - the biggest issue in agriculture worldwide today - and how this relates to Precision Agriculture.
h) Suggest some future priorities.

What Role for Soil Testing in Precision Agriculture ?

Rob Bramley and Simon Cook, Precision Agriculture Research Group, CSIRO Land and Water

Decisions about fertiliser applications are fraught with uncertainty. Uncertainty about the outcome of an application of fertiliser is caused by unknown or uncontrolled variation about the condition of the soil to which it is applied, its fate, and the demand from the crop. Uncertainty can be eased by providing information which reduces ignorance about the likely outcomes of applying fertiliser, thereby increasing the decision-maker's chances of success.

For many years, soil testing has been promoted as a means of acquiring the necessary information for sound fertilizer management, and it is used to a greater or lesser extent in most of the agricultural systems around the world. Australia has tended to be a relatively low user of soil testing (0.34 samples km-2 compared, for example, to around 10 samples km-2 in the USA) for a range of reasons of which cost is probably the most important. In precision agriculture (PA) applications, intensive soil sampling / analysis is being touted as a suitable basis for variable rate application of fertilizers, to the extent that in the USA, "grid sampling" is now seen by many as a fundamental part of the PA lore. In Australia, the relatively high cost of soil testing makes this approach less attractive and mechanised on-the-go soil testing using proximal sensors has been suggested by some as a suitable alternative. In this paper, we present some reasons why we need to be very careful about how soil testing is used in both traditional and precision agricultural systems, whether based on traditional "wet chemistry" or proximal sensors.

Research in the Western Australia (WA) wheatbelt, suggests that conventional soil testing is of limited value in explaining variability of crop response to fertilizer application in the field. Possible reasons for this include the inadequate representation of major sources of variation - in particular water availability, weeds or disease; inaccurate representation of nutrient uptake mechanisms; and errors of calibration over large agro-ecological regions with wide ranges in soil types or properties. We suggest that this situation may be improved somewhat by more sensitive methods which can reflect small but significant variations in soil chemistry and nutrient availability. However, we think that irrespective of the soil test methodology (wet chemistry or proximal sensor), localised test calibration will be critical if soil testing is to be regarded as an essential part of the PA toolkit.

The Potential for Using Airborne Multispectral Imagery for Detecting Wild Oats in a Seedling Triticale Crop

Lisa Rew, Tamworth Centre for Crop Improvement

The current weakness of precision weed management is the capability to rapidly and cost effectively create reliable weed maps. Many research projects have used a grid map (i.e. discrete points), and a few have mapped continuously from a specialised vehicle or combine harvester to create weed maps. However, these methods are time consuming and there is still a need to develop an accurate and cost effective weed mapping system. Airborne remote sensing has been identified as a promising technique for mapping weeds in crops and pastures. In this preliminary study, we obtained multispectral images (440 nm, 550 nm, 650 nm and 770 nm) of the entire target field at 1 m resolution, and of a smaller target area at 0.5 m resolution, using a digital imaging system, which was mounted in a Cessna fixed wing aircraft. The field (52 ha) was sown to triticale, undersown with pasture legumes and naturally infested with wild oats. A sub-region of the field (126 m x 98 m) was sampled on a 7 m x 7 m grid and all wild oat plants counted within square concentric quadrats (0.25, 0.5 and 1.0 m2) at each grid intersection. The imagery was converted into weed maps using an unsupervised image classification technique. The images were then overlaid on the grid weed maps and the data compared. Correlation between the image data and the weed counts was lower for the 1 m image resolution (R2 = 0.61) than the 0.5 m (R2 = 0.74). Low densities of wild oats were poorly classified. However, the technique shows potential and could be used as part of a stratified sampling system. Some possible ways of improving the technique are discussed in relation to resolution, spectral quality and geo-rectification.

This work has been a joint venture between L.J. Rew, R.W. Medd, D. Lemerle of NSW Agriculture and D.W. Lamb, M.M. Weedon, J.L. Lucas and J. Medway of Farrer Centre, Charles Sturt University, Wagga Wagga.

Palmtop Technology and Applications for Precision Agriculture

Brendan Williams, Pathway Precision Farming.

Having recently returned from a trip to the US I would like to share with you some of the recent developments that I think will impact greatly on precision farming in Australia and more specifically your crop scouting operations.

At present many run Notebook PCs out in the field when soil sampling and doing general crop scouting. This is clearly not a good idea as the spinning hard drives are notoriously susceptible to crashing when jolted at the wrong time and the visibility of the screen in direct sunlight is generally poor. Ruggedised Notebooks are much better but the cheapest is about US$4,000.

I think the new handheld computers that run Windows CE provide a much better solution. These devices have no spinning hard drive they are completely solid state so they are not susceptible to vibration and shock loads but best of all they are relatively cheap at less than $1,000 and the colour screens are very visible in direct sunlight (depends on make and model). These devices have normally been very small handheld PCs but now they are available with large screens which makes them more useful for in-vehicle applications.

The units come loaded with cut down versions of Excel and Word and most have internal modems so you have email and web access, so they function reasonably well for normal everyday PC type work. They have a limited memory but you can purchase PCMCIA memory cards relatively cheaply now. Another nice feature is that they have instant on function so there is no waiting for windows to load. All units come with a docking station that will automatically download all the information to your desktop PC in the office. The larger models have a PCMCIA card slot the small units have compact card slots.

Software Functionality (a list of functions that are useful for field scouting):

a) Download PC cards
b) Supports the use of color
c) Drive over yield (any) map or geo-referenced photo.
d) Navigate to target points for soil sampling etc.
e) Mark and log points and store notes.
f) Grid a paddock?
g) Log EM or yield (any) data.
h) Create real time maps.
i) Drive variable rate controllers.
j) Downloads to a GIS desktop program.

- StarPal - does a few of the above functions.
- Pocket Survey - has been dropped by Agrilogic / Casecorp
- Farmworks - SiteMate does all of the above. It comes in 3 packages - basic, scouting and vrt and is available from Pathway Precision Farming.

Identifying Potential Within-Field Management Zones from Cotton Yield Estimates

Broughton Boydell, The Australian Centre for Precision Agriculture, The University of Sydney

While the implicit aim of site-specific management is to treat each site in a field specific to its individual requirements, the enormous expense of collecting the data required to make informed decisions at this scale, currently precludes adoption of such an intensive management program. Instead, based on the premise that the spatial variability in crop yield is influenced by spatial variability in soil factors at a similar scale, researchers have begun to examine the patterns observed in crop yield maps. These maps, obtained from continuous monitoring, may be used as a means of obtaining finer resolution crop requirement predictions and for creating potential management zones.

Here, remotely sensed cotton yield estimates, collected mid-season over the past 11 years, were investigated to identify the degree of temporal stability exhibited in two irrigated fields on "Colly Central" farm, Collarenabri, NSW, Australia. In particular, the aims of the investigation were: Firstly, to develop stable yield zones from multi-year yield estimates derived from 11 consecutive years' mid-season Landsat TM imagery; Secondly, to discover the number of consecutive years of yield estimates required to give similar `stable' estimates of yield zones to those derived from all 11 years of available data.

Results of the investigation indicate that the fields described in the study exhibit a strong degree of temporal stability. Additionally, where an assumption is made that 11 years worth of yield estimates will cluster to generate the most temporally stable "regions of similarity", the mapping of clusters generated using 5 or more years will generate comparable "regions of similarity" with high confidence that the regions will indeed closely match those of the temporally stable 11 year estimates.

This work has been funded by the CRDC with satellite data made available by IAMA.

Airborne Remote Sensing Roles in Precision Agriculture

David Lamb, The Farrer Centre, Charles Sturt University

In the last five years, airborne multispectral imaging has been utilised both as a research support and a commercial monitoring tool over Australian crops. Composite visible and near-infrared imaging is an effective means of highlighting variability in soil structure, crop biomass and vigour. While initially employed as a tool for simply monitoring variability in crops, current research has focused on integrating the remotely sensed data into precision weed and nutrient management systems. A number of recent applications of the technology over croplands and vineyards in will be discussed, including the mapping of soil zones and associated crop design, early detection of pests and diseases, siting of treatment plots, precision weed mapping, nutrient prescription and early detection of yield variability.

Practical Decision-Making for Variable-Rate Fertiliser Application

Michael Smith, "Tarnee" (North-west NSW)

At this stage I am using precision farming techniques to verify crop performance against the physical variation of our soils. I expect to be able to concentrate our management on the water holding capacity of the soil as this is a major component of the northern cropping system.

Mapping has provided indicators to make improvements to our management of each field using basic farm practices along with the definition of zones within each field. Computer crop modelling programs like "Wheatman" could help to manage zones by giving the ability to run `what if' scenarios.

Precision Agriculture in Australian Viticulture

James Taylor, The Australian Centre for Precision Agriculture, The University of Sydney

Precision Agriculture in Australia has been driven by the grain and cotton industries that have pioneered the technology. This has been due to the early development of effective yield monitors for both crops allowing yield mapping to occur. Precision Agriculture in other cropping industries e.g. viticulture, horticulture and root crops, has been stilted by the absence of yield monitors. Research in the US, France and Australia has been undertaken to develop yield monitors for these industries. This research has lead to the recent commercial development of a generic load cell based yield monitor for horticultural crops. For lighter crops, e.g. wine grapes, an alternative yield monitor based on ultrasonics has been developed. This year several yield monitors were used in Australia to record the wine grape harvest.

Viticultural and horticultural crops offer a unique opportunity for precision agriculture as they are generally perennial crops. Measurements over several years can be geo-referenced to specific vines giving accurate temporal data. Crops are generally high-profit and intensively managed meaning small productivity increases are profitable even with the high initial cost of PA. Many vineyards and orchards already record growth indicators during the season and the irrigation of the crops decreases the impact of water, the main yield determinant in Australia, on crop production. By controlling the impact of water other yield/quality determining factors e.g. soil nitrogen, become more influential and potentially easier to manage. With intensive data collection already commonplace, and a highly mechanized industry the opportunity to adapt PA techniques to viticulture is very good.

While further refinement of the yield sensors is required the commercialisation of these yield monitors has necessitated the development of management practises to analyze, interpret and act on the information obtained. Such agronomic research is vital to the effective implementation of PA into the viticultural industry. Central to the interpretation of the yield map is a detailed understanding of the different crop/yield/quality determining factors in the vineyard.

Quality as well as quantity is a very important factor in viticulture. It is generally assumed that quality is achieved at the expense of quantity however recent research has shown that this is not necessarily the case with high quality high yielding harvests recorded. By developing a detailed vineyard database and understanding crop-environment interactions precision viticulture has the potential to not only maximise yield but also maximise grape quality in Australian viticulture

Precision Agriculture, Spatial Information and Organization

Simon Cook, Precision Agriculture Research Group, CSIRO Land and Water

Information, we are told, is king. Information is what makes managers effective because good information enables them to improve the flow of materials and energy within complex systems. But information per se has no value until it is interpreted. Because proper interpretation is difficult, it eventually requires specialist skills. These are normally provided by integration of human resources within a firm, industrial sector, or society.

Precision agriculture provides information which is potentially of enormous benefit. Much of the potential has yet to be realised, however, and is unlikely to be realised until farmers are shown how the information can be used. As in other industries, this will require new skills and (something which is often understated) new understanding of what the information shows. Such skills are likely to be of marginal benefit to individual farmers, so they must be provided by yet-to-appear specialists using yet-to-be-proven methods.

This paper discusses the problem of organizing analytical skills to interpret spatial information and suggests possible ways of getting around it. These include the development of:

a) `Standardised' methods of processing information, which can be distributed widely at low cost
b) Farmer-participatory methods of improvement such as on-farm experimentation
c) Specialist farm consultancy services
d) Distributed IT to provide remote support via the Internet.

Integration of Precision Agricultural Systems with Farm Management Techniques

Jean-Paul Pratt[1], John Maber[1] and Ian Yule[2]

[1]Agrichemicals Group, Lincoln Technology, Hamilton New Zealand

[2]Institute of Technology and Engineering, Massey University, New Zealand

Initial hopes were high for the adoption of precision agricultural systems for site specific management in mainstream agriculture. The system automatically records and graphically highlights areas on farms where efficiencies can be improved. However, adoption of precision agricultural systems appears to have faltered (Lowenberg-DeBoer, 1999). The problem is that it is unclear if farmers will achieve sufficient return from their investment in the technology. This report relates experience with the technology to date in New Zealand, outlines barriers to further uptake of the technology and proposes strategies for integrating the technology into existing operations.

Read the full version of this paper in Appendix A

Improving Yield Map Interpretation

Rob Kelly, Troy Jensen, David Butler, Wayne Strong, Farming Systems Institute,
Queensland Department of Primary Industries, Toowoomba

With the advent of new generation harvesters and site-specific data logging devices, yield logging and mapping is set to become an industry standard, particularly within the grain-growing regions of Australia. However, the drive and investment towards map creation has mostly outstripped that put towards the interpretation of such maps. A strategy that enhances the agronomic interpretation of yield maps would advantage both growers and advisers, and would enable yield maps to become a prescriptive as well as a descriptive tool.

In conjunction with several grain growers and GRDC, we are integrating agronomy with statistics in three stages to improve yield map interpretation. Firstly, maps of grain yield will be built by yield monitoring. Grain samples, needed for post-harvest assessment of protein, will be collected in-field using a custom-built programmable device capable of recording position and distance. Both layers of information can be used to make interpretations about the nitrogen availability and moisture status of grain crops. Secondly, other site-specific recordings will be taken such as aerial imagery, soil boundary maps, and past events. Thirdly, a statistical framework will be explored that begins with spatial modelling of the individual data layers and leads to predictive models using known agronomic relationships between grain yield and other measured or inferred spatial covariables, in particular, grain protein. Outputs might include a decision-support package giving probability surfaces for the candidate causes of yield variability. Informed management decisions can then be made using the yield map as the basis of a diagnostic tool.

Precision Guidance with the BEELINE NAVIGATOR

Aleks Velde, AgSystems, Inc.

The Beeline Navigator is a system which uses Differential GPS (DGPS) and inertial navigation sensors (INS) to navigate agricultural equipment in a highly accurate and efficient manner. The system provides obvious benefits including reduced input costs due to minimal overlap, reduced driver fatigue, facilitation of 24-hour farming and controlled traffic.

This year the Beeline has undergone a number of developments to further boost the performance of the system. These include automated guidance of articulated and "Case QuadTrac" vehicles, improved GPS and INS integration, adaptive control techniques, detailed tuning and performance analysis and satellite outage prediction.

Currently Agsystems is working on a number of projects. These include wide area differential GPS, base station and beeline networking, automatic tuning of steering, vehicle modelling and "round and round" guidance.

Summary & Discussion

Brett Whelan, The Australian Centre for Precision Agriculture, The University of Sydney

As Precision Agriculture expands in the research and production arenas more technologies and techniques are introduced. Today we have seen a cross-section of this phenomenon. In the past symposia we have spent more time on grain yield monitoring, and while this is a very important part of PA that is still developing, we have tried to provide a view here of some other important aspects of PA. Just what (in my opinion) have we seen and been told?

We have learnt that we are all here because of a desire to deal more effectively with variability in the production of agricultural food and fibre crops. The interaction between the soil and crop has been a major focus in trying to characterise and manage this variability. The variability in many important soil attributes is very large and the ability to characterise this through traditional soil sampling and analysis is problematic. One suggestion to follow is that by using maps of crop yield, together with other ancillary data (elevation, clay content, depth of top soil, aerial & satellite images), it appears possible to gain an integrated perspective on the general variability in production potential within a paddock. Using this information to delineate potential management zones can help in directing soil sampling and also fertiliser response experimental designs.

Remote sensing is gaining greater impetus in PA as it allows us to gather data on many attributes on a finer resolution than economically feasible with grid sampling. We have seen the possibilities for weed detection, crop yield estimates and other aspects of crop health and soil properties. One great advantage that has been highlighted is the opportunity to gather information from archived data. This could allow us to identify potential management zones without waiting for the gathering of data. All this is mindful of course of the crucial need to ground truth the images and eventually reduce the cost to the end-user.

We have seen today yield monitoring moving into cotton and grapes. The monitoring systems for grapes will be suitable for other horticultural crops. These crops are high input and/or high establishment cost crops and should be very well suited to PA. It has also been pointed out that the real-time protein sensor for grain crops is due for imminent commercial release and this should help with the interpretation and management of soil nitrogen in the PA system. The GPS technology is also rapidly improving and being used in novel and practical ways.

As far as applying the management philosophy now, we have seen that it is wise to observe and keep things relatively simple at first. Integrating information that gives a handle on the available soil moisture capacity is a very useful start for delineating management units in dryland cropping (especially in the north).

Finally, it is information that PA is all about. It's interpretation and incorporation into the farm management system is the key. It should be the goal to have standard (and robust) methodologies for analysis and interpretation, but this may prove difficult with commercial interests. Standardising experimentation may be simpler as we move towards educating the agricultural community in the philosophy of PA.

Apendix A

Integration of Precision Agricultural Systems with Farm Management Techniques

Jean-Paul Pratt[1], John Maber[1] and Ian Yule[2]
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Integration of Precision Agricultural Systems with Farm Management Techniques

Praat, J.P.
Maber,J.
Yule, I.J.

Initial hopes were high for the adoption of precision agricultural systems for site specific management in mainstream agriculture. The system automatically records and graphically highlights areas on farms where efficiencies can be improved. However, adoption of precision agricultural systems appears to have faltered (Lowenberg-DeBoer, 1999). The problem is that it is unclear if farmers will achieve sufficient return from their investment in the technology. This report relates experience with the technology to date in New Zealand, outlines barriers to further uptake of the technology and proposes strategies for integrating the technology into existing operations.

New Zealand Experience

While the agricultural aviation industry in New Zealand has used Global Positioning Satellites (GPS) for swath guidance for over 10 years, few operators have used this technology for ground based vehicles (e.g. combines, tractors, sprayers). Several operators, spread throughout New Zealand, have yield mapping equipment on combines used for cereal harvesting. Two, one in the South Island and one in the North Island have been the subject of some detailed study. These studies indicate similar trends to overseas studies in variation of soil nutrient levels (Table 1). Interestingly the values calculated for both studies show similar variation and although the variability is clear the relationship with yield is less so. A number of studies around the world have indicated higher levels of P and K on lower yielding areas. Mohamed et al (1997) suggested this was due to over-application through the spreading of blanket fertiliser rates with insufficient turnover of nutrients in lower yielding areas. This suggests that savings could be made on P and K applications using variable rate fertiliser application while maintaining an acceptable level of fertility.

Table 1 Coefficient of variation (%) for soil nutrient levels found in two New Zealand Studies

North Island§						
	P	K	Ca	Mg	N (kg/ha)	CEC
Coefficient of variation (%)	35	32	13	17	18	12.2
South Island¥						
	P	K	Ca	Mg	N (kg/ha)	pH

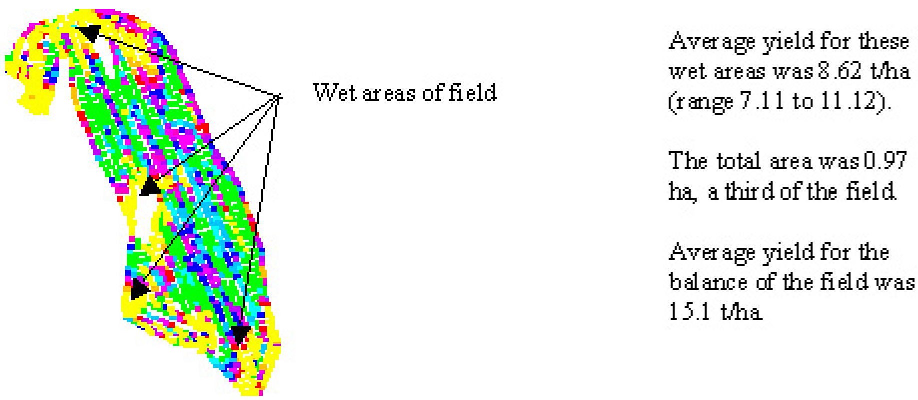
Coefficient of variation (%)	33	31	15	16	20	3.5

§ - 160 soil samples taken on 1 ha grid from 7 fields in the Waikato

¥ - 260 soil samples taken from 46 ha from three fields in Canerbury

The system under study in the North Island is operated by John Austin Ltd. Yield maps have been produced for three seasons for approximately 300 fields with the John Deere GreenStar™ system. These maps have been used in the field. A number of yield reducing factors were identified, and a hierarchy of factors soon became apparent. The most easily recognised factors included hybrid, drainage, weeds, insects, old field boundaries and limitations due to soil type. The costs and benefits associated with these limitations and potential remedies can be confidently costed. For example Figure 1 shows that approximately 6.5t/ha yield reduction was due to wet soil conditions which cost NZ$1527/ha (@NZ$235/t maize). The capital required to improve drainage can be balanced against a quantifiable increase in production.

Figure 1 Areas of poor yield resulting from wet soil conditions



In another field a superior hybrid was identified and a portion of the same field with light soil was retired (planted in trees) as the yield was not sufficient to cover production costs. The relationship between soil nutrient level and yield was less obvious although one field in particular appeared to benefit from site specific soil sampling. A field was soil sampled on a grid basis (1 sample/ha) to test links with yield variation. Potassium levels appeared to be associated with yield variations. Areas of low and high K were identified and an application map was prescribed using three rates of muriate of potash (0, 50 and 100 kg/ha). The subsequent yield map was more even as previously low yielding areas yielded close to the field average. The cost of intensive grid soil sampling appeared to be justified in this case. However, this tended to be the exception rather than the rule. Soil quality was another factor which was harder to identify as a limitation to yield. For example identification of layers in the soil which may restrict root penetration or areas where soil structure (density, stability, porosity) is limiting growth is often difficult due to temporal and moisture changes.

In the Canterbury study soil depth was identified as having the strongest correlation to yield on the downland site. Two further sites on the Canterbury plains have greater variability in soil depth despite being much flatter. These sites were irrigated which if scheduled correctly should nullify the effects of soil depth. The study is just beginning the second year and caution should be exercised in interpreting these results as the conditions at the time were exceptionally dry, McBratney (1999) observed that temporal variation can be greater than spatial. The three year study is still in the initial phase, having collected two years of yield maps and extensive field data from selected sites on the three properties for one growing season.

Factors limiting the uptake of precision agriculture systems

The economics of swath guidance are easily identified. Improvements such as 5 to 8 % increase in accuracy of bout width, the ability to spray at night and improved confidence in novice operators are measurable economic benefits swath guidance technology (Strautman, 1999). Minimising overlaps and misses optimise labour, fuel and agrichemical inputs. The profitability of site specific management are however less certain. Initial yield mapping systems have been developed on headers for two main reasons. Firstly; a larger market than any other harvesting machinery and secondly, it is simpler to accurately measure the flow of a granular material. However it must be remembered that most of the crops going through the header are less valuable per hectare than many other crops such as potatoes, vegetables and wine grapes. Our initial focus has been on savings of input costs but this is less profitable than increasing yield and it is that we should be concentrating on. For the farmer the aim of increased profitability is clear, the mechanism of how to achieve it is not. Many of the support structures required are not yet in place.

At this stage it is likely that only large farmers or contractors will be able to justify the $20,000 to $50,000 investment required to implement precision agriculture systems as they are able to spread the fixed cost over a large area. In the case of the large farmer, value is required from improved efficiencies of inputs. In the case of the contractor, value may be obtained from either attracting more clientele, charging a premium or, which is more likely the case, maintain market share. Part of the drive for adopting these systems is related to the perceived requirement of future markets to require rigorous audit trails in order that "good agricultural practice" is evidenced. Those involved in the export trade have already witnessed this as part of their customer s quality assurance schemes.

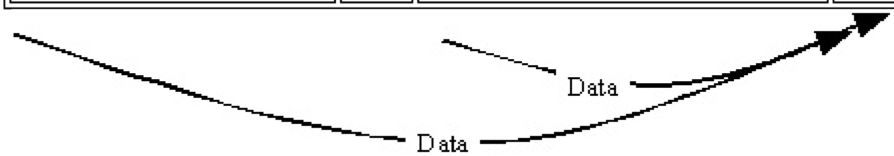
Opportunities

What is missing? Why have farmers not embraced the technology with both arms? As researchers we constantly hear farmers (decision makers) complaining that the system does not tell them what they need (or want) to know in order that they can manage their production unit more efficiently. The critical aspects or the "need to know" parts of the business include the relationships between inputs, outputs and externalities. The data on these aspects must have appropriate precision and be available in a timely manner. The production unit, the manager and the environment are described in Figure 2 as a typical pressure-state-response model (Smyth and Dumanski, 1994). The pressure side of the model is the issues which may impact on the current position (state) which the decision maker has little or no control over. The state means the current position that the farmer is in. The response is action taken to deal with these issues.

Figure 2 Description of an agricultural production unit

Pressure		**State**		**Response**

Prices	↔	Product mix	←	Decision maker
Market Signals		Yield		
Weather		Risk strategies		



The quality of the response is determined by a number of things but the response is generally made with imperfect information or data eg. price and weather predictions. Precision agriculture incorporates the computing, digital and electronic technologies of GIS/GPS, DSS, monitoring and control equipment. The combination of these technologies should give farmers superior information to that they have had in the past in order to make more informed decisions. The system would include information such as; expected prices, insect and weed threshold levels, weather and crop development data. This must be presented in a form which the decision maker can use easily and have confidence in. We need to move on from describing relationships between yield and various crop/soil factors for individual fields to develop decision support systems which can help farmers make sense of yield maps on their farm as well as monitoring temporal factors that will have a direct impact on yield and yield spatial distribution.

Reading the scientific literature and conference proceedings indicates that hundreds of studies have been completed over the last ten years. Many of these studies have attempted to describe the relationship between yield and factors limiting yield. Almost invariablely they show high levels of spatial variation in soil properties and spatial variation in yield. Some identify the limiting factor for yield in that particular case. Longer term trials often come up with the idea of identifying stability in the system. For example Blackmore (1997) examined the consistency of yield between years in order to place areas under three management classes. These were; high yield and stable, low yield and stable and unstable. The proportions of the total paddock area placed in each category and will clearly vary between sites as will the effect of crop management and other temporal factors. This approach works when considering a stable system and we can differentiate areas of high and low yield, but what happens if part of the system is not stable. In this case we have to rely on shorter feedback loops and more monitoring through the crop s growth cycle in order to make management decisions.

This perhaps begins to give us a clue as to the apparent lack of adoption of precision farming. What we have done is to try to convince farmers to invest in a concept that:

1. Requires a major capital investment and shift in the way the business is managed.
2. Researchers have a lack of certainty as to the benefits. Most are careful to use the words "Potential Benefits" as they recognise no two cases are alike.
3. Requires a whole raft of skills that farmers do not feel they have in order to support it.
4. Has been described as having long term "Potential Benefits" in an industry where most are pressurised into making decisions for short term survival.

Under these circumstances is it surprising that so few have "seen the light". The underlying concept of precision farming is a powerful one however and is still worth pursuing.

There is a wide gap between the work researchers have carried out and what needs to be done in order to facilitate the uptake of precision farming methods. We still seem to be in the experimental phase but we need to move to the developmental. This prolonged experimental phase is perhaps indicative of our own uncertainty as we recognise that most cases are different. Having done that we should move to examining ways the technology could be more readily adopted into the management structure of agricultural and horticultural businesses. There should be greater focus on the development of management tools that will allow the farmer to complete complex analysis tasks without having to be a software writer. These tools must be reliable, flexible, easy to use and at a price farmers can afford. They must be able to integrate and communicate with other computer systems and offer financial analysis as well as physical.

Appropriate DSS are required. Farmers need planning software to determine economic/environmental trade-offs on farms. It is unlikely that a DSS will exist for every farmer and every situation he strikes every year. Inevitably DSS models have to be simplified to get them working. Generic models which provide return on investment type information and the impact of decisions on the whole farm are required. These models must be easy to customise using the farmers own data so that as the farmers collects his own data from year to year this data can be added to improve the accuracy of the model. (Rosiland Buick pers com. 1999). Developing such a will be difficult but without such a focus much software will miss it s mark.

There are a lot of data available now which are under-utilised. An example of this in New Zealand is that of fruit harvesting. Currently apples are picked into bins with the block, variety and picker noted on card stapled to the bin. When the bin gets to the grader the card is removed and the link to packout yield and the orchard operations is lost. What is needed is tracking system for individual bins which is compatible with the grading operation and can accommodate orchard data such as the tree or group of trees the fruit came from, the management of those trees (pruning, irrigation, fertiliser) and the associated costs of production. Work should focus on making that data available to the decision maker in a form they can use. Precision agricultural systems should be thought of as management tools rather than research tools.

Spray drift is another good example. A great deal is known about the various factors that each have an effect e.g. droplet size, wind speed, emission point. What is missing is a system that brings this information together in a way that a sprayer operator can use. A current project aims to use precision agriculture systems to provide a link between what we know about spray drift from orchards, the weather at the time of spraying and the features of the orchard and it s surrounds. The aim is to provide a system to help the sprayer operator manage the risk of spray drift. Potential spray drift will be predicted using available models based on realtime data on wind speed and direction. The resulting spray concentration levels will be overlaid with threshold levels set for the properties surrounding the orchard. From this a "safe spray" area may be identified to the operator.

Horses for courses.

For those contemplating investment in precision agricultural system our advice would be to get into it. Yield mapping is the first logical step of this process and we believe there will be benefits from this although the nature of these benefits may be unclear initially they will be surprising. It is possible to produce yield maps for combineable and root crops now. These can be used in their simplest form by using your feet and walking across fields with map in hand and observing the crop and factors such as weeds, insects, drainage, soil quality cultivation / planting effects. Farmers should not be put off by thinking that variable rate technology (VRT) and associated sampling / scouting costs are required to extract a viable return from precision agriculture. They may miss the opportunity to gather some very cost effective data in the form of yield contour maps for their fields. Generally three to five years of yield maps for a field are required before it will be obvious how inputs such as agrichemicals, cultivation, fertiliser and seed should be economically adjusted across a field. These decisions can and should be made at a later date. Even three years of yield maps may not be enough as two of the three may be unusually dry or wet although extreme years may in fact help to segregate discrete management units in a field.

Conclusion

Until recently the author was immersed in a business which used precision agricultural systems to provide yield maps for clients and for a cropping operation. After three years of experience the owner of that business is unsure as to what his next step should be in terms of further investment in the technology. The benefits of the system were there and observed in terms of identifying and quantifying some obvious limitations to yield. However, there is a feeling that the system has not quite delivered on expectations. The next step should be focused on providing the information the decision maker needs to know in order that he can maximise his profits. This is important to the farmer and should be the focus of the workers in this area.

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