



Australian Centre for Precision Agriculture



The University of Sydney

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

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Programme of Presentation

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Welcome

We'd like to welcome you all to our sixth annual symposium. This year we're back at the University of Sydney. We have visitors from all over Australia and New Zealand as well as people from as far a field as France and Croatia. Welcome.

The program is a diverse and healthy one, consisting of a variety of topics, problems, commodities and points of view. We'll hear about the latest research in Australia, New Zealand and overseas and update ourselves on commercial activities and policy issues.

As we have said in the past, that while we have a very responsive and well-educated grower community, progress in precision agriculture (PA) in Australia has been somewhat hampered by the level of research investment as compared with overseas. Over the last year perhaps the most significant single development in Australia has been GRDC's strategic initiative on precision agriculture. We'll get the lowdown on that.

There has also been an increased interest in PA from established farming groups around the country, culminating in the formation of the first industry-wide PA association. The Southern Precision Agriculture Association has grown from the enthusiasm and foresight of farmers and advisors in SA. We'll hear from the President today and you can read the inaugural newsletter and access membership forms from the ACPA website.

While we are on the ACPA, we have made significant progress in developing our mapping and management zone farming system which is now ready to be implemented and tested around the country. On the training side, the 2002 undergraduate class in PA was the largest we have had in the 5 years the course has been offered - a philip we hope to service and consulting enterprises.

Finally, it seems that the consequences of the El Nino/La Nina cycle have turned dramatic again for Australia. A fitting time to consider what PA may be able to do for us in drier than average conditions. Can we identify the within-field zones where investment of inputs can be made, and those where investment should definitely not be made? This kind of question will help us improve our understanding of the link between spatial and temporal variation, and the responses required to achieve optimal management.

Today is about sharing experiences in PA so that the whole industry may benefit. Enjoy what the speakers have to say, feel free to participate in discussions, both formal and informal, and we hope you make some valuable contacts.

Staff & Students

The Australian Centre for Precision Agriculture, The University of Sydney

Spatial and Temporal Crop Yield Variation - Methods of Measurement & Examples

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

Site-specific crop management (SSCM) is an aspect of precision agriculture that relates to the differential management of a crop production system in an attempt to:

- a) maximise production efficiency
- b) maximise quality
- c) minimise environmental impact
- d) minimise risk

From a scientific point of view the success of SSCM in a particular field rests on disproving two null hypotheses.

- a) Management of variability at a finer spatial resolution than is currently undertaken would not be an improvement on uniform management
- b) Given the large temporal variation evident in crop yield relative to the scale of a single field, then the optimal risk aversion strategy is uniform management

The first hypothesis relates to the magnitude and spatial structure of crop variation and our ability to quantify this variation. If the magnitude of variation is too small to economically justify the additional capital investment and on-going information costs of SSCM then uniform management is the preferred management strategy. The magnitude of yield variation required to justify SSCM will differ between production systems depending on the value of the crop and the cost of the technology. As well as the magnitude of variation the spatial structure of variation will also determine whether SSCM is preferable to uniform management. If a field exhibits little spatial structure i.e. variability is random or akin to white noise, then given the spatial limitations of current technologies SSCM is unfeasible. Fields exhibiting strong spatial structure, e.g. broad trends or large contiguous zones of similar crop production, are more conducive to SSCM.

The second hypothesis tests the stability of this spatial variation over time. Currently much of the data collected on crop production is either retrospective e.g. yield mapping, or done too late in the season, e.g. aerial imagery, to allow for within season differential corrective management or alternatively the management strategy is determined before crop emergence e.g. pre-emergent fertilizer, planting density. This creates a reliance on archived data to provide a blueprint for crop development in future seasons. This reliance is based on the assumption that some of the variability is linked to intrinsic environmental properties that are temporally stable e.g. soil texture, moisture holding capacity, topography etc. Thus, given a certain level of spatio-temporal stability in crop variability, agronomists should be able to use archived records to predict site-specific responses for future crops. However if temporal variability is high then historical data cannot be used with confidence for predictive management strategies. Therefore even with significant magnitude and spatial structure to the crop variability, SSCM is difficult as the location of the variability is uncertain. Quantification of the temporal stability of variation is therefore just as important as the magnitude and structure of spatial variation.

This short exposition seeks to outline some of the more commonly used methods for describing variation in crop production systems and the advantages and disadvantages of the methods.

Application of ASTER Imagery to Crop Management in Queensland

Troy Jensen, Rob Kelly, Wayne Strong, David Butler, Queensland Department of Primary Industries

ASTER (Advanced Spaceborne Thermal Emission and Reflectance Radiometer) is an imaging instrument on board Terra - the first Earth Observing System (EOS) satellite. Terra was launched on December 18, 1999 from the Vandenberg Air Force Base in California and flies in a sun-synchronous polar orbit, crossing the equator in the morning at 10:30.

ASTER is one of the five state-of-the-art instrument sensor systems on-board Terra with a unique combination of wide spectral coverage and high spatial resolution in the visible near-infrared through shortwave infrared to the thermal infrared regions. It was built by a consortium of Japanese government, industry, and research groups. ASTER data is expected to contribute to a wide array of global change-related application areas including vegetation and ecosystem dynamics, hazard monitoring, geology and soils, land surface climatology, hydrology, and land cover change.

Crop Disease Management using Precision Agriculture

John Heap, South Australian Research and Development Institute

Soilborne diseases have the potential to cause major yield losses in Australian field crops. Rotations are often driven by considerations of diseases such as take-all and cereal cyst nematode. SARDI and CSIRO have developed a test for DNA of disease inoculum in soil samples (RDTS) that allows growers to test for major soilborne diseases prior to sowing.

Soilborne disease inoculum has a high degree of spatial variability over short, medium and large distances. Reliable soil sampling strategies are critical to assess the potential disease risk for crops. This paper reports on some early results from a GRDC project (DAS311) that aims to improve the efficiency and reliability of sampling strategies for soilborne disease tests. This includes research on the optimum number of sample cores required, the distribution of inoculum at the crop row level, spatial variability of disease inoculum, and the use of production zones to direct targeted sampling.

Initially 22 paddocks in southern Australia were divided into production zones using proximal data (Whelan, 2001). Targeted soil samples were taken from each production zone and tested for soilborne diseases. There was an average of 4.9 different diseases detected in each paddock. Soil DNA tests from production zones derived from proximal data in this survey gave a different disease risk category (inoculum level) for at least one disease between the zones in all 22 paddocks.

Seven paddocks were chosen for further intensive sampling based on production zones. Production zones were created using two types of data sets:

- a) Proximal data yield, EM38 and DEM; and
- b) Satellite data, NDVI data.

Soil tests from production zones derived from proximal data suggested different disease inoculum levels between the zones in 7 out of 23 observed disease cases, while tests from zones derived from satellite data gave differences in 13 out of 26 observed disease cases. Some diseases (eg *Pratylenchus* spp.) appear to be more strongly correlated with production zones than others (eg Blackspot complex of peas).

Preliminary results from this work show that levels of soilborne diseases are correlated with production zones derived from both proximal and satellite data, and that these correlations have great potential to improve the efficiency and reliability of soil sampling strategies. These correlations also offer the potential for differential disease management at the production zone level.

CropView 2002

Jonathan Sobels, Royal Melbourne Institute of Technology University

CropView is a near real-time (ie. within 24 hours of SPOT satellite overpass) delivery service of remotely sensed crop vigour. The CropView service delivers accurate information on crop growth across an entire paddock. This reduces the risk that an area or problem might be missed in either consideration or treatment. We see the CropView service delivered as part of a tailored agronomic package, with the support of local agronomists and consultants.

CropView delivers its images via e-mail up to six times during the cropping cycle. The service model is applicable to any and all farms across Australia. The combination of accurate information, timeliness, local agronomic support and low cost is ahead of any similar service in the world in 2002. The CropView program seeks the support of subscribers for a pilot scheme from among farmers, farmer groups and agricultural consultants in the Wimmera and southern NSW in 2002.

Background

CropView is based on a prototype that was tested during the 2001 growing season with six farmers in the Wimmera district in Victoria. That experience proved that images can be repeatedly delivered within 24 hours of satellite overpass.

CropView identifies spatial patterns in crop paddocks. Each picture element (pixel) represents the average crop vigour reflectance of an area of 20 metres by 20 metres. Crop vigour is then measured with the proprietary Vegetation Index (VI) algorithm, which evaluates crop health and biomass as indicated by chlorophyll activity. In 2001 CropView supplied a QuickLook image whose spatial variation was relative only to that image. A calibrated Vegetation Index version of the same image was also produced that was relative to absolute values in the landscape, allowing comparison between successive images.

In 2002 the calibration allows a third image to be produced that shows the extent of change in crop activity from one date to the next (not available on ARC Explorer). Participants in the 2001 season preferred CropView imagery to be delivered as part of an agronomic package to realise its information value. In 2002 the CropView monitoring service is priced at 1.9% of the cost per hectare for growing wheat at \$150/ha.

Benefits

The outcomes of CropView monitoring as suggested by growers and consultants include:

- a) CropView acts as a timely trigger to ask appropriate questions about real variation in crop performance as the crop is growing. It displays variation that might be anomalies such as straight lines that are the likely result of human activity; other patterns caused by landscape factors, such as soil type and

moisture, nutrition or topography; or the influence of pests and diseases, or hail and frost.

- b) CropView increases the accuracy and extent of the information about the whole crop, not only those areas seen on foot or by vehicle. This is especially true for large programs when the crop is tillering or elongating and driving over the crop might cause damage. Crop View makes this information available to crop managers and consultants in a visual medium that is easily understood, at a low price and in a realistic time frame that is appropriate for crop management decision making. CropView effectively adds another set of visits to the property by an adviser, allowing crops to be monitored more intensively.
- c) Asking the right questions at the right time about specific parts of the crop is a key part of critical thinking in crop management. With CropView, the farmer brings together diverse sources of information such as spraying and seeding logs, the farmer's memory and local knowledge, yield maps, weather records, soil test results, and farm photographs or other mapping products. CropView is a dynamic forum that involves group or advisor support, which helps to provide explanations and an objective basis for decisions, rather than following recipes.
- d) CropView provides an invaluable set of objective information for those farmers leasing or purchasing new fields.
- e) The sequence of imagery contains useful information not available in a single snapshot, such as yield prediction, crop change in response to damage from disease, pests or weeds, moisture stress, nutritional status and frost damage. Some of this information is not otherwise available, if it is not visible to the naked eye, for example, or is only available at much higher cost, or after the event.

Investigating the relationship between on-the-go yield and protein

Sorn Norng, Queensland University of Technology

Agronomists have used coincidental protein and yield maps to identify limiting factors in both yield and protein. Management decisions can be derived from knowing what and where these limiting factors are. In using protein and yield in this manner, there is a strong assumption on a significant relationship between protein and yield at the local level.

In this paper we investigate whether or not this assumption can be justified. The protein-yield relationship is modelled using weighted regression with global and local neighbourhoods in both 1-D time order of harvest and 2-D spatial location frameworks. The results from both 1-D and 2-D analyses showed that the local relationship between protein and yield is significant at both the macro and the micro-scale. Therefore, the assumption of a significant local relationship between protein and yield may be justified and any management decision determined by using this relationship is feasible.

Precision Agriculture for Pastoral Systems

I.J.Yule and Allan Gillingham, New Zealand Centre for Precision Agriculture, Massey University, Palmerston North, NZ.

Introduction

Pastoral systems have not been strongly associated with precision agriculture in the past as they are often perceived as low value systems and therefore presenting limited opportunity to adopt these new technologies. Pastoral systems dominate New Zealand agriculture and are an important part of the economy, it is therefore important to examine the potential of P.A. to our systems. A number of features of pastoral systems lend themselves to P.A. They are highly variable, variable application of fertiliser has a stronger correlation with dry matter production than it does with seed yield in cropping systems. It is a simpler system and fertiliser is its main variable cost. We need to improve our utilisation of fertiliser for both environmental and economic reasons. It is therefore necessary to re-assess the management scale at which we operate.

Both intensive dairying and hill country systems are examined. Different methods of fertiliser application are used, in the case of hill country aerial spreading from aircraft is the preferred method of application. From an environmental standpoint, phosphate is the main problem in hill country while nitrogen is the main problem under intensive dairying. In both cases we want to stay clear of waterways and water bodies.

Most New Zealand livestock sectors have a declared an intent to increase annual production level by 4 - 5 % per annum. One way to do this would be by adopting precision agriculture.

Hill Country Systems

The concept that we have developed for cropping through the work of the New Zealand Centre for Precision Agriculture is to try and encourage the farmer to think in terms of management zones. This is not a new concept, the idea of Land Management Units (LMU's) was proposed in New Zealand as far back as 1973 by Alan Gillingham, in Gillingham and During (1973). They examined 5 differing zones in the Waikato with annual pasture production ranging from 14,800 kg DM ha⁻¹ to 4,500 kg DM ha⁻¹. Does it make sense to treat these five zones the same?

What has happened in recent times is that technology has allowed us to consider variable rate inputs on a scale and at a price that is feasible. The objectives of the work are to:

- a) Improve utilisation of fertiliser to increase efficiency of production
- b) Assist pilots in accurate and effective spreading
- c) Reduce adverse environmental impact from misplaced or mis-applied fertiliser

Agricultural pilots have a tradition of using GPS for guidance but only recently have steps been taken to provide systems to control and or record (map) the application of fertiliser. The centre has experience of two systems, one, a NZ system which is still in the final stages of development and the AgNav system. The AgNav system logs the flight path of the aircraft and boundary files can be put into the AgNav computer which will

give the pilot a screen view of his present position on the block he is about to spread. This system has not been used for variable rate application.

The other systems operates in a similar way but has the ability to variably apply fertiliser according to a treatment map loaded into the aircraft. This maps is derived from a digit elevation model DEM and the fertiliser rates recommended on the basis of earlier work such as that produced by Gillingham and During (1973). The severity of slope and the aspect is derived from the DEM and each category within the area to be spread is mapped and boundaries formed. Within the presentation part of a grazing station is illustrated and the slope are categorised are presented in Table 1. The map of part of the property is illustrated in Figure 1. The area highlighted demonstrates the systems, the area is 15.12 ha under a uniform rate of 200 kg ha⁻¹ a total of 3024 kg would be required, under the variable rate 2890 kg were required, but importantly it was put on areas that could better utilise the fertiliser.

Code	Properties	Total area ha	Area ha. Highlighted	Fert Applied
1	North slope < 20 deg	68	7.2	1800 kg
2	North slope >20 deg	53	1.9	190 kg
3	South Slopes	60	Nil	Nil
4	East and West	255	6.02	900 kg
5	Bush	16	Nil	Nil

Table 1. Slope and Aspect categories for part of station

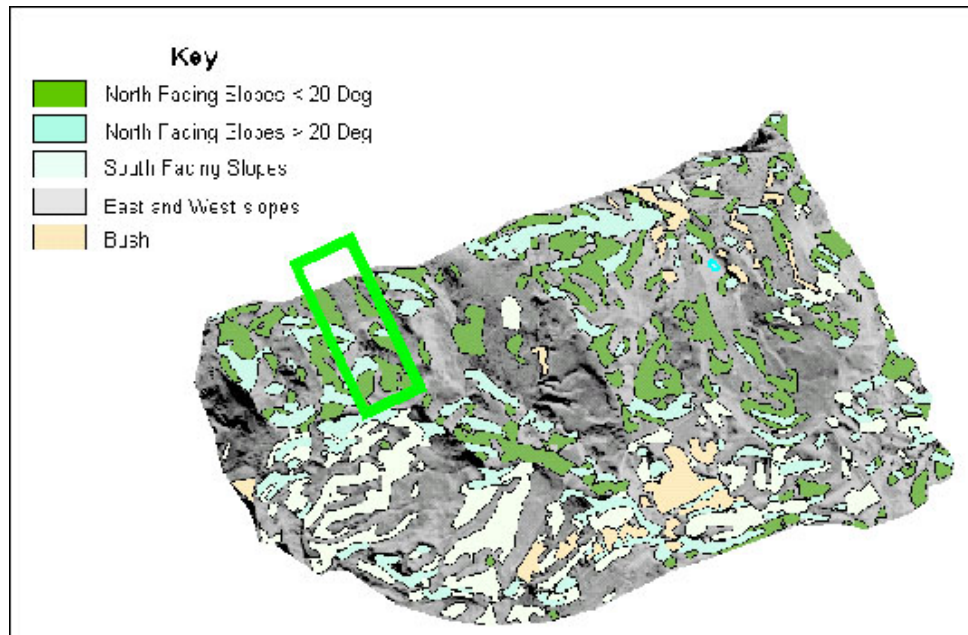


Figure 1. Slope and aspect categories superimposed on orthophoto, (Grey scale removed). Area relating to Table 1 boxed

The controller onboard the aircraft has the ability to change the rate of application as it flies over. The application is tracked, recorded and a permanent record kept. The system is under test on a number of properties.

Opportunities to improve production efficiencies from aerial fertilizer application are derived from the following

- a) Product value low but variability high.
- b) Relationships between input and yield easier to define.
- c) Better utilization of fertilizer which is main variable cost.
- d) Assist in planning of application process.
- e) Assist pilot, (Guidance within areas to be spread, automatic control of hopper doors).
- f) Reduce error level to decrease environmental impact. Avoid water bodies etc., better control of spreading rate.
- g) Tracking to provide environmental and economic audit.

Intensive Dairy Production

Under intensive dairy production the following areas are seen as important:

- a) Animal behaviour
- b) Spatial variance of forage growth
- c) Forage utilisation under intensive grazing
- d) Variability of production costs

The advent of cheaper DGPS units means that it is now feasible to use individual GPS units to accurately track animals. This can be useful to study the grazing behaviour of individual animals to match it with grass measurement studies. Work by Woodward (2001) indicated that not only was the sward production variable but the cows utilisation of the sward also varied. This has a significant effect on the economic performance of the system. Grass variable cost was taken as an average of 5 cents per kg of dm. over the whole farm. But within individual paddocks the effect of the spatial variability meant that the true variable cost varied from around 3 cents per kg of dm. to 10 cents due to the varied response to fertilizer. The variation was clearly non-random and had a spatial relationship with soil type and the presence of trees being important factors. In terms of milk production cost the reality was that the annual variable cost of grazing an animal producing the herd average of 310 kg of milk solids would vary between NZ\$120 and NZ\$400. Clearly a significant difference in input costs.

From the studies conducted so far a number of conclusions can be drawn:

- a) Clear opportunities to add intelligence to the way we manage pasture based dairy production systems
- b) Grass production clearly spatially variable, relationships between yield and inputs more easily influenced than cropping systems.
- c) Intelligent fertiliser planning year round. (areas prone to drought treated differently to heavier textured soils)
- d) Spatial variability has very strong influence on financial performance.
- e) New technology allows linkage to be made between animal behaviour and forage utilisation.
- f) Environmental accountability and reduced adverse impact.

- g) With additional information such as EM and topography better design of irrigation systems and effluent disposal.

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A Low-Cost Method for Estimating Nitrogen in Pastures

David Lamb, Physics & Electronics, School of Biological, Biomedical and Molecular Sciences, The University of New England

Nitrogen is one of six macronutrients that are essential for pasture growth; it is necessary for the production of protein and chlorophyll and these are essential for plant development, yield, post-grazing regrowth and reproduction. Protein or non-protein nitrogen are required by grazing ruminant animals to sustain microbial activity in the rumen and ensure an adequate supply of microbial protein for subsequent digestion.

In-field fertilizer-response trials have long been used for determining the “adequacy” of nitrogen levels in pasture production; however, they are increasingly expensive and extrapolation to nearby soils is unreliable. Direct measurement of leaf nitrogen concentration in pasture grasses, either as a means of assessing pasture condition or nutritional value, is completed on pasture samples in the laboratory either by a chemical process known widely as the Kjeldahl technique or using near infrared reflectance spectroscopy (NIR). Because both Kjeldahl and NIR processes involve field sampling and preparation (usually oven drying) of pasture samples prior to laboratory measurements, the determination of nitrogen in pastures can be time consuming and expensive, especially when large numbers of samples are involved. Furthermore, the chemicals associated with the Kjeldahl technique makes it potentially hazardous to the user.

Plant canopy reflectance in visible-near infrared wavelengths is predominantly influenced by chlorophyll-related plant pigments (400-700 nm) and leaf cell structure (600-900 nm). Therefore, plant nitrogen levels would be expected to influence canopy reflectance in these wavelengths. Reflectance spectroscopy is potentially a low-cost, in-situ and convenient means of estimating nitrogen status of green pasture. Reflectance spectroscopy involving the use of visible-near infrared wavelengths, and in particular features of the “chlorophyll red-edge”, have been investigated by numerous workers for delineating different levels of chlorophyll in plant canopies. The chlorophyll red-edge describes the region of steep positive gradient in the reflectance spectra of chlorophyll-containing plants in the range 690-740 nm.

In this present work, chlorophyll red-edge descriptors have been used directly to estimate leaf nitrogen concentration in ryegrass (*Lolium* spp.) pasture. The process involves extracting values of the “red-edge wavelengths” from measured spectra by fitting a complex mathematical function to the acquired spectra. In an experiment involving one-hundred samples of ryegrass of different nitrogen levels, changes in the descriptors used to describe the chlorophyll red-edge were observed to explain 60 % of the variance of leaf nitrogen concentration. The resulting regression equation was found to predict leaf nitrogen concentration, in the range of 2% to 5.5%, with a standard error of prediction (SEP) of 0.4%, confirming the potential of using the chlorophyll red-edge as a biomass-independent means of estimating nitrogen concentration in ryegrass pastures.

The Fallacy of Management for the Average - Another Lesson from Precision Viticulture

Robert Bramley, CSIRO Land and Water and Cooperative Research Centre for Viticulture

Precision agriculture (PA) research has demonstrated that crop variability may be very significant, irrespective of the crop of interest. Both winegrapes and sugarcane, for example, show coefficients of variation in yield of 35% or more within single blocks, very often accompanied by strong spatial structure in this variation. This sort of knowledge is starting to elicit considerable change to the process of crop management, and many farmers are adoption at least some of the elements of PA. Less evident however, are changes to the methodologies employed to underpin Australia's rural industries, particularly amongst researchers working outside the domain of PA. As PA researchers and practitioners, participants at this meeting might ponder why this situation exists? Do we have a credibility problem? Why do many of our agronomic colleagues still favour white pegs and randomised blocks?

Drawing on an old grains, and new winegrape example, the purpose of this presentation is to elicit change in the research process employed in support of crop management, and to suggest that maybe we need to start influencing our colleagues as much as our funders and clients.

Variability, Crop Rotation & Cultural Practices - the NZ Experience

Murray Craighead¹ and Ian Yule²

¹Nutrient Solutions Ltd

²New Zealand Centre for Precision Agriculture

Although in New Zealand paddock sizes are small by Australian and US standards, treating small areas differently can be justified because yields are good, crop values can be high and there is reasonable moisture security. This paper looks at lessons we have learnt to date in two arable precision agriculture projects in deciding whether differential treatment is justified.

The decision to apply differential treatment must consider:

Seasonal issues: Three years cereal results strongly demonstrate the greatest gains are made in drier seasons where the limitations of soil texture and depth and therefore moisture retention are more evident.

Performance zones: In isolating different production zones within paddocks and differentially applying N, the best gains were made in applying N to the already above average performing parts of the paddock. Further, in two irrigated paddocks it was those areas slightly below the best performing area that responded the most suggesting that as moisture limitations were reached N became the limiting factor.

Crop Issues: Economically, the justification of differential treatment will depend on a specific crop's returns. Using one paddock as an example, the type of wheat (milling vs feed) or barley (malting vs. feed), the current price and risk of quality damage, dictated how much of the paddock could receive further N. Further, in areas where it was of marginal benefit to add extra N it was probably better to reallocate N within the paddock rather than use extra N.

Cultural Issues: Having identified zones that are physically different and perform differently we are finding one does not always perform better, sometimes it performs poorer. This is because while better soil moisture retention properties may give better dry matter production, and while this leads to better cereal and Brassica seed yields it is counterproductive to better grass seed (and I suspect small legume seed) yields as it encourages vegetative instead of reproductive tillers.

Operational Issues: Easiest economic gains can be made by minimizing crop damage. Irrigation hoses and water jets and large turning areas dragging down large areas of crop, all reduce production. Using turning areas to suit adjoining paddocks or farm tracks and the orientation of tramlines and irrigation passes to suit long runs, preferably running parallel to water courses or soil type changes all help.

One off changes: Paddock monitoring can identify problem areas such as wet patches that can be overcome by localized drainage. Plant establishment associated with shading

can be overcome by thinning or removing shelterbelts on Northern boundaries and also reduces nesting sites for birds which attack seed heads.

Crop measurements considered important in future work
(once soil is characterized):

- a) moisture measurements coming out of winter (to check if over wet) and leading into summer (proneness to drought)
- b) dry matter as related to above moisture / crop development
- c) soil pH is becoming more important as N rates are high and transient trace element issues arise (macronutrients can be checked less regularly)
- d) those parameters measured closer to harvest show better correlations with yield and may lead to altered management in the future
- e) looking at the extremes in paddock performance seem the best place to concentrate future short term measurements

Southern Precision Agriculture Association

Malcolm Sargent , President, Southern Precision Agriculture Association

SPAA was formed following an inaugural meeting of people involved in agricultural industries at Roseworthy in April 2002. Financial assistance from the SA Grains Industry Trust has been significant in providing seed funding for the association. We are interested in input from other agricultural industries. SPAA have initiated a comprehensive program for its first year of operation, beginning with a Precision Agriculture Workshop at the Roseworthy Information Centre at Roseworthy Campus on Wednesday the 4 th September 2002. There will be guest speakers, workshops and technical presentations on the latest precision agriculture technology by farmers, PA manufacturers and Scientists.

The SPAA committee which consists of elected farmers, consultants and scientists have appointed Dr Rohan Rainbow as their Executive Officer and Dr Allan Mayfield as their Trials Coordinator. SPAA have already initiated some PA variable rate fertiliser application trials in SA at Crystal Brook, Snowtown and Stockport. These trials will be highlighted during the SANTFA Crop walks in July.

The SPAA committee is encouraging interested farmers, advisers and manufacturers to join SPAA which has a low membership fee of \$55 (inc GST). Members will be kept up to date by electronic email of coming events and also interesting electronic articles associated with PA. SPAA can be contacted on (08) 8842 1568 or by email at info@spaa.com.au for a membership form.

Precision Agriculture - Industry Perspective

Ole Hansen, Farmscan

The Farmscan product brand is a registered product trademark owned by Computronics Corp Ltd, a public unlisted company, founded in 1976 by Ole Hansen the present day CEO and technical director. Computronics Corporation Ltd is wholly Australian owned and has grown to be the largest agricultural electronics manufacturer in the southern hemisphere and is a significant player in the global market.

Farmscan products offer a complete range of machine control and guidance solutions for infield operations in grains, cotton, and the viticultural market segments. The products are innovative, user friendly and extremely well priced against international competitors.

The company provides a range of 'boxed' aftermarket products through an established dealer network and is the major supplier to manufacturers of seeding, spreading and spraying equipment in Australia and New Zealand. The company employs a total of 65 people involved in product design, manufacturing and customer support. Farmscan have established an office in Europe (Farmscan EU) based in Denmark to develop OEM market opportunities.

Computronics Corporation has a significant ongoing investment in product R&D with a team of 13 engineers and support staff dedicated to developing new products and tailoring products to meet specific OEM or market requirements. The company has established semi-automated production facilities with the capacity needed to meet both short and long production runs in a controlled environment.

Practical Field Experimentation - Optimising Design for Economics and Risk.

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

One of the key issues we face is the development of strategies for within-field management. This could be either through management zones or continuous moving-window management. Take the case for example, fertilisers, here we would like to know the response function for different management zones within the field or as a continuous function of spatial coordinates. Variable-rate technology allows the setting down of sophisticated field experiments in farmers' fields by the farmers themselves to acquire this knowledge, and yield-monitoring technology allows the measurement of response.

The spatial design of such "on-farm" experiments are in their infancy. Where the object is to produce a local moving-window response function, and one is not concerned about the grower's production from the experimental field, systematic designs such as a modified "draught board" or an "gg-box" design (sometimes called a two-dimensional sine wave) have been used. These designs are highly invasive, in the sense that they can impact heavily on a farmer's production and therefore may be very expensive. Our experience with such experiments suggests farmers do not like to apply very low rates of inputs in case they impact heavily on production.

Perhaps more practical, less-invasive, designs are needed. Designs that potentially can be used in every paddock, on every farm and which we believe are crucial for the implementation of site-specific crop management. For paddocks, divided up into management zones, an efficient design would seem to be the "fleck" design where randomised block experimentation is done with spatial constraints and economic considerations. The economic consideration being that one does not want to penalise the grower's expected profit by using sub-optimal application rates over much of the field. Most of the field can have a uniform treatment which the grower considers his best practice. Data from all of the field can be used in the analysis. The proper objective function and design for these experiments have yet to be developed, but an approach homologous with the use of spatial simulated annealing for spatial sampling, seems the most obvious one.

Here we make a first tentative attempt at such a design. The objective function is divided into two parts. First, we select designs that meet the economic criterion of $x\%$ penalty on expected profit. The consensus (in Australia) seems to be that x should be no larger than around 2.5. From those candidate designs we optimise the position of the plots in some biometric sense. The two parts could be placed in the single optimisation if an appropriate loss function could be developed :- this is difficult and is not attempted here.

We give an example, for a 70 hectare field in Eastern Australia. The field has three management classes spread over some 18 parcels or zones. The agronomic question to

be answered is do the three management classes have different response functions for applied nitrogen for wheat production?

The field is laid out with controlled-traffic tramlines (another product of GPS technology) 9.14 metres apart. The sowing and harvesting equipment travel on these tramlines. The sowing equipment treats a width of three tramlines, whereas the combine harvester travels down each tramline. From previous experiments, a length of 100 m is required to obtain a 50 m section in the middle where one can be assured of a fixed amount of applied N and a good estimate of yield. So plots in this field are ideally 100 m long running along the tramlines by 27.42 m wide. The usual N application rate is 100 kg/ha. To proceed we need to make a number of assumptions, we assume:-

- a) The farmer has through trial and error has discovered the optimal rate for the field,
- b) The response is quadratic with a maximum at 100 kg/ha
- c) The response is one half the maximum at zero applied nitrogen.
- d) The maximum rate to be applied is 150 kg/ha.
- e) The field has an expected uniform response function with its maximum at the long-term average for the field, 4.7 Mg wheat /ha.

This gives us an expected response function, along with fixed costs, cost of fertiliser and the price of wheat we can evaluate various designs with 3 management classes and 1 nitrogen levels equally spaced between, and including, 0 and 150 kg N /ha. The results for x are shown for one paddock. The “best” design that falls under the $x < 2.5\%$ criterion is that with 5 levels of N (l) and two replicates (r). No three replicate designs meet the criterion. For this design, it is worth noting that $x = 2.34\%$, the experiment takes up 8.22 ha of the 70 ha, and costs around A\$20/ha in expected lost production per annum.

We also show a randomised layout for the five N level and two replicate experiment. It is not completely random because the plots are spatially constrained to fit onto tramlines and must not cross class boundaries. It is worth noting here that the rest of the field will receive 100kg N/ha and there are around 225 “plot equivalents” (areas the same size as the “reatment” plots) that receive 100 kg N/ha. The thirty “treatment” plots are then spatially optimised in the D-optimal sense using the variogram of residuals from the expected management class mean yields under a uniform 100kg N/ha treatment. The class means and residual variogram are derived from a prior yield map.

The residual variogram is $g(h) = C_0 + C(1 - e^{-h/a})$, with $C_0 = 0.12 \text{ Mg/ha}^2$, $C = 0.61 \text{ Mg/ha}^2$, and $a = 330 \text{ m}$. The spatial optimisation is achieved by simulated annealing.

We have arrived at an economically, agronomically and biometrically optimal design. This is a start that we would be comfortable to recommend to farmers to implement for two to several years. In Australia this would be for an El Nino / La Nina cycle. In reality, the design is only partially optimal because we have not allowed for the optimal choice

of N levels or for the fact that 100 kg N/ha is applied over 92% of the field, so further enhancement is necessary.

We shall not discuss the analysis of these experiments here. It is worth noting that the observations of yield are at a much finer resolution than the plot scale, so there is the opportunity for a more detailed spatial analysis, once again global maximum likelihood will be difficult with the large number of yield observations. Local methods are perhaps preferable in any case.

There is no doubt that there is a huge potential for new field experimental designs and analyses for use in site-specific crop management. It is important that these are delivered in user-friendly software that can be used by agricultural consultants and growers. The prospect is one of properly designed and implemented experiments on most fields on most farms.

Economic and Environmental Benefits /Risks of Precision

Agriculture

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This project is concerned with the development of methods and tools for the assessment of the economic and environmental benefits and risks associated with technologies that address spatial variability in Australian farming systems. Crop simulation models, economic models and spatial analysis techniques are being deployed in case studies involving participation of farmers and their advisors. The broad focus is on exploring alternative farming system designs that exploit spatial variation on farms e.g. at a paddock scale (precision agriculture) and at a whole farm scale (mosaic farming) through crop management and enterprise mix in relation to soil variability (e.g. precision agriculture) and lateral hydrological processes (e.g. mosaic farming).

Background to research

The decision problem of farmers applying precision agriculture technologies

The 3 key stages involved with applying precision agriculture technologies to a particular site on a farm are:

- a) Data capture e.g., generating yield maps or some other spatially referenced information
- b) Data interpretation e.g., how to explain the observed variation.
- c) Taking informed action to manage spatial variability e.g., managing variation on the farm to achieve an economic and/or environmental benefit

Discussions with collaborating farmers and precision agriculture advisors at the outset of this project revealed that a problematic area for precision agriculture practitioners is the knowledge gap between the operation of precision agriculture technologies (Step 1) and the final step of taking informed action, based on the data captured, to manage spatial variability (Step 3). A big issue that has emerged in our discussions is the interaction between spatial and temporal variability and their respective interactions with management practice.

Precision agriculture provides the capability to capture large amounts of detailed data on farm performance (Step 1), but the capturing is not enough. Because obtaining and applying spatial information presents the property planners with substantial costs, there is a need for economic information about profit potential and risk management implications. To date, much attention has focused on the technical aspects of precision farming technologies in the absence of a framework in which to assess the economic and environmental benefits, or allow for consideration of variability which occurs over time.

Research approach

This project is exploring issues in steps 2 and 3 of this problem mentioned above. A “bio-economic” analysis framework is being developed to encompass implications of spatial management options at both whole farm or multiple farm (e.g. in relation to mosaic farming) and within paddock (e.g. in relation to precision agriculture) scales. The framework will be applied to case studies involving key stakeholders (e.g. landholders, agribusiness) to identify useful ways in which management systems that seek to capitalise on spatial variability e.g. through crop management and enterprise mix in relation to soil variability and lateral hydrological processes, can be designed and evaluated. In particular it will address the issues of space x time x management interactions.

Agricultural Production Systems Simulator

A key component of our approach is the use of the Agricultural Productions Systems Simulator (APSIM) - a simulation model that has been used extensively for the management of cropping systems. Simulation models can be used address the difficulties involved with interpretation and management of spatial variability resulting from temporal variation, by enhancing understanding of temporal x spatial interactions when factors such as soil input parameters are modified to account for spatial variability. A strength of the modeling approach is it allows year to year variability to be explored and, in conjunction with long term weather records, overall risks to be assessed. A tool that can allow for the assessment of temporal variability has a potential role in both interpretation and assessment of possible actions taken in precision agriculture. With our collaborators, we will explore how APSIM can be combined with economic analysis to provide a framework to explore the nature and consequences of spatial variability in farm paddocks.

Case studies

We are exploring the issue of interaction between spatial and temporal variability, and how this has implications for the actions taken by a farmer to manage cropping land, with three case studies in NSW, based on farms where yield monitors have been used to map spatial variability. At all three sites we have assembled existing data for the particular paddocks of interest (eg yield maps, economic data) and have completed field measurements at selected points across each paddock to obtain farm-specific soil and weather data. These data sets were produced to enable the application of production systems simulation, using APSIM, to explore such temporal x spatial issues for these case studies. The first step in this process - benchmarking the simulated crop yields to actual crop yields - has been completed. Using simulation, preliminary bio-economic analysis of selected spatially variable management practices (e.g. varying crop inputs) has also been conducted. Together with our collaborating farmers from the three case study sites and our broader project consultative network, we have met to discuss and interpret results, and agree on spatially variable management scenarios requiring further investigation during the project.

Support

The project is supported from the Resilient Agricultural Systems Program of RIRDC.

GRDC National Precision Agriculture Initiative- Managing Variability

Phillip Price, Mackellar Consulting Group

Precision Agriculture (PA) technologies are evolving rapidly around the world. The GRDC wishes to make coordinated and strategic investments in this area to ensure Australian grain growers benefit from advances in these technologies.

For the purpose of this initiative, precision agriculture is defined broadly as, “Information-rich agriculture. The use of yield maps, other spatial information and input control technologies to increase the precision of paddock management, leading to increased profit and environmental benefits”. The primary goals of the initiative are to develop practical methods that enable growers to recognize, locate, and manage landscape variability in order to improve profitability and environmental sustainability, and to substantially accelerate the adoption of PA methods by Australian grain growers over the next five years.

The GRDC intends that this initiative will cover all aspects of using PA systems on farms, including understanding the underlying causes of landscape variability, information capture and analysis, improved agronomic practice, economic analysis of PA farming, decision support, machinery for in-field crop management, and training programs. This initiative will utilise and build on advances in controlled traffic and precision guidance systems, and raised bed cropping systems. It will also establish close links with business that has a vital role to play in delivering practical and efficient systems to growers.

A Roundup of Developments from the 6th International Conference on Precision Agriculture- Minnesota July 2002

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

The 6th International Conference on PA was held as usual in the international metropolis of Minneapolis. There were 549 participants involved in presenting or attending 136 general session papers, 101 poster presentations, 26 commercial displays, 25 interactive sessions designed for growers and the agribusiness community, 8 software demonstration presentations, 4 hands-on workshops and 1 conference dinner that now allows participants to exchange cash for beer.

The crops under consideration included wheat, corn, soybeans, cotton, canola, barley, peanuts, grapes, rice, coffee, sweet potato, oil palm and pasture species. Evidence of the broad potential impact PA has on world agricultural production.

So briefly, what happened?

- a) There was a number of soil sensors shown under development or in production: a real-time soil spectrophotometer; soil profile compaction sensor; profile compaction/EC sensor; bipolar EM instruments.
- b) There were a number of recently developed/improved crop sensing systems: the Hydro N-Sensor and the Greenseeker from NTech.
- c) Much was presented on the use of remotely sensed imagery in the detection of crop biomass, yield, fertiliser response/requirement, management zone delineation. Some use in weed detection.
- d) A greater increase over previous years in interest/testing/application of guidance systems
- e) A whole afternoon spent on various ways to define management zones, with many still trying to over complicate the situation and also forgetting the yield/bottom-line aspect. (surprisingly the latest industry survey suggests grid soil sampling is increasing despite the progress on management zones and the obvious use for directed soil sampling)
- f) Many presentations providing evidence for the usefulness of real-time soil ECa measurements, however no real indication that work is being conducted on calibration/interpretation of the instruments to the soil factors of influence.

There was quite a few commercial companies offering analysis and interpretation of PA data, with the majority concentrating on remote sensed imagery. A number of new products will be available here in Australia in the short-term that may help progress the cause of PA.

But the most exciting and promising aspect of the conference was the revelation by the Evans Property orchard company of its vertically integrated system which combines excellent spatial data with non-spatial production data at all levels of production. From the soil/crop interactions through harvest, transport, marketing and business management - it shows a company totally committed to the full philosophy of PA. If one company can do it, then there is great hope for the rest of us.

Commercial PA Services

Andrew Smart, Precision Cropping Technologies

Precision Cropping Technologies P/L is an outcome focused business specialising in Precision Agriculture. PCT was founded by Colin Lye, Broughton Boydell and Andrew Smart to service, in particular, the cotton industry of Australia. PCT's aim is to provide outcomes through action plans that allow growers through agronomy and management to make decisions using technology with a positive ROI.

PCT is a fully commercial P/A consultancy business dealing in only data acquisition, processing and analysis. PCT fills the missing link between data collection and its ability to help agronomist and management make informed decisions. Even though the initial focus was in cotton, innovative farmers in other industries have recognised the ability of PCT to produce results. Therefore PCT is gaining a reputation in other farming sectors interested in gaining value and an ROI from P/A.

This presentation is about the commercialisation of PA and how important it is to the farming sector to have commercial business focused on PA, and from a business perspective, how important it is that research is being turned into commercial reality.

Precision Ag. Are We Being One Dimensional?

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Introduction

In the fifteen years that precision agriculture has been going, what progress has been made? We started by suddenly discovering that we could be two dimensional in our approach to describing yield. We no longer had to work with averages, we saw the degree to which yield varied and identified the clear financial opportunities that this created. At first there was an anticipation that all we had to do was match our yield variation to nutrient levels, alter our recipe and we would fix the situation. Clearly this was somewhat naive.

In the late nineties the advent of affordable RTK DGPS allowed us to become three dimensional, this offers a huge range of possibilities. Alex McBratney (2000) "EM and topography, a great deal of information". The level of accuracy achievable with RTK allows us to use GPS for a huge range of tasks in terms of creating an efficient agricultural resource, describing that agricultural resource and operating efficiently on it.

Longer term studies such as the one reported by Craighead (2002) demonstrate the importance of temporal variation, the fourth dimension. Clearly climate and climatic variation is a very important driver. In the case of New Zealand, weather has a huge influence on crop yields. In some years soil moisture deficit may be the most important factor, while in others the crop protection programme will have a pivotal role in determining final yield. We are only as strong as the weakest link in the production chain, that chain will be tested at different points according to the temporal variation. Management is a time dependant activity, therefore our management system has to cover all four dimensions. Again it is clear that the idea of timeliness of operations is hugely important.

The central argument in this paper is that although the technology has changed significantly in the last 3 - 5 years, our general perception of it has been largely very one-dimensional, expressed in the original concept of yield mapping and variable rate treatments. The way we try and quantify the benefits of the technology is also very much agriculturally driven and passive in the sense that the gains from improved performance have not been adequately examined. It is these gains that will drive our production systems forward from being "mechanized" to "mechatronic-ised". Precision agriculture is simply the first step in the development of agromechatronics and the wider use of information technology in our land based industries.

What the first generation of precision agriculture tools has taught us.

The first generation of P.A. applications gathered momentum in the early nineties but these early adopters have not been followed by an increasing wave of users. Two main reasons appear to be offered by non-adopters, first, lack of conclusive evidence that the

yield mapping - variable rate control loop will produce a consistent payback. Second; the level of complexity and the fact that many new and unfamiliar skills are required.

Moving into unfamiliar areas was not restricted to farmers, machinery manufacturers saw the opportunity for additional sales by developing new products and creating their individually badged P.A. system. In some cases this has appeared to be successful, others have not. The level of design is improving from a fairly crude first generation. Efficient and reliable data recording, handling and storage methods were not adequately considered and this created many difficulties for users. Systems quickly filled with unnecessary data and lack of reliability caused user frustration and made others very wary about getting involved. There does appear to have been a change in attitude in the last few years. Many companies underestimated the cost of developing such systems and over estimated the sales. This situation has encouraged them to utilise specialist companies for their development.

Companies new to the agriculture sector that had previously worked in other electronic and control application fields also saw an opportunity. One of the main problems they encountered was in achieving the level of sales and field support for their products. Farmers traditionally enjoy a high level of service provided through extensive dealer networks which are expensive to run. Servicing this dispersed market with a very low level of service expertise, low user knowledge and an unfriendly environment for electronic devices has also proved problematic for some. A number of precision equipment manufacturers are now selling via large agricultural equipment manufacturers to overcome these issues.

The technology relies on specialist GIS software, these systems generally represent data in 2 or 3 dimensions and require at least some level of training to operate them efficiently. They are generally used to give a physical or statistical description of the data rather than be totally geared towards management decision making. These systems have some way to go before they can be used for seamless management decision making. There are a number of issues surrounding who is the best person to carry out this task, the manager is the decision maker but is that manager necessarily the best data processor.

Second generation opportunities

Are we at the same stage with agro-mechatronics that we were with agricultural mechanisation 70 - 80 years ago?

There has been a significant change in technological development in the last 3 - 5 years. Many of the problems outlined previously are being addressed and we are beginning to see an increasing level of opportunity created through developments in the enabling technologies we apply to our industries.

The increasing affordability of accurate DGPS is a good example of where the enabling technology becomes affordable. Units are now being sold to the land based industries in increasing numbers for applications such as guidance and machine control. Driver assistance, by lightbar or other guidance device has been around for a number of years,

as has RTK and DGPS for auto-piloting vehicles. The sub-meter DGPS receivers will now allow systems such as the Trimble AgGPS EZ-Guide system to be used much more readily.

Buick (2002) gives an extensive explanation of DGPS accuracy issues. The difference between static accuracy and dynamic pass to pass accuracy is explored. A rule of thumb is presented that a GPS receiver provides a relative pass-to-pass accuracy that is 2 to 3 times more accurate (i.e., a lower value) than the same GPS receiver's absolute accuracy. Buick presented that this rule of thumb is dependent on a number of variables. Further data that indicated under favourable GPS conditions using WAAS the factor of improvement from static to dynamic pass-to-pass accuracy was a factor of five. Taking the Trimble AgGPS EZ-Guide system from a static horizontal RMS error of 50 cm to a pass-to-pass error of 9 cm under ideal GPS and WAAS conditions. Also presented was a list of applications that can be achieved by varying classes of GPS receiver (Buick 2002). The results are summarised in Table 1.

This second generation of receiver and controller solutions will allow the greater use of control systems within harvesting and other field operations. Yule (1999) demonstrated the significant savings that could be achieved by something as simple as driving in the correct gear and throttle setting. As saving in cultivating cost of 35% was demonstrated, differences in cost while operating on slope and in compacted soil were also observed from a fully instrumented tractor and implement combination. Fully automated and optimised vehicles may be the third generation of precision farming tools.

Economic examples

A number of payback examples can be given, it should be remembered that one receiver can be used for a number of different purposes as illustrated in table 1.

Potato mechanisation: \$800 spent per ha on mechanisation, (NSW Agriculture Web Page from <http://www.agric.nsw.gov.au/reader/2897>) \$232 on cultivation. \$560 on harvesting. Improving the efficiency of cultivation equipment will be of major advantage. Opportunities for steering systems on larger rigs will also help to relieve width limitation while extending working hours. Being able to reduce these costs by just 10% would present a considerable opportunity. Reducing timeliness losses will be an added advantage.

Wilson (2000) also illustrated an increase in output from applying variable rate seeding, as well as savings derived from variable rate lime and fertiliser application.

Spraying:

Buick (2002) described a payback period of just 4 months for a US\$3,750 AgGPS EZ-Guide 110 system used on a 1500 broad-acre situation. These results depend on individual management and farm practices. But generally it is fairly easy to demonstrate payback within a season or year for manual guidance applications. Perry et al (2001) reported a saving in herbicide of 42% from spraying certain species of weed which had a patchy habit. This gave an estimated saving of in materials cost of between £2 and £18


ha⁻¹ (AUS\$6 to AUS\$56). Advantages through increased accuracy due to use of guidance have a direct financial benefit. This can become significant when crops are repeatedly sprayed, such as the potato crop where fungicides have to be regularly applied. Extending the working hours safely into the hours of darkness is of major benefit to contractors and large farm operators.

Cereal harvesting:

Experience with automatic steering systems in maize harvesters motivated Claas to develop a system for larger combine harvesters. The full width of larger machines are not well utilised by drivers and steering the machine takes up to 60% of the drivers time. High capacity machines now run at 10km/hr in European conditions, (faster in lighter crops), this level of performance is very difficult to maintain over long harvest days. Hieronymus (2000) outlined the advantages as being; Reduced driver stress, better utilization of the capacity of the machine through better use of the full width of the head. The driver has more time to maintain machine settings and best forward speed. Performance is maintained throughout the day. Increase in accuracy of yield measuring and mapping.

Improved utilisation of the harvester not only has advantages from the machine cost point of view but it also saves on timeliness losses as the crop goes beyond its optimum harvest date. Yule (1986) studied combine harvester fleet size for a range of case study farms. It was found that the optimum level of crop loss for the largest farm in the study (556 ha with an average wheat yield of over 10 tonnes ha⁻¹) was 4.4 per cent, (total in-field loss and threshing loss), whereas most drivers actually operated at a point where the harvester was losing less than 1 per cent. Smaller farms had reduced losses due to their short season and had the luxury of slower combine speeds.

Drainage example:

The New Zealand Centre for Precision Agriculture runs a drainage extension service which designs and installs drainage systems. An RTKDGPS system is used for surveying, this has a number of advantages over the old laser based system. Not least is the increase in output, but the fact that the data is in a GIS ready environment from the start of the process. This allows the design to be georeferenced, other surveys can be incorporated and information layers added. The next stage of controlling a trencher has been achieved in Australia where the Trimble Site Vision  system has been utilised. This allows the georeferenced design to be loaded into the machine which is then controlled from the drainage layout and plan in the Site Vision unit. This saves time for the operator as well as reducing the risk of error.

One design focus has been to use this technology combined with EM technology for soil surveying. This data along with accurate topography gives a far more detailed level of information which takes full account of spatial variability. Irrigation system requirements can be calculated to match site variation. This has been taken up with some enthusiasm by the New Zealand wine industry.

Conclusions

There have been many mistakes made over the last ten to fifteen years in precision agriculture, but there has also been considerable progress. There is a growing awareness that we are not challenging the boundaries of the technology and we perhaps need to refocus our efforts on areas which have received little attention in the first phase of precision agriculture.

These second generation DGPS systems offer greater financial advantage through improved performance and increased efficiency, they also provide a valuable platform for additional control applications which will have further financial benefit. This will allow us to take systems mechanisation to a new level and continue a trend that was started 70 - 80 years ago and has successfully managed to reduce our food production costs in that era. New techniques and knowledge will be integrated into these systems which will help to safeguard our environment, farmers and the consumer.

The next increase in use of P.A. technology is likely to come through greater machine control resulting in improved utilisation of larger machines and thus cost reduction. This trend has already started with increased sales of guidance systems and increased interest in auto-pilots. These systems will have further potential for information gathering and the incorporation of measurement sensors while vehicles are on the land. Perhaps by Symposium number 10 we will be looking at another step change in this technology.

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Class definitions from Buick(2002) for Figure 1.

Class I: 1 to 2 meter or even 2 to 5 meter absolute accuracy. Differential corrections from radio beacons or WAAS.

Class II: Sub meter or meter static accuracy. Differential corrections received from Radio beacons, L- Band satellite and/or WAAS. Fast update rate 5Hz or higher.

Class III: Decimeter static accuracy 0.1 - 0.3 meter. Typically dual frequency receivers. Some wide area services are available otherwise local base station.

Class IV: Real Time Kinematic (RTK) Receivers. Requires dedicated base station or series of base stations (to cover wider area) or VRS (Virtual Reference System). Based on dual frequency GPS receiver technology. Centimeter level of accuracy.

Application	Class I	Class II	Class III	Class IV
Positioning for mapping with yield monitors to increase yield maps	✓	✓	✓	✓
Rate control applications during planting or fertilizer/chemical applications	✓	✓	✓	✓
Crop scouting	✓	✓	✓	✓
Sampling	✓	✓	✓	✓
General feature and field boundary mapping	✓	✓	✓	✓
Guidance during fertilizer applications		✓	✓	✓
Guidance during crop protection applications		✓	✓	✓
Guidance during field tillage		✓	✓	✓
Guidance during broad-acre planting			✓	✓
Guidance during row-crop planting			✓	✓
Guidance during seeding			✓	✓
Guidance during cultivation			✓	✓
Guidance during bed forming or listing in high value vegetable crops				✓
Guidance relative to an existing mapped or logged feature (e.g., during the laying of drip tape on beds, planting of seed along pre-plant fertilizer strips, or cultivation back down crop rows)				✓
Machine control for such systems as Site Vision Trimble™, applied to drainage and land levelling operations.				✓

Figure 1. DGPS suitability for applications.