GRDC Precision Agriculture Manual

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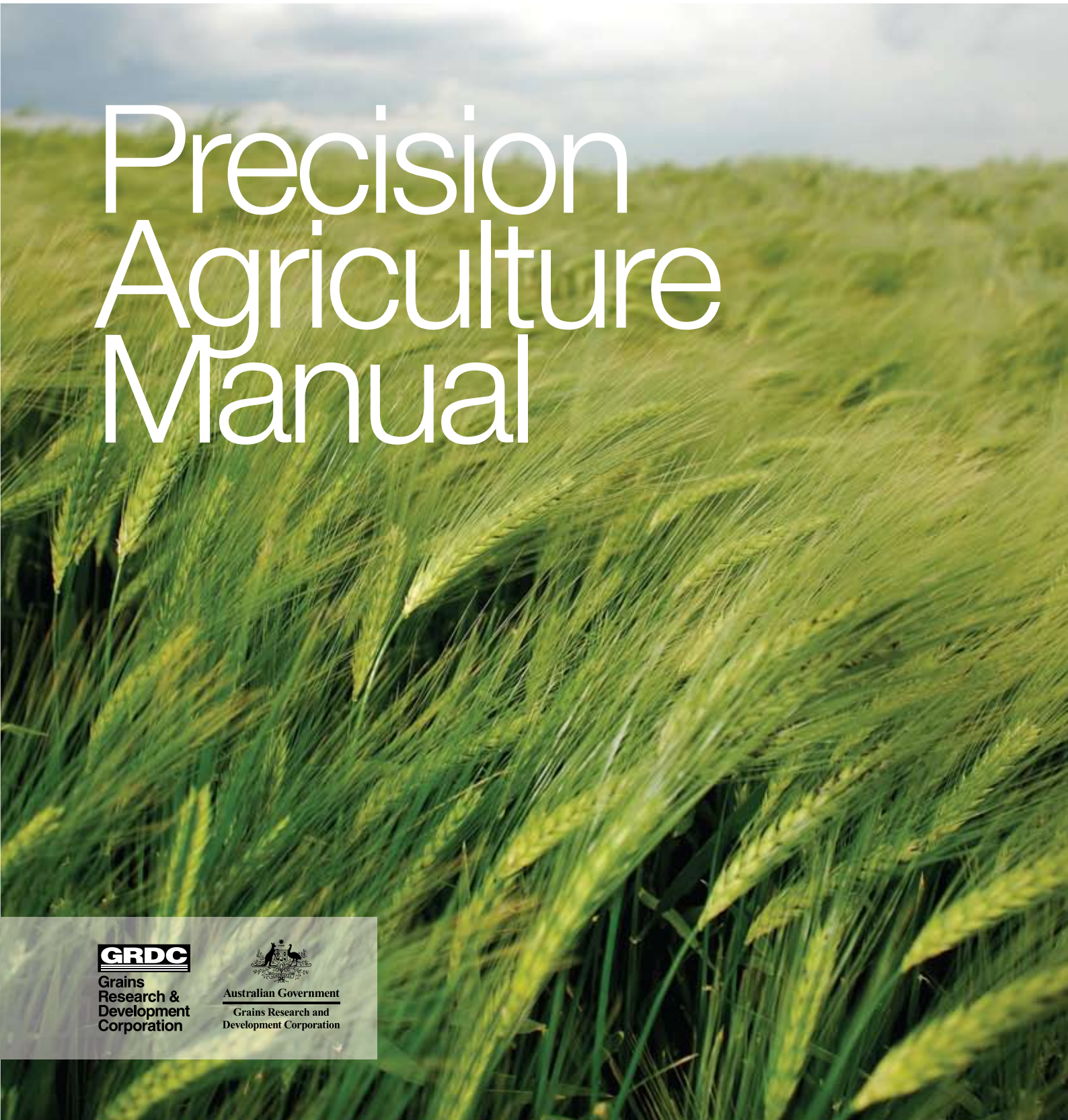
Precision Agriculture Manual



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PRECISION AGRICULTURE MANUAL

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Edited by:

Emma Leonard, AgriKnowHow, Urania, Via Maitland, SA 5573.

Philip Price, Mackellar Consulting Group P/L, PO Box 683, Jamison, ACT 2614

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FOREWORD

Precision Agriculture, or PA, is a topic of increasing interest and discussion within the Australian grains industry. New varieties and improved methods of agronomic management have enabled growers to progressively overcome limitations to crop growth. In most regions, yield, profit and productivity have steadily increased when averaged across seasonal conditions. This has drawn attention to the inherent variability in yield and margin within paddocks and across the farm. Growers are now looking for ways to manage this spatial variability by better matching inputs to the productive potential of particular paddocks or sites within a single paddock. This would enable them to increase profit, and at the same time improve environmental management.

PA involves collecting information about specific sites and then using this information to make and apply management decisions. This could be as simple as using Global Positioning System guidance on the spray rig to reduce overlap, or as complex as using a computer card and map of paddock management zones or soil pH to vary fertiliser or lime application on-the-go with a variable rate applicator.

The basic tools needed for PA have been available for more than a decade, but uptake of this new technology within the grains industry has been slow, especially for the more complex techniques that involve mapping crop or soil characteristics. Several reasons for this slow adoption have been reported by growers in surveys by the GRDC and others. One reason is that investment in equipment for the full suite of PA methods is expensive and growers are uncertain whether a return will follow, nor is it clear if PA will be effective in lifting margins in all farms or cropping regions. Also, to make full use of PA, skills are required in data collection and integration, and in interpreting PA data to enable better management decisions to be made. As yet, there are few people with this combination of skills to support grain growers in using PA in practice.

In 2003, in response to these gaps in knowledge and skills, the GRDC established a 5 year national research program in PA involving 10 R&D teams working with growers across all cropping regions. One aim of this initiative is to test different ways of using PA to determine which are the most useful for growers in particular situations, and at the same time to uncover the main underlying causes of spatial variability. The program is also developing a range of tools that growers can use to help decide whether PA is likely to be a good financial investment for them. Attention is being given to improving education and training in PA to help provide the skilled people that the industry needs if it is to gain maximum benefit from this technology.

This PA Manual is the first major product from our PA research initiative. It aims to bring together much of the technical information that agronomists, farm consultants, extension staff and others in the industry need in order to understand how PA methods work and how they can be put into practice on-farm. It is not aimed directly at the average grain grower, although some growers already familiar with PA will find useful information here. Our intention is that organisations and groups will use this technical manual to help underpin their own training programs and as a reference work on PA. The GRDC is working with other groups to develop more education and training products that will meet the need of growers for less-technical information on how to make PA work in practice, and that could be incorporated into tertiary courses.

This Manual has been prepared by a large number of researchers working within the GRDC national PA initiative, and I would like to thank them for their efforts in bringing together for the first time in Australia such detailed technical information. We know that the coverage of different PA topics varies within the Manual, and that new information is becoming available from the current research. However, it was our decision that this information is needed urgently in the public domain, and that we should make the Manual available as soon as possible. The GRDC intends to update and re-issue this Manual at the completion of our national PA program in 2007. We would therefore welcome your comments on how this version could be improved, so please use the feedback form provided and email or print and post back to us.

In the meantime, the GRDC encourages you to use the information provided here, including for your own or your organisation's education and training programs. Please feel free to copy and modify sections from the Manual to suit your own purposes. Our only request is that you acknowledge the authors and the GRDC.

Peter Reading
Managing Director
August 2006

1. WHAT IS PRECISION AGRICULTURE?

Section topics

1.1 What is precision agriculture?
1.2.1 Who is precision agriculture for?
1.2.2 Does precision agriculture pay?
1.2.3 Is precision agriculture likely to be worthwhile financially? An investment analysis approach
1.2.4 GRDC precision agriculture research initiative

1.1 What is precision agriculture?

Precision Agriculture (PA) is a general term that describes a wide range of technologies and their use. These technologies provide detailed information about geographic location and spatial variability in soils or crops. This information can be used by growers and advisers to improve cropping decisions, crop agronomy and the efficiency of farming operations.

PA combines a wide range of data sources based on a common geographic location. For example yield may be monitored directly during harvest with geographic location provided from a Global Positioning System (GPS) and compared to biomass estimates made from satellite images or to soils data from an electromagnetic induction (EM or EMI) survey. PA is a tool that can be used in all aspects of agronomy including soil improvement, nutrition, and pest and weed control. PA is underpinned by data, much of which reflects spatial variability due to past management and crop performance, such as high fertiliser levels remaining where crop yield has been poor.

The extent to which PA technologies and methods are used in grain cropping depends on the purpose. For example, some growers may use GPS only when establishing raised beds or controlled traffic systems or for sowing into the previous year's inter-row, or just to reduce overlap when spraying or seeding. Others use yield maps to check the performance of different varieties or the impact of a pesticide. Others again are establishing paddock management zones and using variable rate application to better match expensive inputs with potential yield. A grower wanting to use PA can begin by either using one or two technologies and build on these, or by adopting a whole suite of technologies right from the start. Therefore it is important to remember that there are many ways in which PA can be adopted and used to make or save money, improve timeliness or environmental management and to carry out on-farm trials.

There are two further, sometimes forgotten, benefits of PA, whose impacts may not be as immediate but can be more far-reaching. The first is the greater information and understanding that growers gain from seeing maps of variability in soils, crops or pests, an understanding that translates into improved cropping decisions and greater efficiency over time. The second is the potential for growers to use PA for their own on-farm trials, where new varieties, fertiliser type or rate, or soil or pest management, can be tested on a small area and the results assessed cheaply using yield or other PA data.

The definition of PA adopted by the GRDC and used throughout this Manual is:

'Information-rich agriculture. The use of yield maps, other spatial information and input-control technologies to better match agronomy to paddock variability. The aims are to increase profit and improve environmental management.'

This definition emphasises one of the underlying concepts of PA, by better matching crop inputs and agronomy to the specific characteristics of particular parts of a paddock or farm, a grain grower can improve profit and protect the natural resource base by reducing over or under application of expensive inputs. There are three possible ways that effectively match inputs with site characteristics and yield potential to improve profit:

higher yields achieved with higher inputs, where the value of the extra yield outweighs the cost of the extra inputs;
the same yield is achieved but with a lower level of inputs;
a lower yield is accepted with lower inputs, where the savings in input costs exceed the reduced value of yield.
In a single paddock each of these strategies could be applied depending on the yield potential of a defined zone.

The result may be that by using PA the same total amount of input is applied, compared with not using PA, but its distribution across the paddock is changed.

However, PA cannot help yield and improve profit unless a grain grower already has the basics of good production and environmental management in hand.

PA generally involves knowing the precise location of particular sites within a paddock. Global Positioning Systems (See Section 3.2.1 Global Navigation Satellite Systems) are used to determine the exact location of each site. Using GPS, information is collected from each precise location, at multiple times during the year and over several years, and this information can be used to determine crop choice and management of the crop during the season. Information may be collected (See Section 3.1.1 Methods of data collection) on-ground (e.g. soil samples) or remotely (e.g. satellite imagery) (See section 3.2.4). Stewart, Boydell and McBratney (2005) provides a thorough overview of use of PA within the cotton industry.

There is a common misconception that PA requires large capital investment with an extended pay-back period. This is not necessarily true. A GPS-autosteer guidance system with 10 or 2 cm accuracy will cost between A$20,000 and $60,000 depending on the accuracy required and source of correction signal. This will enable a grower to reduce spray overlap or to establish tramlines for controlled traffic cropping, and can provide immediate savings or gains of $7.50-30/ha. For a large cropping program, the time needed for a positive return on this investment could be as little as two seasons (ignoring additional potential benefits from reduced operator fatigue, night spraying etc.). Cheaper guidance systems are available and may be a good investment for growers who just want something more accurate than a foam marker.

For growers interested in using variable rate technology (VRT, also known as variable rate application, VRA), the first steps towards understanding variability can be achieved by selecting one of the best paddocks on the farm, obtaining several years of biomass imagery, which is available from historic satellite data, and having this data analysed and mapped into areas of stable or unstable high and low performance. This information can then be used to determine whether applying PA to the crop management of that paddock will result in significant profit gains. The entire cost of this exercise can start at $10/ha making it a good introduction for growers to some of the PA techniques without the need for large expenditure. If PA can be made to work profitably on one paddock, then it may be worth investigating its use for other paddocks.
Within the Australian grains industry, interest in PA has grown over the past decade and continues to grow. This interest has been driven by five key factors:

the advent and integration of technologies that allow the efficient collection of geographically located (spatial) information;
an increase in the range of variables affecting crop performance that can now be addressed using PA - research is developing PA tools to improve the management of disease, weeds, nutrition and the timeliness of operations;
the tools needed for PA (GPS for positioning and guidance, yield monitors, remote sensing technologies, maps of variation in soils and crops and variable-rate technology- VRT) have become increasingly available and affordable (See section 3.1.1);
early research into the application of PA methods on-farm showed the potential for significantly improved crop returns of about $10-50/ha;
increased farm and paddock size, and greater mechanisation, require larger areas to be managed as one unit and have resulted in larger paddocks that have more variability.

At present within the grains industry, application of PA is generally considered at the paddock scale. However, there is no reason why improved decisions on land use and crop agronomy at a paddock scale could not be made at a whole-farm scale by ignoring the fence lines, and eventually at a catchment scale (See section 4.2.9). It is dependent on understanding what types of information will enable better decision making, and finding cost-effective ways of collecting spatially referenced information and using this to improve land use and land management decisions within particular parts of a catchment or areas within a farm. Some generalised steps in uptake of PA for different management objectives are shown in Figure 1.1.1.

	Objective	How PA tools and techniques can be used
1	Optimise average crop management and increase farming efficiency	GPS location and recording for crop scouting and soil sampling, and simple paddock experimentation (e.g. new varieties or pesticides). Vehicle guidance and auto-steer to increase efficiency (e.g. reduced overlap), establish controlled traffic or raised bed systems, sow into inter-row, shielded spraying etc.
2	Determine the location and magnitude of spatial and seasonal variability	GPS linked to yield quantity/quality monitors and soil sensors, and geo-referenced remotely-sensed data, used to develop maps of variability. Gross margin maps prepared based on yield and quality. Maps can be compared across seasons and crops to identify areas of stable relative yield or margin
3	Determine causes of spatial variability and optimal management response	Combine several seasons of PA data layers to identify likely causal factors, followed by targeted field investigation (e.g. soil profile sampling) to confirm. Use climate data with crop and financial models to test alternative management responses (e.g. avoid, reduce inputs, grow tolerant crop or ameliorate)
4	Optimise production input:output ratio for grain quantity and quality. Maximise gross margin and minimise environmental footprint	Use PA data layers to delineate management zones at a paddock or farm scale, use these to base crop decisions (e.g. type and variety) and prepare input application maps for VRT using variable rate controllers. Use yield monitors and financial analysis to check results and underpin further adaptive management
4	Improve grain quality control and product marketing	Use GPS with grain quality monitors and segregation tools to meet quality requirements and achieve price premiums. Electronic information tagging of field operations and grain loads, and downloading into Environmental Management Systems, provides data to support marketing and quality control/assurance
5	Increase on-farm experimentation/trials	Use PA maps to design on-farm trials, with GPS to enable accurate lay-out and yield monitors to record the results

Figure 1.1.1. A list of Precision Agriculture objectives and the relevant tools and techniques that can be used.

1.2.1 Who is precision agriculture for?

Many grain growers will benefit from the use of some parts of the PA suite of technologies, for example GPS for machinery guidance or the testing of new varieties using yield data, as described above.

However, PA may not be for everyone, at least not straight away. Dealing with spatial variability is not always a grain grower's first or immediate priority. Growers first need to make sure that they have addressed the basic components of their cropping system (crop type and varieties, rotations, nutrition, disease, weed and pest control) and have these working satisfactorily, before dealing with spatial variation. In other words, make sure the basics are right before considering PA. There is little point in trying to manage spatial variability in a paddock that suffers from waterlogging or compaction. Sorting out these more important problems, for example with controlled traffic or raised bed systems, will often reduce the variability seen within the paddock.

In many parts of Australia, managing climate variability, by matching inputs to the season, will be the next priority (See Section 4.3.3). Soil moisture is the biggest limiting factor for crop production over most of Australia, and managing this is the second priority for growers. In the North, growers often base cropping decisions on the amount of water stored in the soil profile and rainfall probability. In the South and West growers are now setting target yields based on seasonal outlook, and matching fertiliser application to those targets (targets that are revised as the season progresses). Improved seasonal forecasting and climate risk management tools are becoming available and are being combined with PA techniques. In many cropping districts, climate variability has a bigger impact on yield and profit than spatial variability and should therefore be addressed first. (See Section 4.3.3 about spatial versus seasonal variability, and the summary)

Once the basics of the cropping system are working well, and account is taken of seasonal (or temporal) variability, then the next challenge for many growers is managing spatial variability. There are situations where managing variability may be of little benefit or not feasible. Lack of variation in soil characteristics and lack of responsiveness of crops to agronomic inputs (where yield is limited by a consistent, shallow soil depth), are examples where managing spatial variability may not yield a return. The factors that determine whether management of spatial variability is likely to be financially worthwhile include (as well as the expenditure required on PA): the size and pattern of yield zones; the size of the differences in yield and margin between zones; the consistency of zones in their relative performance across seasons and crops; and the cost to collect, interpret and then apply the PA data and variable management to the zones. Experience so far suggests that for many growers PA could lead to significant increases in profit if used correctly. (See Case Studies section).

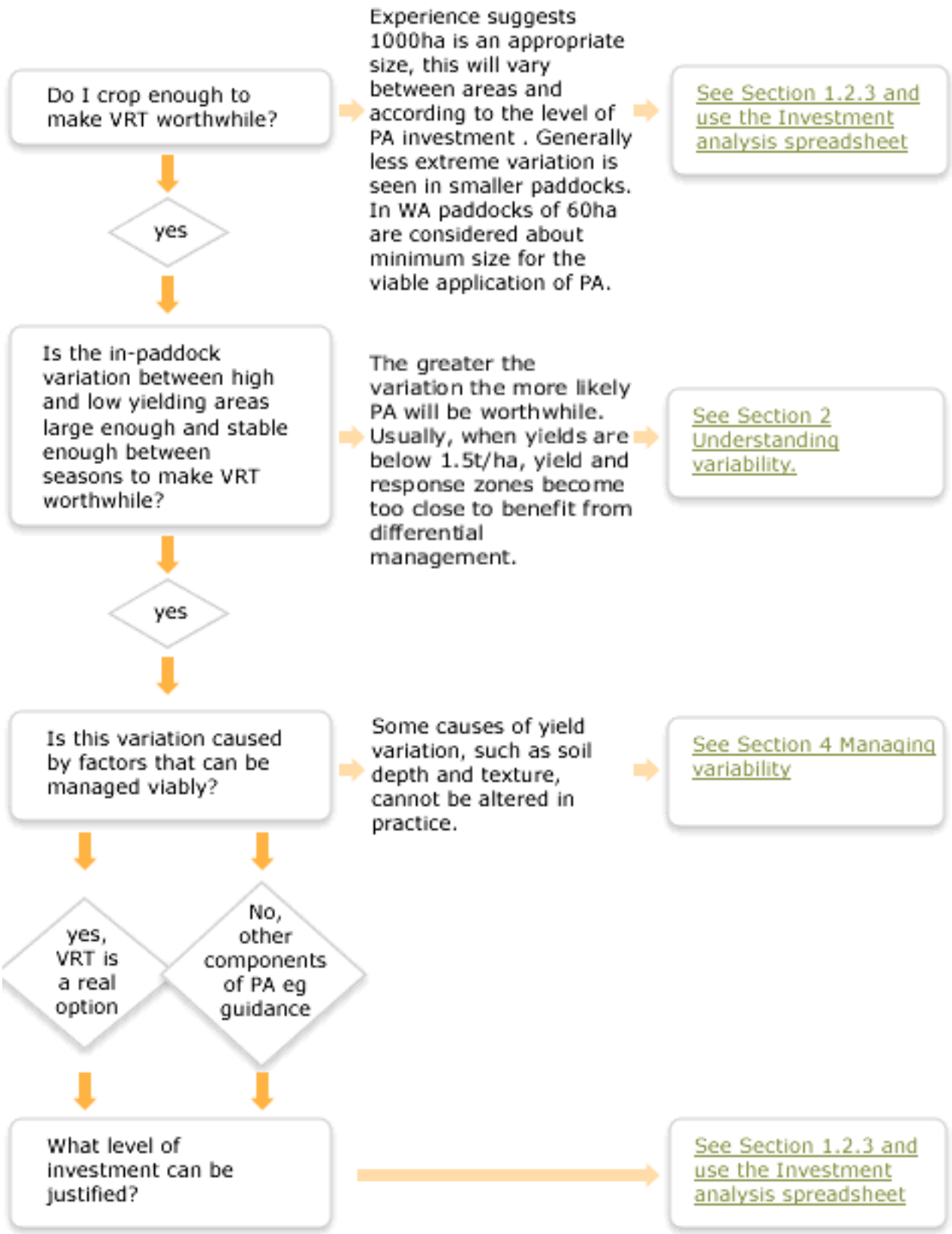


Figure 1.2.11. The questions that need to be addressed when considering adopting precision agriculture (PA) for variable rate technology (VRT).

1.2.2 Does precision agriculture pay?

When presented with evidence of yield variation, the most common reaction is to want to 'fix' the worst areas and improve their performance to at least the paddock or farm average. Experience and analysis suggests this may be the most expensive and risky course to follow. It is better for growers to start by identifying the top performing areas of a paddock and if these are stable to optimise inputs in these areas. This is likely to yield the biggest return on the additional expenditure involved. Once this has been achieved, then attention can be turned to the average yielding zones.

How big should this expenditure on inputs be? Table 1.2.21 illustrates that how targeting inputs by paddock zone has substantially impacted on gross margin, reflecting the large differences in potential yield and profit. This table represents the potential but not necessarily achievable returns due to the influence of seasonal uncertainty (See Section 4.3.3, spatial vs seasonal variability) at the time of the fertiliser decision.

&INPUT	LOW						HIGH		
	Yield (t/ha)	Protein (%)	Gross margin ($/ha)	Yield (t/ha)	Protein (%)	Gross margin ($/ha)	Yield (t/ha)	Protein (%)	Gross margin ($/ha)
Low = 33N/11P	1.54 (a)	9.3	105	2.1 (b)	8.3	248	2.45 (b)	9.2	254
Med. = 56N/17P	1.68 (a)	9.6	38	3.56 (c)	11.1	303	3.62 (c)	9.8	320
High = 75N/23P	1.67 (a)	12.7	--26	3.69 (c)	11.3	238	4.26 (d)	12.2	398

Same letter indicates the yield is not significantly different; Note:LSD between yields is 0.17 t/ha.

Table 1.2.2. Changes in gross margin due to adjusting nutrient inputs (N, nitrogen; P, phosphorus) on wheat in three yield potential zones in the Western Australian wheat belt (Blake et al., Department of Agriculture WA)

In the low potential zone, the best profit was made with the lowest level of input, even though the yield was lower than at a higher level of inputs. The opposite was true for the high yielding zone.

A team at CSIRO has developed an investment analysis spreadsheet to help growers assess whether or not investment in PA is feasible for an individual farm. The investment analysis spreadsheet (PA Economics Calculator [Excel doc, 44.6mb]) is located on this disc. The following information provides background and examples of the outputs from the spreadsheet.

1.2.3 Is precision agriculture likely to be worthwhile financially? An investment analysis approach

Authors: Peter Stone (formerly of CSIRO Sustainable Ecosystems), and Lisa Brennan, CSIRO Sustainable Ecosystems

The key to making money from PA is for individual farmers to choose an aspect of the technology that provides rapid and certain benefits across a wide area of their farm. While PA has been used in Australia for about 10 years, until recently only a small proportion of farmers have adopted the technology. A key reason for the low adoption rate was the understandable reluctance of farmers to invest many thousands of dollars in PA without knowing if the technology would return a profit.

With the advent of cheaper GPS guidance systems, and growing evidence of the efficiency gains that can be made with them, more growers are buying this part of the PA equipment suite. However, uptake of yield monitoring with VRT remains low and it will not be possible to gather evidence regarding the profitability of this aspect of PA unless more farmers invest in it. But this circle can be broken (or at least weakened) using a simple investment analysis. An investment analysis developed by CSIRO, indicates whether or not some level of investment in PA is financially feasible for an individual farm. The analysis process using a simple spreadsheet the 'PA Economics Calculator [Excel doc, 44.6mb]' is described in more detail in this section.

Investment value

A range of factors affect the investment value of PA including:

- current farm gross margin;
- cost of PA equipment;
- area and number of years over which the equipment is used; and
- rate at which benefits from adoption of PA start to occur.

The investment analysis uses a 'discounting' process that recognises that a dollar received today is worth more than a dollar received next year.

How the analysis works

Many existing analyses of PA rely on unsubstantiated estimates of the yield or gross margin benefits PA will provide. Rather than guessing how much benefit PA might provide, the CSIRO analysis determines how much benefit the new technology needs to provide to make the investment in PA profitable. This value is presented as a 'breakeven' increase in gross margin, enabling the investor to aim for a gross margin that is realistic for their farming operation and to choose an investment strategy to achieve the profit increase.

Growers may already be familiar with this type of investment analysis which can be used to evaluate any capital investment.

Analysis assumptions for the whole farm

The CSIRO analysis illustrates factors that affect the investment value of PA technology. In the following example the analysis assumes that:

- all of the costs to implement the PA technology occur in the first year and also that the benefits from using the technology begin in the first year of operation;
- maximum benefit from using the technology will occur in year 10 and that the benefit from the investment lasts until year 10;
- the PA technology is used across 1500 hectares of crop;
- the current cropping gross margin is $110/ha; and
- the discount rate (interest rate plus risk premium) is 10%.

These assumptions will not apply equally to every farm and advisers/growers are encouraged to modify the assumptions and do their own sums using the PA Economics Calculator [Excel doc, 44.6mb]. It is important to remember that not every PA technology will be used across every cropped hectare. For example investment in VRT is likely to be used across a smaller area than auto steer or GPS guidance to reduce overlap.

Technology costs affect returns

The amount spent on PA technology will determine the increase in gross margin required to make it pay for itself (Figure 1.2.3a).

For example, a $20,000 investment in PA needs to increase the gross margin by 4% if it is to breakeven. If after 10 years, the gross margin from PA crops is not at least 4% higher than the gross margin from crops grown conventionally, the investment in PA will have made a financial loss. The increase in margin required is not compound, that is an additional 4% increase is not required in each subsequent year, but the 4% increase over the 'no PA' baseline must be maintained for each of the 10 years used in the analysis.

Technology costs affect returns

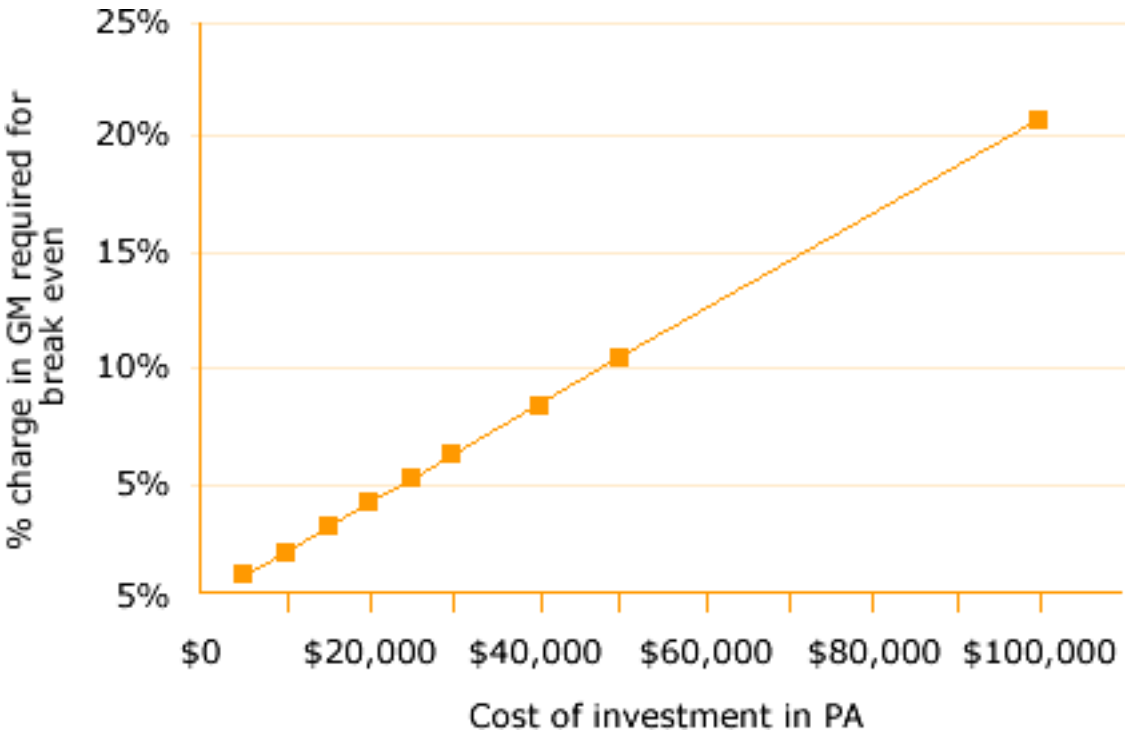


Figure 1.2.3a Percent change in gross margin (GM) required to breakeven as a function of costs of investment in PA.

Cropping gross margin

For a farm with a current cropping gross margin of $50/ha, $20,000 spent on PA needs to raise the gross margin by 8% to breakeven (see Figure 1.2.3b). However, if the current gross margin is $200/ha, the required increase in gross margin needed to breakeven is only 2%.

Technology costs affect returns

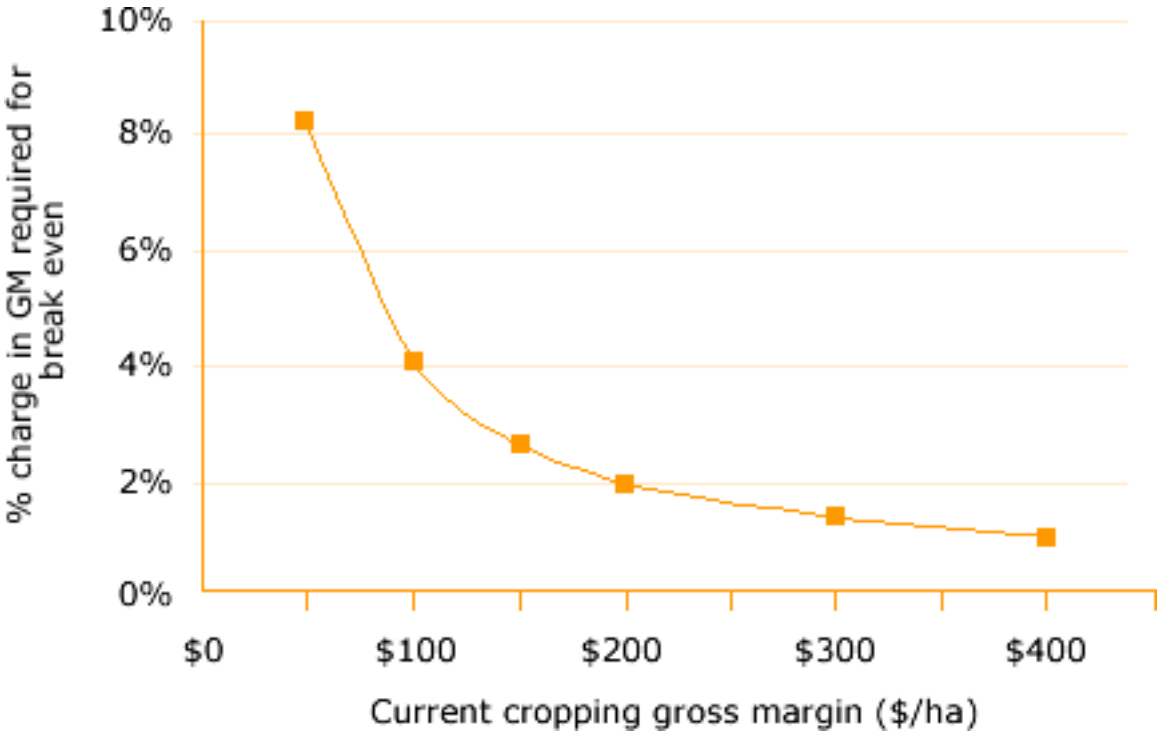


Figure 1.2.3b Percent change in gross margin (GM) required to breakeven as a function of current cropping GM.

The range of percentage gross margin increases required to breakeven from an investment in PA of $10,000, $20,000 and $50,000 are shown in Table 1.2.3a. These are based on two gross margin values of $200/ha and $110/ha.

Investment	GM $200/ha	GM $110/ha
$10,000	1%	2%
$20,000	2%	4%
$50,000	5%	9%

Table 1.2.3a. Percentage increase in gross margin (GM) required to achieve breakeven from three precision agriculture investment levels.

Start of benefit

Since time erodes or discounts the value of money, the delay between paying for PA technology and receiving a benefit from the investment has a large impact on whether the investment will pay.

For this example, if benefits start to occur in the year of a $20,000 investment in PA, the breakeven increase in gross margin is 4%. However, if the start of benefit is delayed until year 5, the breakeven bar is raised to 7% (see Figure 1.2.3c).

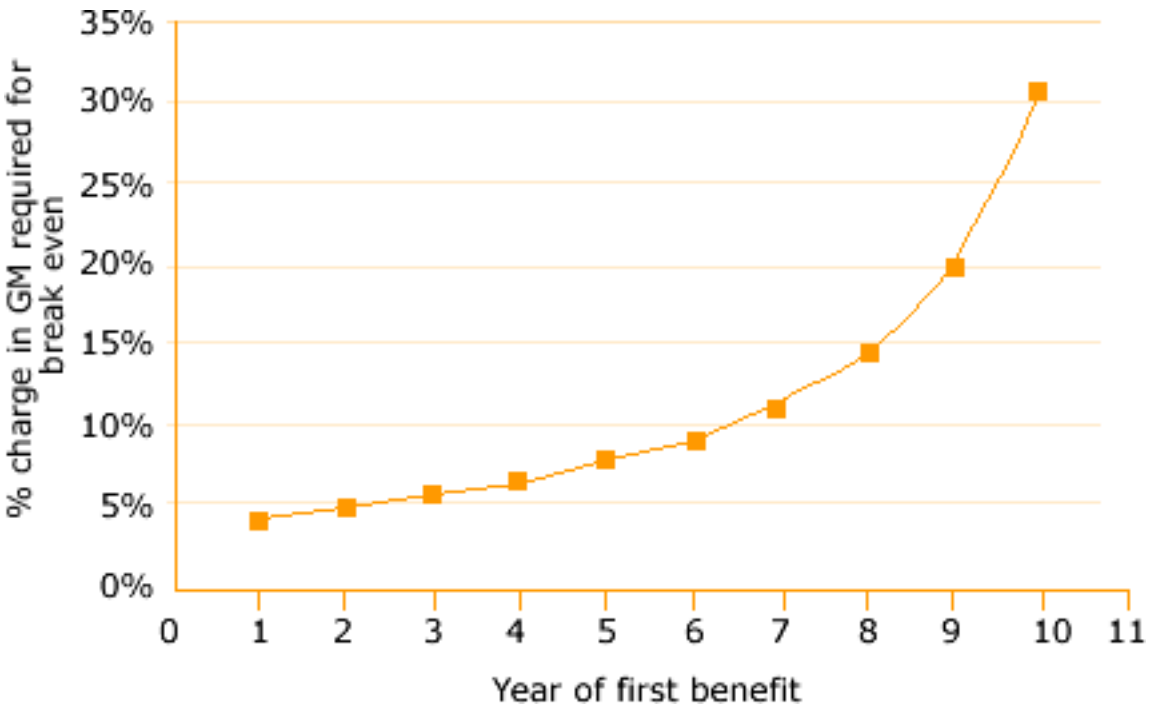


Figure 1.2.3c Percent change in gross margin (fvGM) required to breakeven as a function of year of first benefit.

Start of maximum benefit

The time taken to reach maximum benefit from an investment also affects its ability to pay. For this example, $20,000 spent on PA will breakeven if it increases the gross margin by 2% if the maximum benefits occur in the first year of purchase. However, if it takes 10 years to achieve maximum benefit from the investment, the gross margin increase required to breakeven rises to 4% (see Figure 1.2.3d).

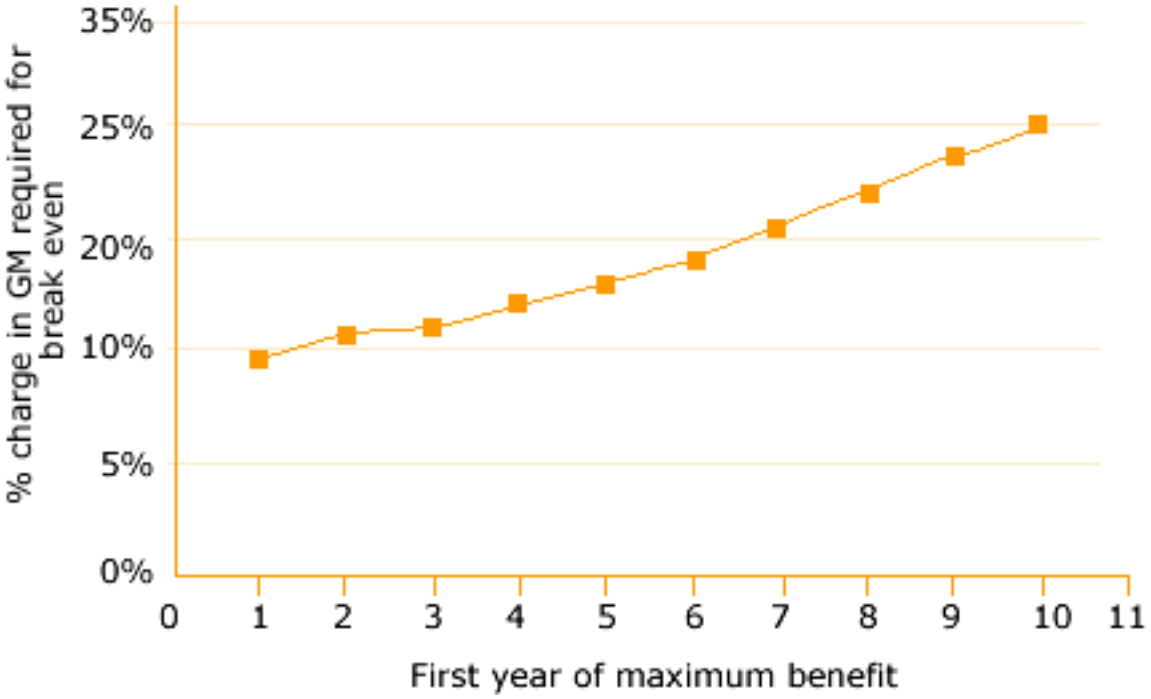


Figure 1.2.3d Percent change in gross margin (GM) required to breakeven as a function of first year of maximum benefit

Duration of payback

If the benefits of using PA technology last only 1 year, then $20,000 spent on the new technology will breakeven only if it increases the gross margin by 13% in the year of purchase. However, if the benefits of using PA last for 10 years (a more likely scenario), and the maximum benefits occur in year 1, the gross margin required to breakeven decreases to 2% (see Figure 1.2.3e).

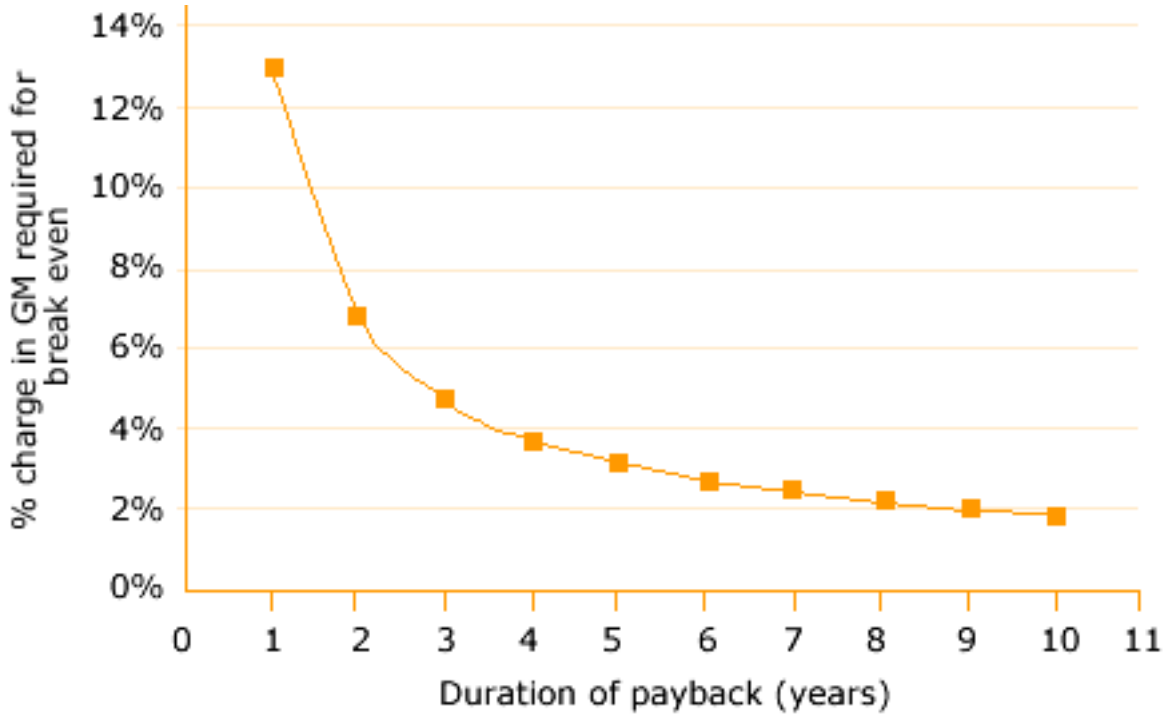


Figure 1.2.3e Percent change in gross margin (GM) required to breakeven as a function of duration of playback.

Annual fees

While the annual fees required to keep using some forms of PA technology might not seem small compared with the initial set-up costs, they can accumulate and subsequently impact significantly on the value of the investment in PA. Adding $1000 of annual fees to the initial implementation costs increases the gross margin required to breakeven by almost 2% (see Figure 1.2.3f).

1.2.4 GRDC precision agriculture research initiative

The potential for PA to help improve cropping decisions has been apparent for many years, but to date less than 10% of grain growers in Australia are using PA methods in any form and less than 3% are using the full suite of PA data and methods. Against the background of great promise for PA, but relatively little uptake, the GRDC established a new national research initiative in PA in 2002-03. This research initiative aims to continue the development of PA methods for Australian grain growers, evaluate and demonstrate these methods in different cropping regions and systems, and provide education and training information about the practical use of PA.

The initiative was funded at $6.25 m over 5 years. It comprises 10 projects, with research organisations working with grower groups in different regions on various aspects of and approaches to PA.

Key to SIP09 Sites

1	Mingenew	9	Crystal Brook	17	Trangie
2	Buntine	10	Snowtown	18	Gilgandra
3	Casuarina	11	Waikerie	19	Nyngan
4	Corrigin	12	Birchip	20	Gurley
5	Kimba	13	St Arnaud	21	Spring Ridge
6	Cummins	14	Murtoa	22	Macalister
7	Urania	15	Yarrawonga	23	Oakey
8	Lochiel	16	Barmedman	24	Capella

Figure 1.2.4. Map showing approximate locations of some of the PA experimental and demonstration sites associated with SIP09.

By the end of the initiative in 2007-08, a significant number of growers and grower groups will have used and tested PA methods through all the four stages listed below, with the results reported widely throughout the grains industry. At this point of the initiative, the research teams are focused mainly on working with their grower groups in development, testing and demonstration of PA methods. Development and release of education and training material to support the uptake of PA in Australia is a key output of the PA initiative. This Manual is the first major product to be released.

Within the PA initiative four broad stages in developing PA are considered:

Stage 1 is about recognising that significant variability in yield and profit is occurring within a paddock or across the farm, and determining whether the yield zones are stable or unstable between years (seasons) and different crops. This stage is generally based on growers' own knowledge of paddocks, biomass imagery, and yield or gross margin maps based on processed data from the header.

Stage 2 is about identifying the underlying causes of yield variability. These could include soil depth, soil type, water holding capacity, nutrients, elevation, aspect, acidity, subsurface salinity, compaction, presence of pests and diseases, or the influence of past management (e.g. old fence lines, windrows, previous crop type). This stage requires the comparison of yield zone maps with other mapped data for the paddock, for example from soil tests, electromagnetic induction (EM or EMI) or gammaradiometric survey, disease testing, aerial photographs, or contour data, followed by field inspection and trials to ensure the correct causal factors have been determined. By the end of this stage, growers should know the main underlying causes of yield variability, and whether it is practical to directly ameliorate them (e.g. to rip, correct nutrient deficiency, lime), or to change management (e.g. use of tolerant crop variety, reducing fertiliser inputs on non-responsive areas and increasing them where there is a good yield response).

Stage 3 is about asking 'does it matter?' In other words, knowing the scale of variation in yield (stage 1) and the underlying causes and possible solutions (stage 2), is it worth doing anything about it? In this stage grower/adviser experience and crop models are used to assess the likely impact on yield under different seasonal conditions and between different crops. By combining the results with financial analysis, growers can determine whether it is economically sensible to address yield variability using PA, and the priority this should take in the farm or cropping budget.

Stage 4 is PA 'roll out' within a cropping district. By working through stages 1-3 on several paddocks or farms within the district, growers, advisers, farm consultants or extension officers should have developed the ability to quickly identify the likely underlying cause(s) of yield variation in a new paddock or farm. Advice can then be provided on whether and how that variation can be managed to improve overall yield and return.

2. UNDERSTANDING VARIABILITY

Section topics

2.1.1 Causes of yield variability within a paddock
2.2.1 What do we mean by spatial and temporal variability?
2.2.2 Impact of soil attributes on crop variability
2.2.3 Yield variability due to weeds, insects or disease, and to some abiotic factors and past management
2.3.1 Using simulation modelling to interpret patterns of spatial variability

2.1.1 Causes of yield variability within a paddock

Crop yield is known to change across a paddock due to variation in growing conditions. The implementation of precision agriculture (PA) technology makes it feasible to identify and manage this variability within a paddock or across the farm to maximise economic returns and minimise adverse environmental impacts.

Within a paddock, variation in soil type, texture, structure, depth, moisture content and nutrient chemistry all significantly contribute to the spatial variability in crop yield. Insects, diseases, weeds, temperature and rainfall extremes, and topography also produce yield variation at the paddock scale. The effects of past management are also important and may over-ride other sources of variability. The influence of these factors on crop yield can change during the growing season, and between growing seasons, giving rise to temporal variability. The size of the impact can also vary with crop type.

Although crop potential is determined by a number of these properties, the present objective of PA is to identify the production parameters that cause most variation and alter the management system accordingly. This section will discuss some possible underlying causes of crop variability that can be seen on a yield map or satellite image. Key factors causing yield variation will be regionally and locally specific, thus local agronomic knowledge is essential to interpret the PA data and to improve management.

Chapter Four provides information on how to manage variation.

2.2.1 What do we mean by spatial and temporal variability?

Author: Michael Robertson, CSIRO Sustainable Ecosystems

Spatial variability: the variation found in soil and crop parameters (e.g. soil pH, crop yield) across an area at a given time.

Temporal variability: the variation found in soil and crop parameters within a given area at different measurement times.

In PA at present, the area over which both these types of variability may be estimated can range from within-paddock to farm scale. For estimating temporal variability, the time between measurements is typically from one significant crop growth stage to another or from one season to another.

Measurements of spatial variation reflect that the average yield for a given area is made up of patches that are different from the average. An average yield of 2 t/ha could come from two equal size parts of a paddock yielding 1 and 3 t/ha each. In contrast, temporal variability illustrates that in the same paddock, the average wheat yield for three different seasons was, for example 2, 4 and 3 t/ha respectively.

Spatial and temporal variability can combine to make management decisions more complex than the individual situations described above. For this reason spatial data should be collected over several seasons in order to provide a sound base for agronomic interpretation. Yield patches may change in size and/or average yield from year-to-year. The practical and financial importance of simultaneous temporal and spatial variation depends on the possible responses to variation.

The relationship between spatial and temporal variability for a single hypothetical paddock is demonstrated in Figure 2.2.1a. It is important to understand how the two interact in order to provide a sound basis for crop management decisions.

Spatial : average yield for two paddock zones for one year only

Paddock name: 100 acre south	Year 1 - average yield 2 t/ha	
	1 t/ha	3 t/ha

Temporal: average for whole paddock (treated as a single zone) for three separate years

Paddock name: 100 acre south	Year 1	Year 2	Year 3
	2 t/ha average yield	4 t/ha average yield	3 t/ha average yield

Combining spatial and temporal variation: two zones for each of three years

Paddock name: 100 acre south	Year 1 - 2 t/ha average		Year 2 - 4 t/ha average		Year 3 - 3 t/ha average	
	1 t/ha	3 t/ha	2 t/ha	6 t/ha	2 t/ha	5 t/ha

Figure 2.2.1a. An illustration of measuring spatial or temporal variation or combining measurements for spatial and temporal variation in the same paddock over the same seasons.

Estimating temporal (seasonal) variability in crop yield

Crop yield and quality can vary from season to season in the same paddock due to climate variation influencing the timing of management events (e.g. sowing, topdressing, harvesting) and the growth and development of crops. Other

influences that are not associated with climate variation include carry-over of weeds or pesticide residues.

Various methods are available to estimate the impact of seasonal conditions on yield and crop quality. They vary in comprehensiveness, simplicity and data requirements, and the main ones are listed in Table 2.2.1a.

Also see Linking seasonal forecasting with PA section 4.3.1

Estimating temporal (seasonal) variability in crop yield

Method	Experience / paddock records	Yield maps See section 3.3.1 and 3.3.2	Water use efficiency	Plant available rainfall	APSIM
Description	Observations of yield over multiple years indicate how crops perform in different seasons	Measurements of yield over multiple years and in different parts of a paddock indicate how crops perform in different seasons	The French-Schulz equation where yield expectation is a function of growing season rainfall (e.g. April-October for winter crops) minus a threshold for evaporation loss (usually 110 mm) multiplied by a theoretical maximum crop WUE (20 kg/ha/mm for wheat, 11 kg/ha/mm for canola, 8 kg/ha/mm for grain legumes)	A modified French-Schulz equation using a monthly water balance, soil PAWC and assumed WUE as for the WUE approach.	A dynamic daily-time step simulation computer model that calculates crop growth and development in relation to weather, nitrogen and water supply. See Section 2.3.1 "Using Simulation modelling to interpret patterns of spatial variability" for a fuller description
Output	Recorded yield/quality observations in good, average and poor seasons	Yield/quality measurements in good, average and poor seasons/zones	Yield distribution (actual vs potential) for length of available rainfall record	Yield/quality distribution for length of available rainfall record	Yield/quality distribution for length of available climate record
Data requirements	Up to 10 years experience	Up to 10 years of yield maps to give good, average and poor seasons	Total seasonal rainfall	Initial PAW Monthly seasonal rainfall, soil PAWC	Daily rainfall, temperatures and radiation, soil and management parameters
Computational requirements	Nil	Medium	Low	High	Very high unless using Yield Prophet (an adaptation of APSIM)
Precision	Low	Medium	Medium	Medium-high	High
	Low	Medium	Medium	Medium	High

Weakness	Biased towards those seasons experienced. Confounded by any changes in crop management, variety, new technology, carry-over effects etc.	Biased towards those seasons with yield maps, confounded by changes in crop management, variety, carry-over, climatic event such as frost etc.	Assumes that rainfall is the key driver of yield variation. Not sensitive to soil type and timing of rainfall	Assumes that rainfall is key driver of yield variation and that timing within the month is not important	High data requirements for accurate prediction. Lower data requirement if using via Yield Prophet.
Background information			bettersoils.com.au, msfp.org.au		apsim.info, yieldprophet.com.au

Table 2.2.1a. Summary of the main methods for estimating the impact of seasonal variation on crop yield.

WUE, water use efficiency; PAR, plant available rainfall; PAWC, plant available water capacity; PAW, plant available stored water.

2.2.2 Impact of soil attributes on crop variability

Authors: Brett Whelan, Australian Centre for Precision Agriculture, The University of Sydney, Bindi Isbister, Department of Agriculture & Food WA, Alan Palmer, NSW Department of Primary Industries, and Peter Fisher, Department of Primary Industries Victoria

Edited by Brett Whelan, Australian Centre for Precision Agriculture

Cropped paddocks often exhibit significant variation of several soil attributes, and these can be an important underlying cause of variation in yield. Understanding the amount and location of this soil variability, as well as variability in pest populations, can be the key to improving both profit and environmental sustainability, as outlined in Table 2.2.2 below.

Attribute	Economically significant yield loss	Excess fertiliser cost	Excess fertilisers in tailwater or groundwater	Excess denitrification products	Excess pesticide cost	Excess pesticide in tailwater or groundwater	Pesticide residues in soil
Soil texture	✓	✓	✓	✓	✓	✓	✓
Soil structure	✓	✓	✓	✓		✓	
Soil organic matter (%)	✓	✓	✓	✓	✓	✓	✓
Soil moisture	✓	✓	✓	✓		✓	
Soil nutrients	✓	✓	✓	✓			
Soil pH	✓	✓	✓	✓			
Pest infestations	✓				✓	✓	✓

Table 2.2.2. Problems associated with not treating spatial variation in influential soil-crop system components (B. Whelan, Australian Centre for Precision Agriculture).

2.2.2a Soil water

In most regions of Australia, a lack of soil water is the factor most limiting yield. Studies have shown that 50% of the variation in wheat yield can often be explained by variability in soil moisture at the time of sowing. Variability in soil water content also significantly influences soil biological activity and soil temperature, which in turn affect nutrient uptake in roots and root elongation.

The total amount of water that can be stored in the soil profile and that is available to plants is called the Plant Available Water Capacity (PAWC) of the soil. This is the maximum amount of water that can be stored in the root zone, after all drainage has occurred, less the water bound so strongly to the soil that it cannot be extracted by the plant roots. The PAWC is essentially governed by the soil's structure, texture and depth. Although growers cannot easily alter the soil texture or depth, soil structure and crop rooting depth can in some situations be changed by management practices. Subsoil constraints such as salinity, boron, sodicity and layers of extreme pH can prevent roots extracting all of the available water at depth.

Spatial variation in PAWC is very important in regions where cropping relies heavily on stored soil water. It is less important where in-season rainfall is sufficiently uniform to supply all crop needs during the season. However, the factors that contribute to a larger PAWC also allow the soil to hold more water between rain events, which is also important.

Plant Available Water (PAW) is the total amount of water stored in the profile and available for crop uptake at a particular time (e.g. at sowing). It is the difference between the drained upper limit (DUL) and the crop lower limit (CLL). Measuring the spatial variability in soil water at a given time can be performed using capacitance or neutron moderation measurement probes in different parts of a paddock. Electromagnetic induction (EM or EMI) techniques, measuring soil conductivity (ECa), have been tested as a potential low cost method of collecting this data prior to sowing. All of these techniques need to be calibrated by soil type and are influenced by soil properties. Data has shown that as soil water content increases, water variability decreases. This maxim forms part of the rationale for crop irrigation. However, too much water causing waterlogging will produce negative impacts and another influence on paddock variation.

For PA, changes in the amount of soil moisture stored around a paddock may significantly affect the observed spatial pattern of crop growth and yield.

Although lack of soil water is usually a limiting factor to crop yield, excess water can also be important. Waterlogging, due to ponding on the surface or to a high perched watertable above an impermeable subsoil layer, can be very detrimental to crop growth and yield, even if it is only temporary. Transient waterlogging is common on paddocks in southern Australia during the winter period when rainfall exceeds infiltration, evaporation and crop water use, especially on soils with sodic or compacted layers where very low hydraulic conductivity acts as a choke to prevent water moving down the profile. Waterlogging for as little as 1 or 2 weeks can slow or prevent tiller initiation in cereals, and can be an important cause of yield variability that may not be seen by growers due to its transience.

2.2.2b Soil texture

Soil texture is usually defined by the percentages of sand, silt and clay in a soil. Particle size analysis has become the default measurement for soil texture, but it should be acknowledged that the type of clays present, other inorganic and organic coatings, and deposits from soil water on the surface of soil particles all combine to create the soil texture. It is possible to provide a qualitative estimate of the soil texture in the paddock using simple hand-texturing techniques (www.bettersoils.com.au). Soil texture influences the yield potential of a site by contributing to the variation in nutrient storage and availability, water retention and transport, the binding/degradation of agrochemicals and soil stability to potentially disruptive processes. Figure 2.2.2a tabulates the influence of different soil textures on these second-order soil properties.

For PA, spatial variation in soil texture within a paddock may contribute to the final pattern of crop yield. Soil conductivity (ECa) surveys, carried out by electromagnetic induction (EM) (See section 3.2.8) have been used to locate major changes in soil texture that can be used to select soil sampling sites to characterise changes in soil texture.

Property	Texture classes, with average clay percentages				
	Sands (5%)	Sandy Loams (15%)	Loams (20%)	Clay Loams (30%)	Clays (55%)
Total available water	Very low to low	Low to medium	High to medium	Medium to high	Medium to low
Rate of water movement	Very fast	Fast to medium	Medium	Medium to slow	Slow
Nutrient supply capacity	Low	Low to medium	Medium	Medium to high	High
Leaching of nutrients and herbicides	High	High to moderate	Moderate	Moderate to low	Low
Tendency to hardsetting or surface sealing	Low	High	High to moderate	Medium	Medium to low
Rate of warming after watering	Rapid	Rapid	Rapid to medium	Medium	Slow
Trafficability and workability after rain or irrigation	Soon	Intermediate	Intermediate	Intermediate	Delayed
Susceptibility to compaction by cropping machinery	Low	Moderate	Moderate to High	Low	High unless cracking clay

Figure 2.2.2a. Effects of texture on other soil characteristics important to grain cropping.

2.2.2c Soil structure

Soil structure can be defined as the arrangement of particles that form the soil and the distribution of voids between these particles. The structure of the soil governs the physical penetration, growth and anchorage of roots. It also regulates the air-moisture balance required for plant growth and microbial activity, the soil drainage-water retention characteristic and the erosion potential.

It follows that a decline in soil structure may result in a broad range of deleterious affects on crop growth. These are commonly:

- a reduction in the availability of oxygen required for metabolic processes;
- reduced infiltration, increased ponding, runoff and loss by evaporation;
- a reduction in the PAWC;
- restriction in root volume; and
- slowing in root elongation.

Mechanical forces, such as cultivation or other traffic may damage soil structure. Cultivation can destroy soil structure by tillage-induced sorting of particle sizes. The fine particles move to the bottom of a soil layer disturbed by tillage in the same way that crumbs of breakfast cereal descend to the bottom of the box, when shaken.

Compaction of soils is a result of mechanical damage by animals and heavy machinery. Grazing commonly causes surface compaction. This is usually in the top 15 cm of the soil and is often removed in normal tillage operations. Plough pans usually form directly under the cultivation depth, whereas traffic pans often occur 10-60 cm below the soil surface. These can create a subsurface barrier for roots, water and nutrient infiltration, limiting the effective plant rooting depth.

Structural degradation through compaction, and the ensuing increase in soil strength, has been shown to increase the energy required to undertake tillage operations. Studies have shown a reduction in cultivation energy requirements of up to 46% under controlled traffic (4.2.3) conditions where compaction has been removed from between the wheel tracks (Murray & Tullberg 1986).

Areas prone to soil structural damage by compaction may be identified using spatial information and be targeted for strategic management. For example, the risk of soil compaction resulting from animal or machinery traffic or tillage is highest when the soil is wet. Therefore low-lying areas in the landscape are more likely to be trafficked when wet, as they remain wet longer than areas higher in the landscape. Low-lying areas maybe identified using elevation maps. Soils susceptible to structural damage include those without natural structure, low in organic matter or soils of a particular particle size distribution. For example, traffic pans are common in coarse textured soils, and plough pans are common in fine textured soils. In some cases these soil types can be identified using soil ECa using EMI or (Standards for EM mapping for the grains industry) electrical resistivity surveys (See section3.2.8) or gammaradiometrics (See section 3.2.9).

Wetting and drying cycles cause physical forces that reduce soil structural stability, especially frequent saturation of the soil through irrigation. Soils high in sodium ions, referred to as sodic soils, are very susceptible to structural collapse.

Surface crusting is a sign of soil structural decline in the topsoil. Surface crusting is usually a symptom of some other problem such as sodicity or low organic carbon. Crusting is the result of mechanical destruction of pore space in the surface few millimetres by raindrop impact or dispersion of sodic clay soils. Crusting in susceptible areas may be exacerbated by a lack of surface cover. A crust forming on the surface of the soil can reduce water infiltration and plant germination. This can lead to patchy plant growth and crop yield that could be evident on a yield map or satellite image.

Structural degradation can influence yield but the degree of impact may be determined by the season. For example, in a wet year, effects of compaction may cause increased waterlogging, while in a dry year, especially in a hardsetting soil, compaction effects will reduce the quantity of soil water and may restrict root exploration. The different impacts of soil structure decline mean that when interpreting crop variability in a paddock, it is important to consider variability over several years with the recorded seasonal conditions.

For PA, any spatial variability in soil structure can affect the efficient use of inputs such as fuel and nutrients, and also contribute to the spatial pattern of crop yield within a paddock.

Options for detecting the spatial variability in soil structure include: measurements of soil strength using tillage draught; tractor fuel consumption during tillage and cone-penetrometer resistance; pore/solid relationships via air permeametry; soil bulk density sampling; compaction layer location using ground penetrating radar; and soil ECa, via EMI surveys.

Soil pits can be used in combination with spatial information to observe soil strength and plant root interaction with layers of differing strength.

For identifying spatial variability in surface crusting, susceptible areas are best detected by sampling for the underlying cause (e.g. sodicity or low organic matter) or by visual assessment after the soil dries following a rainfall event sufficient to cause crusting.

2.2.2d Soil depth

Soil depth is referred to here as the depth of soil that can be readily accessed by crop roots. This depth is a very important parameter because it greatly influences the total quantity of water and nutrients available to the plant. It may be the total depth of soil to bedrock or the depth to a subsoil layer impenetrable by plant roots. Some subsoil layers are a permanent feature of the soil (boron layers, salinity, acidity, alkalinity) resulting from the mechanism by which the soil was formed, such as an impervious clay layer in a depositional or duplex soil, while others may

be artefacts of previous usage such as a plough pan. The actual rooting depth of a plant depends on the plant species, especially whether they are an annual or perennial, and can also be dependent on the soil water regime. This is because if there is no soil water at depth, roots will tend to grow only in the surface soil. It should be noted that any water or nutrients that pass below the actual rooting depth of a plant are unavailable and may contribute to environmental damage, such as salinity or pollution.

All soil, even soil that consists entirely of a single texture class, has at least two layers: topsoil and subsoil. In Australian soils, the topsoil layer is usually thin, sometimes only 2-3 cm thick, although in cultivated paddocks the top 10-15 cm may be referred to and constitute a topsoil. This layer is usually characterised by higher organic carbon and nutrient content than the soil below. Even though the organic carbon content in the topsoil is higher than in the subsoil, it is still relatively low in most Australian cropping soils when compared with typical soils of other continents. The shallowness of this layer renders it fragile and easily lost to erosion. One source of spatial variability in soil depth is the partial or complete loss of this layer.

The subsoil may contain multiple layers of soil or horizons. In depositional soils, these layers may be of quite different textures. For example, a mostly clay soil formed during two or more deposition periods may contain a lens of sand that blew in or was deposited by water, between two of the clay depositions. The presence of such a lens would dramatically change the PAWC, infiltration and drainage. In the Mallee of New South Wales, South Australia and Victoria, it is quite common for wind-blown sand to overlay heavier clay.

A subsoil layer, such as gravel or clay may impede root growth and hence limit the plant's access to water, which has drained through. The depth at which such a layer occurs, along with its thickness, will be a source of within-paddock spatial variability in rooting depth. A saucer-shaped impervious clay layer may collect water and form a perched watertable, which, if it is close enough to the surface, may cause a waterlogging problem (Figure 2.2.2d).

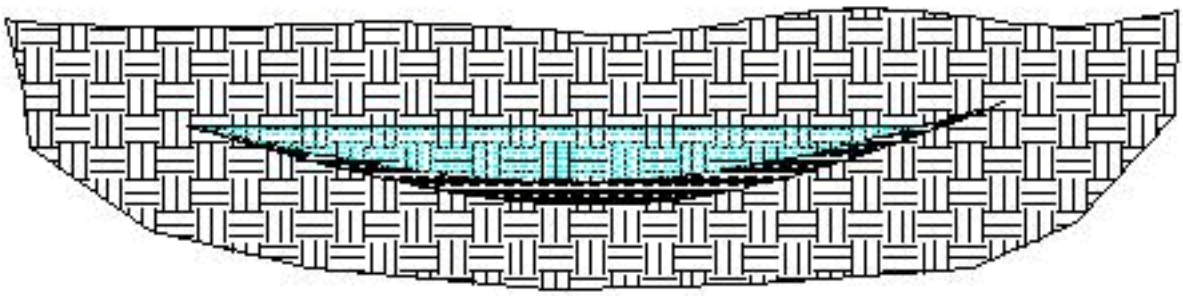


Figure 2.2.2d. Perched watertable above impervious clay.

Duplex soils with sand over clay soil are common in Western Australia. The high density and low permeability of the clay B-horizon restricts plant growth, and water and nutrient movement. Low fertility, runoff, erosion, waterlogging, and the development of secondary salinity and water repellence, are common problems in these soils.

In some shallow soils, the depth to bedrock may be determined by using a graduated push probe. This operation is most easily undertaken when the soil is wet. If there is no information on the variation in depth, probing on a coarse grid will indicate the magnitude of the variation and areas where probing on a finer grid would be worthwhile. There is no point probing on a fine grid in an area where there is little variation.

Probing may be used to locate some subsoil layers when there is a sufficiently large difference in strength between the layer sought and the overlying soil. Some relatively shallow and thin layers, such as a plough pan, may be difficult to locate when the soil is wet and the strength of all layers is low. When there are multiple layers, it may be difficult to differentiate between them using a push probe, especially if the depth and thickness of the layers are highly variable. In these circumstances coring or other sampling will be needed to identity the layers. Ground penetrating radar is under development, which will allow a much higher measurement density. None of these methods enables good measurement of the cracks that might exist in subsoil layers. Although only small quantities of roots may find these cracks they can play a very important part in crop growth by providing a pathway for infiltration of rain and for access by crop roots to deeper and moist soil layers.

Where there is a marked difference in the properties of one layer and another deeper layer, an EMI survey (See section 3.2.8) may help to indicate the depth of the surface layer, but this method will be far less precise than probing/sampling or the use of ground penetrating radar.

2.2.2e Soil organic matter

In most soil types the amount of soil organic matter (OM) provides an indicator of the inherent soil fertility. OM plays a significant role in stabilising soil structure by binding soil particles together, and in storing and releasing nutrients. The amount and type of OM also influence the quality and quantity of soil microbial activity. Of particular interest is the ability of OM to provide mineralisable nitrogen, phosphorus and sulphur as this may influence the requirements for synthetic fertiliser application.

In Australian soils the slow rate of mineralisation will limit the release of these nutrients, but nutrients from OM can still provide a significant contribution to dryland cropping or during the drying cycle on irrigated land. The importance of OM in storage and release of moisture and plant available nutrients increases as the percentage clay content decreases.

The amount of OM present also affects the degree and manner in which herbicides and pesticides are adsorbed or broken down. The more OM the greater the degree of binding that may occur. Such linear relationships between soil OM and the required herbicide rate for a designated degree of weed control have been published for atrazine, cyanazine, simazine, alachlor, metolachlor, metribuzin, trifluralin, pendimethalin and diuron.

For PA, spatial variation in OM may affect decisions about fertiliser rate and stubble retention. Spatial variability in OM has been measured experimentally using tyne-based soil colour sensors as well as remotely sensed soil reflectance information but these methods need to take into account changes in soil texture.

2.2.2f Soil pH

Soil pH is a logarithmic index of hydrogen ion (H^+) concentration in the soil solution. The level of H^+ ion concentration in the soil solution affects the ionic charge of soil organic and inorganic particles making them more or less available for plant uptake. For example, at low pH levels (a high level of H^+ ions) aluminium and manganese become highly available, often at levels toxic to plants.

Variation in pH generally decreases in horizons further down the soil profile due to a decreasing variability in soil OM and texture (especially the clay content). In the topsoil, variability in OM and texture also controls the buffering capacity (BC) of the soil. This is a measure of the ability of the soil to resist changes in pH. It is used in calculations of the amount of lime required to increase the soil pH by one unit (e.g. from pH 6 to 7). The BC is closely linked to the geology and cropping history of a paddock, for example a long history of legume pasture results in a lower pH (i.e. more acidic soil).

Spatial variation in pH across a paddock will undoubtedly affect the plant availability of nutrients, even if fertiliser is applied in uniform quantities. A measure of the spatial variability in BC would be useful for PA in order to calculate the actual changes in the amount of lime required to be spread for pH amelioration. Measurements of soil pH can now be made using sensing systems attached to a tyned implement. In-paddock measurement of BC will be available soon.

2.2.2g Soil nutrients

The interaction with management and other soil attributes ensures that the spatial variability in soil nutrient status is very site specific. Variability in soil nutrients is ultimately governed by variability in physical factors, moisture regimes and soil pH. These factors influence plant root growth, and control the supply of nutrients to the roots by metering the total quantity of available nutrients, the diffusion rate and the convolution of pathways to the roots. The application of fertilisers, past management (e.g. windrowing), past variation in crop yield (and hence nutrient removal), and the inherent soil OM content contribute to the total nutrient load and its spatial variability within a paddock. The spatial variability in the major nutrients is usually related to increasing nutrient mobility in the soil (nitro gen>potassium>phosphorus).

Measurement of the spatial variability in soil nutrients for PA has been aimed at determining changes in the levels of nitrogen, phosphorus and potassium prior to sowing, and of deep soil N prior to preseeding nitrogen applications in the Mediterranean-type climatic regions of Australia . The levels of soil nutrients are generally determined by soil sampling and sending the samples away for analysis in a laboratory. Strategic sampling is recommended, for example if moving towards zone management, separate sampling is required for low, medium and high productive

areas. In-paddock soil nutrient sensing systems are under development.

A summary of soil attributes that impact on yield variability and their measurement techniques is shown in Table 2.2.2g.

2.2.2g Soil nutrients

Potential causes of yield variation	Limitations to yield	Remote sensing or continuous sampling techniques for identification**	Measurement methods* and tests for ground truthing remotely sensed data
Soil water - PAWC	Low plant available water capacity	Calibrated EMI or resistivity Thermal infrared Visible/near/shortwave infrared Radar	Drained upper limit (DUL) Crop lower limit (CLL)
Soil water - PAW	Low PAW	Thermal infrared Visible/near/shortwave infrared Radar Time differential satellite imagery Harvest index maps Using yield or ECa map conversions to PAWC	Soil sampling and laboratory measurement (use intact cores unless bulk density is known) In situ neutron/ capacitance/TDR (time domain reflectometry) probes Estimate from soil texture
Waterlogging	Reduced oxygen availability	Elevation maps may indicate potential areas EMI indicates areas of risk	Piezometers/dip wells Visual observation in crop and surface water ponding Soil hydraulic properties
Water repellence	Reduced moisture availability		Visual clues - look for plant establishment problems Soil sample Water droplet test or methanol droplet test
Soil texture/type	Low inherent yield potential due to low: CEC, PAWC, inherent fertility	Gamma radiometrics EMI or resistivity (clay content) Shortwave infrared	Hand texturing PSA (particle size analysis) laboratory measurements
Soil structure	Poor soil structure	Tillage draft	Penetrometer Bulk density Soil hydraulic properties Visual observations in pit
Organic matter	Low organic matter	Visible/near infrared	Soil sample laboratory test -organic carbon, organic matter fractions Shortwave infrared now becoming available

Rooting depth - structural	Shallow rooting depth	Also inferred from other measures	Soil profile assessment, push probe
	Physical barriers to rooting depth	Calibrated EMI or resistivity Ground penetrating radar	Soil profile assessment, push probe
	Hard layers Contrasting soil textures, Surface compaction, Subsurface compaction, Traffic pans, Plough pans, Rocks	Calibrated EMI or resistivity Ground penetrating radar	Soil profile assessment Push probe
	Crusting		Visual observations poor crop emergence
Rooting depth - chemical	Chemical barriers to rooting depth		Soil profile assessment
	pH acid or alkaline	Soil pH sensor	Soil sample laboratory analysis Soil pit assessment
	Sodicity	Calibrated EMI or resistivity	Dispersion test on soil sample Chemical CEC
	Salinity	Calibrated EMI or resistivity Ground penetrating radar	Soil sample laboratory analysis Visual indication - patchiness of crop
Soil nutrients	Deficient (e.g. N, P, K S and trace elements) or toxic nutrients (e.g. Al, B)	Visible/near/mid or shortwave infrared for N status	Soil sample Plant tissue test Crop visual indicators

***A yield map or biomass image can be used to pinpoint sampling locations.**

****Refer to section 3.1 for more detail on spatial information.**

Table 2.2.2g. Potential soil-related causes of yield variation within a paddock.

PAWC, plant available water capacity; PAW, plant available water; EMI, electromagnetic induction; ECa, soil conductivity; CEC, cation exchange capacity.

2.2.2h Subsoil constraints

A range of soil factors, especially poor soil structure, may restrict root growth or function in the subsoil (i.e. below about 20 cm). Chemical and physical subsoil constraints commonly found in cropping paddocks include:

- salinity, which may be primary or standing salinity due to a naturally occurring high level of salts, or secondary or dryland salinity due to rising groundwater levels bringing salt from depth;
- sodicity, where high natural levels of sodium cause clays to disperse and form an impermeable and often anoxic layer;
- natural and induced compacted layers, the latter often resulting from heavy traffic or a plough pan; and layers of natural high soil strength;
- acid soils with pH of 4.5 or less; and highly alkaline soils with pH of 9.0 or more
- low nutrient levels (a particular problem for immobile nutrients under no-till cropping);
- toxic ions (e.g. aluminium or boron), often associated with highly acid or alkaline soils

The effect of these constraints may be thought of as reducing the soil PAWC, that is, although the soil may contain adequate moisture, either crop roots cannot penetrate the subsoil to access it and/or they cannot function to take up the water. Areas of a paddock with one or more of these constraints may show on maps as having consistently low biomass or yield despite no obvious surface differences, or as areas where biomass fails to translate into yield. PA data can be used to pinpoint these areas of the paddock for closer inspection (Table 2.2 2g).

Reference

Murray, S.T. & Tullberg, J.N. (1986). Controlled traffic cropping systems. Conference on Agricultural Engineering. Adelaide 24-28 August 1986. The Institution of Engineers, Australia, National Conference Publication No. 86/9. pp. 234-238.

2.2.3 Yield variability due to weeds, insects or disease, and to some abiotic factors and past management

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

It is widely understood that the colonisation mechanisms of most crop pests, such as insects, weeds and disease, result in a clustered/patchy spatial distribution. Yield loss studies confirm that efficiently reducing the density of pest infestations benefits crop yield and enterprise gross margin. As the potential yield increases the financial loss through crop pests also increases, if pests remain untreated. This emphasises the importance of accurately describing the spatial distribution of pest population densities prior to treatment, so treatment can concentrate on areas with high yield potential and high pest infestation. Knowing the spatial distribution of pest infestations may also help with segregations at harvest (particularly for weeds).

2.2.3a Weeds

Weed infestations are generally described as aggregations at random. The aggregation processes are not stable between paddocks for a given weed species but often show significant stability between years in the same paddock for the same species. Such instability between paddocks confirms that individual paddock recommendations for treatment will be required.

Aggregation also infers that parts of a field may remain pest free. Results from a 10 year study of weed distribution during grazing/cereal crop phases showed irregular patterns but that >60% of the area had no weeds (Wilson & Brain 1991). In single seasons it is possible for up to 97% of a paddock to be weed free (Rew et al. 1996).

Overall, the spatial distribution of weed plants is a function of species (weed and crop), environmental conditions (Cardina et al. 1997) and previous/current cultural practices. In the context of PA the spatial distribution of weeds has been measured using a number of different methods. The location of weed patches can be identified using positioning equipment and mapped using hand-held devices, mapped during harvest operations or mapped via remote sensing. In-paddock sensing systems are also available to identify and treat weed infestations in crops (See section 4.2.7b).

2.2.3b Insects

The distribution pattern of insect pests is often more dynamic than that of weeds and is a function of insect species and possibly the stage of the insect and crop life-cycle. Fundamental to the spatial distribution of insect species are the separate processes of immigration, colonisation, reproduction, emigration, predation and mortality.
The spatial variability of insect pests can often be linked to the impact that spatial variation in soil and host plant conditions has on insect mortality. Many insect pests are attracted to healthy or better growing host plants because they provide the greatest chance of sustaining their life-cycle. Obviously many insect pests are crop specific, but climatic conditions along with spatial variation in soil conditions may interact to provide areas in a paddock that are more attractive for attack. Therefore, knowledge of the spatial variability in soil/cropping conditions before pest infection might aid prediction of the spatial distribution of subsequent pest infestations.

2.2.3c Diseases

Author: John Heap, South Australian Research and Development Institute

The risk of disease developing in crops is dependent on many factors, some local and others distant. Soil- and stubble-borne diseases are mostly determined by the carry-over of the pathogen at the site. For example yield loss

caused by cereal cyst nematode is determined by the number of eggs in the soil, and for take-all it is the number of infected crowns and roots persisting from the previous year. Therefore, it is possible to estimate the risk of such diseases by testing soil samples, especially now that DNA-based tests are available (Heap and McKay, 2004). Australian research has shown that production zones within a paddock can have different disease risks and can be potentially managed at that scale.

Leaf diseases, such as rusts, often result from spores that are blown from neighbouring farms or even other districts. In this case disease prediction needs to consider factors at a district or regional scale, such as climatic conditions. Production zones may be useful to target application of late fungicide treatments to protect high yielding zones, however early sprays to delay the build up of epidemics need to be applied across the whole paddock.

Refer to 3.2.7 for information on soil sampling for disease

2.2.3d Yield variability due to other, abiotic, causes

Elevation can be an important cause of crop variability, either directly through frost effects due to cold air drainage, or indirectly due to its influence on other soil factors. Over time elevation, slope and aspect can all influence leaching and chemical reduction of ions through soil wetting and drying cycles or prolonged period of saturation. Elevation can thus be a surrogate indicator for some soil attributes; it is easy to measure (See section 3.2.10) and proving to be a valuable data layer for PA.

Aspect is another potential cause of crop variability. This can have direct effects when north- and west-facing slopes are hotter and dry more quickly than those facing south and east. Depending on the source of the weather system there may be differences in rainfall due to aspect. Indirect effects of aspect include variation in soil characteristics between paddocks on the same ridge facing north-west and south-east.

Uneven rainfall distribution can be another cause of crop variability, especially over large paddocks. There can be more than 10% variation in growing season rainfall (GSR) across a 100 ha paddock, and depending on the total GSR and its distribution over time this can lead to significant yield differences. This source of variation is difficult to detect except with an array of accurate rain gauges (Figure 2.2.3).

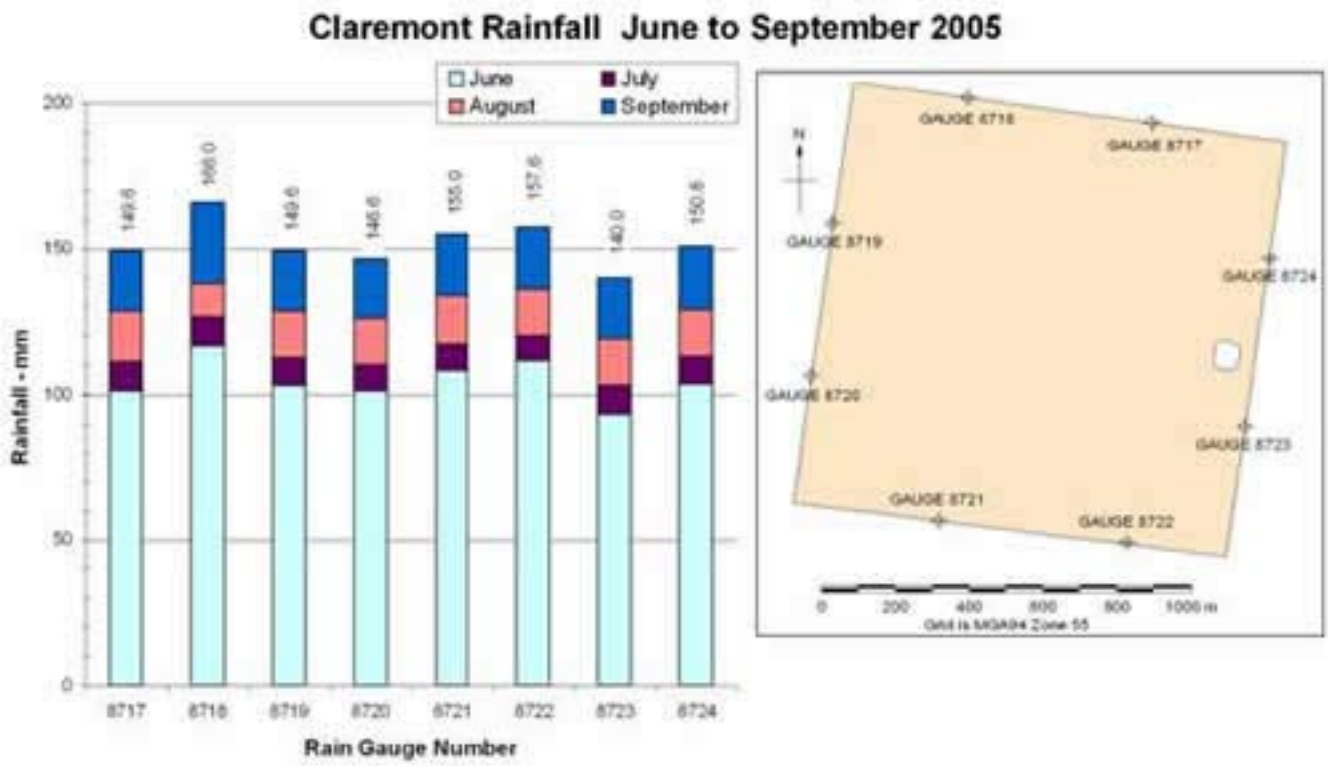


Figure 2.2.3. Variation in rainfall across a 100 ha paddock illustrated by readings from eight rain gauges.

Past management of the paddock is also an important source of variation in crop growth and yield. Crops grown in past seasons can have a large influence, for example lucerne grown over part of a paddock will dry the soil, leave N behind and may pierce subsoil layers otherwise impenetrable to cereal roots. Windrowing canola may leave swathes of soil with above average potassium levels. The residual effect of herbicides such as sulphonylureas may be seen in highly alkaline soil, especially if rainfall is low. The effects of faulty fertiliser or pesticide application may be apparent for several seasons. It is, therefore, important for growers to record past management so that it can be considered when PA data layers are being interpreted.

References

Wilson, B.J. & Brain, P. (1991). Long-term stability of distribution of Alopecurus myosuroides Huds. within cereal fields. Weed Research 31: 367-373.

Rew, L.J., Cussans, G.W., Mugglestone, M.A. & Miller, P.C.H. (1996). A technique for mapping the spatial distribution of Elymus repens, with estimates of the potential reduction in herbicide usage from patch spraying. Weed Research 36: 283-292.

Heap, J.W. & McKay, A.C. (2004). Spatial distribution of soilborne disease inoculum DNA in cereal crops and implications for soil sampling protocols. In: Proceedings of the 3rd Australasian Soilborne Diseases Symposium. (Edited by K. Ophel-Keller & B. Hall). p. 106.

2.3.1 Using simulation modelling to interpret patterns of spatial variability

Author: Michael Robertson, CSIRO Sustainable Ecosystems

The first step in managing spatial variability is to understand the cause. This is not always straightforward because it may not be apparent or there could be several possible explanations. Yield maps alone do not explain why a paddock shows yield variability, and year-to-year variation in crop performance, related to weather and management factors, can further complicate this task.

This is where cropping systems simulation models can help. By predicting how a crop might yield in various parts of a paddock in relation to weather variation, management practices and soil properties, simulation models can help explain observed paddock variability. Another strength of models is that they can be combined with long-term weather records to predict the impact of weather variation on the patterns of variability from year-to-year.

Models have been recently applied in research projects to test farmers' hypotheses about the causes of variability within paddocks. The extent to which variation in factors such as soil depth, soil properties and topography could explain the variability observed in yield maps was determined. By varying these factors in the model, it was possible to compare simulated yields with those measured in the paddock.

A recent example of the application of a simulation model to explain spatial and temporal variability in a paddock in southern New South Wales highlights the role of models. In this paddock it was suspected that the causes of variation were multi-factorial, not immediately obvious, and perhaps influenced by landscape-scale processes. The soil was characterised at four points that were representative of contrasting points in the paddock, as shown by historical yield maps taken in a canola-wheat-triticale-lupin-wheat sequence. Yields at these points were read off kriged yield maps and compared with actual yields taken at these points in seasons 3, 4 and 5 and with simulated yields based on daily weather data, management information (sowing date, variety, density, nitrogen fertiliser applied) and the PAWC characterised at the four points. The modelling analysis highlighted the following points:

- Good agreement between yields from the yield maps, quadrats and simulations at the four points on the slope, in three out of the five seasons, suggested that differences in PAWC could explain differences in yield.
- In another season, quadrats and simulated yield agreed well but were both greater than mapped yield. This was not evidence of a biophysical constraint unable to be captured by the model, but a difference that may be due to harvesting efficiency.
- In another season, both measures of yield were less than the simulated at only the lowest position on the slope. Inspection of the temperature record suggested that a yield-damaging frost occurring at wheat flowering may have occurred at the lowest position on the slope - a factor not taken account of by the model.

In summary, this example illustrates that it was possible to tease out the separate and interacting impacts of soil variation (PAWC), management (harvesting efficiency) and microclimate effects (frost at the lowest position of the paddock). Some of these influences are directly amenable to management and some have implications for management, for example use of different rates of fertiliser on different PAWC soils, use of later/earlier flowering varieties in frost-prone positions in the landscape. The application of models to exploring the feasibility of these different management options is explored in Chapter 4.

Although simulation models can play a useful role in decisions about managing spatial variability they are not widely used. The models have very high data requirements, particularly as they need to be able to simulate yield at multiple points in a paddock to capture the variation in crop/soil/landscapes characteristics (See Table 2.2.1a). For commercial purposes, farmers need to access specialised skills to run these models. One such cropping systems model, APSIM, is being used by grain growers and agribusiness through the industry via the Yield Prophet system (www.yieldprophet.com.au). Yield Prophet allows simulations of individual paddocks or zones within paddocks to be made in real time through the season using rainfall data collected on site and supplemented by the nearest available Bureau of Meteorology historical record to calculate the probability of outcomes for the season based on management (sowing date, variety, nitrogen applied).

3. GETTING STARTED

3.1.1 Methods of data collection
3.2.1 Global navigation satellite systems
3.2.2 Coordinate systems and map projections
3.2.3 Aerial photography and bare soil images
3.2.4 Satellite and airborne imagery
3.2.5 Measuring variability in grain yield and quality
3.2.6 Measurement techniques for spatial variability
3.2.7 Soil sampling and testing methods
3.2.8 Electromagnetic induction survey
3.2.9 Gammaradiometrics
3.2.10 Elevation mapping
3.3.1 Collecting yield data
3.3.2 Yield map analysis
3.3.3 Preparing a gross margin map

3.1.1 Methods of data collection

Taking the first steps into precision agriculture (PA) can be daunting but those steps do not have to be expensive. PA is all about geographically located data - its collection, integration, interpretation and finally its implementation in site-specific management. Remotely sensed data such as satellite data and aerial photographs can be purchased. Contractors and PA specialists undertake electromagnetic induction (EMI) and gammaradiometric surveys and provide services that integrate and interpret data from these sources as well as data collected on-ground from yield monitors, machinery mounted biomass sensors or soil samples, for example.

Growers already collect information on their farm and this may be recorded as a map (e.g. soil maps). This data must be gathered with a known spatial reference if data from different sources is to be accurately overlayed or integrated. (See section 3.2.2). The spatial reference may come from a global positioning system (GPS) receiver or be provided by a third party (e.g. an Orthophoto- see Glossary).

Data can be categorised by frequency and method of collection. Static data are only gathered once or infrequently, whilst other data are collected annually.

Static data are often produced by a third party therefore the grain grower does not require equipment for data collection; they purchase the data as maps or electronic files.

Crop, yield and grain quality data can be collected annually from yield and protein monitors (See section 3.2.5) mounted on the harvester. Crop cover or biomass data can also be purchased in the form of analysed satellite, aircraft or balloon imagery. Maps of estimated biomass (See section 3.2.4) derived from Landsat satellite imagery may be particularly useful in the first year that a grower uses PA as these maps provide historic data on variation across a paddock, potentially from 1986 until the present day.

Data may be collected on-ground by physical samples or remotely by aerial photography or satellite imagery. However, there is a grey area where data are gathered by equipment close to or on the soil surface but where no physical samples are taken. This is known as proximal sensing. EMI mapping is an example of this type of data collection.

Data collected annually and on-ground are usually gathered by PA equipment owned by the grain grower or a contractor. Figure 3.1.1 shows the steps and data that may be required to use PA on-farm, and Table 3.1.1 summarises the soil or crop attributes estimated by different remote sensing techniques.

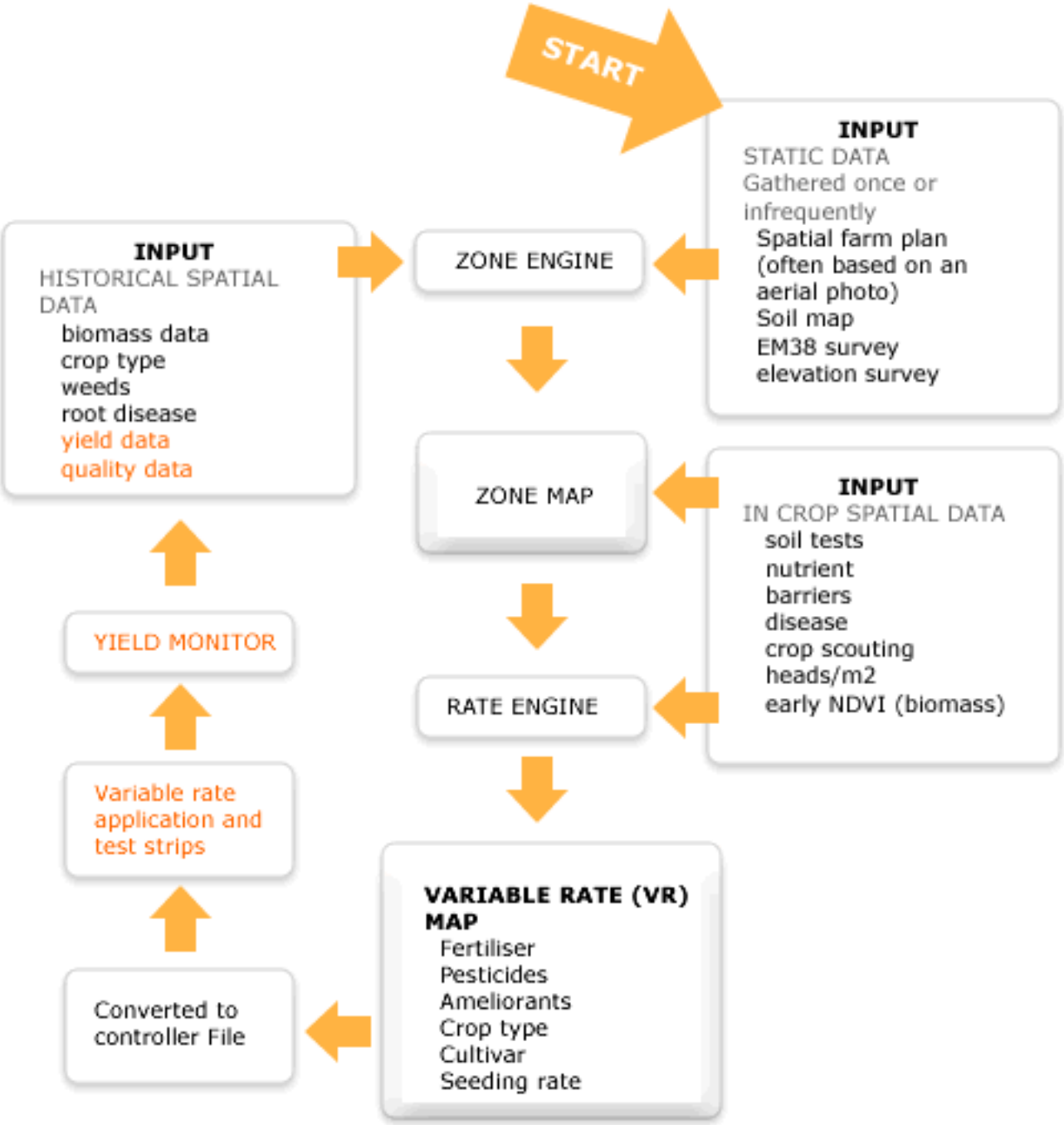


Figure 3.1.1. Possible stages and data inputs and outputs in an on-farm precision agriculture program. Items in orange require farm owned equipment (source: Silverfox Solutions P/L) .

Observation technique	Platform	Attribute estimated		
		Soil	Crop	Other
Visible/near/short wave infrared reflectance	Aircraft/satellite Ground-based sensors (proximal)	Moisture content Colour Organic matter Surface soil mineralogy (hyperspectral only)	Colour Vigour Leaf area index Biomass Nitrogen status and potential responsiveness Photosynthetic activity Crop type and yield potential Stress Physical damage (hail, lodging) Insect and disease incidence Moisture content and senescence Harvest index or stubble quantity	Digital elevation models Soil and plant tissue sampling locations Management zones Land use
Thermal infrared (TIR)	Aircraft/satellite/ / proximal	Moisture content	Canopy temperature Moisture stress Disease incidence Vigour Evapo-transpiration	Soil and plant sampling locations
Radar	Aircraft/satellite	Moisture content Surface roughness Salinity Texture	Leaf area index Biomass Moisture content Crop type Crop structure and height Stubble quantity	Digital elevation models Management zones Land use
Ground penetrating radar	Proximal	Depth to texture contrast Hardpans		Management zones
Gamma emission (Gammaradiometrics)	Aircraft/Proximal	Mineralogy Clay content Potassium content Soil depth		Digital elevation models (proximal, with Real Time Kinematic GPS) Soil sampling locations Management zones
Electromagnetic induction	Aircraft/proximal	Clay content Salinity Sodicity Plant available water		Digital elevation models (proximal, with RTK GPS) Soil sampling locations Management zones

Table 3.1.1. Summary of the remote sensing techniques and the relevant attributes that can be estimated using them (Ian McGowen, Department of Primary Industries NSW, based on data provided by Brett Whelan, Australian Centre for Precision Agriculture)

3.2.1 Global navigation satellite systems

Authors: James Taylor and Brett Whelan, Australian Centre for Precision Agriculture, the University of Sydney and Rohan Rainbow, Southern Precision Agriculture Association

Global navigation satellite systems use a constellation of satellites orbiting the earth to geo-locate a receiver's position on or near the earth's surface.

Two systems are currently in operation, the NAVSTAR GPS, owned by the government of the United States of America, and the Global Navigation Satellite System (GLONASS), which is controlled by a consortium headed by the Russian Government.

Two more systems are being planned. The European Space Agency intends to have their network, Galileo, fully operational in 2008. A Japanese consortium is also planning to launch a satellite navigation system designed for satellite navigation and communication for automobiles.

All four existing and proposed systems are similar. However, the majority of receivers developed by commercial enterprises to date use the information from the NAVSTAR GPS satellites, so this is the system of most interest to agriculture.

3.2.1a How the GPS works (geo-location)

Geo-location using satellite-based navigation systems is based on the ability to measure the time taken for a signal to travel from a satellite to the receiver. Radio signals travel at the speed of light, which is constant, so if the time of travel is known then the distance between the satellite and the receiver can be determined. Since the position of the satellites is always known, due to constant monitoring of satellite orbits, the location of the user's receiver can be calculated, if the receiver is obtaining signals from at least four satellites.

Each GPS navigation satellite continuously broadcasts its position along with timing data on two frequencies (L1 and L2).

The L1 band carries two codes, Coarse Acquisition (C/A) code and Precision (P) code. The C/A signal is also termed 'code phase' or 'Standard Positioning Service' (SPS) and is the main signal used in civilian activity. The P signal is also referred to as 'Precise Positioning Service' and was designed for US government. It is a signal that military GPS units can immediately read and with the same level of accuracy without a differential GPS (DGPS), while civilians require a DGPS to reach a similar accuracy.
The L2 band only carries the P code.
Both the C/A and P signals have a time reference digital code referred to as a pseudo random code. Receivers contain an almanac of the pseudo random codes generated by the satellites and the time they are generated. When a receiver intercepts the digital code from a satellite it can compare the digital signal to its almanac to determine when the signal was generated. The time of travel is the difference between the time the signal was intercepted and the time it was generated (Figure 3.2.1a1). The difference between the C/A and P code is in the resolution of the code and thus the accuracy of timing and distance determination.

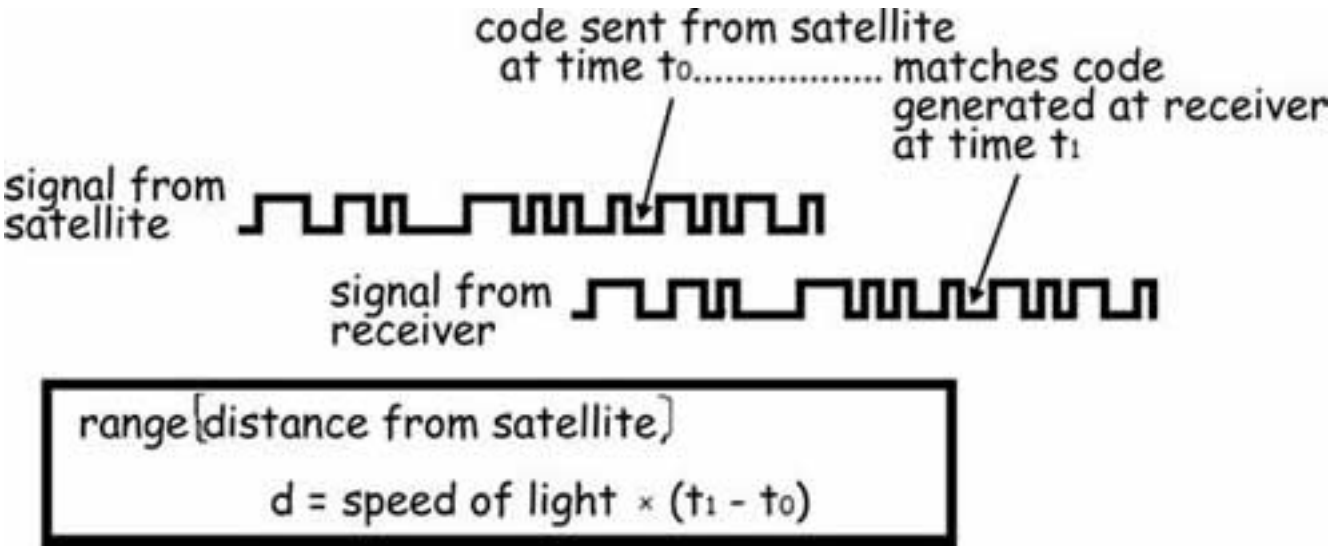


Figure 3.2.1a1. Showing how signals from satellite and receiver are compared.

3.2.1a How the GPS works (geo-location)

As well as transmitting in 'code phase', satellites also transmit general satellite information in 'carrier phase'. Carrier phase signals are broadcast on both the L1 and L2 bands and at a much higher frequency than the code phase. The higher frequency permits a more accurate measurement of the range between the satellite and receiver. However the carrier phase is not time referenced like the code phase. This makes the interpretation of the signal susceptible to 'cycle slip'. To minimise this effect, carrier phase receivers use the C/A code to provide a rough estimation and the carrier phase signal to improve this estimation. Only advanced GPS units are able to interpret the 'carrier phase' signal.

If a GPS receiver is communicating with three satellites (i.e. it is at a certain distance from each satellite) then its position must lie at the intersection of the three 'distance' spheres it forms with them. This gives two possible locations (see Figure 3.2.1a2), one of which is unrealistic. If a fourth satellite is being tracked then errors associated with timing can also be accounted for and a more precise location found. Most receivers will not give a reading unless four satellites are being simultaneously tracked.

a) with a range measurement from one satellite, the receiver is positioned somewhere on the sphere defined by the satellite position and the range distance, r

b) with two satellites, the receiver is somewhere on a circle where the two spheres intersect

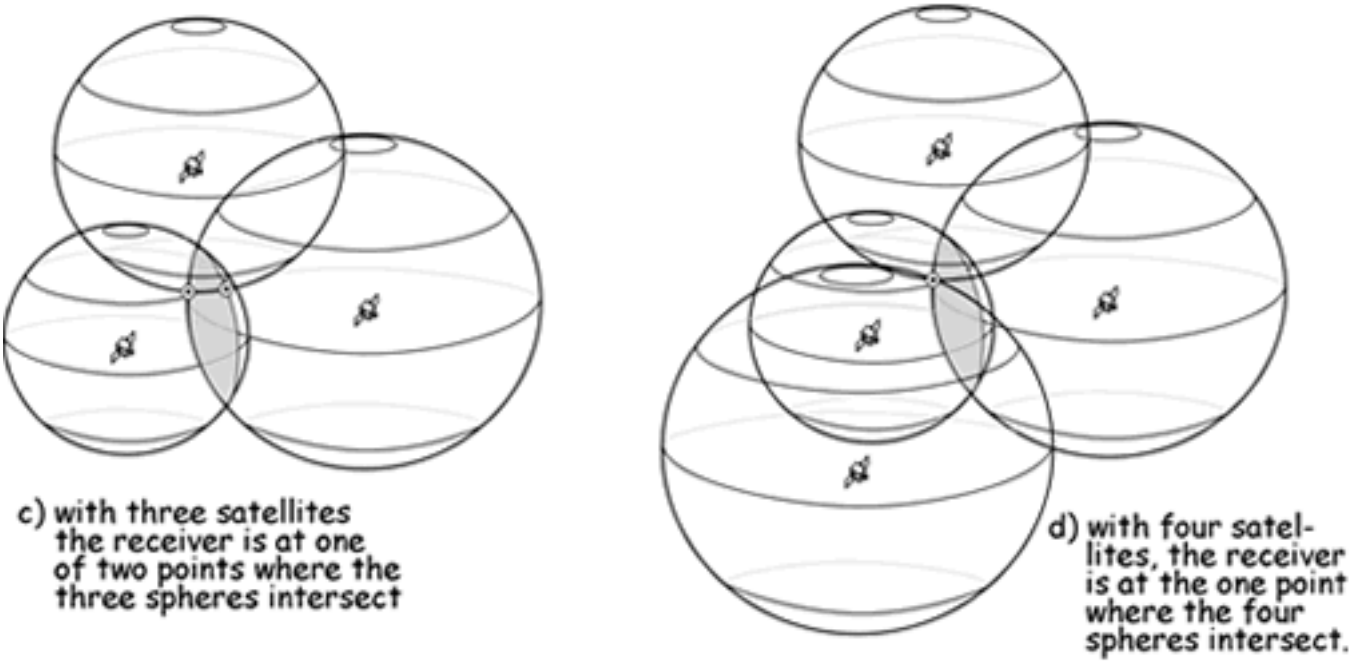


Figure 3.2.1a2. The influence of the number of satellites communicating with a GPS receiver on accurate position location.

3.2.1b GPS errors

Apart from the quality of the signal (C/A versus P versus carrier) the error in geo-location calculated by a receiver may be affected by one or more of the following error sources.

Satellite errors. Errors in the timing of the onboard atomic clocks or an error in the transmitted location of the satellite (ephemeris error).

Receiver errors. The ability of the GPS receiver and associated software to cope with thermal and electronic noise from external sources such as motors, will affect how accurately the receiver can geo-locate itself.

Atmospheric errors. To reach a GPS receiver, the satellite signal needs to pass through the Earth's atmosphere and, in particular, the ionosphere and troposphere that degrade/slow the signal speed.

Multipath errors. These are errors caused when the GPS antenna receives signals that have been reflected from a secondary source, such as nearby sheds or silos. This lengthens the travel time and thus creates error in the distance determination. Multipath errors can be minimised by not placing a fixed base-station antenna near buildings and operating mobile systems away from large structures.

Continental drift errors. Australia drifts are 7 cm in a north-easterly direction every year. A fixed DGPS base station is required to overcome this problem and ensure repeatability from one season to the next and accuracy of ±2 cm.

Conversion errors. There are two commonly used methods of logging geographic locations degrees, minute and seconds or Universal Transverse Mercator (UTM) (See section 3.2.2) system where longitude and latitude is converted into easting and northing coordinates using a transverse projection. These do not match 100%. Therefore, if a grower purchases a GPS unit using one system and then changes to one using the other system, locations will not be translate accurately. This is only a problem if systems are changed.

Satellite geometry. Apart from errors in determining the distance between the satellites and receiver, the accuracy of geo-location is also a function of the geometry of the satellites used for geo-location. The optimum geometry is for one satellite to be directly overhead and the other three spread out evenly. As satellites orbit the earth, their geometry relative to a receiver varies and the dilution of position errors will vary; this is the main cause of daily variation in the accuracy of geo-location. Receivers with upwards of 12 satellite tracking channels help minimise this effect.

3.2.1c Types of GPS receivers

Stand-alone GPS receivers. These receivers, also known as Standard Position System (SPS) receivers, operate using only the basic C/A code on the L1 band from the navigation satellites. They are the cheapest GPS receivers available as there is no additional correction signal or complex circuitry to utilise the P code or carrier phase. SPS receivers have the lowest geo-location accuracy (usually ±5 m but may be greater) of all the GPS receivers on the market. Most SPS receivers contain filtering algorithms designed to smooth the signal noise when the GPS is moving. This makes SPS receivers more accurate when moving and suitable for wide swathing, low resolution applications

Differential correction receivers. The error in a GPS signal can be determined by recording the GPS signal at a fixed surveyed location. By comparing the GPS receiver position to the surveyed position the physical error can be determined. Differential GPS (DGPS) takes advantage of this known error to correct the SPS geo-location. The correction can be recorded independently and the SPS geo-location corrected later (post-processing) or the correction can be applied in real-time.

Real-time DGPS. These require two antennas: one to collect the C/A code and determine a geo-location and a second to receive a correction factor to improve the accuracy of the geo-location. A variety of different sources are available for the correction signal, for example from a local base-station, free-to-air coastal navigation beacon or a Wide Area (WADGPS) network. These GPS receivers tend to be more expensive than the stand-alone GPS receivers, as they require extra components to accept the correction signal and update the geo-location.

Carrier phase receivers. Carrier phase GPS receivers use the phase shift of the information carrier signal between propagation at the satellite and reception by the user. This method offers potentially greater accuracy (centimetre level) but also requires more expensive receivers. Carrier phase systems may be either single frequency (i.e. accessing only the L1 band signals) or dual frequency (i.e. accessing both L1 and L2 band signals). Dual frequency receivers have the advantage of faster acquisition time. Many receivers are also capable of accessing the GLONASS as well as GPS satellites if required. Similar to code phase receivers, carrier phase receivers can be improved by using a local base station or a WADGPS correction. If a local base station is used and the correction calculated and broadcast via radio transmitter, the system is said to be operating in real-time kinematic (RTK) mode.

3.2.1d Agricultural uses for GPS

Table 3.2.1d1 gives an indication of what different GPS receivers are able to be used for in agriculture.

Use	Stand-alone GPS $200-1000	DGPS (C/A code) ~$5000	DGPS (high quality) $15-30,000	Carrier phase GPS (own base station) ~$40-60,000
Soil tests	*	*	*	*
Crop scouting	*	*	*	*
Fertiliser strips	*	*	*	*
Strategic trials	*	*	*	*
Yield mapping	*	*	*	*
Guidance		*	*	*
Auto-steer			*	*

Table 3.2.1d1. Uses and cost estimates for GPS receivers (June 2005) (B. Whelan).

Further reading

McElroy, S., Robins, I., Jones, G. & Kinlyside, D. (2001). Exploring GPS: a GPS User's Guide (2nd Edn). The Global Positioning System Consortium (GPSCO), NSW Department of Lands, Land and Property Information Division.

3.2.2 Coordinate systems and map projections

Author: Robert Corner, Curtin University, Western Australia

In order to be useful for analytical purposes, all of the spatial information used in PA needs to be in the same frame of reference; that is, it should be on the same map projection and in the same coordinate system. That should be easy, but unfortunately there are a number of possible reference systems and some of them are close enough to each other to cause trouble.

GPS data are collected, in a raw form, as latitude and longitude. A GPS unit may project it into a plane projection in metres of eastings and northings such as Map Grid of Australia (MGA) or the Universal Transverse Mercator (UTM) projection. However, it is important that the conversion parameters are correctly specified, otherwise errors can be introduced.

These notes describe the most common coordinate systems and their use.

What is a coordinate system?

A coordinate system is a frame of reference that allows the position of any location with respect to an origin to be described. There are two main types of coordinates that may be observed in PA; geographical coordinates and projected (or plane) coordinates.

Geographical coordinates

Geographical coordinates are also referred to as the latitude and longitude system. Both latitude and longitude are measured as angles subtended on the surface of the earth from the centre of the earth. The basic reference is with respect to the equator and the Greenwich Meridian. The Greenwich Meridian passes through Greenwich, near London in the United Kingdom and represents zero degrees east or west longitude. The units used are either degrees, minutes, seconds and decimal seconds; degrees, minutes and decimal minutes or degrees and decimal degrees. Conversion between them is easy since there are 60 minutes in a degree and 60 seconds in a minute. However it is important to know which you are working with. Table 3.2.2.1 shows the same point in each of the three notations, whilst Figure 3.2.2.1 illustrates latitude and longitude measurements on a spherical Earth.

By convention, longitudes to the east of the Greenwich Meridian are positive and latitudes north of the equator are positive. This means that values for Australia have negative latitudes and positive longitudes.

Different way of describing the same latitude and longitude		
Degrees minutes seconds and decimal seconds (with quadrant letter)	Longitude	117° 17' 37.86" E
	Latitude	31° 47' 4.49" S
Degrees minutes seconds and decimal seconds (signed)	Longitude	117° 17' 37.86"
	Latitude	-31° 47' 4.49"
Degrees minutes and decimal minutes (signed)	Longitude	117° 17.6310'
	Latitude	-31° 47.0915'
Degrees and decimal degrees (signed)	Longitude	117.293850°
	Latitude	-31.784858°

Table 3.2.2.1. Different way of describing the same latitude and longitude.

Figure 3.2.2.1. Latitude and longitude measurements on a spherical earth.

The location in Table 3.2.2.1 is described to an accuracy of 0.01 seconds of arc measured from the centre of the Earth. That type of description is useful for navigating a ship; but what does it mean in the paddock, where distances are measured in metres? This is where the main failing of geographic (or angular) coordinates is encountered. While a degree, minute or second of latitude represents the same thing from the pole to the equator, a second of longitude varies from 31 m at the equator to about 25 m in southern Australia. This is not helpful when working in hectares and metres. Therefore, for PA, geographical data needs to be projected into a plane coordinate system.

Plane coordinate systems

A plane coordinate system has units measured in metres from a defined origin. Whilst most systems make the origin an intersection between the equator and a line of latitude, the numbers are altered by the addition of a false easting and false northing, so they remain positive in an area of interest. Most of the coordinate systems encountered in Australia are based on the UTM system, which is generally suitable at the individual state level, although large states such as Western Australia span more than one zone. There are some plane coordinate systems based on other projections that are designed to cover the whole continent.

The UTM system converts the latitude and longitude angular measure into easting and northing coordinates using a transverse projection. Imagine a sheet of paper is fastened around the Earth with its axis parallel to the Equator and stretching around the entire circumference from one pole to the other and back again. Points on the Earth's surface are then 'projected' onto this cylinder which can then be unrolled to give a flat map (see Figure 3.2.2.2).

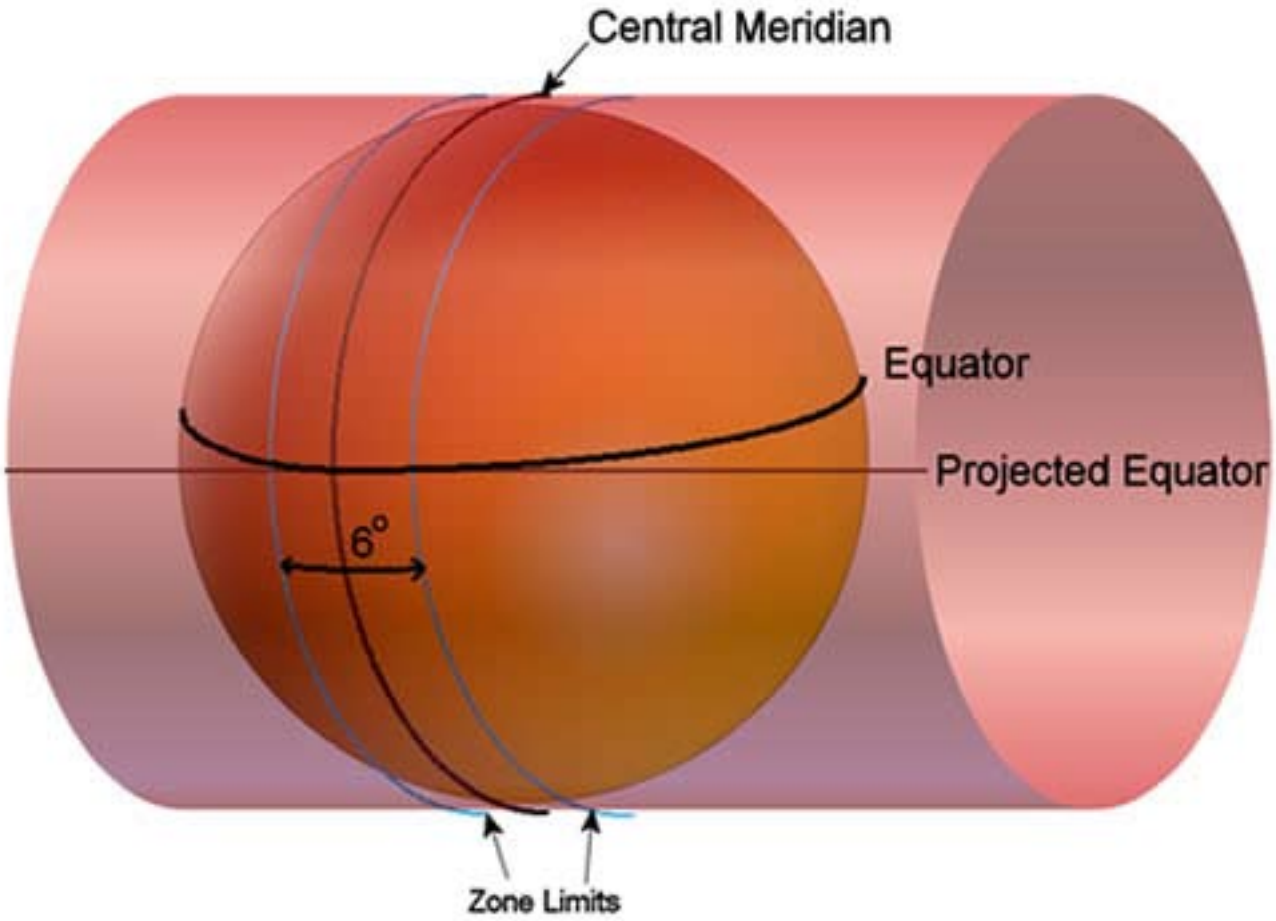


Figure 3.2.2.2. Universal Transverse Mercator is a transverse cylindrical projection.

Plane coordinate systems

In order to minimise distortion the world is divided into zones, each of them six degrees of longitude wide. Imagine this as moving the paper roll in Figure 3.2.22 round six degrees at a time. The central line of each six-degree zone is

referred to as the central meridian. Most projections are organised so that the projection surface does not touch the Earth at the central meridian but is a little to each side of it. This minimises the overall scale distortion caused by the move from a curved to a flat surface. There are 60 UTM zones around the earth. Zone 1 runs from 180°W to 174°W giving it a central meridian at 177°W. The zone numbers then proceed in an easterly direction around the Earth. The zone numbers of the UTM projection are also used by the MGA (see Figure 3.2.2.3). For practical purposes Australia is spanned by zones 50-56.

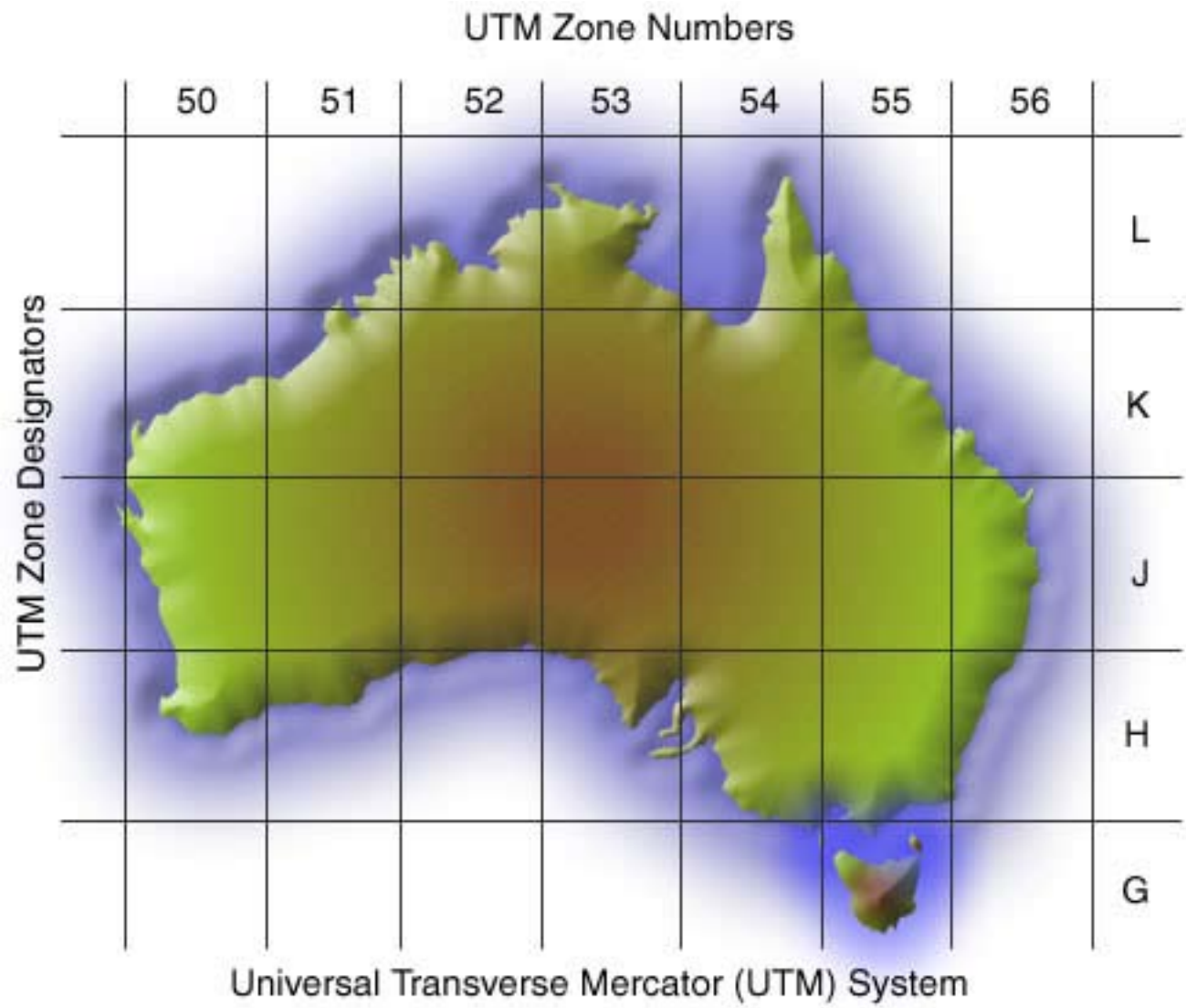


Figure 3.2.2.3 - UTM zones in Australia as used by Map Grid of Australia

Scale factors, false origins and repeating coordinate values

The UTM zones are constructed so that the surface onto which the projection is made actually cuts the Earth surface either side of the central meridian. On either side of these lines there is some minor distortion, which requires the application of a scale factor. However, the use of two cut points means the scale factor's departure from unity is minimised (see Figure 3.2.2.4). Across a zone there is a variation of scale factor between 0.9996 at the central meridian to 1.0006 at the edge of the zone.

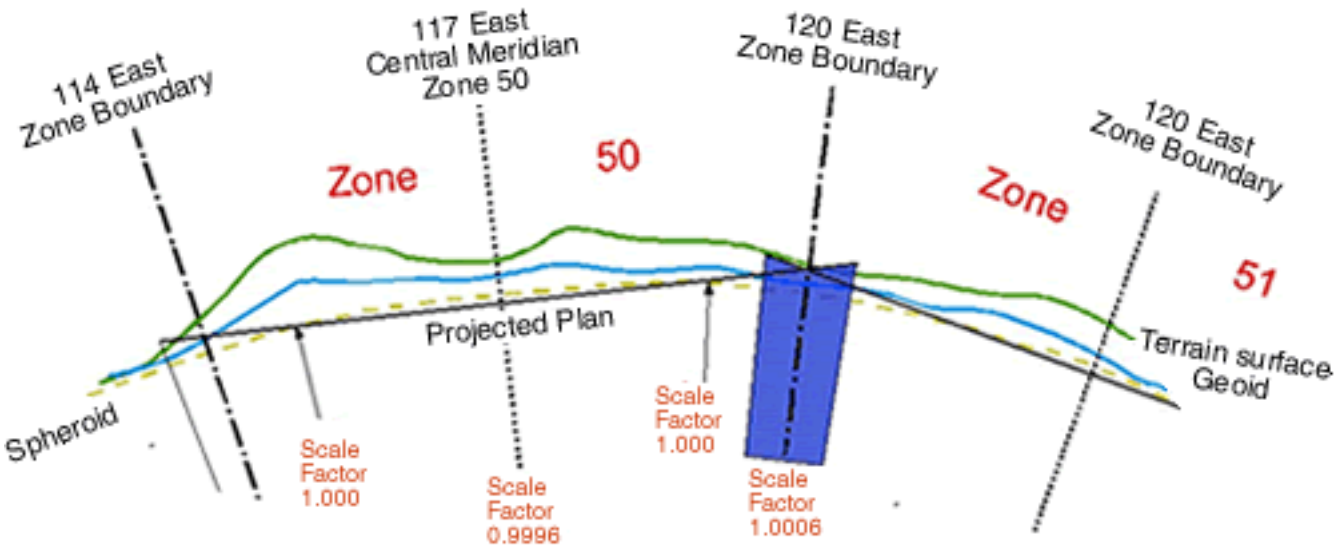


Figure 3.2.2.4. Scale factors and overlap of Universal Transverse Mercator and Map Grid of Australia zones (ICSM 2000).

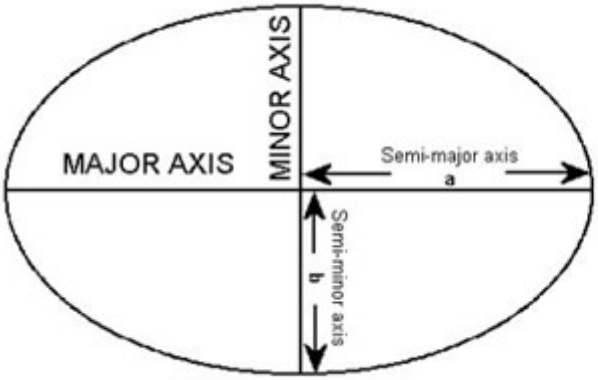
The origin for plane coordinates on the UTM system, and systems based on it, is the point at which the equator and the zone's central meridian (CM) cross. For the southern half of the zone this gives negative northing coordinates and for the western part of the zone this gives negative easting coordinates. This is compensated for by creating what is known as a false origin. For the parts of UTM zones south of the equator the false origin is positioned so that the true origin (equator/central meridian intersection) has a coordinate of E 500,000.00 m and N 10,000,000.00 m.

In practical terms this means that within Australia the coordinates in any one map zone have a six figure easting (before the decimal point) and a seven figure northing. Eastings range from about 250,000 to 750,000 whilst northings range from about 5,500,000 to 8,500,000.

Coordinates repeat for each zone. So, while geographic coordinates are unique, any pair of UTM coordinates can refer to six different locations throughout Australia. The zone number is an important piece of information to be included with any coordinate information that is being recorded.

The figure of the Earth

The Earth's surface has been described as a sphere, however, it is not exactly spherical. The actual surface is what is known as a geoid. This is a complicated figure that depends on the local density of rocks and other phenomena. To keep the mathematics relatively simple it can be approximated by an ellipsoid. Sometimes this is referred to as a spheroid which is a special case of an ellipsoid. An ellipsoid has properties that are described by the dimensions of its major and minor axes and the ratio between them. This ratio is known as flattening (Figure 3.2.2.5).



$$flattening \quad f = \frac{(a-b)}{a}$$

For WGS84:

$a = 6378137.0$ *metres*

$f = 0.003352811$

$1/f = 298.2572236$

Figure 3.2.2.5. The basic parameters of an ellipsoid. WGS84 refers to the World Geodetic System 1984.

There have been many attempts to create a mathematically defined ellipsoid that fits closely to the surface of the Earth. Several different such ellipsoids have been used to describe the surface for Australia. This surface is known as a datum and its definition affects the coordinates that are obtained for any particular location on the Earth's surface. This is true for both geographical and projected coordinate systems.

The GPS system is designed to work with a spheroid known as the World Geodetic System 1984 (WGS84), which was designed by the US military. It is possible to set GPS equipment to provide latitude and longitude based on other spheroids, hence it is important to ensure the correct set-up. The current (since 2000) reference spheroid for Australia is the Geodetic Reference System 1980 (GRS80), which is, for all practical purposes in broadacre PA, the same as WGS84.

Both WGS84 and GRS80 are what are known as geocentric datums. This means that the centre of the ellipsoid is at the centre of the Earth's mass. Older datums used for Australia such as the Australian Geodetic Datum (which referred to the Australian National Spheroid) were derived as a mathematical best fit and their centre was not at the Earth's centre of mass but displaced by a few hundred metres. The result is geographical coordinates differ between systems that use different spheroids and datums. This means that there are differences in the projected easting and northing coordinates too.

The fundamental defining entity of a coordinate system is the spheroid. The datum can be regarded as essentially indicating where the origins of the system are in relation to the spheroid. Some common coordinate systems are described below.

The Map Grid of Australia 1994 (MGA94)

MGA94 is the most up to date mapping system for Australia and is the one that should be used in building-up a spatial database of georeferenced data. It is defined with reference to the Geocentric Datum of Australia 1994 (GDA94) and the GRS80 spheroid. The MGA uses the same zones as the UTM projection.

Other coordinate systems

When spatial data are obtained from a provider it should be supplied with metadata that should include information about the coordinate system used. Each coordinate system is defined by spheroid and datum.

Some coordinate systems that data in Australia may be provided on are:

- Australian Map Grid 1984 (AMG84),
- Australian Map Grid 1966 (AMG66).

On the assumption that any current data being collected from yield monitors etc. is being stored as MGA94 coordinates, it is worthwhile looking at these in relation to that system.

Australian Map Grid 1984 (AMG84)

AMG84 was defined with reference to the Australian Geodetic Datum and the Australian National Spheroid. This is not a geocentric system; the centre of this system is displaced from the Earth's centre of mass by about 200 m. In practical terms, this means that the coordinates of a point on the Earth's surface quoted in this system will appear to be about 200 m south west of their location when quoted in MGA94 coordinates. The actual value varies throughout the country (Figure 3.2.2.6).

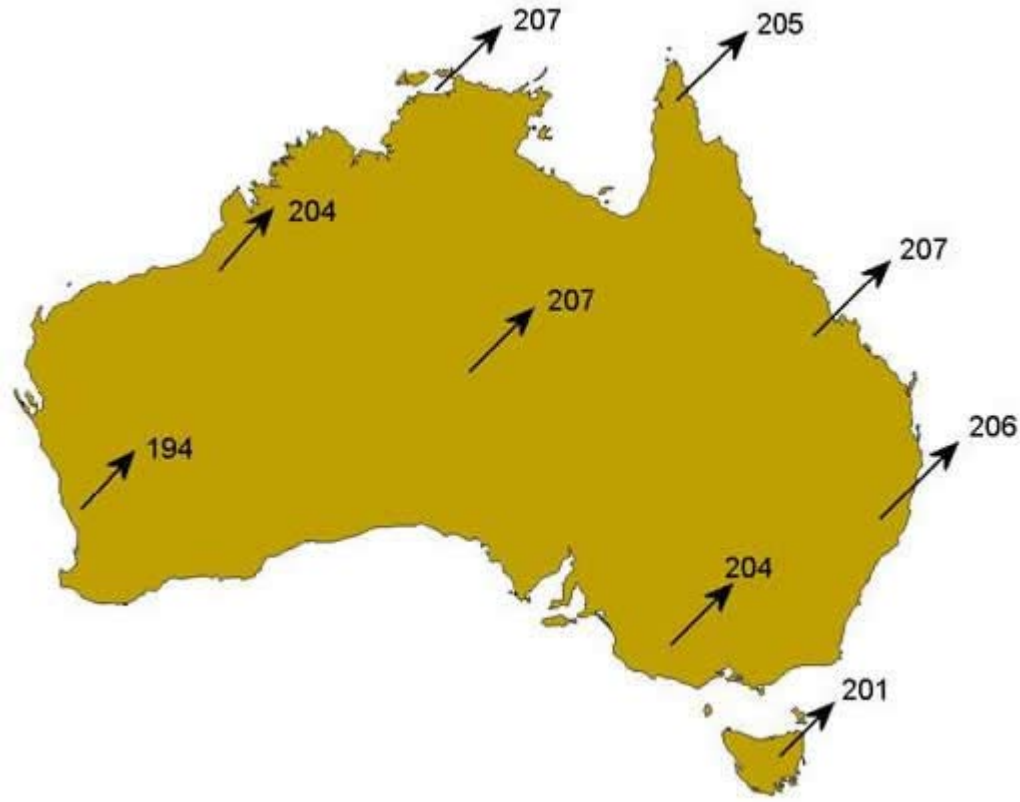


Figure 3.2.2.6 Offsets between AMG and MGA coordinates

Australian Map Grid 1966 (AMG66)

While earlier systems were used in Australia, AMG66 is likely to be the oldest encountered. This system used an earlier version of the same spheroid and datum that made up AMG84, with a less sophisticated geoid model. The coordinates differ from those in the AMG84 system by an amount that varies throughout Australia, but is generally between 2 and 6 m.

Moving data between coordinate systems

The process of going from a geographic system to a plane coordinate system is referred to as 'projection'. Moving from one plane system to another is referred to as 'transformation'.

Most GPS equipment can be set to a variety of spheroids and projections and can collect data in either degrees or metres. The projection calculations in some equipment may not be of a very high accuracy. It is better to collect GPS data in latitude and longitude coordinates using the WGS84 spheroid and these can then be converted into easting and northing coordinates on the GDA94 system. Most Geographical Information Systems (GIS) software is capable of making these conversions, as is some PA software.

Similarly, most GIS software is able to transform spatial data such as soil maps, paddock and farm boundaries etc. from one coordinate system to another. Most packages also offer the capability to georeference aerial photographs and remotely sensed data sets using a variety of coordinate systems.

Tabular data of eastings and northings in one coordinate system can be converted into another coordinate system using freely available software. An example of this is DatumTran which is available from the NSW Department of Lands (http://www.lands.nsw.gov.au/Records/Surveying/GDA/transsoftware.htm).

DatumTran enables conversion between Australian Geodetic Datums (AGD84/AGD66) and GDA94. It also enables conversion between projected (MGA, AMG etc.) coordinates and geographic (latitude/longitude) positions. It can read a number of GIS field formats as well as 'open' text formats.

Further reading

Featherstone, W.E (1996). An updated explanation of the geocentric datum of Australia and its effects upon future mapping. Australian Surveyor 41(2): 121-130. PDF version available at: http://www.cage.curtin.edu.au/~will/composit.1.pdf

ICSM (2000). Geodetic Datum of Australia, Technical Manual. V2.2. Intergovernmental Committee of Surveying and Mapping. http://www.icsm.gov.au/gda/gdatm/index.html

Iliffe, J.C. (2000). Datums and Map Projections for Remote Sensing GIS and Surveying. CRC Publications

3.2.3 Aerial photography and bare soil images

Authors: Tim Neale: CTF Projects Pty Ltd, and Troy Jensen, Queensland Department of Primary Industries and Fisheries

A spatially referenced farm plan is the first important piece of spatial information required to start using PA. This plan forms a base layer on which other spatial information can be overlayed. A popular way to produce this plan is from aerial photographs.

3.2.3a What are aerial photographs?

Aerial photographs are image data with many uses in PA. State and federal government departments have obtained aerial photographs since the Second World War for many areas and this continuity makes them a significant resource as changes or stability over a long period of time can be tracked. The photographs in the early days were black and white; more recently (mid 1990s on) colour images have become available.

Aerial photographs are captured from high flying light aircraft with high resolution film cameras attached to the floor of the aircraft. To cover an area, consecutive photos are taken in parallel runs with 60-90% overlap east/west (this allows stereoscopic analysis of topography) and 30% north/south. Typically there are repeat captures every 3-10 years.

Aerial photographs are mostly captured at 1:50,000 and 1:25,000 scales, so only one medium size cropping enterprise can be covered under one photograph. At 1:25,000 scale, an aerial photograph covers an area of about 5 x 5 km, and 10 x 10 km at 1:50,000 scale, although this varies with the altitude at which the photographs are taken and the focal length of the camera lens.

Aerial photographs have very good spatial resolution. Due to the high resolution photographic paper and lenses used, the resolution is typically as low as tens of centimetres. Latest digital aerial photographic technology can have a pixel size of 15 cm. This provides the user with detailed information and clarity, and allows accurate assessments of the ground conditions.

Historic aerial photographs cost from about $20, with the price increasing with the size of the grower's property. Detailed and current photographs cost considerably more; the price varies with supplier.

3.2.3b Uses of aerial photography

Seasonal (temporal) changes such as erosion, areas of cultivation over time and cropping history can be detected with historical aerial photographs. Aerial photographs are often used in grazing lands to identify and monitor vegetation types and densities, fence lines, watering points, and infrastructure.

Historical aerial photographs usually show bare soil attributes in cropping areas due to the cultivated farming systems used. From work conducted in Queensland, New South Wales and Victoria photograph differences, particularly in soil colour, relate well to significant differences in the soil texture and to soil type (i.e. red sandy loam versus black self-mulching clay). However, ground truthing is essential.

Examples of aerial photographs are below.

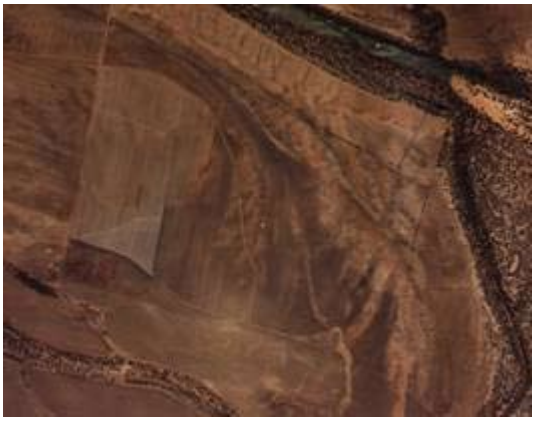


Figure 3.2.3b1. An aerial photograph showing sandy soils (lighter areas along river) and clay soils (darker areas). Cultivation history (different paddocks), erosion scars and formation of the landscape (deposition from river) can also be seen (source: Queensland Department of Natural Resources and Mines).

Figure 3.2.3b2. This aerial photograph shows different soil types (pale areas in fallow land), an erosion scar through the middle of the paddock, and strip cropping history (source: Queensland Department of Natural Resources and Mines).

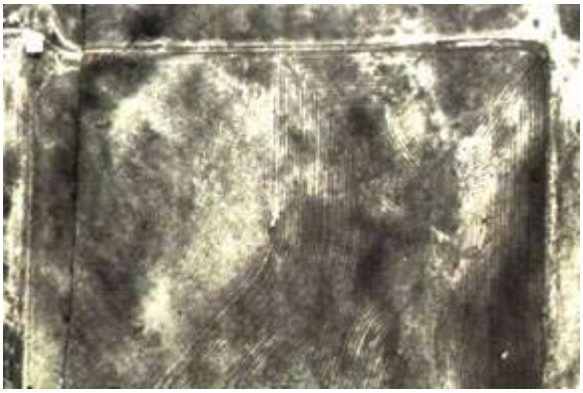


Figure 3.2.3b3. This aerial photo, taken over 50 years ago, holds very important information about soil type differences (white areas are duplex soils, black areas are clay soils) (source: CTF Solutions).

3.2.3c How do we put aerial photography in a PA/spatial context?

A difficulty with traditional aerial photography is transforming it into a format that can be used in a PA context. Some of the issues include:

- **Digitising.** Historical aerial photographs are paper based, and thus need to be scanned (digitised) to make them compatible with GIS computer software. Standard aerial photograph contact prints are larger than an A4 scanner and cannot be scanned with the fiducial marks, which are necessary to remove distortion. Newer images are taken with high resolution digital cameras which omit the need for scanning.
- **Distortion.** Since aerial photographs are taken with a lens, there is distortion around the edge of the picture. This creates problems with rectification and mosaicing (joining many photographs together). Newer images taken with digital cameras have improved this.
- **Mosaicing**. For large areas, many photographs may need to be joined together, and these may be from different years. This can be costly to perform and difficult to do with accuracy.
- **Rectifying**. Aerial photographs have no spatial reference to the earth and need to be related to known points in the photograph (e.g. with GPS ground reference points). This is called rectification, and is time consuming and expensive. Some government departments now offer 'ortho photos' which are orthorectified (to remove distortion) and digitally joined.
- **Spectral bands**. Aerial photographs generally do not have a near infrared (NIR) band. They are colour or black and white photographs. Some companies do provide colour NIR aerial photography, which is useful for applications in crops such as identifying stresses caused by nutrition, waterlogging, compaction, poor establishment, and leaf and root disease.
- **Age**. Aerial photographs of many areas are 5-10 years old, and therefore have limited information for up-to-date applications.
- **Cost.** Specific acquisitions can be expensive and often require minimum capture areas. Individual historical aerial photographs are inexpensive, averaging about $30 each.

Once digitised, orthorectified and mosaiced, the image has spatial attributes and can be compared with other layers of information using GIS software. This may include yield monitor data, EMI surveys and crop imagery. In work conducted in Victoria, good correlations between EM38 data and the classification of bare soil aerial photographs have been observed.

3.2.3d Useful aerial photography websites

- http://www.terranean.com.au/aerial_photo.htm
- http://www.ga.gov.au/nmd/products/photos/
- http://www.nla.gov.au/ntwkpubs/gw/48/p19a01.html
- http://www.qasco.com.au/
- http://www.webmap.com.au/
- http://www.dse.vic.gov.au/dse/nrenptm.nsf/Home+Page/DSE+Property~Home+Page?open
- http://www.nrm.qld.gov.au/property/mapping/aerial_photography.html
- http://maps.nsw.gov.au/
- http://www.lpi.nsw.gov.au/airview/
- http://www.landonline.com.au/skyviewwa/content/asp/skyviewwa_index.asp?product_group_id=78

3.2.4 Satellite and airborne imagery

Authors: Matthew Adams, Satellite Remote Sensing Services, WA Department of Land Information, and Ian McGowen, NSW Department of Primary Industries

Additional input from Rob Kelly, formerly of the Queensland Department of Primary Industries and Fisheries

3.2.4a Understanding optical and radar remote sensing systems

Most optical (passive) remote sensing systems work by detecting the amount of energy reflected and transmitted by the target in particular areas of the electromagnetic spectrum, ranging from visible light (wavelengths of 0.4-0.7 µm) through to the near infrared (NIR, 0.7-1.3 µm) and shortwave (mid) infrared (SWIR, 1.3-2.5 µm). Other systems include thermal sensors that detect the amount of emitted heat (8-14 µm). The amount of energy reflected, transmitted or emitted in these areas of the electromagnetic spectrum provides information linked to many vegetation and soil characteristics. Optical remote sensing provides a useful, inexpensive means of assessing such characteristics at a paddock, property and regional scale within and between seasons (see Table 3.2.4e1 in later section).

Optical systems are carried on airborne and satellite platforms. Most optical systems are 'multispectral', having 3-10 spectral bands covering the visible to shortwave infrared area. Satellite systems tend to have wide spectral bands, whereas airborne systems use narrow spectral bands. More advanced systems (sometimes termed 'superspectral') have up to 36 spectral bands and may cover from the visible to thermal infrared. Many multispectral optical systems also have a single high spatial resolution 'panchromatic' band, which can be used to enhance the multispectral bands. The most advanced optical sensors are 'hyperspectral', with 126-224 very narrow spectral bands, often less than 0.01 µm in width (Table 3.2.4e1) for a comparison with the wide spectral bands of Landsat and SPOT). Multispectral thermal infrared sensors are also under development.

Optical sensing is affected by atmospheric conditions such as cloud, thick haze, dust or smoke. Thermal and shortwave infrared bands are less susceptible to haze, smoke or dust than the visible and NIR bands.

Modern radar systems use active sensors, both sending and receiving microwave energy in different wavelengths and polarisations (orientations). They are not affected by most atmospheric conditions or time of day. Synthetic aperture radar (SAR) imagery has potential for the assessment of plant biomass, leaf area index, moisture content, structure and height, storm damage and lodging, as well as the assessment of land use and soil factors such as salinity and moisture content. Capabilities depend on the wavelength and polarisation of the radar band. The bands commonly used in imaging radars are X, C, S, L and P. Other bands (such as Ka, K and Ku) are less commonly used. Each band can be used in two linear polarisations for the transmitter and receiver-horizontal or vertical. This provides four combinations for each band (HH, VV, HV and VH). Microwaves interact with an object with dimensions of half their wavelength or greater. The shorter wavelengths (e.g. X and C band) interact with vegetation canopies (leaves, and small branches of trees). The longer wavelengths (e.g. L and P band) penetrate the canopy and interact with larger components such as branches and trunks, and may penetrate to the ground surface providing information about the canopy structure, biomass and the soil surface. The amount of interaction depends on the band, polarisation, incidence (look) angle and the characteristics of the target (particularly its orientation, dimensions, biomass, density, roughness, dielectric and moisture content). Imagery collected in different bands and polarisations provides much more information than a single band or polarisation. HH polarisations are most likely to interact with the ground surface, VV with vegetation structures such as the heads and stems of cereal crops, tree trunks and vertically oriented branches, while HV provides volume scattering and crop type information.

Due to the interactions between the bands, polarisations, range of sensor look directions and incidence (look) angles as well as topographic effects, the analysis of radar imagery is extremely specialised. Radar systems are primarily satellite based, with a limited number of specialised airborne systems. Current satellite-based radar systems have

only a single band and polarisation, and are of limited use for PA, but have shown some potential. Future systems will have sufficient spatial and spectral resolution for this purpose (e.g. Radarsat 2, COSMO SkyMed). The full potential of radar will be not reached until high resolution imagery from multiple bands and sensor orientations is available, and radar imagery is combined with that from optical remote sensing systems.

3.2.4b Comparing optical remotely-sensed imagery

To interpret and compare optical remotely-sensed imagery, it is important to understand how the image was captured, the characteristics of the sensor, the scale and the level of detail.

The wide range of optical remote sensing systems makes comparison confusing. All systems have advantages and disadvantages, and selection or comparison of imagery must be based on:

- The number of spectral bands (spectral resolution) and their relevant bandwidth;
- Ground/spatial resolution (not quite the same as 'pixel' or 'picture element' size, but often used interchangeably);
- The range of spectral data levels (radiometric resolution);
- Scene size (footprint) or minimum area of purchase;
- The repeat or revisit cycle (temporal resolution);
- Cost;
- The delay in obtaining the data; and
- The turnaround time in having the data corrected and analysed before use.

3.2.4c Optical satellite imagery

The range of optical satellite imagery available makes it a very flexible means of assessing crop and soil characteristics over moderate to large areas. Imagery for PA purposes includes that from the multispectral Landsat, ASTER, SPOT, IRS, IKONOS and Quickbird systems.

Although special algorithms must be employed to eliminate atmospheric distortions, the high-altitude deployment reduces geometric errors ensuring most satellite imagery is spatially highly accurate.

The spatial resolution (pixel size) varies considerably between systems: high resolution imagery (e.g. IKONOS, Quickbird, OrbView 3) may be <5 m, whereas moderate resolution imagery (e.g. SPOT, Landsat) is between 10 and 30 m. Very coarse imagery, such as the free MODIS imagery, is applicable for regional classifications but does not generally allow for site-specific management in agriculture.

The radiometric resolution (number of data levels) of the imagery also varies between the systems. Most imagery is 8 bit, that is, it has 256 or 2 8 data levels. Landsat and SPOT have 8 bit sensors. Imagery from some of the newer satellite systems is 11 bit, having 2,048 (2 11) data levels (e.g. imagery from IKONOS, Quickbird and OrbView 3). Higher radiometric resolution means the imagery is less likely to saturate on bright targets, and more able to detect subtle differences (particularly when shadow is present). However, just as the storage size of an image is greater at smaller pixel sizes or with a larger number of bands, it is also greater where the imagery has a high radiometric resolution.

The main moderate resolution data that growers may use is likely to be from Landsat and SPOT. See section 3.2.4e Multispectral imagery from these sensors ranges from $0.03 to $1.18/km ^{2}, excluding analysis costs.

Multispectral imagery from the newer high resolution sensors is more expensive, due to their high price per square kilometre and minimum purchase price/area. Such imagery from these sensors ranges from about $10 to $30/km ^{2}.

Timing of imagery capture for PA purposes can be critical. This limits the usefulness of some systems (e.g. Landsat, which has a 16 day overpass cycle). Cloud cover during an overpass can be a major problem. This difficulty has been partially overcome by the availability of multi-satellite systems (e.g. the SPOT satellites) and/or systems with pointable (or 'off-nadir') sensors (e.g. ASTER, SPOT, IKONOS, and Quickbird) which allow for overpass cycles of less than 5 days.

Several satellite missions are planned by North American, Asian and European consortiums in the near future, ensuring that scene costs will continue to be reduced at the same time as spatial and radiometric resolutions are

being enhanced. Some of these missions are to include systems and sensors intended for PA (as well as other) purposes. Those of greatest potential for PA are the Pleiades satellites (scheduled for 2008 and 2010) and the RapidEye constellation of five satellites (scheduled for 2007), as well as the OrbImage OrbView 5 and Digital Globe WorldView/NextView satellites.

3.2.4d Optical airborne digital imagery

Airborne digital imagery has the advantages of flexible mission timing, high spatial resolution (25 cm-5 m, commonly 1-2m), high radiometric resolution (commonly 1,024-65,536 data levels, i.e. 10-16 bit), and narrow spectral bandwidths. All these factors allow for good characterisation of the target. Airborne imaging also allows for rapid acquisition, data processing and turn around times. It is less affected by general atmospheric conditions than satellite imagery, as the sensor is much closer to the target. However, the footprint (scene size or area within a flight path) depends on the elevation of the aircraft/sensor, and the higher the spatial resolution the smaller the footprint.

Disadvantages of airborne digital imagery are the limited scene size, the need to reference the imagery geographically, and difficulties in mosaicing (or merging) side-by-side scenes. Aircraft provide a much less stable sensor platform than satellites; altitude variations (roll, pitch and yaw) while capturing the imagery can cause distortion problems. Brightness differences between scenes due to a change in aircraft orientation also cause problems when mosaicing and analysing imagery. In some cases 'hot spots' can occur on the imagery due to the position of the sun and aircraft (Figure 3.2.4d1). The point of despatch may also raise the costs of airborne missions, and unstable or humid atmospheric conditions such as in the north-east of Australia may increase the risk of useful data not being captured. Airborne imagery is best captured when the solar zenith angle is 25-40 degrees (i.e. a solar elevation of 60-75 degrees off the horizon) and where the aircraft is flying into the sun. A program to calculate solar zenith angles and flight bearings can be downloaded from http://www.eoc.csiro.au/hswww/oz_pi/util.htm. As a rule of thumb capture of imagery is usually restricted to about 1.5 h either side of solar noon to provide adequate illumination and minimise shadowing, and can be curtailed by rapid cloud build-up obscuring the target. Imagery capture is also restricted in winter due to low solar angles.

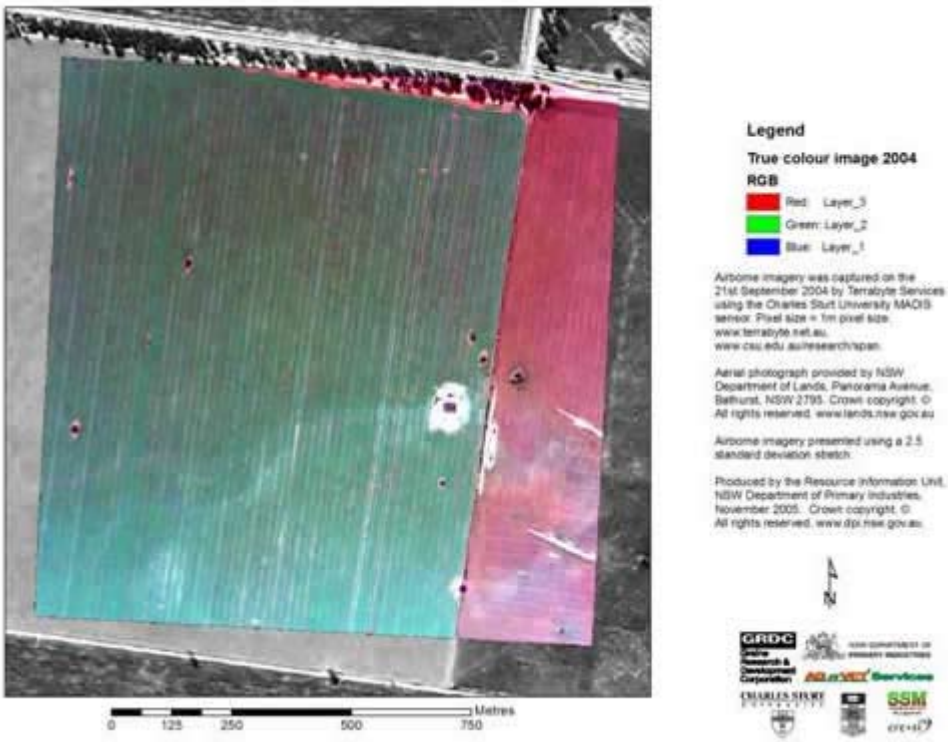


Figure 3.2.4d1. An example of a true colour airborne image with hotspot showing in the lower part of the frame.

Most airborne multispectral systems have a limited number of spectral bands (3-4), although some have up to 12. Compared with satellite multispectral systems, the widths of the spectral bands are usually narrow, which is an advantage for target discrimination. Extremely advanced airborne hyperspectral sensors have a very large number of

narrow bands (e.g. HyMap™, which has 126 bands). The analysis of imagery from such sensors is complex, although it offers potential for detection and mapping of such factors as nutrient responsiveness, weed species, crop moisture content, stubble quantity and soil characteristics such as clay content, salinity and sodicity.

3.2.4e Landsat and SPOT

The Landsat series of satellites has been in operation since the 1970s and has a 30 m resolution, although the imagery is usually re-sampled to 25 m. The most important of the Landsat satellites are 4, 5 and 7 (Landsat 6 was lost at launch). Images from Landsat have been acquired over Australia since 1987, on every overpass of the satellites.

Landsat 4 was launched in 1982 and carried the Thematic Mapper (TM), which had 7 bands (see Table 3.2.4e1). Landsat 5 was launched in 1984, and Landsat 7 in 1999.

Landsat 7 carries the Enhanced Thematic Mapper (ETM+), which has an eighth 15 m panchromatic band (usually re-sampled to 12.5 m), and a higher resolution thermal band. Unfortunately, Landsat 7 suffered a mechanical failure in 2003, and while imagery can still be obtained it is no longer useful for PA purposes. This failure has meant that gaps exist in each image, and can only be corrected by creating a composite using previous or subsequent imagery.

Of the Landsat satellites only imagery from Landsat 5 is currently suitable for PA use. The schedule for launch of a replacement satellite for Landsat 7 is under review, but is not expected until mid 2008 at the earliest. The remaining Landsat Data Continuity Mission satellites are scheduled for launch in late 2009 and early 2016. These new satellites are planned to carry a 10 band sensor (with no thermal band) called the Operational Land Imager (OLI).

The smallest Landsat scene that can be purchased is called a 'small scene' and contains 625 km 2 of data, which can be supplied orthorectified for $550. Larger scene sizes are available (ninth scene, 3600 km 2; quarter scene, 8100 km 2; half scene, 16,900 km 2; full scene, 41,625 km 2; double scene, 95,850 km 2; triple scene, 164,300 km 2). Larger scenes reduce the cost per square kilometre.

The French SPOT series of satellites are the major alternative to Landsat. A single SPOT scene contains 3600 km 2 of data at a resolution of 10-20 m. Unlike Landsat, imagery is not continuously acquired, and requests for capture must be made. The cost per hectare is greater than that for Landsat, particularly for SPOT 5 (SPOT 2 and 4 retails from $2500 per scene; SPOT 5 multispectural data retails from $4230 per scene). The early SPOT satellites carried a 3 band multispectral sensor with a 20 m resolution and a panchromatic or monospectral sensor with 10m resolution. An additional shortwave infrared (SWIR) band was added with SPOT 4 in 1998, and a 1 km coarse resolution vegetation sensor. SPOT 5 was launched in 2002. It has a 2.5 and 5 m panchromatic mode, with 10 m resolution for the visible and NIR bands and 20 m for the SWIR band. SPOT 5 also carries a 1 km resolution vegetation sensor. The SPOT 2, 4 and 5 satellites are currently operational. The SPOT satellites will be augmented by the Pleiades high resolution satellites, the first two of which are planned for launch at the end of 2008 and in early 2010.

3.2.4e Landsat and SPOT

Although SPOT has better spatial resolution than Landsat, the size of a standard SPOT image is only 1/9th the size of a standard image of Landsat. Therefore, in an industry that is geographically widely dispersed, such as agriculture, Landsat is often the preferred source of satellite imagery based on cost, even though the spatial resolution is somewhat coarser.

Several companies offer products based on either Landsat or SPOT imagery. More information on suppliers can be found on the web. The Southern Precision Agriculture Association (SPAA) site is s a useful reference www.spaa.com.au

Spectral zone	Landsat 5/7 band	[Q22] Landsat 5/7 resolution (m)	Landsat 5/7 spectral range (µm)	SPOT 2/4/5 band	SPOT 2/4/5 resolution (m)	SPOT 2/4/5 spectral range (µm)	Application
Blue-green	1	30	0.45-0.52	-	-	-	Differentiate vegetation from soils, chlorophyll absorption
Green	2	30	0.53-0.60	1	10 (SPOT 5) 20 (SPOT2/4)	0.50-0.59	Assessment of vegetation vigour
Red	3	30	0.63-0.69	2	10 (SPOT 5) 20 (SPOT2/4)	0.61-0.68	Chlorophyll absorption for vegetation differentiation, canola flowering. Differentiation of soil from vegetation
Near infrared	4	30	0.75-0.90	3	10 (SPOT 5) 20 (SPOT2/4)	0.78-0.89	Vegetative health, vigour, moisture content and biomass. Soil moisture
Shortwave infrared 1 (mid Infrared)	5	30	1.55-1.75	4	20 (SPOT 4/5 only)	1.58-1.75	Vegetation and soil moisture and other characteristics. Not available on SPOT 2
Thermal infrared	6	120 (Landsat 5) 60 (Landsat 7)	10.40-12.5				Surface temperature, soil moisture and plant heat stress measurement, plant water content
Shortwave infrared 2 (mid infrared)	7	30	2.09-2.35				Mineral and rock discrimination. Vegetation and soil moisture and other characteristics, including stubble. Not widely used for agriculture
Pan-chromatic or Monospectral (SPOT 4 only)	8	15	0.52-0.90 (Landsat 7 only)	5	2.5-5 (SPOT 5) 10 (SPOT 2/4)	0.48-0.71 (SPOT 5) 0.50-0.73 (SPOT 2) 0.61-0.68 (SPOT4)	Panchromatic (high spatial resolution band covering the visible area of the spectrum, and sometimes part of the near infrared). Monospectral (red band only) for SPOT 4. Used for textural detail

Table 3.2.4e1. Landsat 5/7 and comparable SPOT 2/4/5 sensor characteristics.

3.2.4f Suggested timing of imagery capture for crops

Cereals

- Early grass weed infestation: Zadoks Growth Stage (GS) 13-14;
- Early nitrogen application: GS 21-29 (note that this is often left until GS 30 to ensure good ground cover for imaging);
- Late nitrogen application (for protein): GS 40-45;
- Yield potential (for estimated from late biomass): GS 60-65.

Canola

Nitrogen application/biomass: from 6 to 8 leaf to bud formation in the rosette (i.e. when full ground cover occurs, at mid-late winter).

Yield potential (assessed from intensity of flowering): mid flowering.

Note that low solar angles in winter result in low illumination and brightness differences across an optically remotely sensed image, and therefore affect the analysis of such imagery.

The analysis of imagery captured for nitrogen application usually requires the crop to have achieved at least 30% ground cover.

3.2.4g Methods of analysing satellite and airborne images

Raw satellite or airborne imagery can be useful for basic identification of crop and soil differences, but needs to be analysed to provide the most information. Unfortunately, most image analysis/GIS software is both costly and complex to use, therefore imagery analysis is best left to a consultant. Despite this, it is important to understand how to display the raw and analysed imagery and how particular analyses are carried out.

Displaying imagery

Imagery obtained from a satellite or airborne sensor should not be thought of as a photograph. The sensors measure the amount of light reflected by a target in each of their spectral bands as a digital number. Landsat and SPOT use 8-bit sensors. That is, the values of digital numbers in each sensor band range between 0 and 255 (256 levels, or 2 8). More sensitive and advanced sensors provide from 10 (1024 levels, or 2 10) to 12 bit (4096 levels, or 2 12) imagery up to 16 bit (65,536 levels, or 2 16), which allows more subtle variation to be shown and is less likely to saturate. This imagery is usually also available in a degraded 8 bit format to allow 8 bit programs to display the image without any special manipulations and to reduce the size of the image files. Note that some early GIS packages have trouble displaying and manipulating data that is greater than 8 bit.

Digital images are usually displayed and printed as colour composites, with three image bands assigned to the three primary colours (red, green and blue). If displaying a three or more colour image in GIS or image processing software, it is possible to choose which bands to assign to each of the primary colours. To ensure the image is not too light or too dark, it may be necessary to look at the histograms in each channel, and limit the stretch of the data to drop off the top and bottom 0.5-5% of values (a 90-99% stretch). Some programs use standard deviations instead of percentages. In this case, 2-3 standard deviations are equivalent to 95-99% (assuming the data are normally distributed).

3.2.4g Methods of analysing satellite and airborne images

Displaying imagery

Grey scale

The most basic way to display an image is to show a single band as grey scale (Figure 3.2.4g1). Here the pixels with the highest values (digital numbers) will appear bright, and those with the lower values will appear dark. A vigorous crop will appear as dark in a blue or red band due to chlorophyll absorption, slightly bright in a green band, very bright in a NIR band and moderately bright in a SWIR band.

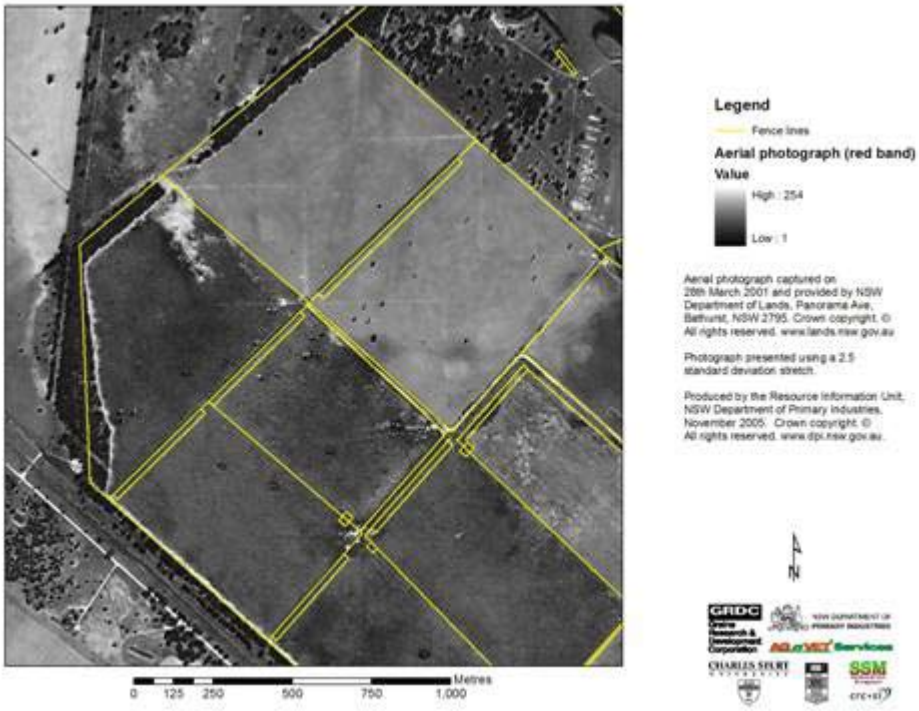


Figure 3.2.4g1. A grey scale aerial photograph.

True colour

A standard true colour display has the image's red, green and blue (RGB) bands assigned to the same primary colours (Figures 3.2.4g2 and 3.2.4g3). The colours of the true colour composite resemble closely what would be seen by the human eye. True colour displays can be useful for determining differences in soil colour, weed identification and monitoring canola or pulse crop flowering.

Figure 3.2.4g2. A true colour image of wheat crops in five paddocks, 2005.

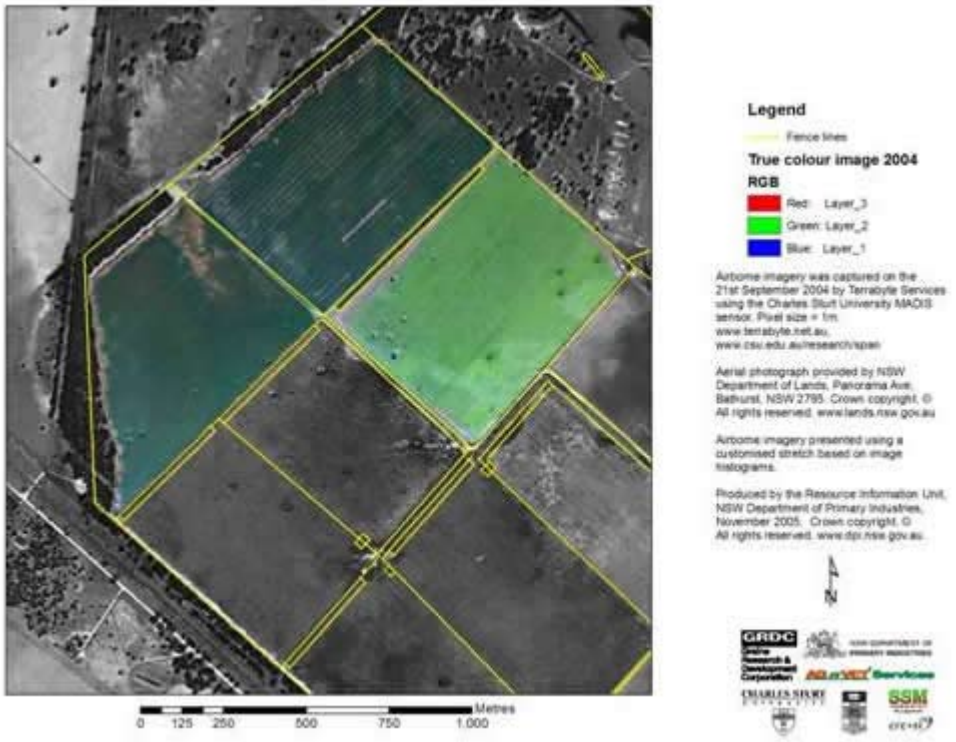


Figure 3.2.4g3. A true colour image of two oat crops and a canola crop in three paddocks at peak canola flowering, 2004.

False colour

Most differences in vegetation vigour are not noticeable on an image displayed in 'true colour'. A standard false colour display can be created by assigning the image's NIR, red and green bands to the red, green and blue primary

colours; examples are shown in Figures 3.2.4g4 and 3.2.4g5 below, compare these with the true colour images in Figures 3.2.4g2 and 3. Vigorous vegetation then appears as shades of red, with less vigorous vegetation showing as shades of pink. Bare soil appears as shades of blue–green to brown, depending on colour and organic matter. Deep water is dark blue to black, with shallow or turbid water a cyan colour. Other false colour composites use a SWIR band as red instead of the NIR band to provide information on crop moisture status (see below). A 'false colour image is more effective than true colour for determining vigour, and for identifying weak and strong growth areas within a crop to allow investigation or sampling.

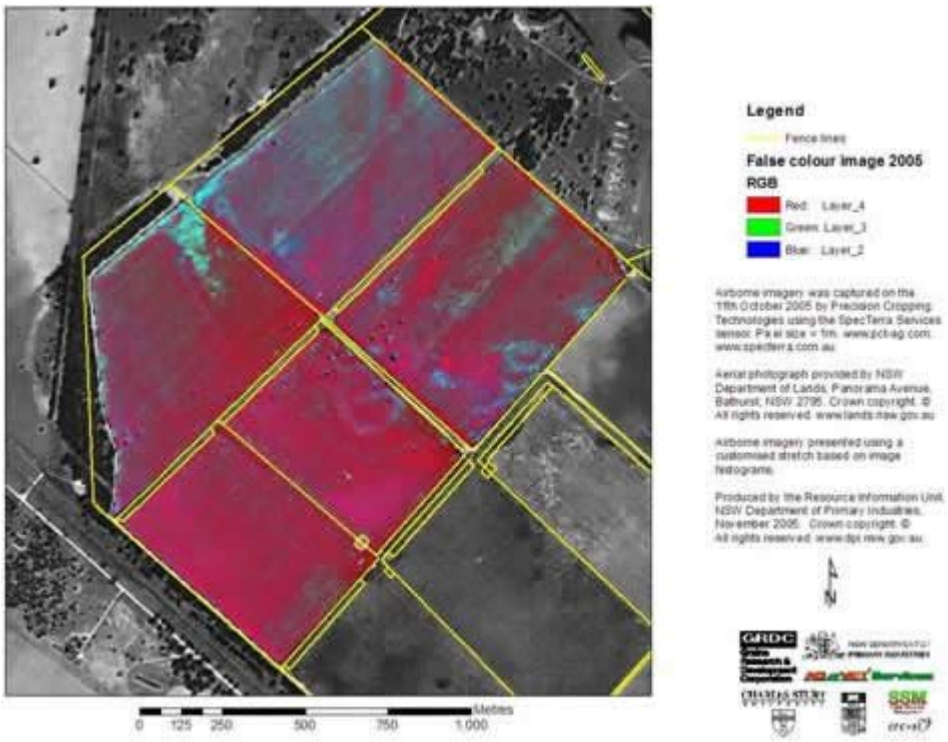


Figure 3.2.4g4. A false colour image of wheat crops in five paddocks, 2005.

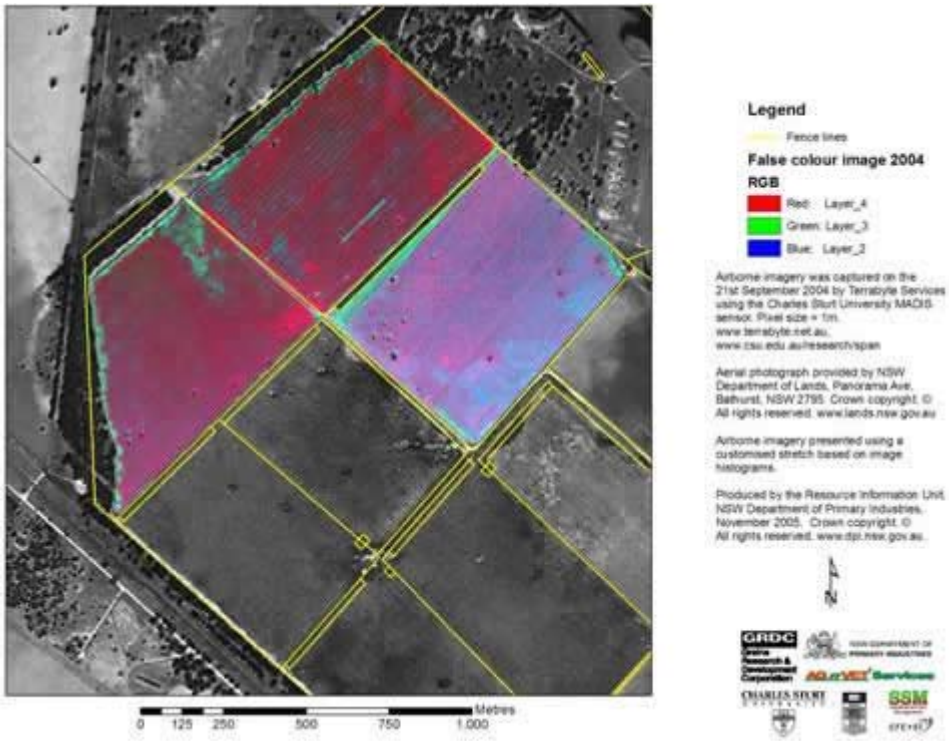


Figure 3.2.4g5. A false colour image of two oat crops and a canola crop, 2004. Note the pale colour of the canola due to higher red and green reflectance caused by the flowers.

Psuedo-true colour

As the concept of seeing healthy vegetation appearing as shades of red can be difficult to grasp, analysts often create pseudo-true colour displays by assigning the image's SWIR, NIR and red bands to the red, green and blue primary colours respectively. In such an image, vegetation will appear as shades of green, with vigorous vegetation bright green. Bare soil appears as shades of lilac, magenta and purple.

As SWIR reflectance is affected by plant moisture content, a pseudo-true colour image also provides a useful means of identifying vegetation differences and stressed vegetation, particularly when compared with a standard false colour image. For Landsat imagery, band 5 is normally used as the SWIR band of choice (so that Landsat bands 5, 4 and 3 are assigned to the red, green and blue primary colours). However, either SWIR band can be used. For purposes of haze penetration and highlighting vegetation vigour a pseudo-true colour image can be created where Landsat bands 7, 5 and 4 (see Table 3.2.4e1) are assigned to the red, green and blue primary colours. As SPOT 4 and 5 have only one SWIR band, bands 4, 3 and 2 are normally assigned to red, green and blue to create a pseudo-true colour image. Other combinations are also used (e.g. bands 4, 3, 1 as red, green, blue for SPOT 4/5, or bands 7, 5, 2 for Landsat). Psuedo-true colour images using the SWIR bands are also useful for detecting changes in the moisture status of soils (due to soil type and disturbance).

Different combinations of image bands can be used in these ways to highlight particular soil and vegetation features.

Natural colour

Natural colour composites, such as those produced from SPOT imagery are similar to pseudo-true colour, but are generally only used for display purposes or as a backdrop for other data. They are produced where the imagery lacks one or more of the primary colours, and are created by special manipulation of the spectral bands prior to display [e.g. red = SPOT band 2, green = (3 x SPOT band 1 + SPOT band 3)/4, blue = SPOT band 1 or (3 x SPOT band 1 - SPOT band 3)/4]. Such manipulation makes the resulting composites appear similar to a true colour image.

Pan-sharpening

For display purposes, satellite images are often sharpened using their high resolution panchromatic band. This is known as pan-sharpening. For this procedure, three multispectral bands of the image (e.g. red, green and blue) are converted using one of several algorithms. One common method is to transform the pixels in an image into hue, saturation and intensity (HSI). Hue refers to a particular colour (and is calculated as an angle anticlockwise between 0 and 360 degrees), saturation the richness or purity of the colour, and intensity the brightness of the colour. Humans perceive colour as HSI rather than as RGB, therefore control over colour appearance is best carried out as HSI. Once the HSI image is created, the spatial resolution is altered to match that of the panchromatic band (e.g. from 30 to 15 m for Landsat). The intensity component is replaced by the panchromatic band, and the image is converted back from HSI to RGB for viewing. HSI-based pan-sharpening distorts the original spectral characteristics of the image, and such imagery is not normally used for analysis. Other methods of pan-sharpening are available in high end remote sensing packages [or in the relatively inexpensive Highview (A$175 from http://www.geosage.com/)].

Psuedocolour

Single band images [such as a nomalised difference vegetation index (NDVI)] are not limited to a monochromatic (e.g. grey scale) display. They can be assigned a particular or arbitrary colour scheme to enhance the different data values. When displayed in this way, they are called pseudocolour images. The most commonly used colour range used for agricultural purposes has red for low values, through green (mid values) to blue or purple (high values) in a reversed spectrum. However, these scales can easily be inverted so that red is high and blue or purple is low, following the normal colour spectrum. Such ranges are used for imagery that provides information on yield or vigour. Monochrome colour ranges are used for other applications, such as the display of EMI imagery. The Southern Precision Agriculture Association (http://www.spaa.com.au) recommends an 8 class pseudocolour range for display of yield data, ranging from red to blue (low to high values). A similar pseudocolour range can be used for vegetation index data (for details, see http://www.usyd.edu.au/su/agric/acpa/pag.htm and click on the newsletter link or http://www.spaa.com.au/downloads/SPAAwinter2003.pdf).

Basic analysis of imagery

There are many ways of analysing digital imagery. Special transformations and classifications can be used, however the most simple and effective method is though the creation of band ratios and indices. The most common bands used are the red and NIR bands. In actively growing plant leaves, blue (about 0.4-0.5 µm) and red light (about 0.6-0.7 µm) are strongly absorbed by chlorophyll for photosynthesis, while NIR light (0.7-1.3 µm) is strongly reflected due to internal leaf structure. The amount of green light (about 0.5-0.6 µm) reflected by the plant is linked to the chlorophyll (particularly chlorophyll-a) content of the foliage. The SWIR reflectance (1.3-2.5 µm, particularly 1.5-1.75 µm) of healthy plants tends to be low due to moisture content, but rises with maturity or senescence, as does red reflectance (see Figure 3.2.4g6 below). The healthier the plant, the more red light is absorbed and the greater the reflection of NIR light. Plants under stress typically have a lower red absorption, lower NIR reflectance and often a higher SWIR reflectance. Bare soil has a higher red, lower NIR and higher SWIR reflectance than healthy plant tissue (Figure 3.2.4g7).

The ratio of NIR and red bands highlights the differences between them in a much more powerful way than simply viewing a false colour image. It provides a single band image where the brightness of the pixels represents the vigour, health or greenness of the crop. The brighter the pixel, the higher the ratio, while the darker the pixel, the lower the ratio. Ratios developed using combinations of other bands provides information on other physical information such as plant water content and chlorophyll concentration or absorption. Generally, ratios of narrow spectral bands provide more specific information than those created from sensors with broad spectral bands.

Correction of the imagery to remove atmospheric effects is recommended prior to analysis. This is more critical for satellite than airborne imagery. These effects include scattering and absorption. Scattering occurs due to gas molecules and particulate matter in the atmosphere. This influences the shorter wavelength image bands (e.g. blue and green) more than longer wavelength bands (NIR and SWIR). Blue light is highly scattered by the atmosphere and this is why the sky appears blue. While correction of imagery for atmospheric effects is a complex procedure, the analysis of the imagery is best with such corrected data, where digital numbers have been converted to actual reflectance. For 8 bit imagery, the standard range of digital numbers is between 0 and 255. When corrected, the output reflectance values will range between 0 and 1. However that reflectance is generally stored in a four byte, floating format, which takes up four times the space as an 8 bit/1 byte image.

As a rough rule of thumb where imagery has not been corrected, an estimate can be calculated by a normalising procedure using the maximum or the maximum and minimum values for each band. For example, a basic formula for correcting the imagery for the red band is:

$$Red_{Normalised} = \frac{Red_{Pixel}}{Red_{Maximum}}$$

A more rigorous procedure uses the band maxima and minima, and allows better comparison between imagery captured on different dates or over different years:

$$Red_{Normalised} = \frac{Red_{Pixel} - Red_{Minimum}}{Red_{Maximum} - Red_{Minimum}}$$ (Moran et al. 1997).

In both cases, the calculations should be set to ignore pixel values of zero for the minimum values.

These equations will convert the data to floating point format. Floating point files are extremely large. As an alternative, the resulting values can be rescaled to the original data range. Thus, for 8 bit data the equation becomes (note that an 8 bit image has 256 data levels, from 0 to a maximum of 255):

$$Red_{Normalised} = \left(\frac{Red_{Pixel} - Red_{Minimum}}{Red_{Maximum} - Red_{Minimum}} \right) \times 255$$

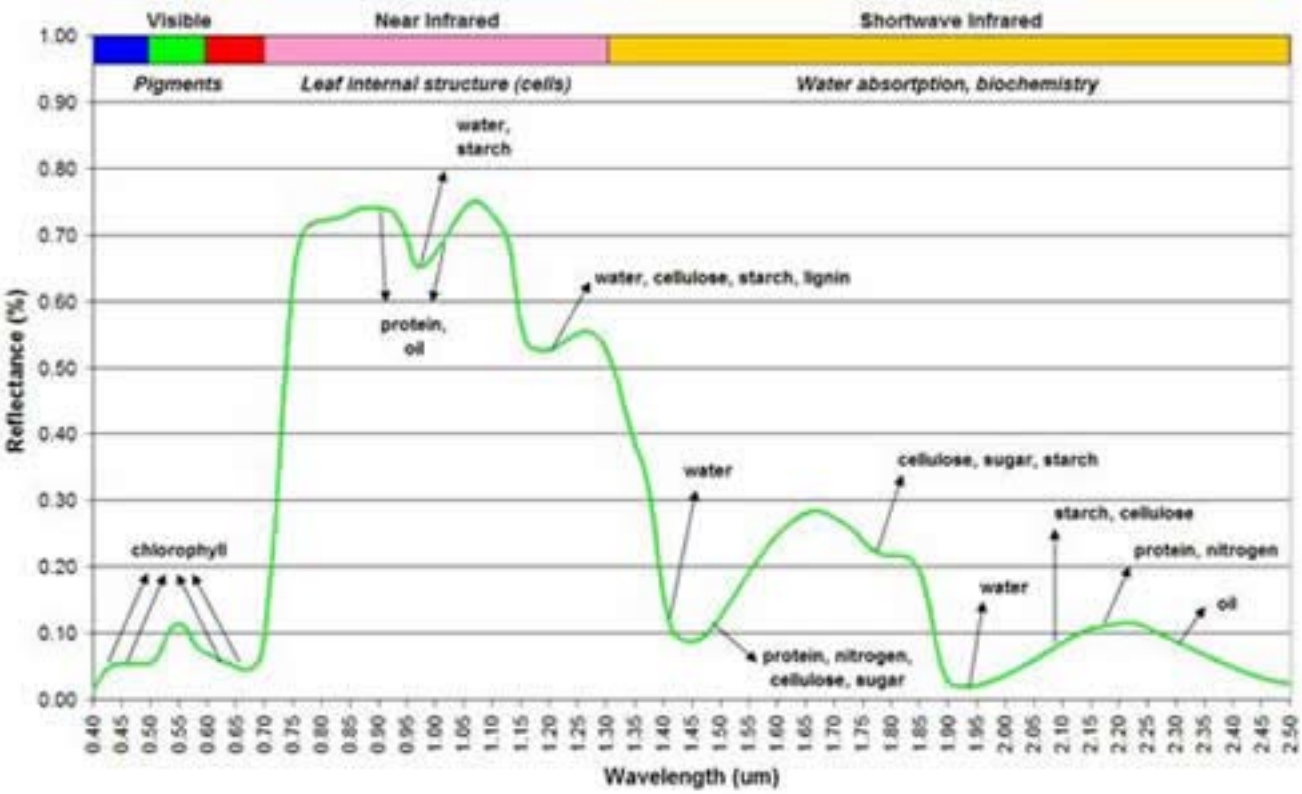


Figure 3.2.4g6. Different portions of the electromagnetic spectrum provide relevant information on plant features (source: Curran 1989; ata provided by University of NSW and based on information supplied by Queensland Department of Primary Industries and Fisheries and University of Queensland).

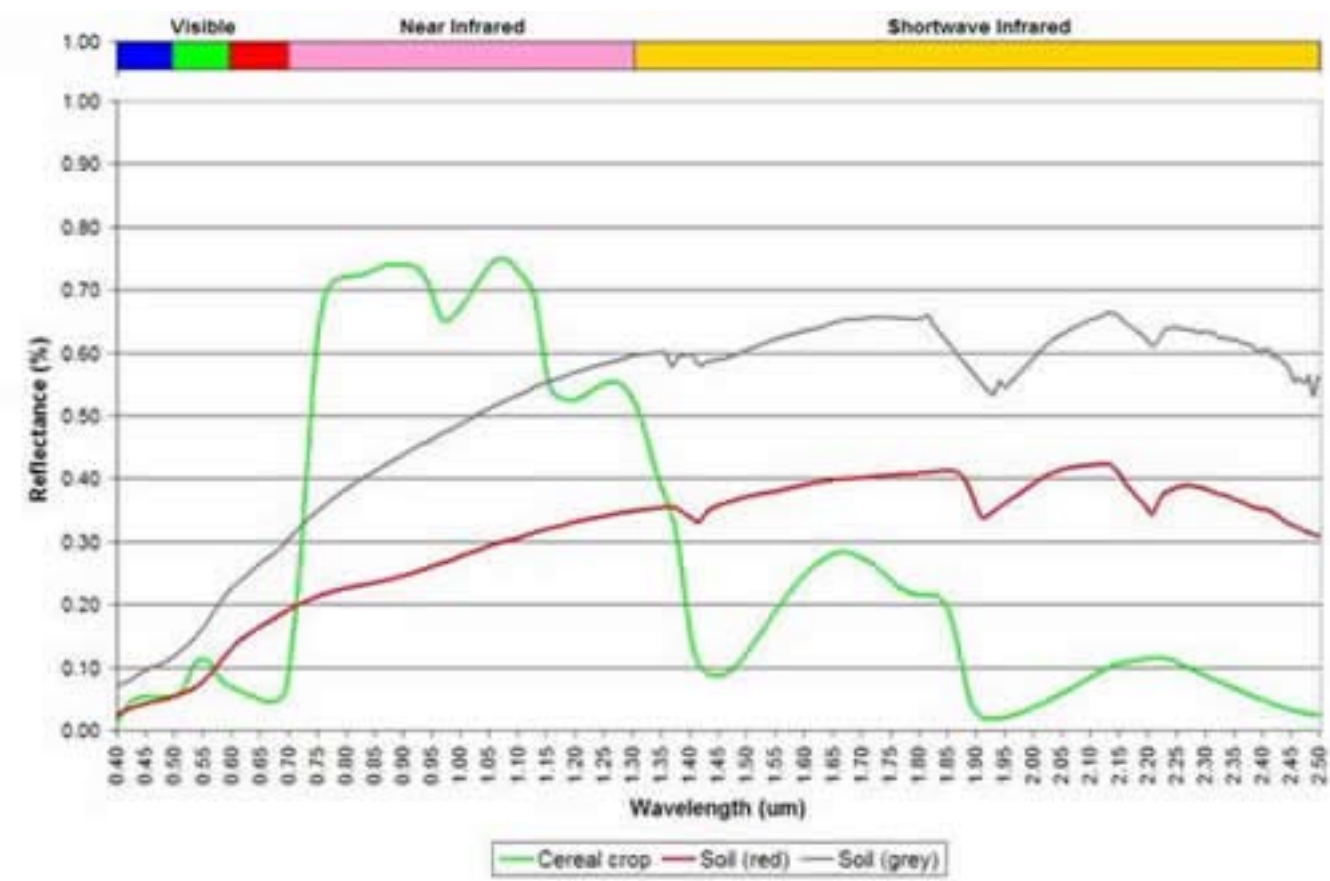


Figure 3.2.4g7. Typical reflectance spectrum for an actively growing cereal crop and two soil types. Spectra have been generalised for the grey soil example. Source data provided by University of NSW.

Simple (vegetation) ratio

The most basic method to determine crop vigour is to use the ratio of NIR to red bands, sometimes called the vegetation ratio or ratio vegetation index (RVI):

$$SR = \frac{NIR}{Red}$$

Vegetated surfaces will provide a high ratio, and non-vegetated surfaces a low ratio. This ratio does not tend to saturate as rapidly at high leaf area index (LAI) and biomass as some others (including the NDVI), but is more sensitive to the influence of bare soil.

Normalised difference vegetation index and soil-adjusted indices

The most commonly used ratio using red and NIR bands is the Normalised Difference Vegetation Index (NDVI), which provides information on plant greenness, vigour or health (Rouse et al. 1973; Jensen 2004). It is sensitive to low chlorophyll concentrations, the amount of vegetation cover and to the absorbed photosynthetically active solar radiation (Gitelson et al. 1996). This index is more appropriate for comparisons over time than the simple ratio, as the NDVI is less affected by atmospheric differences and changes in solar angle. The index is created by subtracting the value of the red band from that of the NIR band, and then dividing this by the sum of the red and NIR bands:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

In its raw form, this index has a range of -1 to 1. The approximate value of the NDVI for water is less than 0, bare soil is about 0-0.15, stubble is about 0.25, senescing vegetation is about 0.3-0.4 and green vegetation ranges from 0.5 - 0.6 (low-moderate vigour) up to 0.85-0.90 for dense crop canopies.

As a crop reaches peak biomass, leaf area index (LAI) or high chlorophyll concentrations, the NDVI values begin to plateau (saturate). Under such conditions, there is some indication that substituting the green band for red in the equation (to create the so-called 'green' NDVI or plant cell ratio) provides superior discrimination. The green NDVI is a good general indicator of chlorophyll content in yellow to dark green vegetation, plant cell density and plant stress (Gitelson et al. 1996; Gitelson and Merzlyak 1997; Metternicht et al. 2000; Metternicht 2003; SpecTerra Services 2004).

The values of the NDVI are usually rescaled to a range of 0-255 for ease of display, storage and interpretation. Rescaling is carried out using the following method (Mather 2004):

$$ScaledNDVI = (NDVI + 1) \times 127$$

A more rigorous method is to create a scaled NDVI using the maximum and minimum NDVI values as the range. For each pixel in the image, the scaled NDVI is then calculated by (Mather 2004):

$$ScaledNDVI = \left(\frac{NDVI_{Pixel} - NDVI_{Min}}{NDVI_{Max} - NDVI_{Min}} \right) \times 255$$

The NDVI is normally calculated across the crop's vegetative growth period, and can be related to a range of parameters such as biomass, LAI, percentage ground cover, nutrition, disease/damage and final yield. Its major disadvantage is that it tends to saturate at LAI levels of between 2.5 and 4, which normally occurs between full tillering (Zadoks GS 29-30) and booting to anthesis (GS 40-65). This is seen in the NDVI values, which normally increase linearly with crop growth up to about 0.7-0.8, then asymptotically (increase slowly, or plateau) afterwards.

The NDVI provides poor or variable results where ground cover is sparse (≤30%), due to background soil effects (Ray 1994). Such soil effects can be minimised by using special soil-adjusted indices such as the Soil Adjusted Vegetation Index (SAVI) or Modified Soil Adjusted Vegetation Index No. 2 (MSAVI2). These indices assume that the values in the

red band will be influenced by the soil. They are more appropriate at lower ground cover than the NDVI, but still have a limit of about 15% ground cover (Ray 1994). The SAVI index is calculated as follows:

$$SAVI = \frac{(NIR - Red)}{(NIR + Red + L)} \times (1 + L)$$

In the equation, L is a soil adjustment factor ranging from 0 to 1; the value chosen depends upon the amount of ground cover. In most situations, a factor of 0.5 is used for L as this reduces soil effects over a wide range of vegetation densities and LAI values. This value is also appropriate for intermediate vegetation cover. However, the use of such a factor has the result of reducing the dynamic range of the index (Huete 1988; Qi et al. 1994; Ray 1994).

The MSAVI2 is a more complex index that removes the need for a soil adjustment factor by automating its derivation. It has a greater dynamic range than the SAVI, is more sensitive to vegetation amount, and there is even less effect of the soil on the index values (Qi et al. 1994). Compared with the NDVI, it saturates less rapidly at high LAI values, and gives better discrimination at low LAI, biomass and ground cover. However, the MSAVI2 and the SAVI are much less commonly used than the NDVI. The MSAVI2 is calculated as follows:

$$MSAVI2 = \frac{(2 \times NIR + 1) - \sqrt{(2 \times NIR + 1)^2 - [8 \times (NIR - Red)]}}{2}$$ (Qi et al. 1994).

Note that the first function in the index is often incorrectly expressed as $2 \times (NIR + 1)$, which has the result of making the range of index values -0.5 to 1.5 instead of -1 to 1.

Figures 3.2.4g8 and 3.2.4g9 provide NDVI images for the same paddocks as shown earlier in true and false colour sown to wheat in 2005. In the first the NDVI range has been calculated across all paddocks, in the next it has been calculated for each paddock separately.

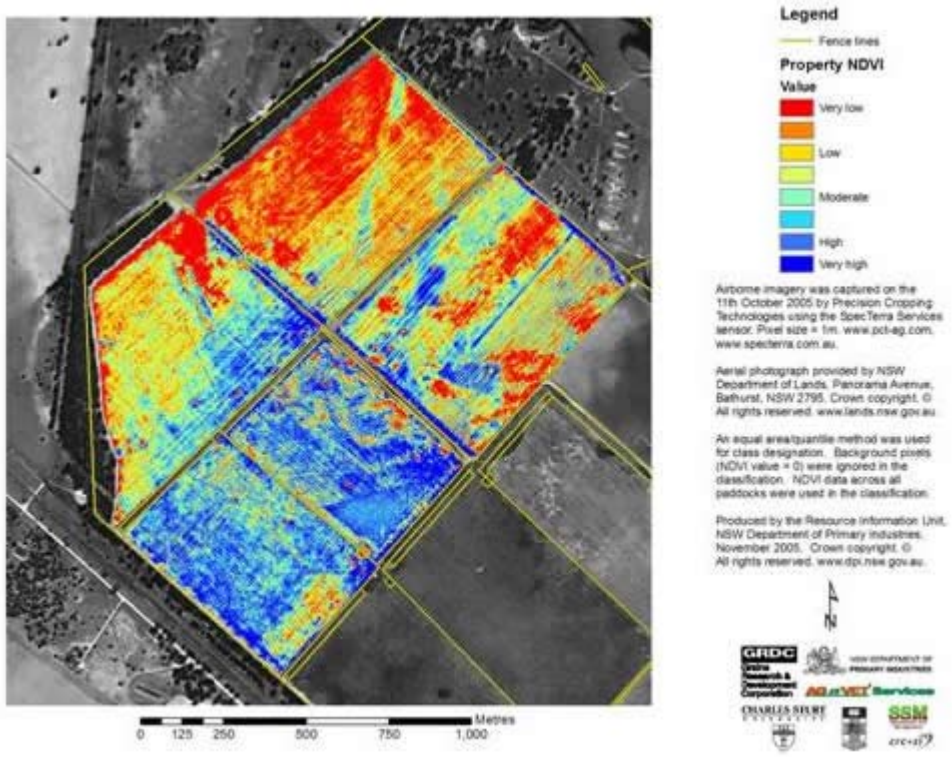


Figure 3.2.4g8. A property level Normalised Difference Vegetation Index (NDVI) classification of 5 wheat paddocks (2005), with NDVI range calculated across all 5 paddocks. This image highlights the between-paddock variability and shows major differences in vigour between the northern and southern paddocks.

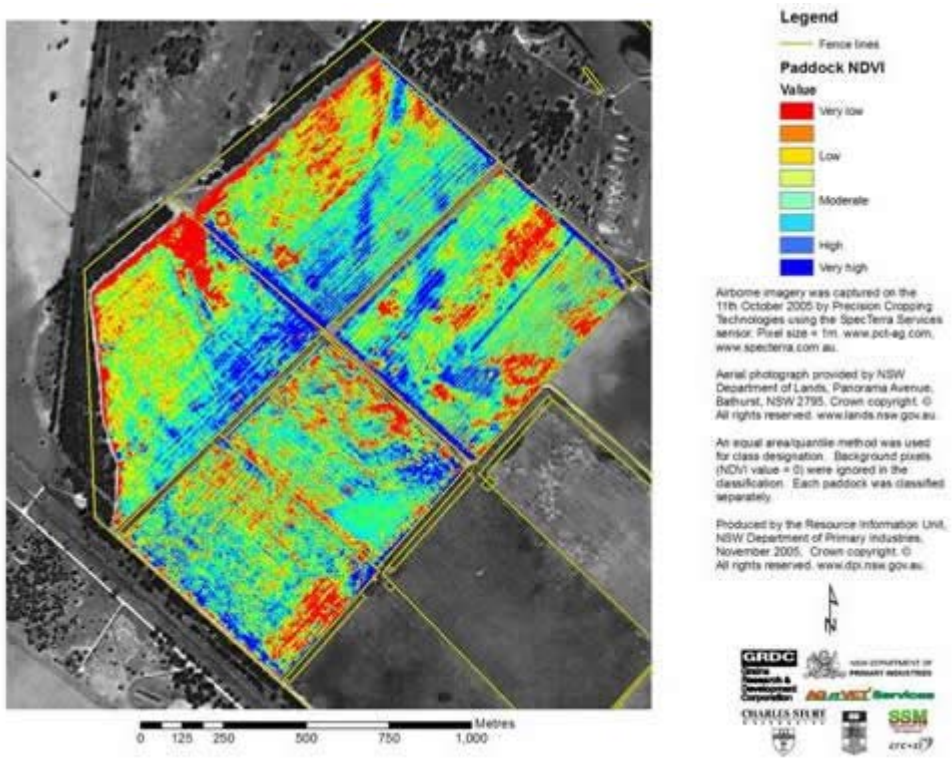


Figure 3.2.4g9. A Normalised Difference Vegetation Index (NDVI) for the same paddocks as Figure 3.2.4g8, but in this case the NDVI range has been calculated for each paddock separately. This highlights the variation within each individual paddock.

Photosynthetic vigour ratio (index)

Where imagery does not have a NIR band, such as colour aerial photography, the 'photosynthetic vigour ratio' can be used to assess crop vigour. It is less sensitive than the NDVI to changes in crop vigour, being based on green rather than NIR reflectance. However, the ratio gives high readings for leaves with strong chlorophyll absorption and thus high photosynthetic activity, and is sensitive to plant stress and senescence (Gitelson et al. 1996; Metternicht et al. 2000; Specterra Services 2004; Warren and Metternicht 2005). This ratio is normally created using narrow-band airborne multispectral or hyperspectral imagery, but can also be created from broad band satellite imagery. The photosynthetic vigour ratio can be calculated as a simple ratio, or as an index as shown below. The advantage of the index is that it can be rescaled using the procedure detailed for the NDVI.

$$PVR = \frac{Green}{Red} \quad \text{or} \quad PVI = \frac{(Green - Red)}{(Green + Red)}$$

Plant pigment ratio (index)

Blue, green and SWIR bands are also used in ratios to enhance different plant pigments and features. The plant pigment ratio produces high values in strongly pigmented foliage (where green reflectance and blue absorption is high), and low values in weakly pigmented foliage (Spectra Services 2004). Ratios of such bands are often used where the NDVI is of limited application, such as when canola is in mid to full flower (compare Figures 3.2.4g8 and 3.2.4g9) (Metternicht et al. 2000; Metternicht 2003; Specterra Services 2004; Warren and Metternicht 2005). Here the plant pigment ratio provides a useful means of assessing the intensity of flowering, which provides an indication of final yield. This ratio is normally created using narrow-band airborne multispectral or hyperspectral imagery, but can also be created from broad band satellite imagery. The plant pigment ratio can be calculated as a simple ratio or an index.

$$PPR = \frac{Green}{Blue} \quad \text{or} \quad PPI = \frac{(Green - Blue)}{(Green + Blue)}$$

The use of the red and blue bands in ratios (a red-blue index) has also shown some promise for assessment of the density of canola flowering, but has had limited testing (compare Figures 3.2.4g10 and 3.2.4g11 below). A red-blue ratio is also strongly influenced by soil background.

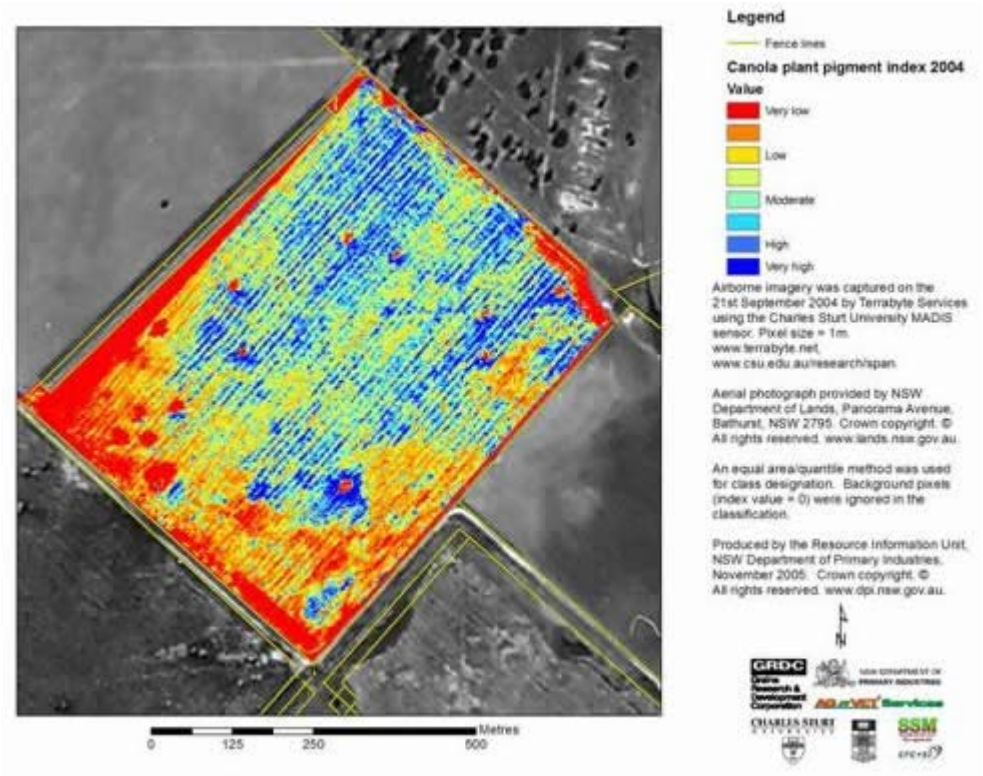


Figure 3.2.4g10. An example of an image prepared using the plant pigment ratio index for a canola paddock. The areas of most intense canola flowering show as high values (green-blue).

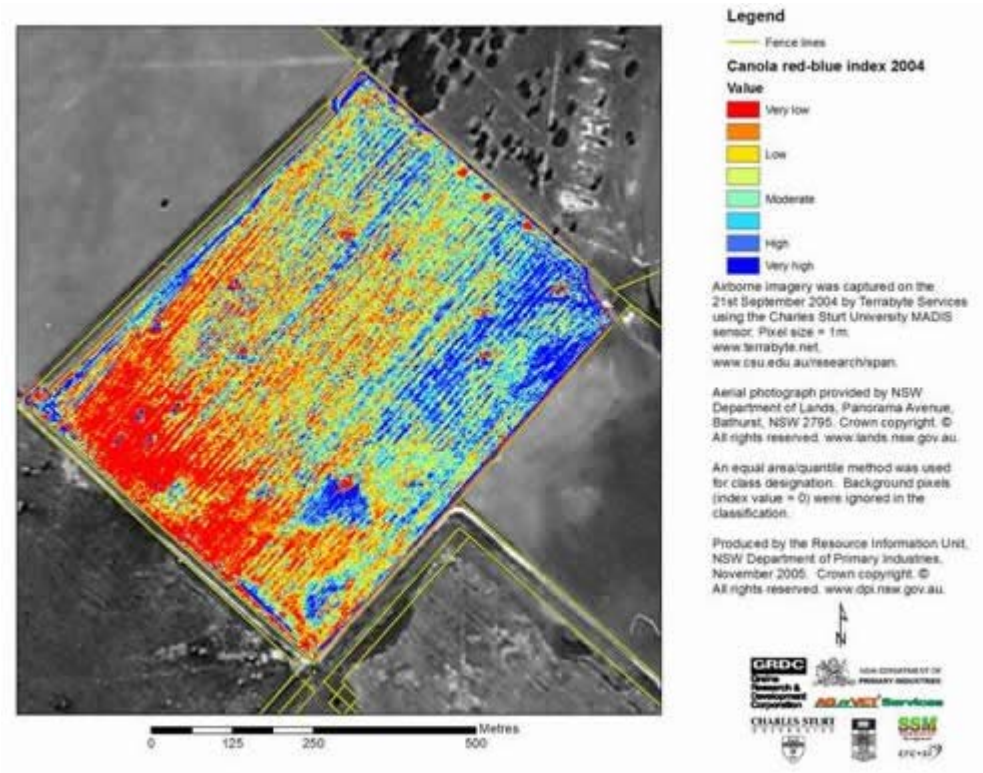


Figure 3.2.4g11. An example of the red-blue index for the same paddock as in Figure 3.2.4g10. The most intense canola flowering areas show as high values (green-blue). As complete canopy cover was not obtained due to drought, the red soil background has affected the result in the centre of the paddock

Red index (soil classification)

For analysis of soil properties, more rigorous methods are usually used, such as an unsupervised classification of raw imagery or of the first principal component from a principal components analysis (PCA) of the imagery. Similar classification routines can also be used on crop canopies to determine vigour classes [for more information on such topics see Jensen (2000, 2004)]. However, a simple redness index works well at discriminating soil colour differences over many soil types and colours, particularly where the soils are shades of red or grey due to different levels of iron oxide and organic matter (Drysdale and Metternicht 2003; Reyniers et al. 2004). The index can also be useful in discriminating differences in soil moisture content, although it is better to use ratios containing the SWIR bands for this purpose. The redness index can be used for analysis of aerial photographs and multispectral imagery, and is calculated as follows:

$$RI = \frac{(Red - Green)}{(Red + Green)}$$

Note that the redness index assumes a high red reflectance and a relatively lower green reflectance. On vegetated surfaces, the opposite will be the case, although senescing vegetation will show high red and moderate green reflectance. Bare soil will generally have a positive index value, while healthy vegetation will generally have a negative value (due to higher green reflectance). Also, soil reflectance characteristics are strongly affected by soil moisture and organic matter content. In mineral soils (as distinct from organic soils) as moisture and organic matter content increase, reflectance will decrease.

All the calculations above that use sums and differences can be scaled using the procedures for scaling the NDVI.

Other ratios and techniques

A wide range of classification techniques are used on remotely sensed imagery. These include supervised and unsupervised classification, and 'tasselled cap' analysis. Other specialised techniques have been developed, particularly for analysis of superspectral and hyperspectral imagery. A discussion of most of these is beyond the scope of this publication; for more information on such topics, see Jensen (2004).

Specific narrow spectral bands or ratios from hyperspectral imagery can be used to accurately monitor changes in the concentration of chlorophyll and other plant pigments, plant water content, nitrogen status and the amount of cellulose (Curran 1989) (see Figure 3.2.4g6). Narrow band simple ratios and NDVI are often created using the narrow bands at 0.68 µm (red) and 0.77-0.8 µm (NIR), as these provide more information than the wide spectral bands in most satellite imagery. Ratios using specific narrow visible and SWIR bands have been found to be of particular use for determining nitrogen status and responsiveness, and for assessment of the amount of cellulose.

Other more advanced analysis techniques are used for the classification of soil parameters, assessment of stubble quantity, discrimination of certain weed infestations and broadscale mapping of different vegetation types.

Information from calibrated thermal sensors can monitor the temperature of the plant canopy, allowing accurate assessment variability in water use, moisture stress and for irrigation scheduling.

Advanced analysis techniques

Some analysis techniques use complex models based on field information, known crop/variety characteristics, past yield data and information from satellite or airborne imagery to provide data on biomass, LAI and yield. Information from remotely sensed data across growing seasons is also used in general crop growth models to assist in yield prediction.

A discussion of these techniques is beyond the scope of this publication.

Interpreting the data from ratios

Difficulties can arise in interpreting information derived from remotely sensed data due to differences in presentation, and in comparisons between different years. It is a particular problem where imagery is not obtained at the same

crop growth stage in each year. The problem is similar to comparing yield monitor data between years, where the upper and lower yield values and range are different.

To display the information from the ratio/index calculations, the data are often scaled and split over a range of 5-12 data levels, similar to those used for yield maps, and assigned particular colours.

How the data are split into these levels can dramatically alter the way it is interpreted. The most common means of presenting ratio data are:

- Fixed or user set intervals: allocation of the values to a set number of classes. For example, scaled index values of 0-128 might become level 1, 129-160 might become level 2 etc.
- Linear stretch: stretching the classes to fit the full data range, using a colour gradient (see 'Pseudocolour' section above). This can cause difficulties in comparison if the upper and lower ends of the range are not consistent between years.
- Percentiles: setting up a relationship where certain percentages of data fall within a fixed number of classes. For example, the lower 15% of values may form class 1, and the upper 15% may form class 8 etc. An adaptation of this process is to use a standard deviation stretch, which highlights how the values differ from the mean.
- Equal area or quantile: setting up a relationship where equal numbers of pixels fall within a fixed number of classes. For example, if the total number of pixels is 100,000 and there are 5 classes, then each class must contain 20,000 pixels.
- Normalisation: in a classification scheme that compares change over time (see section 3.2.4i).

Additionally, ratio data can be presented to highlight within- and between-paddock variability across a property, and even variability between properties.

- For within-paddock variability, the data for each paddock is presented separately, and the output is not comparable between paddocks. This highlights the differences in growth within the paddock, and is useful for directing field sampling to investigate why differences are occurring.
- For between-paddock variability, the full range of data values over all crop paddocks across a property are used, and an overall property map produced. This procedure reduces the contrasting areas within paddocks, but highlights major differences between paddocks and how crop vigour compares between them. A similar procedure can be used for crop comparison across a number of properties or a region (Terrabyte Services 2005). Note that separate analyses are usually conducted for different crops.

These methods are used to enhance different features in the imagery. To compare data over time, it is necessary to use a consistent methodology. There is no best means of presenting the information. Ultimately, the interpreter should, if possible, instigate multiple ways of presenting or displaying the data. Different methods will tend to enhance different sections of the data. This is particularly important when attempting to enhance data within an interval or intervals; for example NDVI values between 0.6 and 0.8 where the range is from 0.1 to 0.9. The visual information is best combined with the area, percentage of values, mean and range within each class to assist in interpretation. In all cases, the legend and methodology should be included with every map.

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3.2.4h Limitations of satellite and airborne imagery - the need for calibration and field validation

Author: Ian McGowen, NSW Department of Primary Industries

Remotely sensed data (including indices such as the NDVI) are useful at highlighting variability at a paddock, farm and regional scale. However, they are at best only surrogates for physical plant characteristics. Even with proper calibration and crop profiling over many seasons, it is difficult to determine consistent direct relationships between such ratios and plant characteristics such as biomass, leaf area index (LAI) and yield except in environments with a very consistent growing season. A large number of factors complicate these relationships, such as saturation of the ratios, atmospheric effects, sun angle (solar zenith and azimuth) differences, background soil effects, variations between crop types and varieties, differences in planting dates relative to the season, and climatic variation both between and within seasons.

For these reasons, satellite data are not in general suitable on their own for determining absolute values of biomass or yield. However, they can be very useful in calculating relative values, for example in biomass across different zones of a paddock. When combined with other data and methods for estimating absolutes (e.g. with known PAW, PAWC and measured seasonal rainfall), they can be used to assist in-season agronomy, such as with maps of yield potential or nitrogen requirement.

Ratio data or index derived from imagery captured at cereal crop late tillering (GS 25-30) and anthesis (GS 60-65) can be used as a guide to crop health, vigour and yield potential. Similarly, an assessment of canola at full canopy (about eight leaves) can assist in determining nitrogen responsiveness, and at mid flowering to assess the potential yield. However, there is not necessarily a direct relationship between the ratio values and the crop physical characteristics, as discussed above, as the ratios can saturate at high LAI and biomass.

To gain the most from remotely sensed data, field validation is essential. Regular monitoring using remotely sensed data allows better directed paddock management, and can identify potential problems before they become obvious to the naked eye. This allows action to be taken to enhance yields and reduce potential losses. An analysed satellite image can be used as a guide to target a crop and soil sampling strategy, and to set up preliminary

management zones. Another example is where an airborne digital image might be captured over a crop that had suffered heavy storm damage at anthesis. It is possible to create a map of various levels of lodging from analysis of the imagery, for insurance purposes. However, the map must be validated by field survey at the time, and ultimately with yield monitor data. This will allow accurate assessment of the extent of yield loss within each class, and the total yield loss within the paddock.

Similarly, an image analysed to produce 'zones' of nitrogen responsiveness within a paddock should be validated by tissue testing the crop within the zones. By this means, the optimum application rate per zone can be determined.

3.2.4i Biomass maps and other outputs from satellite imagery

Author: Matthew Adams, Satellite Remote Sensing Services, WA Department of Land Information

NDVI data gathered from the Landsat series of satellites provides the basis for biomass maps. The value of NDVI data from Landsat lies largely in its historical record of paddock performance across crop rotations and through time/seasons/years. The historical nature of the data allows for analysis for stability or instability in the images associated with a paddock through time. Stable areas can be extrapolated into the future at low risk to the grower.

A series of six biomass maps are shown in Figure 3.2.4i1 for a farm in the northern wheatbelt of Western Australia. For 3 of the 6 years the paddock was planted to wheat, in others it was planted to canola or lupins. Some general patterns can be observed that are independent of crop type and season.

There are areas in the north-western and south-eastern corners of the field that consistently perform better than other parts of the paddocks, irrespective of the season and crop being grown. In addition, there is a strip running in a south-west/north-east direction on the western side of the field which tends to perform poorly relative to the rest of the field in all years. The maps identify variation, however on-ground sampling is required to assess the causes of the variation.

Biomass analysis maps

Biomass maps from multiple years can be classified into categories, in these examples six categories are used: low, medium or high performance and either consistent or inconsistent for each performance level. The actual method used is based on the method described in Adams (1999), but is also similar to method T60-3 given in Dobermann et al. (2003). For this method each cell in a yield grid is standardised by the paddock average yield [(yield at cell i,j minus average yield)/average yield]. An average of standardised yield is calculated over time. Stability is determined by whether the average standardised yield is significantly greater than 0 by means of a t-test. The result in this case produces four classes: high/stable, high/unstable, low/stable, low/unstable.

Three maps can be produced from this analysis:

- A yield or biomass performance map summarises which parts of paddocks have relatively high or low NDVI over time.
- A consistency map classifies each pixel as consistent or inconsistent based on the standard deviation or coefficient of variation of the pixel through time (e.g. over several seasons and crops).
- A combined performance/consistency map combines the two previous maps into one.
  The percentage of total area in each of the six categories is also calculated and tabulated. An example set of these maps is shown in Figure 3.2.4i2 for the same farm as shown in Figure 3.2.4i1.

Soil sampling site maps

The combined performance/consistency map is used to target soil sampling. In Western Australia targeted soil sampling has led to several growers identifying pH and potassium problems that either were missed, or averaged out because of the existing random soil sampling methodology. Corrective measures applied to areas of low pH or potassium have resulted in yield increases of up to 1 t/ha and a return on investment figure averaging between 100 and 300% (Adams et al. 2002). Soil sampling site maps are used in conjunction with estimated yield and gross margin maps to demonstrate the potential gains of correcting a soil chemical or plant nutritional problem.

Estimated yield and gross margin maps

A critical component in the delivery of this information is placing the biomass maps into a financial context. The best way to do this in the absence of actual yield data is to estimate yield from the biomass maps. In Western Australia, there is generally a good relationship between biomass as determined from NDVI and final yields (Smith et al. 1995). The relationship breaks down if frost, leaf diseases, pests or low rainfall occur in spring.

A stretch of the NDVI data is performed to create an estimated yield map. The stretch process is empirical, but it is guided by the grower estimate of minimum yield, maximum yield and an average yield for that paddock. In nearly all cases, estimated average yield for the paddock falls within 300 kg/ha of the figure supplied by the grower. The grower's farm gate price for grain and estimate of costs of production on a dollars per hectare basis are used to convert the estimated yield map into an estimated gross margin map. An example of these two maps is shown below in Figure 3.2.4i3

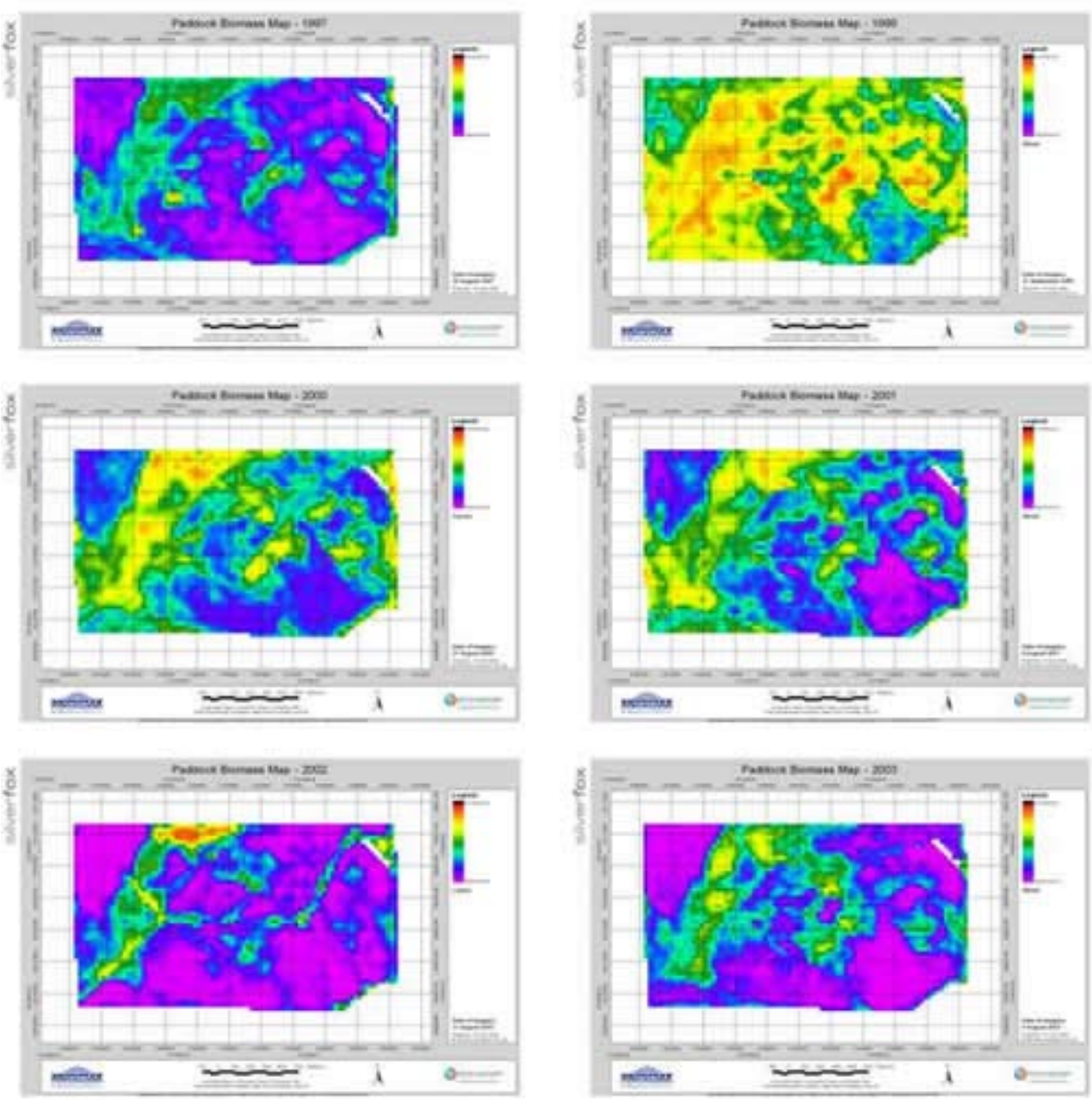


Figure 3.2.4i1. A series of six biomass maps derived from the Agimage system from Landsat-based Normalised Difference Vegetation Index (NDVI). The images were acquired in late winter/early spring in 1997, 1999 and 2000-2003. Note the consistency of patterns irrespective of the colour.

Estimated yield and gross margin maps

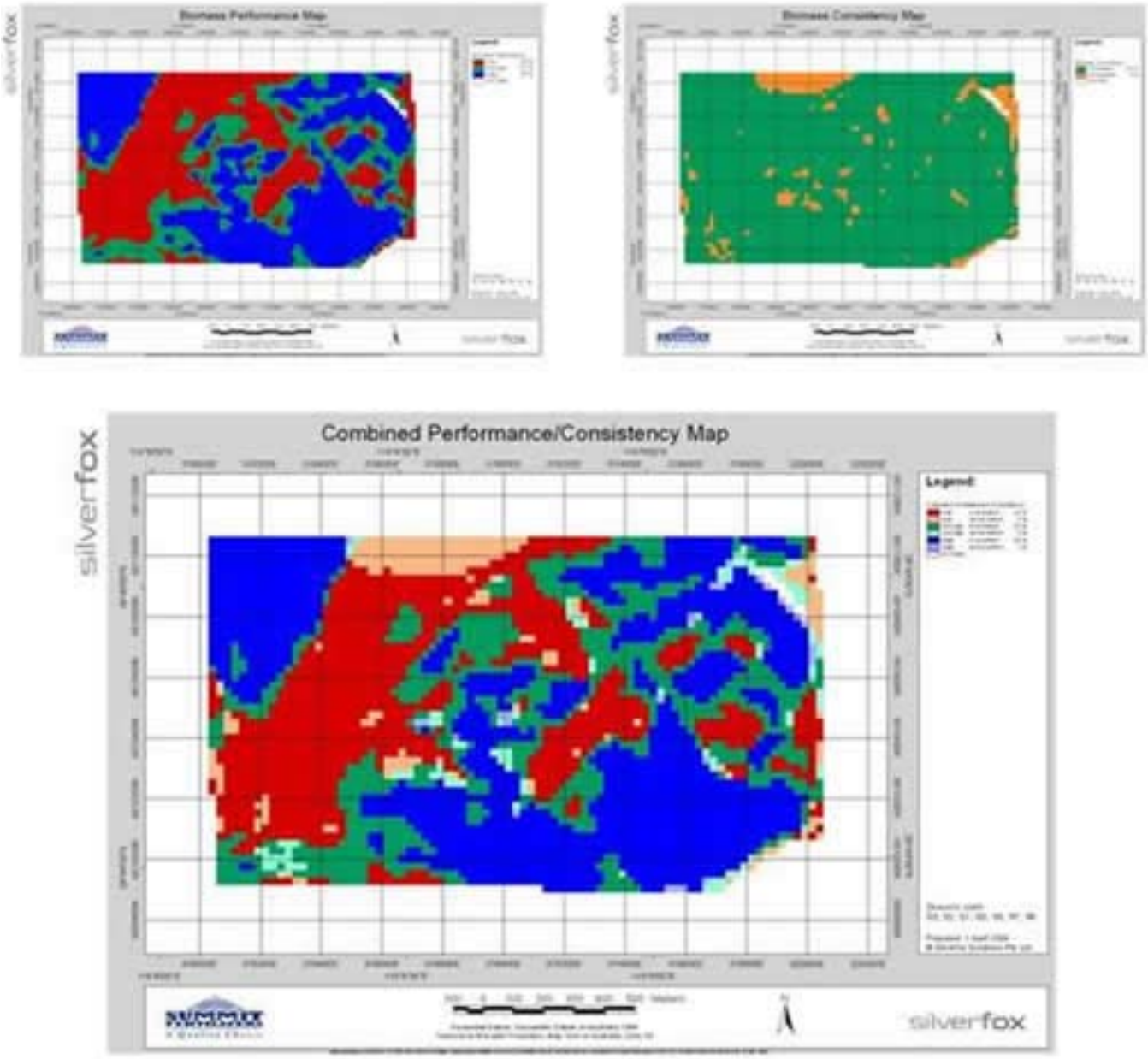
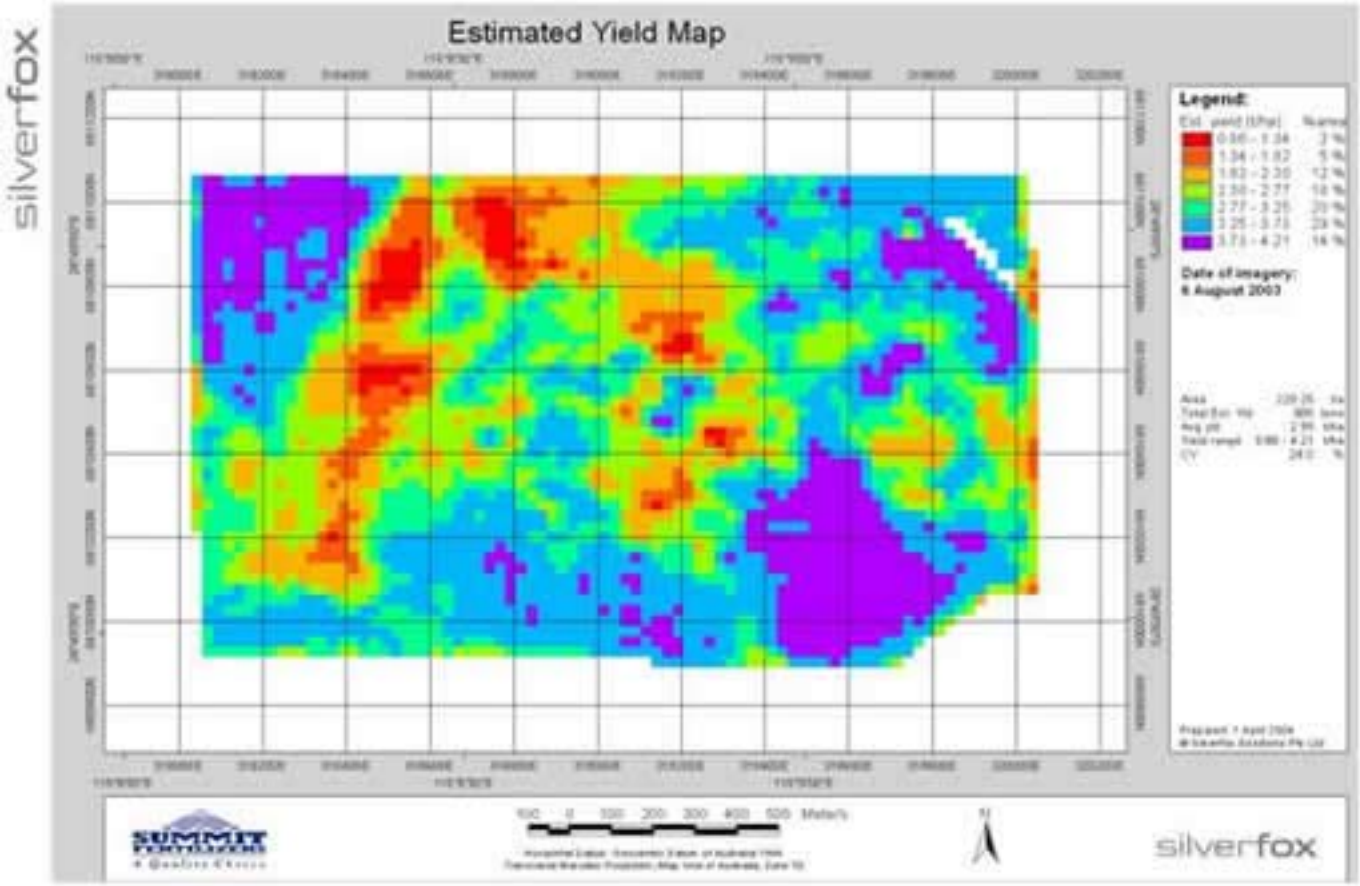


Figure 3.2.4i2. Biomass performance map (upper left), biomass consistency map (upper right) and combined performance/consistency map (centred) for the same client as in Figure 3.2.4i1.



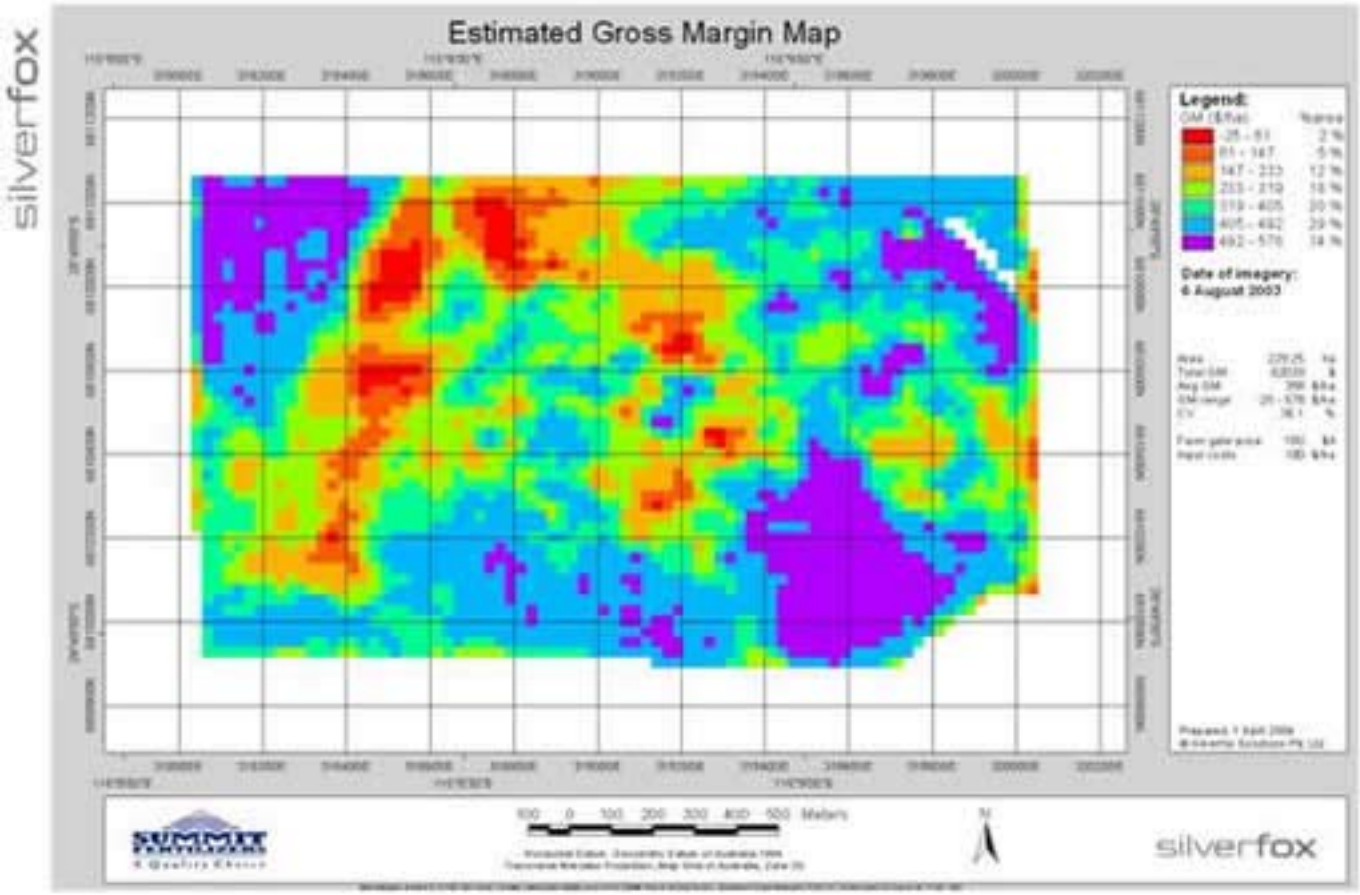


Figure 3.2.4i3. Estimated yield map (top) and estimated gross margin (GM) map (bottom) for the same paddock as shown in Figures 3.2.4i1 and 3.2.4i2. The maps are nearly identical because they are both using a natural break, seven class legend (seven classes of NDVI data based on natural breaks (or gaps) in the data set for the paddock)

Estimated gross margin maps readily identify the parts of a paddock that are making money and parts that are losing money. This information may be used to identify where gross margins could be maximised and to suggest soil sampling sites to help identify whether low biomass performance is due to a nutritional limitation. The gross margin map also allows the grower and their consultant to consider the economics of trying to overcome the factors that may be limiting performance, for example using lime to correct pH imbalance or gypsum to correct soil structural problems.

The estimated yield map is also used to derive a crude fertiliser audit (nutrient inputs minus nutrient exports in grain) to highlight to the grower whether they are removing or adding key nutrients to the soil.

This type of analysis is best performed within a GIS or image processing package, such as ESRI's ArcView or ArcGIS software with the Spatial Analyst extension.

The use of historical satellite data in this way can provide an inexpensive means for growers to look for patterns of variability in a high performing paddock, and to test for themselves whether PA (in the form of management zones and variable rate application of fertilisers) can be of benefit to them.

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3.2.4j Whole farm planning from pseudo yield mapping

Authors: Peter Fisher and Mohammad Abuzar, Department of Primary Industries Victoria

Many growers are uncertain whether the level of variability on their property justifies significant capital investment in PA. Other growers may already be investing in PA, but would like to understand the long-term nature of their paddock variability more immediately than can be obtained by collecting annual yield maps.

For such growers, a team from Department of Primary Industries Victoria have been developing a technique to provide a relatively economical analysis of whole farm crop variability based on pseudo yield mapping (PYM).

This process is based on historical imagery available from the Landsat series of satellites, going back to 1978 in Australasia. The most important prerequisite for this analysis is that growers have good records of their rotation history for each paddock, and average paddock yields for as many seasons as possible. An example of these records is shown in Table 3.2.4j1. Using this information, appropriate images from the Landsat archives can be selected for seasons that have similar crop types. This is important because the images, for example, of cereal, pasture and pulse crops, can be very different and therefore should not be analysed together. The satellite images are usually selected from a period close to anthesis as this is considered to be the best time for images to reflect yield potential (Figure 3.2.4j1). However, work is still continuing to see how the crop growth stage at the time of image capture will affect the analysis results.

Year	Home paddock	Yield (t/ha)	Fence paddock	Yield (t/ha)
1988	Pasture legume		Field peas	
1989	Wheat		Barley	
1990	Field peas		Pasture grass	
1991	Wheat		Wheat	
1992	Pasture grass		Field peas	
1993	Barley		Barley	
1994	Chemical fallow		Pasture legume	
1995	Wheat	1.5	Barley	1.4
1996	Field peas	1.7	Pasture grass	
1997	Wheat		Barley	1.1
1998	Pasture grass		Lentils	0.8
1999	Wheat	1.1	Wheat	2
2000	Wheat	2.6	Oats and medic	
2001	Oats and medic		Wheat	2.8
2002	Wheat	2.76	Oats and medic	
2003	Lentils	0.5	Wheat	1.2
2004	Lentils	1.3	Oats and medic	
2005	Wheat	0.6	Wheat	0.5
2006	Barley	2.1	Barley	1.7

Table 3.2.4j1. Example of the level of rotation history and yield information required from growers to undertake the pseudo yield mapping analysis.

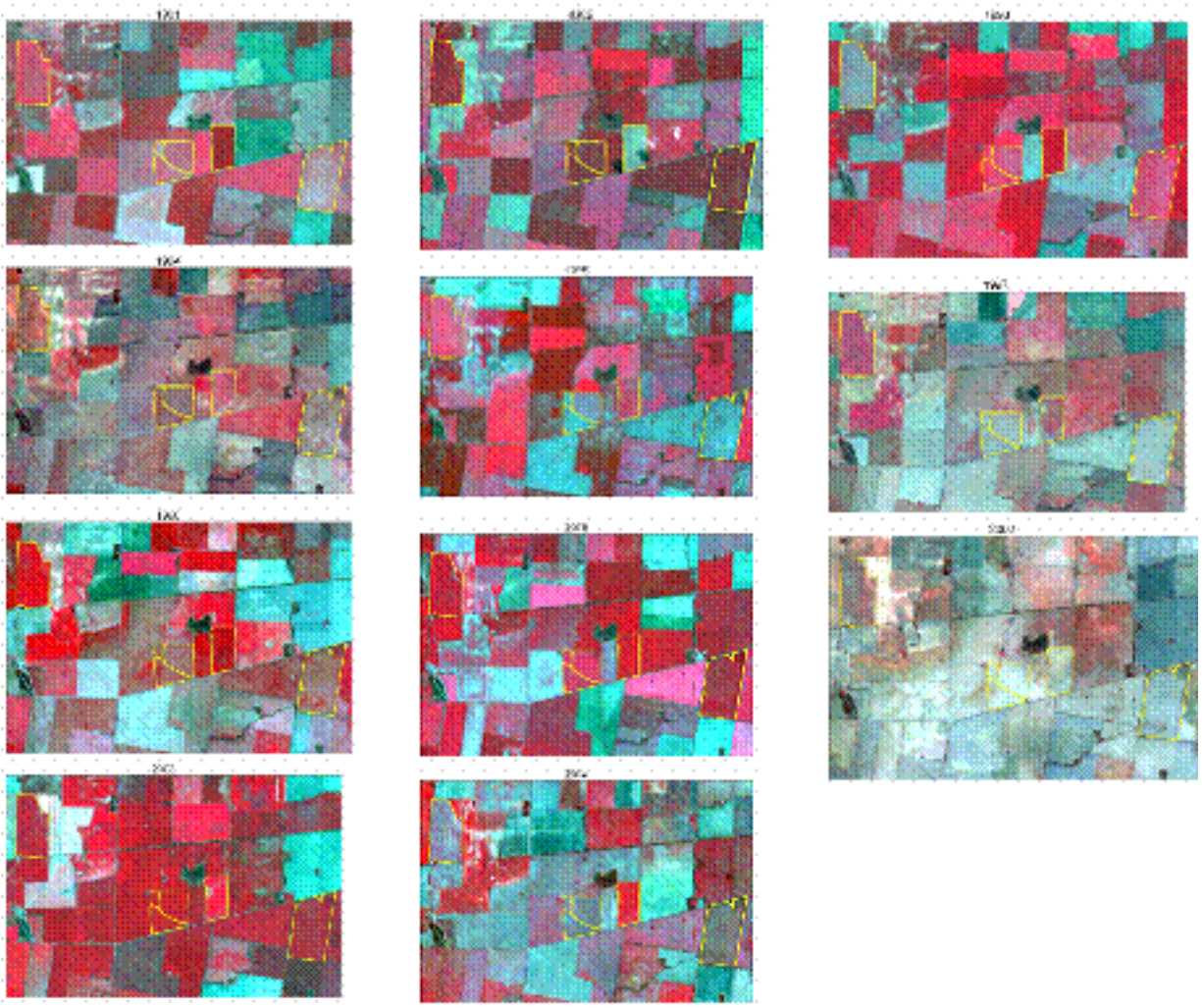

Figure 3.2.4j1. An example of different years of images acquired from the Landsat archives, that are used in the pseudo yield mapping process. The false colour images were taken close to anthesis and show greater vegetation levels as an increasing intensity of red.

The first step in the PYM analysis process involves correcting each image for atmospheric effects. From the corrected satellite images an index is calculated to represent the crop biomass. The index usually used is NDVI (Link to NDVI), although the usefulness of other indices is still a research topic.

Unlike the analysis in section 3.2.4i, in the PYM analysis the NDVI data are not standardised using the annual mean value, instead a global standardisation is required. This is important because only by using a global standardisation will the major seasonal differences, as well as the spatial differences, be retained.
The second step in the PYM process is to produce a map of the 'Globally Standardised NDVI values' (GS-NDVI) for each pixel averaged over all the years of available data.

The third step in the analysis is to develop the relationship between GS-NDVI and yield for each crop. This relationship is made more robust by using the grower's specific information on average paddock yields, and the average paddock GS-NDVI data for the same paddock and season. At present, it is suggested that individual relationships for each paddock are developed, although further research is considering the applicability of a more general relationship. An example of this relationship for cereals on an individual paddock is shown in Figure 3.2.4j2. In this example only 3 years of cereal yield data were available to develop the relationship, and therefore only a linear relationship could be considered.

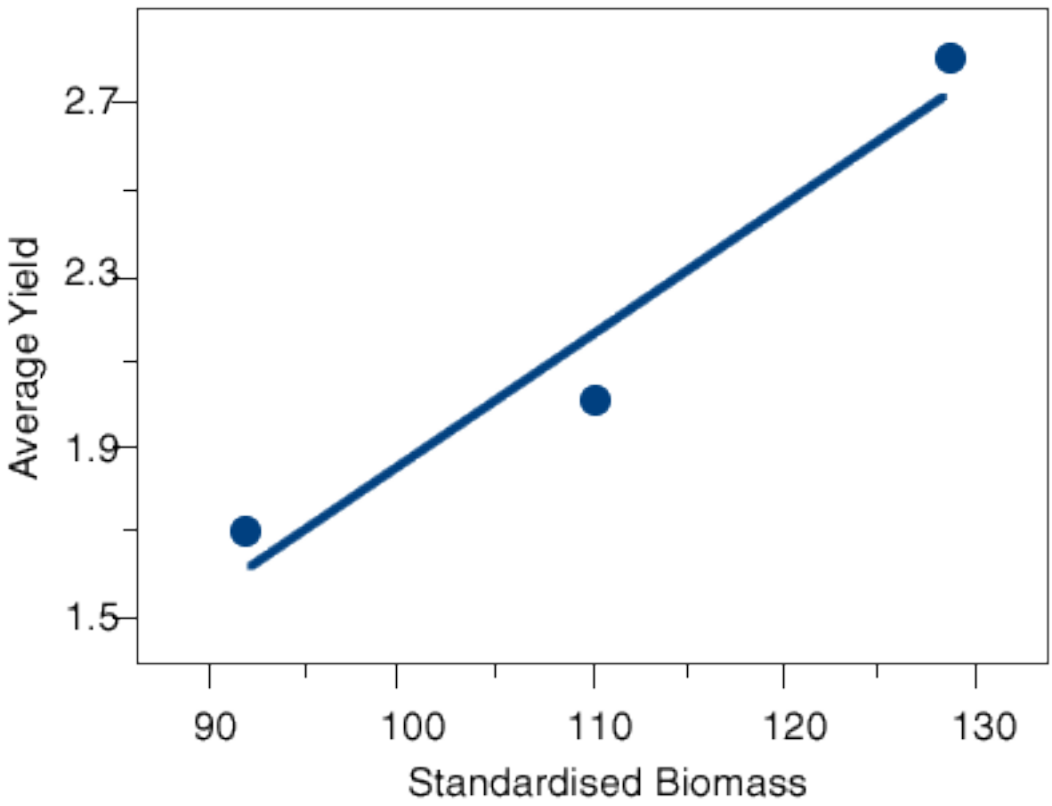

Figure 3.2.4j2. The relationship between paddock average Globally Standardised Normalised Difference Vegetation Index data acquired close to anthesis and average yield for an example paddock.

The final step in the PYM analysis is to calibrate the data in the mean GS-NDVI map using the GS-NDVI to yield relationship developed above. The result of this calibration is the production of a mean pseudo-yield map for each paddock (see Figure 3.2.4j3a). For this paddock actual yield maps for four different seasons were also available, and a map of actual average paddock yield can be obtained by averaging this data (Figure 3.2.4j3b).

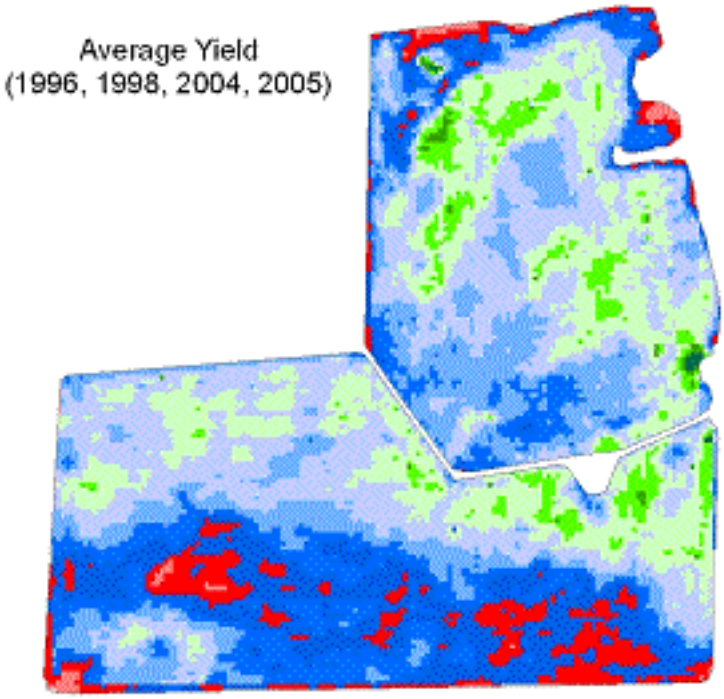

Figure 3.2.4j3. The spatial variation in cereal yield for a single paddock a) (top) developed from the pseudo yield mapping process; and b) (bottom) based on actual yield monitor data over four seasons.

The accuracy of the PYM system on this paddock can be evaluated by subtracting the two images to obtain the difference between them (Figure 3.2.4j4). This example illustrates that 56% of the 160 ha paddock has been estimated using the PYM system with an error of less than ±300 kg/ha of the actual mean yield result. A further 33% of the paddock area has been estimated with an accuracy of < ±800 kg/ha but > ±300 kg/ha of the actual mean yield.

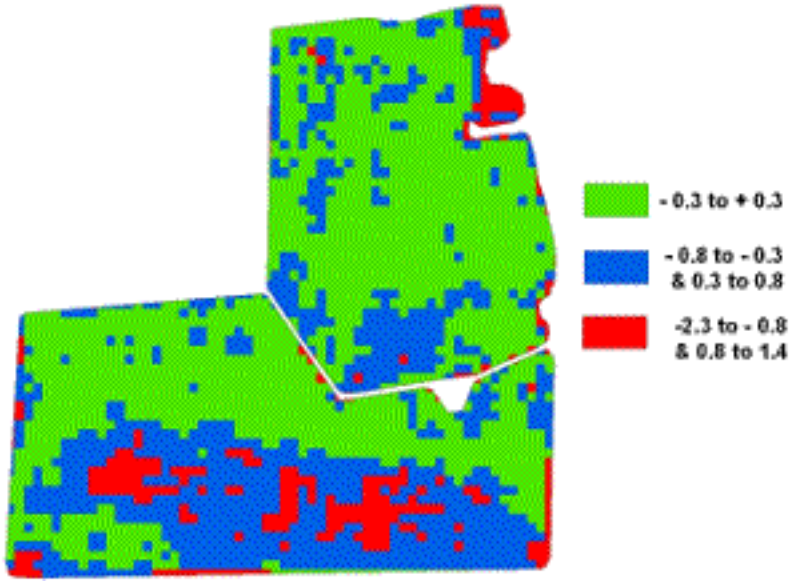

Figure 3.2.4j4. The spatial variation in the difference (t/ha) between cereal yield predicted from the pseudo yield mapping process and the actual yield monitor data over four seasons. Areas in green show good agreement between the two data sets; areas in blue show moderate agreement; and areas in red show poor agreement.

Many factors can cause differences between a pseudo yield map and the actual average yield map. One factor is that the actual yield map is an average of only four seasons, while the PYM analysis has included many more seasons. Other reasons for the differences include processes that occur after image acquisition such as frost or haying off due to lack of finishing rainfall. In the example illustrated in Figures 3.2.4j3 and 3.2.j4, the area that has not been so well estimated corresponds to an area of heavy clay with subsoil constraints where the PYM analysis has overestimated the expected yield. Despite this, a PYM analysis is expected to produce a spatial average yield map that is more accurate than using crop modelling, unless there has been a very considerable collection of model parameter data.

In Figure 3.2.4j5 the PYM process has been applied to a whole farm. The legend for the map is the same for all paddocks, and is in tonnes per hectare of yield. With this information growers and farm consultants can estimate the opportunities, economic value, and future investment needed to develop a PA plan for their property. The results illustrate that although there are considerable yield differences between paddocks, the yield variation in some of the paddocks is so small that the paddock appears apparently uniform. Other paddocks show greater levels of within-paddock variability, and these would be the paddocks where management practices such as variable rate application of nutrients would be most successful. Using the PYM approach it should be expected that the areas of equal yield would merge across paddock boundaries, reflecting the underlying topological and soil properties that control yield. See Chapter 2. This can be seen in some areas of the farm, however, because the data are based on the grower's actual yields, and different crops are grown in different paddocks, in different seasons, some mismatch occurs. For the same reasons a similar difference would appear when comparing data from yield monitors.

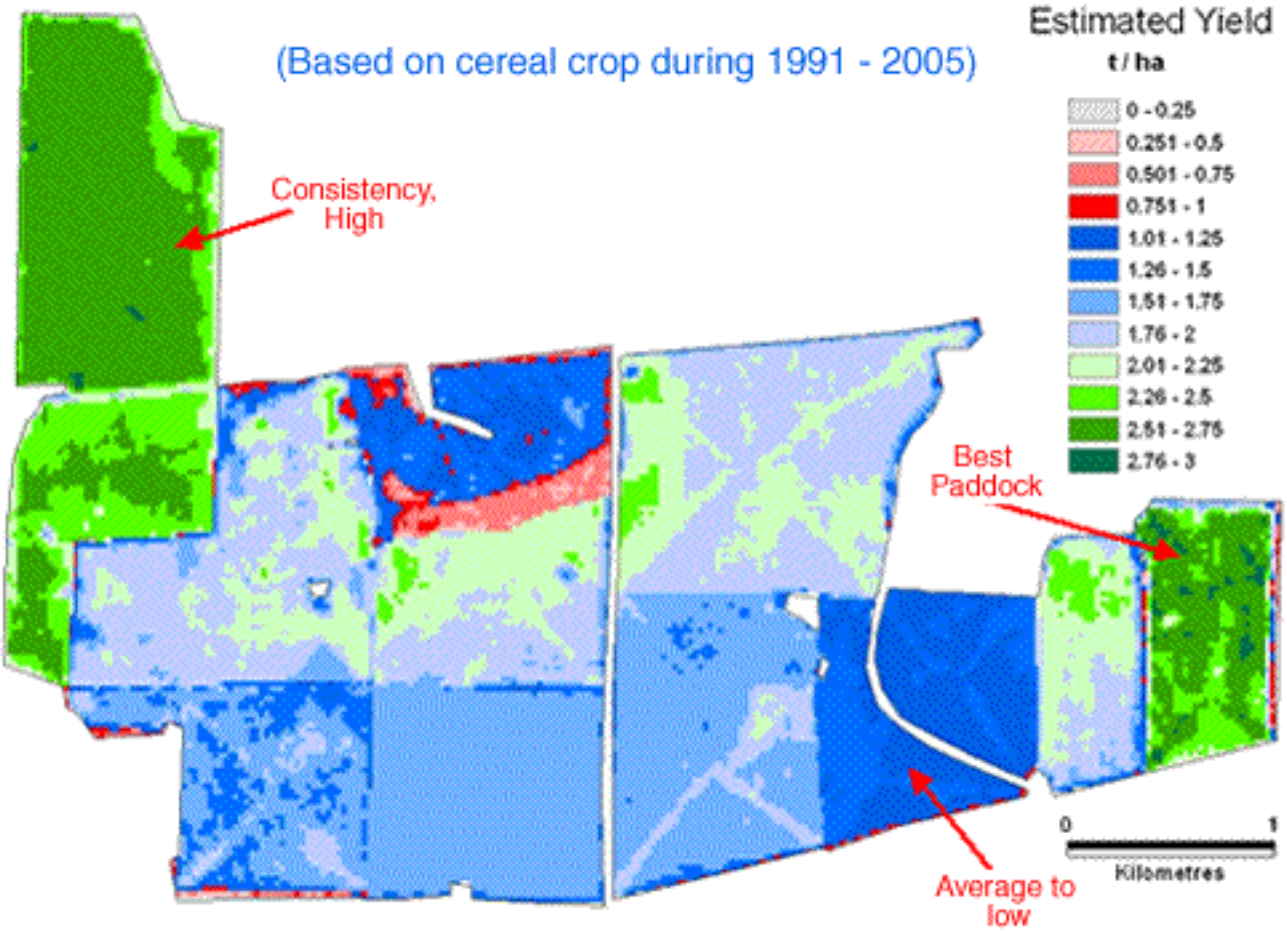

Figure 3.2.4j5. The spatial variation in pseudo yield mapping (PYM) across a whole farm. Farmer comments on some paddocks are in red and agree well with the differences between paddocks shown from the PYM analysis.

In contrast to this information, Figure 3.2.4j6 shows the same farm paddocks but zoned using the conventional approach of zoning each paddock into areas of high, medium and low performance areas. This approach identifies different zones in all paddocks, irrespective of the economic importance of the difference between the zones. A grower is not limited to using one or other approach, but can use both sets of information to gain a greater insight into the management of spatial variability.

The next step which the Department of Primary Industries Victoria team are developing is to convert the yield stability analysis from qualitative measures to a similar quantitative approach. This will provide growers with information on the estimated seasonal variability for each paddock area (in kg/ha), which can then be used to further prioritise actions and analyse risk.

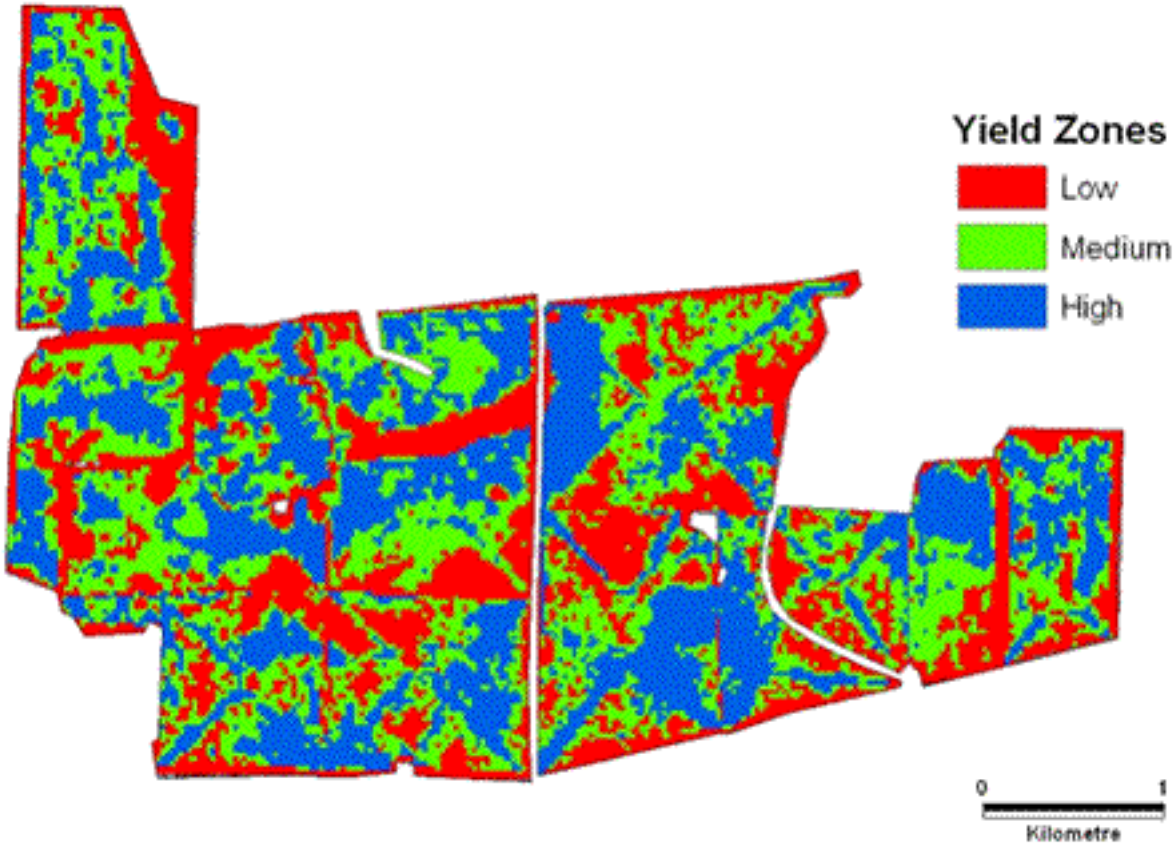

Figure 3.2.4j6. The spatial variation in crop performance across a whole farm based on Globally Standardised Normalised Difference Vegetation Index using a conventional high, medium or low zone for each paddock.

3.2.5 Measuring variability in grain yield and quality

Authors: Rob Kelly, formerly Queensland Department of Primary Industries and Fisheries, Troy Jensen, Queensland Department of Primary Industries and Fisheries, and Brett Whelan and James Taylor, Australian Centre for Precision Agriculture

3.2.5a Yield quantity

Yield monitors

Crop yield may now be monitored in real-time during the harvest process. The grains industry has pioneered the use of these measuring systems, largely due to the extensive use of mechanisation and the suitability of grain harvesters for adaptation.

A grain yield monitoring system requires a number of sensors and computer equipment to be installed on the harvester. The sensors are needed to measure:

- clean-grain flow and moisture content;
- elevator speed;
- harvester speed; and
- harvester location.

The information from these sensors is linked to a cabin-mounted monitor that combines a basic computer with recording and display software and a memory card port for data storage.

There are many commercially available approaches to monitoring the yield on a harvester. They all provide a final output of crop yield in tonnes per hectare. The two most common types of system used in Australia differ in how the grain flow is measured.

The 'impact-plate' type calculates a mass directly from measurements of the force of grain hitting a sensor. This type of sensor is usually located at the top of the clean grain elevator to intercept the grain before it reaches the grain-bin auger. The 'volumetric' type measures the volume of grain on individual elevator paddles as they rise past a light beam that is directed across the interior of the elevator. The measured volume is combined with a grain-specific weight to provide an estimate of mass. Typically these measurements and calculations are made and displayed on the harvester monitor every second. These two types of grain yield sensor cannot differentiate between grain seed and foreign matter.

Calibration

To calculate an accurate yield (t/ha) from the data generated by a flow sensor requires that a calibration be established between the actual weight of grain harvested and that observed by the sensor. With this calibration, the calculated mass is assigned to a harvest area. Most systems assume a fixed crop cutting width (commensurate with comb width) or allow some manual adjustment during operation, and monitor ground speed to gauge distance travelled. These two pieces of information are used to calculate the area covered each second.

Further information on collecting and analysing yield data is found in sections 3.3.1 and 3.3.2.

3.2.5b Yield quality

This section concentrates on measurement of protein content in cereal grain. However, it is important to note that factors other than protein contribute to grain quality. These include the: presence of weed seeds, density of the grain, grain size/screenings and grain colour. Higher protein could also indicate small grain size, which has a negative impact on quality. It would be beneficial to have spatial information about all of these factors in order to produce the most accurate maps of yield and gross margin. However, at present there is no practical way of obtaining this information, other than periodic sampling on the grain elevator, bin or sampling crop heads just before harvest.

Grain protein content

Profits from grain crops are not only derived from yield, the quality of the grain delivered is also important for maximum profit. A large component of quality is determined by the grain protein content. Protein content is, in turn, dependent on factors including grain crop type, crop variety, starting soil nitrate and additional nitrogen supply, and the moisture available as the growing season progresses. For instance, durum wheat is likely to have higher protein content than a biscuit wheat cultivar grown under similar conditions. Agronomic factors are very important. A dry finish where the crop runs out of moisture is more likely to result in grains with a higher protein content.

The most eagerly awaited development in real-time sensing is the ability to monitor grain protein and oil content during harvesting. Recent developments have seen a number of NIR sensing systems emerge. An instrument designed and produced by NIR Technologies Australia became available in 2004 and in 2005 an instrument produced by Zeltex Inc. from Maryland USA was released worldwide. Accurately measuring grain protein in conjunction with yield will be useful in interpreting the yield map, and assigning yield-limiting factors, such as nitrogen or moisture supplies, to specific sites. Protein scanning is slower than yield sensing: readings can be obtained every 15-20 s, allowing a protein map to be created with samples every 25-40 m.

Within-paddock variation in grain protein appears to be widespread (see Table 3.2.5b1, Figure 3.2.5b1). Conditions that might increase the range of grain protein found within a paddock include:

Variable within-paddock nitrogen availability: variation in soil type or soil texture occurs and there may be variation in nitrogen supplies to the crop.
Variable within-paddock moisture availability: the interaction between topography, soil type and seasonal climatic conditions will result in spatial variation in the amount of water available to a crop across a paddock.

Location	Crop	Protein range (%)	Protein average (%)	Coefficient of variation (%)
Gurley, NSW	Barley	8.5-15.6	12.3	9.8
Jimbour, Qld	Wheat	13.1-15.6	14.3	3.5
Wowan, Qld	Sorghum	7.5-10.2	8.8	6.4

Table 3.2.5b1. Examples of the within-field protein ranges found for grain crops grown in northern Australia.

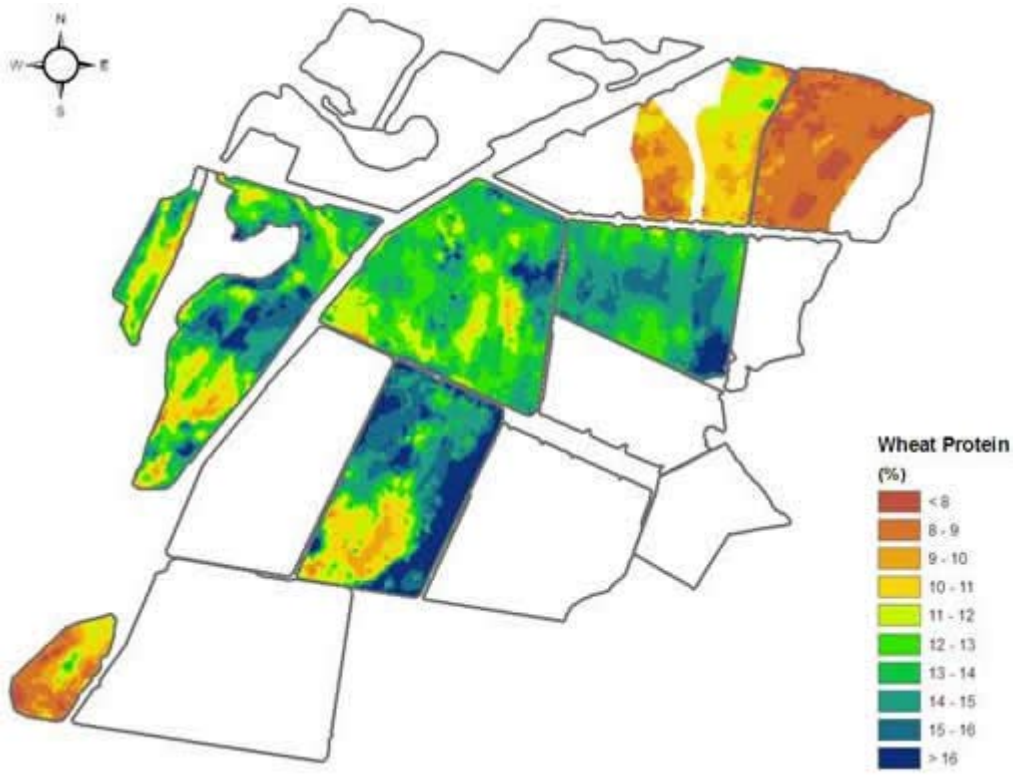

Figure 3.2.5b1. Within- and between-paddock variation in wheat protein content recorded using the Zeltex Accuharvest grain quality monitor in 2004

Why is monitoring of grain protein content important?

While yield maps can provide a useful indication of gross output, protein maps can identify specific yield-limiting factors that may have impacted on the crop for that season (see Table 3.2.5b2). For wheat, protein content greater than 12.5% is indicative of adequate nitrogen supplies for the crop. However, if grain protein is good but yield is relatively poor (e.g. in the poorest 25% of the field), it is likely that moisture supplies were limiting yields. If yield appears high but protein content is less than 11%, nitrogen supplies were limiting to yield.

Wheat grain protein	Barley grain protein	Sorghum grain protein	Indicated nitrogen supply
Less than 11.5%	Less than 11%	Less than 9%	Acute N deficiency. Grain yield would have increased with increased N supply.
11.5 to 12.5%	11 to 12%	9 to 10%	Marginal N deficiency. Grain yield will increase and protein will increase with increasing N supply.
Greater than 12.5%	Greater than 12%	Greater than 10%	N not limiting yield. Higher N supply may increase grain protein.

Table 3.2.5b2. Grain protein thresholds for grain crops that indicate yield-limiting supplies of soil nitrogen (N) (Cahill and Strong 1996). Note in southern Australia , the threshold for wheat and barley is generally 1% less than those quoted here.

A second reason for interest in protein maps is the ability to produce, along with the yield map, a more accurate gross margin map. Wheat and barley attract premiums according to particular protein classes. Areas within a paddock where specific protein grain is sourced may become more lucrative for the grower. Regions where higher protein grain is produced year after year may be usefully segregated to ensure a specific premium is gained.

Grain protein/oil content monitors

Grain quality monitors rely on the use of near infrared (NIR) technology which is also employed in grain receival depots. Grain samples are captured and presented to a light source, from which reflected light is measured. The light interacts with specific chemical bonds within the grain, and is slightly modified as the bonds absorb some energy. The reflected (or transmitted) light then provides a surrogate measure of grain protein content, grain moisture content and oil content.

Calibration

Calibration of these quality sensors is required for most seasons. A number of samples captured by the device should be verified for accuracy with a laboratory-based NIR machine or a direct chemical extraction procedure. Calibrations are also region specific (e.g. northern region versus southern region) and may, in some cases, be cultivar specific (e.g. durum wheats versus hard wheats). Weather-damaged grain will impair the accuracy of NIR to measure grain protein. Dust is also a feature of Australian grain crops, and care must be taken to maintain a clean vessel to allow for the transfer of light through the lens.

References

Cahill, M.J. & Strong, W.M. (1996). Are district recipes obsolete? In: Proceedings of the 8th Australian Agronomy Conference. (Edited by M Asghar). pp. 108-111.

(The Australian Society of Agronomy: Toowoomba, Qld)

Further reading

Conservation Farmers Inc. (2000) Manual from 'The Farmers' Guidance and Precision Farming Expo.' Roma, Queensland, 2000. (45 pp).

Kondinin (2003) Farming Ahead, Volume 141. Contains articles on GPS, yield monitoring etc

3.2.6 Measurement techniques for spatial variability

Author : Brett Whelan, Australian Centre for Precision Agriculture

PA has brought with it a requirement for increased information on crop yield and soil attributes within a paddock or farm. It is necessary to accurately quantify variation in the farm output and also the resources that contribute to the output. There are a number of spatial sampling options now available, and the one to choose is dependent on what information is required.

3.2.6a Discrete (or point) sampling

Field observation has traditionally been based on discrete sampling procedures using either a grid-based or statistically based random sampling strategy. Point sampling by grid is a laborious procedure if large areas are to be tested. For the production of accurate maps, the appropriate sampling scheme and minimum sampling distance must be determined. The inherent variability expected in most attributes would suggest the principle sampling distance should be as small as possible. This inevitably leads to a conflict between accuracy and sampling cost.

To increase the speed and efficiency of such sampling, and eventually reduce the per-sample cost, a small, low ground-pressure all-terrain vehicle (ATV), equipped with positioning technology and an industrial grade personal computer is often used. Such a unit may be used to collect soil samples for ex situ chemical analysis or perform in situ measurements of attributes such as nutrients, moisture content, structural interpretations using air permeability and salinity by EMI. The position of the sample site is logged simultaneously using the on-board GPS. A further step towards greater automation in sampling has been made with a trailed sampling, packaging and labelling machine for field soil sampling.

Grid sampling

Much of the soil and crop attribute sampling for PA has been conducted manually on grids of 100 m or larger. A number of soil studies have shown that much information is lost when a sampling grid is increased from 25 to 100 m. The common choice of grid size appears to indicate that reducing sampling cost has triumphed over accurate spatial resolution.

It is not difficult to see why this has occurred. Different soil attributes have different patterns of spatial variation which means the optimum sampling scheme would be different for each attribute. But in practice, sampling operations are not going to be undertaken at different sample spacings for each attribute. Research has shown that a grid sample spacing of 70 m would be the widest spacing recommended to sample for comprehensive soil analysis and mapping of the real variability in soil attributes.

Stratified or directed sampling

An improvement on grid sampling or random sampling is to use prior knowledge to determine sampling points. Any information that allows the sample area to be carved into smaller units along a soil attribute or crop production basis (or a combination) is useful. On-ground data (e.g. soil type, texture, colour, landscape elevation and slope, and crop yield) as well as remotely sensed data (satellite or aerial imagery) can be used to reflect changes in these attributes.

This strategy underlies the concept of establishing potential management classes/zones within a paddock. This offers a way to reduce cost by taking a smaller number of samples from within each zone and subsampling them for a single average set of values. The cost of individual sample testing limits the detail of information obtained from discrete sampling. While the procedures will continue to be used out of necessity, it is imperative that more intensive and timely methods of data gathering are developed for PA to become an economical and efficient management system. Continuous sampling techniques will help meet this challenge.

3.2.6b Continuous sampling

Continuous sampling refers to the practice of using ground-based vehicles to collect samples, or directly measure, variables 'on-the-go'. Collecting samples or direct data on the variable/s during a pass over the paddock produces a more fluent data set and enhances the observation resolution. In the case of direct or 'real-time' data collection, there are no sample transport/storage concerns, no laboratory variation to contend with and no delay in accessing the results. Ultimately, the results will be available in real-time so that farming operations dependent on analysis outcomes may be accomplished in the same pass of the field.

The development of such sensing and sampling technology in the area of crop yield and quality measurement has been discussed in Section 3.2.5. The more complex chemical and physical attributes of soil and other crop parameters are proving more difficult in real time.

Work is underway to develop on-the-go measuring systems for soil texture, pH, organic matter and nutrients. Some of these scoop up and test a soil sample every few seconds, others use one or more parts of the wavelength spectrum to continuously assess particular soil attributes. These sensors are generally attached to a tillage or sowing implement so that data can be recorded as part of normal cropping operations. Combinations of different types of data offer the potential of being able to map soil characteristics of particular interest to growers (e.g. PAWC).

In Australia at present, the commercially available 'on-the-go' sensor or sampling systems operating in agriculture are used for measuring apparent soil electrical conductivity (ECa) (See section 3.2.8 and Standards for EM mapping in the grains industry), gamma ray emissions (gammaradiometrics) (See section 3.2.9), soil pH and crop reflectance. Another continuous measurement method being developed is for soil strength, determined via a tyne dynamometer either towed alone or attached to an implement; this data may indicate subtle changes in soil type as well as a directly assess compaction.

3.2.7 Soil sampling and testing methods

Author: John Heap, South Australian Research and Development Institute

3.2.7a Why test soil?

PA aims to align crop management with variability within paddocks. Much of this variability is caused by variation in soil properties. Some variation can be seen (e.g. soil colour), but many important variables cannot. Soil testing allows these variables to be measured, and in some cases mapped, so that appropriate management can be applied across the paddock. Targeted soil tests within PA zones can identify limitations to low-yielding zones, quantify fertiliser requirements, provide information on spatial distribution of soilborne diseases and guide variable rate technology (VRT) agronomic inputs.

3.2.7b What and when to test?

There are many types of soil tests available, and the timing of soil sample collection is often specific to the test. Common soil tests include pH, electrical conductivity, nitrogen, exchangeable cations, potassium, phosphorus, soil physical characteristics (e.g. texture, colour), soil moisture and disease pathogen levels. Samples for nutrition are best taken during the dry period of the year, as this is when the various nutrient pools in the soil are at equilibrium. Soil moisture and available nitrogen tests are most commonly collected prior to the break of the season as an indicator of soil reserves. Samples for soilborne disease tests are collected after harvest and before the opening rains.

3.2.7c Who collects the soil sample and does the tests?

Soil samples can be collected by growers or by their agronomists, or in some states by specialist contract soil samplers. Some companies and agronomists have hydraulic vehicle-mounted coring equipment, but growers can also collect samples using hand-held soil corers. It is important that the corer consistently takes cores to the prescribed depth.

The tests are performed in laboratories all around Australia by a range of individuals, companies and organisations. Some laboratories are accredited by the National Association of Testing Authorities (NATA) or take part in an industry system that checks accuracy against calibration samples. These would include the laboratories used by the major fertiliser companies. The tests used should be calibrated within Australia, under local conditions, and it is important that growers have access to expertise to help interpret the results.

3.2.7d Soil sampling - putting a paddock into a bag

Soil properties vary widely across most paddocks. Most soil samples are a composite or bulk sample, made up of a number of small cores from different points in the target area. Representative soil samples are critical for a reliable soil test result. If the test sample consists of only a spade full of soil from just inside the paddock gate, a lot is known about the soil at that point but little about the rest of the paddock. On the other hand the entire topsoil layer cannot be tested! Representative soil samples are a compromise involving time, cost and reliability.

Careful attention must be paid to soil test kit instructions, because a sample collected for one test may be unsuitable for other tests. Various tests require different size samples, and sometimes soil needs to be collected from specific places (e.g. within stubble rows) or depths. Sample storage conditions (e.g. cool storage) are important for some tests, and proper packaging (supplied in the sampling kit) may be required for quarantine reasons.

Collecting soil samples

Growers collecting their own soil samples should have: specific collection instructions from the laboratory performing

the tests, a suitable soil coring device and sample container, a sampling pattern plan and a GPS.

The type of corer will be determined by the size of the soil sample required, the depth required and the number of individual cores making up the final sample. As a general rule increasing the number of individual cores collected within a paddock or zone increases the reliability of results. The number of cores chosen is a balance between acceptable sampling effort and acceptable reliability. For example, 45 cores should be collected for soilborne disease testing (Figure 3.2.7d1), but fewer cores, about 10-15, are normally sufficient for nutrient testing. The size of the soil corer must be chosen so that the number of cores collected will be just enough soil for the test sample (e.g. 500 g for soilborne disease testing). It is important to avoid collecting more soil than is required because mixing and subsampling can be a significant cause of test inaccuracy.

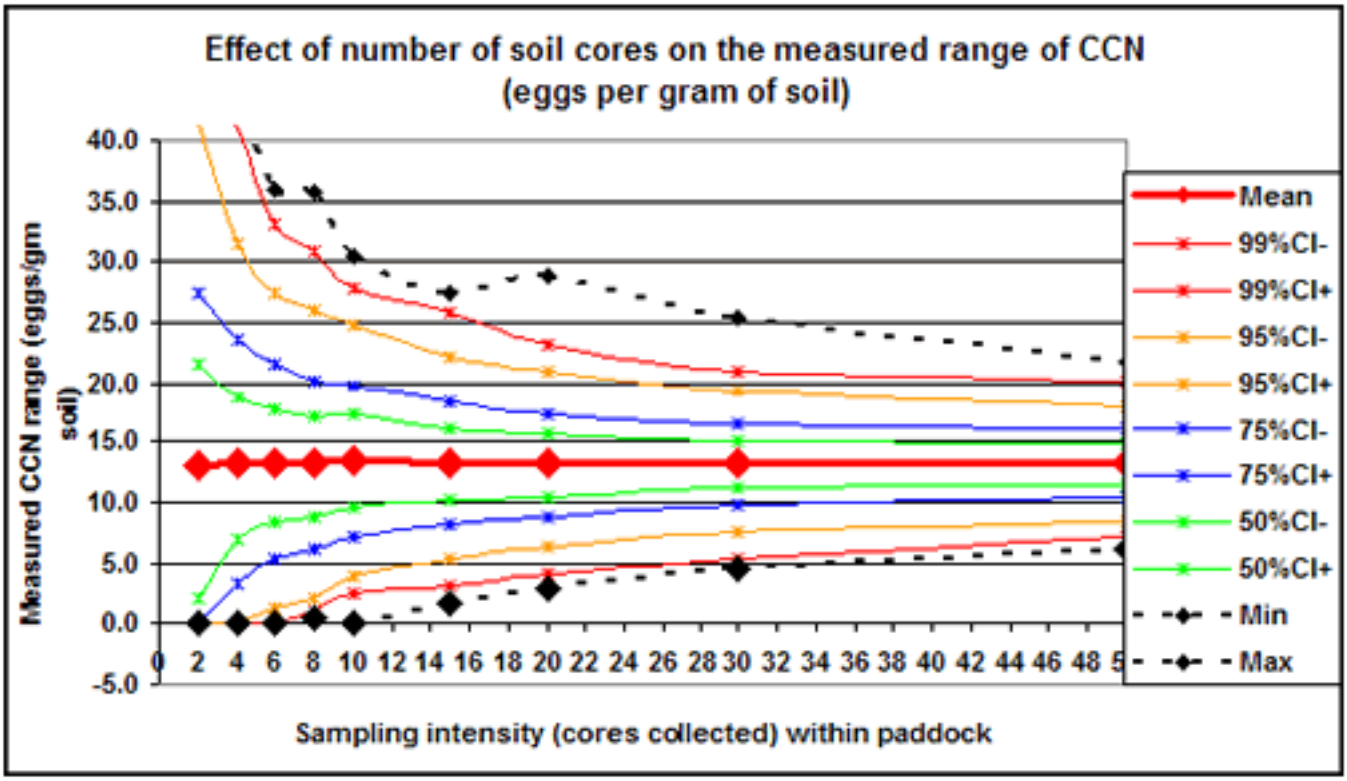

Figure 3.2.7d1. The effect of sampling intensity (number of cores collected in a paddock) on the mean measured inoculum level and confidence intervals (CI) of Cereal Cyst Nematode (CCN) at Hoyleton , South Australia , in 2003.

Where in the paddock?

If a sample is taken to represent the whole paddock, then a zig-zag collecting pattern is usually used (see Figure 3.2.7d2). This gives acceptable coverage and avoids collecting too many cores along one machinery line. The total number of cores can be proportionally allocated between obvious zones (e.g. sand hills versus flats), but two separate samples would be better. PA zones can also be sampled using a zig-zag pattern, or by collecting cores from a series of pre-determined representative GPS positions. PA layer maps (e.g. EMI map) can be interpreted by targeting specific features on the map with separate tests. Soilborne disease testing requires soil cores from within stubble rows, while samples for nutrition testing are usually, but not always, collected between stubble rows. Whenever possible record and store the sampling points using a GPS. This allows retesting over time to detect changes in test results, and allows re-sampling of unusual results.

Avoid sampling in areas that are not representative of the paddock or zone of interest. Unrepresentative areas may include headlands, firebreaks, gateway areas, tree root zones, water troughs, stock camps, stone heaps and around power or telephone poles.

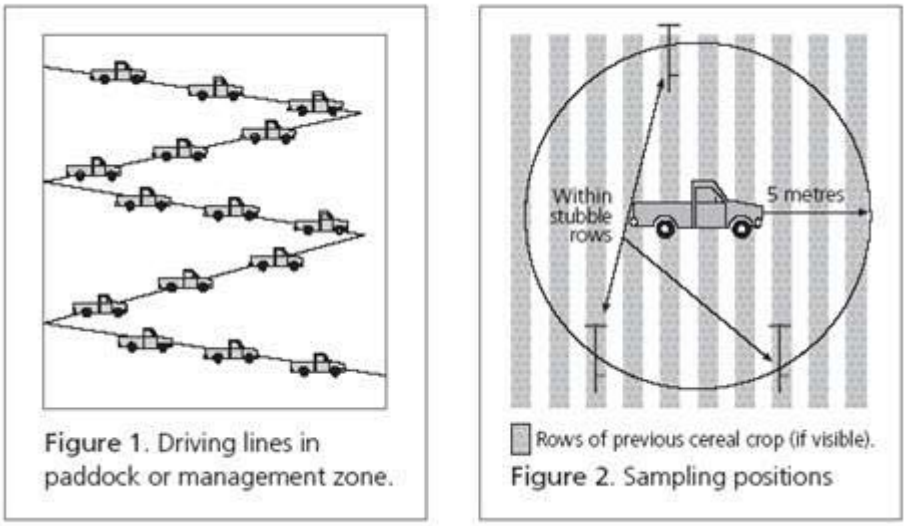

Figure 1. Driving lines in paddock or management zone.

Figure 2. Sampling positions

Figure 3.2.7d2. Driving lines and sampling positions for collecting soil samples for disease tests.

Soilborne disease testing

DNA tests are now available to determine the levels of most soilborne pathogens of cereals before seeding. These tests form the basis of the PreDicta B testing service marketed by Bayer CropScience (Table 3.2.7d1). More tests are expected to be added.

Disease/pathogen	Scientific name
Black spot of peas	Mycosphaerella pinodesPhoma medicaginis var. pinodella
Cereal cyst nematode	Heterodera avenae
Crown rot	Fusarium pseudograminearumFusarium culmorum
Rhizoctonia bare patch	Rhizoctonia solani AG8
Root lesion nematodes	Pratylenchus neglectus Pratylenchus thornei
Take-all	Gaeumannomyces graminis var. tritici(wheat and oat attacking strains)

Table 3.2.7d1. Summary of PreDicta B tests currently available.

The risk of yield loss and management options varies for each disease. For example yield losses in barley caused by take-all are often half that in wheat. Seed treatments are available for take-all, but if the risk is too high a non-host crop should be grown. For cereal cyst nematode the resistance and tolerance of the crop and variety needs to be considered; as a general guide the tolerance to cereal cyst nematode in barley>wheat>oats. For diseases such as rhizoctonia, management options are less developed and currently rely on time of seeding, tillage and nutrient management to maximise crop vigour. Where the disease risk is low, the most profitable crop and variety can be grown.

Disease risk also varies between seasons, districts, soil types and farming systems so it is recommended that an accredited agronomist, in consultation with the grower, interpret the results to determine the most appropriate cropping program.

Variation in root diseases across a paddock or farm can also be assessed from inspection of plants of susceptible crops sampled during the growing season.

Sampling strategies - whole paddock versus zones

The incidence of soilborne diseases often varies significantly between production zones (Heap and McKay, 2004). So sampling the zones separately before seeding will provide a better indication of the disease risk than a composite sample of the whole paddock (link to 4.2.5). Zone samples may also support targeting management strategies such as use of seed treatments to areas of the paddock where yield responses are more likely.

A composite soil sample from the whole paddock will give an indication of the soilborne pathogens that pose a risk to the crop. Consider sampling only the medium and high yielding zones. Diseases in these zones pose the greatest risk to overall profitability. Excluding areas constrained by physical or chemical constraints such as shallow soil and boron toxicity should reduce the risk of the paddock sample over or under estimating the potential disease risk.

Sampling strategies - coring intensity

Soilborne pathogens are usually associated with the root systems and / or crowns of previous host crops and so the levels are spatially more variable that other factors such as nutrients. To compensate for this extra variability, the number of cores taken to make up the composite 500 g sample should be increased.

A good compromise is use a narrow soil core 10 mm diameter X 100 mm long, and take three separate cores from 15 locations across the paddock following a zig-zag pattern (Figure 3.2.7d2). The total soil collected from the 45 core samples should be close to 500 g. Do not remove plant residues, as this can be a significant source of disease.

A PDF version of the detailed instruction sheet for use of the Accucore soil sampler is included on this disc. Accucore Fact Sheet [PDF doc, 531.kb]

Reference

Heap, J.W. and McKay, A.C. 2004. Spatial distribution of soilborne disease inoculum DNA in cereal crops and implications for soil sampling protocols. In: Proceedings of the 3rd Australasian Soilborne Diseases Symposium. Edited by K. Ophel-Keller and B. Hall. pp 106.

3.2.8 Electromagnetic induction survey

Author: Garry O'Leary, Department of Primary Industries Victoria

Electromagnetic induction (EMI) - what it can and cannot do

EMI technology uses sensors applied across the soil surface to measure the bulk soil electrical conductivity is termed the apparent electrical conductivity (ECa). Other variables of interest may be measured with EMI sensors but only those that are well correlated to ECa. For each and every variable of interest calibration against observed data is necessary. For agricultural applications the most common variables that correlate well with ECa are soil water content, soil clay content, soil salt content; however, temperature (air and soil) effects make universal calibrations complex. Additionally, the mineral content of the soil will affect the calibration thus making universal calibrations theoretically attractive but in practice very difficult.

Other variables, including potential rooting depth, that are functions of water, clay and salt content may be measured in some places. The detection of specific elements or compounds (e.g. boron) can only be accommodated to the extent of the strength of the ECa co-correlation with water, salt and clay. Some variables of interest to graingrowers, such as drainage beneath the crop rootzone, cannot be measured directly with EMI because of the complex relationship between other components of the water balance equation and time. Thus, customised calibrations must be derived beforehand to establish what can and cannot be measured with EMI sensors because it is very site specific.

An example of a paddock soil electrical conductivity map is shown in Figure 3.2.8.1 below.

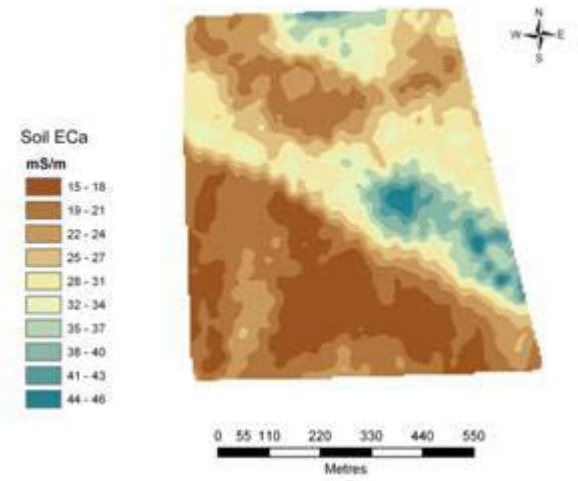

Figure 3.2.8.1. An example of a soil electrical conductivity (Eca) map.

Apparent soil electrical conductivity (ECa)

Soil ECa is a measure of the ability of the soil to conduct electricity. An electrical current may be conducted through the soil via three pathways:

- the pore-connected soil solution of water and ions;
- the cations that are bound to the surfaces of clay particles;
- connected solid soil particles.

Because of these multiple pathways, there are a number of soil attributes that will affect the ability to conduct electricity. They are:

- texture (amount of clay in particular);
- cation exchange capacity (CEC) - driven by clay type and soil organic matter;
- moisture;
- Ions in the soil solution (dissolved salts); and
- temperature.

Soil ECa can be measured using two different techniques: Electromagnetic Induction (EMI) using, for example, a Geonics EM38; or Electrical Resistivity (ER) using, for example, a Veris 3100 series Resistivity Cart.

EMI instruments operate without needing to touch the soil surface. They contain one transmitting and one receiving induction coil at opposite ends of the instrument. The transmitting coil generates a primary magnetic field which induces eddy currents in the soil. These eddy currents (swirling electrical currents) induce a secondary magnetic field which is detected (along with the primary magnetic field) by the receiving coil. The size of the secondary magnetic field is proportional to the amount of current flowing in the soil from which the ECa can be calculated.

ER instruments operate by passing a current into the soil through two metal electrodes that must be in physical contact with the soil. The current is at a known voltage. Two further electrodes that are also in contact with the soil measure the drop in voltage as the current travels through the soil. The drop in voltage can be related to the resistivity of the soil, from which the ECa can be calculated.

How can ECa be used in precision agriculture

Both the EMI and ER instruments have been used widely in Australia , for example on towable sleds/carts for pre-season measurements or on dedicated all terrain vehicles. At present there is no 'universal' calibration that allows the influence of each primary soil property that contributes to the soil ECa to be separated out. On individual paddocks, the soil ECa has been locally calibrated, from soils samples taken at the same time as the EMI or ER survey, to map spatial variability in soil salinity, clay content, topsoil depth in duplex soil and soil moisture in soil with low salt contents. Maps of the changes in these properties are proving to be very useful to growers.

Currently, the most common use of soil ECa maps generated by these instruments remains the identification of soil sampling points for stratified sampling. The data are used either alone or in conjunction with yield, elevation and remotely-sensed images to pin-point areas of difference. ECa maps have also been used to identify paddock areas with high salt load within the rooting zone, variation in clay content and estimated plant available water content, and areas having soil moisture remaining at harvest (possibly indicative of subsoil constraints).

The publication 'Standards for Electromagnetic Induction Mapping in the Grains Industry', which describes key steps in the collection, analysis and interpretation of ECa data, is included on this CD; (See EM Manual) it is also available from the GRDC website at www.grdc.com.au.

3.2.9 Gammaradiometrics

Authors: Matthew Adams, Remote Sensing Services, WA Department of Land Information; Gabby Pracilio, University of Western Australia; and Paul Rampant, formerly Victorian Department of Primary Industries.

3.2.9a Gammaradiometrics - what is it?

Gammaradiometrics is the measurement of natural gamma ray emissions of radioactivity, primarily from the top 30 cm of soil or rock. Often, this can provide information about the parent material of the soil that can be related to soil types across the region or paddock.

Gamma rays are emitted as high-energy short-wavelength electromagnetic radiation, as quanta of energy or photons (Ward 1981). It is part of the natural radioactive decay process in which alpha particles, beta particles and gamma rays are emitted. Unlike alpha and beta particles, gamma rays are detectable to remote sensors due to the absorption of gamma radiation through hundreds of metres of air (Ward 1981).

3.2.9b Uses in agriculture

Gammaradiometrics have been applied as an efficient land resource assessment tool for soil type or soil landscape mapping in Australia. Airborne surveys have provided information for land resource assessment at scales of 1:50,000 and 1:100,000. The information derived from this information may be as simple as a visual assessment of soil type boundaries and may provide a very valuable input for the spatial modelling of soils. If acquired at sufficient line/traverse spacing, the potential exists to determine short-range variation over paddocks and farms that are indicative of soil forming processes and soil parent material - a key component for those wishing to manage within paddock variation. For a 40-50 ha paddock, 100 m line spacing is sufficient for within-paddock estimates.

Useful relationships have been found between gammaradiometrics with or without additional layers (elevation, EMI, biomass etc.), and geomorphology, soil properties (particularly plant available potassium), particle size distribution in topsoil, unsaturated hydraulic conductivity, bulk density, organic carbon, Colwell phosphorus, and pH (see Further Reading section). All of these studies, however, are specific to the areas in which the relationships were observed and can not necessarily be extrapolated Australia-wide.

In addition to gammaradiometrics, magnetics and digital elevation data are usually acquired at the same time. Magnetic data has been found useful in hydrological applications. In Western Australia, it is a particularly useful dataset for locating faults and fractures in the bedrock which affect how water moves through the landscape.

3.2.9c How is it measured?

An energy spectrum is measured by gamma-ray spectrometers typically over the 0.4-2.82 MeV range (see Figure 3.2.9c1) (Ward 1981). The total count is the integrated count over the whole spectrum. Potassium (K), uranium (U), and thorium (Th) are the three major elements derived from unique (photoelectric) peaks, measured over energy windows. Potassium 40K decays due to electron capture (Ward 1981) at the 1.46 MeV energy peak, measured over the 1.37-1.57 MeV window (IAEA, 1991).

The decay series represents an atom that disintegrates from a parent to its daughter products. Uranium and thorium do not emit gamma rays and are therefore measured indirectly from daughter products 214Bi (Bismuth) and 208Tl (Thallium), respectively (Ward 1981; IAEA 1991). These isotopes emit the most energetic or detectable gamma rays of the decay series (Ward 1981), peaking at 1.76 and 2.61 MeV respectively, and are measured over energy windows as represented in Figure 3.2.9c1 (see also IAEA 1991). The indirect measurements are indicated by the naming convention as recommended by International Atomic Energy Agency (IAEA), as equivalent U (eU) and equivalent Th (eTh).

Data processing has been based on the three broad energy windows as described above, for over 20 years (Minty 1996). Recent developments include the multi-channel technique, which uses the whole spectra (typically 256 channels) to determine element concentrations and improvement in radon correction. A reduction in errors for K, eU and eTh by 12.4, 26.5 and 20.3%, respectively was shown (Minty 1996).

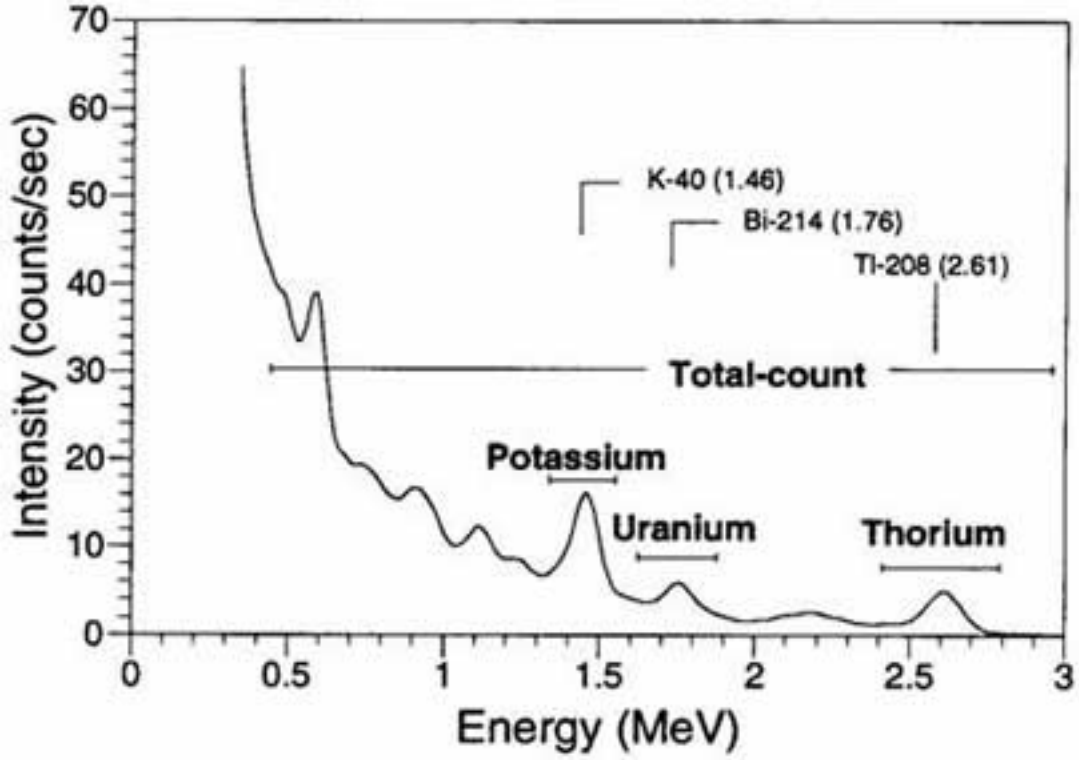

Figure 3.2.9c1. Gamma-ray energy spectrum recorded at 100 m altitude, showing photopeaks as measured by the three-channel window (modified from Minty and Kennett 1995).

3.2.9d Attenuation

The attenuation of gamma rays between 0.15 and 6 MeV (Tyler 1999) is primarily caused by Compton scattering, where the ray loses energy to outer electrons of the target atom, continuing with reduced energy (Cook et al. 1996). The degree of attenuation depends on electron density of the absorbing material (Cook et al. 1996). For example, a soil containing 10% moisture is 1.11 times more effective at attenuating gamma rays than dry soil, because the electrons associated with the water molecules in the moist soil increase the potential for the soil to absorb gamma rays before they are emitted from the soil surface (Grasty 1997).

Ninety percent of the gamma radiation observed from 2.7 g/cm of rock outcrops are emitted by the top 0.15-0.25 m of the rock while 90% of gamma rays observed of dry overburden (dry soil in an agricultural context) at 1.5 g/cm are from the top 0.30-0.45 m (corrected from centimetres in the published paper by Ward 1981).

The effect of vegetation attenuating the signal is minimal over the majority of Australian vegetation conditions due to low densities and dry canopies (Wilford et al. 1997). Attenuation may occur in dense rainforests or pine forests (Wilford et al. 1997) or by standing water in irrigated paddocks.

3.2.9e Field of view: ground versus airborne

The field of view is defined as the area beneath the detector that contributes a percentage of the total detected radiation (Grasty et al. 1979). The most dominant factor influencing the field of view of the instrument is flying height - the higher the instrument the larger the field of view (Duval et al. 1971). Maintaining a relatively constant altitude during a survey is important; height deviations are corrected for as a standard processing step for airborne surveys (Minty et al. 1997). For ground acquisition systems, the field of view would be significantly smaller due to the closeness of the ground source. With a ground-based system collecting measurements at ground level, 95% of the source detected is estimated to be from a radius of 2 m, but this value is dependent on calibration (Wilkes 2001).

3.2.9f Availability

Currently, airborne gammaradiometrics data are available for large areas of Australia. The data are often obtained by government agencies for the purpose of geological exploration. There is complete coverage for Victoria and the coverage is increasing in the other states. These surveys alter in line spacing normally from about 250 to 400 m. While these surveys are good at the regional scale, the usefulness of this data at paddock scale is limited.

Two commercial operators that undertake gammaradiometrics data surveys are Fugro (http://www.fugroairborne.com.au/) and UTS (http://www.uts.com.au/). The cost per hectare or per line kilometre of a gamma survey will depend on the character of the job in terms of size (number of hectares to be flown and number of farms/growers contributing to costs), location to nearest airfield, speed of aircraft and flying height. The cost incurred in relation to gamma surveys for GRDC PA research sites in 2003/04 was roughly $30 per line km, for example.

Pre-existing surveys are available to the public from http://www.geoscience.gov.au/bin/mapserv36?map=/public/http/www/geoportal/gadds/gadds.map&mode=browse

Most are probably not at the resolution recommended for PA, but they do exist and could be of use in certain areas.

There are two ground-based gammaradiometrics units currently in service predominantly for research purposes. One is owned by the Department of Primary Industries Victoria and the other it is owned by the University of Sydney.

Currently, there is one commercial contractor providing a ground-based radiometric service in Western Australia, Geoforce (www.geoforce.com.au). Charges will vary with distance from Perth and line spacing chosen. Other contractors not known to the authors may service the eastern states. With many enquiries from EMI contractors, regarding radiometric sensors for agriculture, it is likely that ground-based radiometric surveys will become more readily available to growers as ground-based radiometric surveys may be acquired at the same time as EM31/38 or Veris surveys.

3.2.9g An example gamma survey and its use

Figure 3.2.9g1 below is a ternary gammaradiometric image from an 8000 ha farm in Western Australia farmed by Glen Fretwell and family. Red areas are high in potassium, green are high in thorium, and blue areas are high in uranium. The red areas are often associated with potassium-containing minerals near the surface, particularly granites with a high component of feldspar minerals.

In the image a hilltop and an alluvial fan can be identified from the gammaradiometrics associated with granite outcrops. The blue and green-blue areas are associated with ironstone gravels, which are also associated with poorer performing areas on this farm. A dyke was located via magnetics in the south-eastern section of the farm. Glen's comment on the dyke shown in this image was 'that's the bit of sloshy ground where we always bog the tractor during seeding'. He also said that gammaradiometrics was probably the most useful layer of information he has acquired for his farm.

Crop performance zones resulting from analysis of historical biomass/NDVI imagery were overlayed on a section of the gammaradiometric data and showed a reasonable correlation between the red areas and high performing zones of the paddock and the poor performing zones being correlated with the bright light blue areas. Based on the relative stability of the yield zones, it was possible to develop a fertiliser application plan and also overlay this onto the gamma image, as shown in Figure 3.2.9g1.

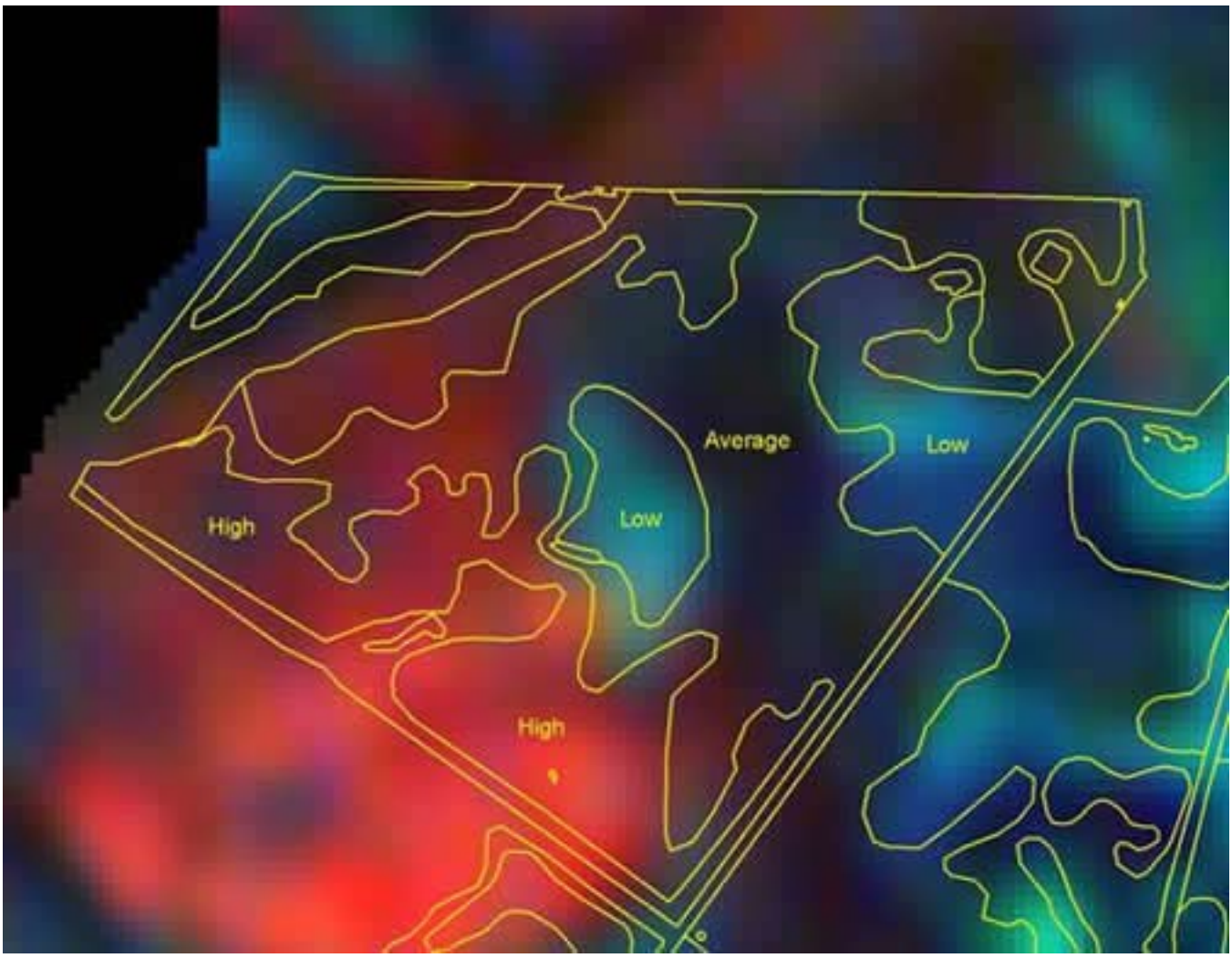

Figure 3.2.9g1. A whole-farm map showing gammaradiometric data with variable rate fertiliser zones overlayed, created by Silverfox Solutions Pty Ltd.

Such good correlations between radiometrics and crop performance do not always exist, as bright red colours may also be correlated with shallow soils over a rock outcrop. Restricted rooting depth is then the overriding factor in the crop's performance and associated biomass. However, this does not diminish the utility of gammaradiometric data as it can help to interpret the cause of yield variability on a subpaddock scale.

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3.2.10 Elevation mapping

Author: Brett Whelan, Australian Centre for Precision Agriculture, the University of Sydney

3.2.10a Local elevation

The high-accuracy positioning receivers being used to provide locations in a paddock also measure elevation at the same time. These include GPS receivers mounted on tractors, harvesters or all-terrain vehicles(ATVs). Elevation information is regarded as 1.5-2 times less accurate than the stated accuracy of the GPS receiver used, so that a quoted receiver accuracy of 2 cm would translate into a 3-4 cm accuracy in the elevation data. Using centimetre and decimetre level positioning receivers to also record elevation data has therefore become quite common when performing guidance operations or conducting soil ECa surveys.

3.2.10b How can elevation be used in precision agriculture

Elevation data are commonly mapped onto a grid to form a digital elevation model (DEM) of the paddock or farm. The DEM is useful because it provides information on the potential movement of water within a paddock, on areas at risk from frost, and on locations where changes in soil type or key attributes may occur. The DEM can also be used to calculate other topographical properties such as aspect, slope, water shedding and accumulation points, which in turn can indicate differences in clay content, soil depth or nutrient status. The DEM is also often used as a data layer in the process of directing soil sampling sites.

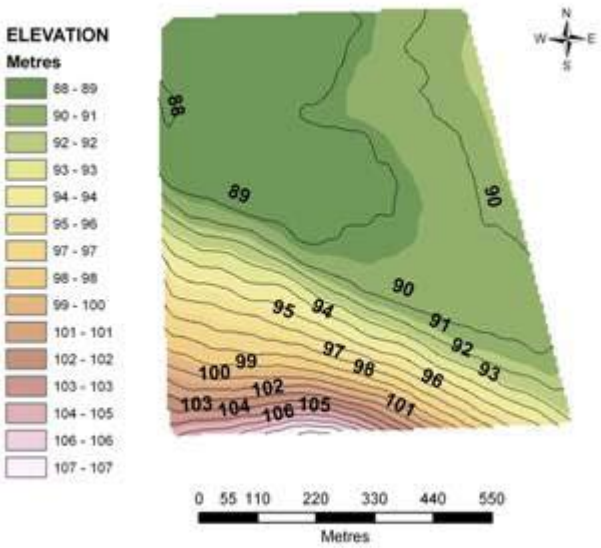


Figure 3.2.10b1. An example of an elevation map for the same paddock as the electrical conductivity map shown in Figure 3.2.8.1.

3.3.1 Collecting yield data

(Originally published in PrecisionAgNews - summer 2004, by the Southern Precision Agriculture Association, SPAA)

Author: Rupert McLaren, farmer, Barmedman, New South Wales Additional information from John Deere AMS

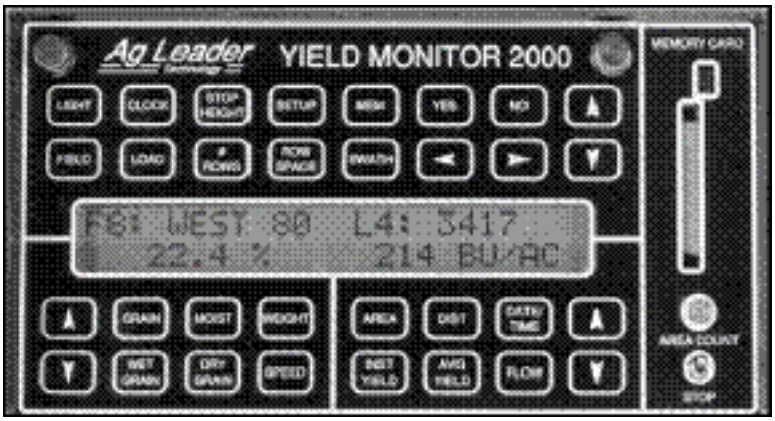
This section attempts to outline problems that might be encountered with yield monitors. It sets out a pre-harvest checklist for yield monitoring components and suggests ways of reliably archiving yield data.

Yield monitors:

- At the time of writing there were brands of yield monitor on the market.
- Black AgLeader
- AgLeader PF 3000
- AgLeader PF Advantage
- Case AFS monitor
- John Deere Yield Monitor
- New Holland Yield Monitor

Of these the most likely you are to come across are the AgLeader, Case AFS, and John Deere yield monitors. As with all things electronic, there are set-up and calibration issues.

AgLeader



The AgLeader Black Box was the first really successful monitor; easy to use and robust (compared to other units on the market at the time), and was successfully retro fitted to many headers. It became standard in the larger Case Axial Flows.

However, there are several issues that need to be considered. The worst of these related to the main memory battery. If the unit was left connected in the header during the harvest season and the main batteries went flat (as they invariably do) the power from the monitor would drain back. This leads to a corruption of the firmware (the software that runs the monitor). However, the monitor would appear to be operating correctly. It was only when data were downloaded to the desktop PC that you found data in the wrong paddocks or worse no data at all. To prevent this:

- Disconnect the monitor from the header during the off-season.
- Every two years send the monitor back to the supplier to have the unit “New Boxed” (firmware reloaded) and new batteries fitted.
- If data starts behaving strangely obtain a replacement unit from your local supplier. Be aware though, I have had faulty spare units off the shelf.

Another issue with these monitors is the PC card (the device for moving data from the header to the PC). These units use a Sram card. This card contains a small battery to maintain the memory. The battery can go flat or fail, I never had this happen over 5 years, but to avoid the problem always remove this battery from the monitor when the monitor is turned off.

The AgLeader Black Box is also difficult to set up with Windows. Windows 95, 98, ME, 2000 and XP are OK but if you are mucking about with NT do not bother; instead update your operating system.

Finally these units lose points and log ridiculously high values on warm days when harvesting heavy wheat crops. The operator sees no evidence of this on the screen, it is only when the data are downloaded that the problem becomes apparent.

Case AFS

The AFS monitor was created in house by Case. It is basically a robust, monochrome touch screen that is very similar it its operation to the AgLeader units. Keep an eye on the plastic mount bracket as this can crack off and falling from a great height does nothing for the monitor or the operatorthey happen to be under it.

There is a problem with the earlier firmware, if the monitor's memory and the Flash card memory become out of sync, a memory issues warning is triggered. The operator is then led through a series of screens asking questions which if followed result in the data on the card being deleted.

If you find yourself on this merry go round: stop, turn the header off, remove the card. Back-up the data on the card to a PC or insert a new card with no data. If neither of these options is possible, reinsert the old card and restart the header. It usually still wants to delete the data on the card, though you never know your luck. The moral is back-up your yield data regularly, at least daily and preferably between paddocks.

I have heard of people only downloading their data annually or biennially only to have the afore mentioned problem occur at the end of the second year so they lose all their data.

The newer firmware versions are supposed to address the issue. Upgrade to the most recent version of firmware whenever possible just as a matter of course.

When changing fronts always make sure you enter the correct width and set the new height position. I have had problems with this system switching back to the original setting of its own accord. Check the width last thing before you start harvesting the new grain type.

I am not in a position to comment on the Greenstar system. According to the John Deere owners and representatives I speak to it is a flawless system without issues. Here is a link to the John Deere website where there is a pre harvest check list.

https://stellarsupport.deere.com/en_US/ag/stellarsupport/support/Checklists.html#s5

John Deere Greenstar
(Source: John Deere PA Newsletter, Fall 2005. www.stellarsupport.com)

GreenStar 2 features three display options, including two new color displays .

In the past John Deere AMS offered the three common components: StarFire iTC™ receiver, GreenStar display and mobile processor. With the introduction of the new GreenStar 2 System PA customers now have choices-not only in StarFire iTC signal levels and in AutoTrac accuracies, but also choices in displays. For customers looking for a color display, they can purchase the new GreenStar Display GSD 2100, the 8.4” (21cm) option with the GS2 System. The GSD 2100 is operated by a display control that can be mounted in three different cab locations depending on user preference and cab layout. There are also bezel buttons on the back of the display for secondary navigation. Customers wanting the ultimate choice in John Deere PA displays can look to the GreenStar Display 2600, a 10.4” (26 cm) color, touch screen display. An optional display control can be used in rough field conditions for greater accuracy, and like the GSD 2100, bezel keys on the back of the display can be used as well. Both GS2 displays, the GSD 2100 and 2600 come preloaded from the factory with software called GreenStar Basics. This includes Field Doc, map based prescriptions and Parallel Tracking manual guidance software applications.

The software also includes numerous new features including on-screen mapping, as-applied maps, a path accuracy indicator (on-screen light bar) and a guidance perspective view to aid in both automatic and manual guidance applications. The architecture has also been opened up between the GS2 Displays and Apex Farm Management Software, to make data set-up even easier.

For customers looking for even more advanced functionality with the GS2 System, Pro Modules are the answer. Add Pivot Pro for use in dry-land regions that operate in center pivots and require circle patterns. GreenStar Pro AutoTrac is another upgrade for growers who want to use automatic guidance to decrease overlap and increase efficiency. Green- Star Pro AutoTrac can operate in straight, curved or circle (if PivotPro is added) guidance modes. John Deere is still offering the complete GreenStar model lineup, and will continue to sell and support the Original GreenStar System with Original GreenStar display, mobile processor and all the existing KeyCard applications available today.

Pre-harvest checklist

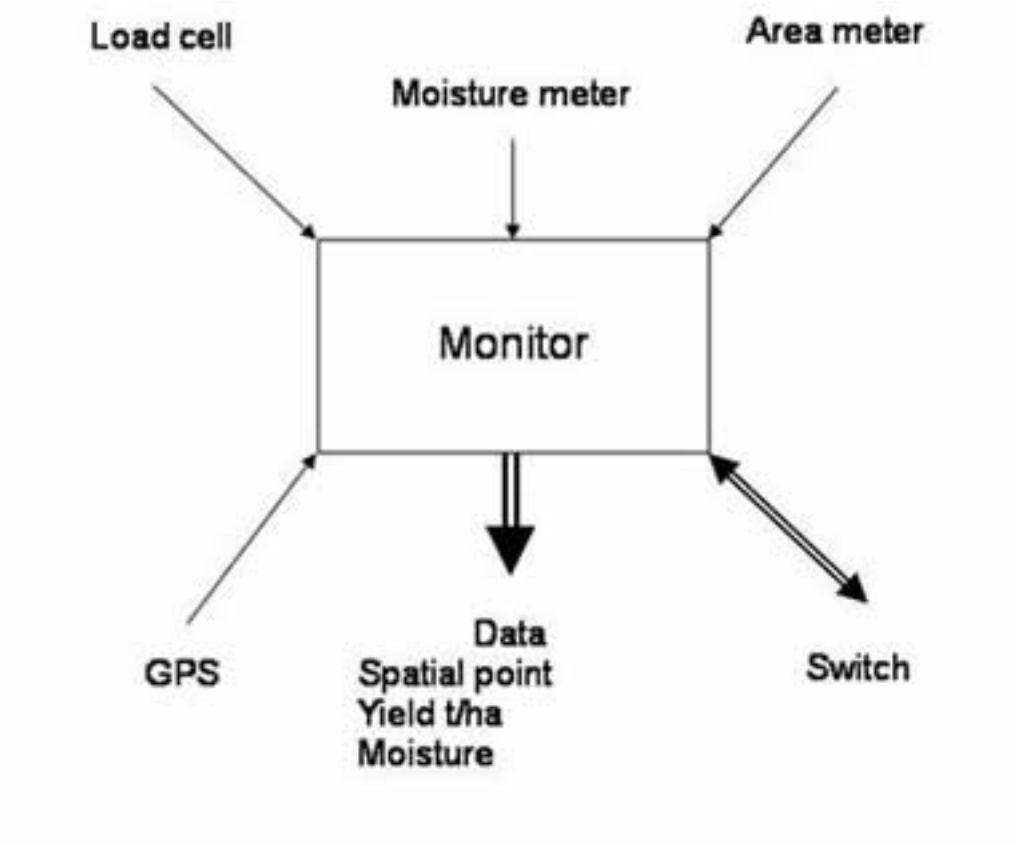


Figure 3.3.1.1. Diagrammatic view of how a yield monitor works

The yield monitor combines data from the GPS, the load cell at the top of the clean grain elevator, and from the combine harvester's wheel sensor (shown in Figure 3.3.1.1) Before harvest each of these components needs to be checked to see that they are functioning individually and 'talking' to each other. Do not leave these checks until the first day of harvest.

GPS

Check the GPS is collecting satellites. If the unit has a differential make sure that it has been turned on. Differential is not crucial for yield mapping.

If you own an AG132 receiver and the GPS is not receiving the differential correction signals, the firmware has probably been corrupted. When you use a starter motor (engine or electric feeder reverser) or have a faulty lighting relay there is a power drop followed by a spike. These spikes are not good for electronic devices. I use a battery filter to overcome this. That is the GPS is coupled directly to a small 12 volt marine battery. This battery is then coupled to the main batteries with a one way diode in the positive line. This prevents the voltage drop and cushions the spikes. Battery filters are cheap to make (A$100) and worth every penny. So if you have problems with any type of electronic device in a machine try fitting a battery filter.

Load cell

Remove it from the header. You will find it at the top of the clean grain elevator. Check the deflector plate for wear; they are not supposed to have holes in them. Check for wasp nests and jammed objects behind the plate and check the cables; then refit.

Wheel sensor (area)

The area harvested is calculated from the swath width and the distance travelled using the wheel speed sensor. When calibrating the wheel sensor the longer the measured length the better. I use the GPS to measure the distance, usually about 400m. Set up this distance over a pasture paddock rather than on the road. The swath width should be set 30cm less than the full width because on average most headers overlap by about 30cm.

Switch

There are several switches of which to be aware. These include height switch, manual switch, flow switch and elevator speed switch. If one of these is incorrectly set your monitor will not collect data.

Do they talk?

Place a blank PC card in the monitor. Create a trial field. Start the mechanism and increase the engine revolutions to operating speed. Lower the comb below the height stop and go for a drive. You may have to select the 'log without crop flow' option. Shut down the harvester and remove the card. Load the information onto your PC. Check that you have data points. If you do not have points investigate and/or seek advice before harvest begins.

Harvest time

Load Cell Calibration

It is not enough to harvest a single load at one speed, weigh the load and then use a single load to calibrate the cell; several loads at different speeds are required in order to calibrate the monitor for different flow rates. The AgLeader and Case systems have 11 constants C1 to C11.

A calibration based on one or two loads can result in the 'relativities' being out. That is when you harvest a poor yielding part of the field and there is a low flow rate for the part of the curve that has not been calibrated; therefore the values recorded may not be correct.

Harvest five or six calibration loads. Drive slowly for the first one and then incrementally faster until the last load when you should be travelling as fast as possible. If possible borrow a weigh bin otherwise carry out calibration truck loads as often as possible, particular if crop conditions change. Generally speaking the higher the crop yield the easier it is to calibrate and wheat is usually easier to calibrate than a crop like canola.

Archiving yield data

See also Section 4.2.2

Computers are unreliable. They are incredibly complicated pieces of machinery, attacked by viruses, built cheaply and designed to operate for short periods of time. On top of that, as farmers, we use them in dusty conditions with poor power supplies.

Treat every computer you use as if were going to blow sometime in the next half hour. Save everything regularly. Treat your hard disc like it is going to fail sometime next week. Backup valuable information to CD or DVD weekly. Yield data can not be retrieved if it is lost.

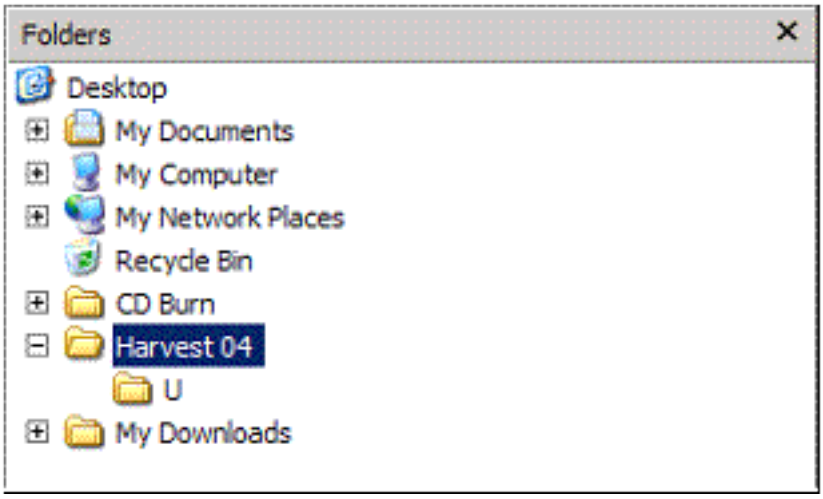
The ten steps to archiving yield data - using Windows

Step 1 New folder on desktop

At the beginning of harvest create a new folder on your desktop. To do this all you do is position your mouse on the desktop and right mouse click. A drop down menu will appear. One of the options is New. Select this and select Folder. A new icon with a little folder will appear on the desktop with new folder written underneath it and highlighted. Type in “Harvest 04” for example and the new folder underneath will be replaced.

Step 2 Bring the card home every day

Every day bring home a used data card. The best way to do this is to have two cards for every header. Alternatively, if you have a laptop you can carry out the archiving in the paddock.



Step 3 Slot in computer

Place in the card into the computer. Often the card will open itself in a window.

Step 4 Create a new sub folder in Harvest 04

Open the ‘Harvest 04’ folder on your desktop by double clicking on it. A blank window will appear. Centre your mouse on the window and right mouse click. A drop down menu will appear, select new and then folder. Name the Folder after the paddocks that you have on the card.

Step 5 Copy harvest file from card

Open the card in a window. If it is not already open go to the icon on your computer desktop called 'My Computer'. Open this by double clicking on it. Then double click on the drive letter that corresponds with your card drive letter. It will be named something like 'removable disc H'. There should be a single file (it could be a folder). Place your mouse on that file and right mouse click. From the drop down menu select copy.

Step 6 Paste it in the correct sub folder

Select the Folder named after the paddocks harvested that day in Harvest 04. Double click on it so a blank window comes up. Right mouse click on that blank window. From the drop down menu that appears select paste. A copy of the card will then be placed in your folder.

Step 7 Archive data in manufactures software

Close Harvest 04 folders. Open manufactures software. Archive card.

Step 8 View data in manufacturers software

Create yield maps. Check they make sense and that data is being logged correctly. The most important thing to check is that data is actually being logged. This also important for monitoring header performance and yield.

Step 9 Format the card

Now that the data is archived the card needs to be wiped clean. If you just highlight the file and press delete on the keyboard a recycled bin is created on the card and this then fills reducing space. To clean the card select 'My Computer' on the desktop and double click. Right mouse click on the removable drive containing your card. Select Format. It will ask if your sure because you will lose data. You say that you are sure. The card can now be removed.

Step 10 Burn data to disc weekly

Once a week burn Harvest 04 Folder to CD or DVD. If you harvest important trial data burn to disc the day that it is harvested. Use a new CD each burn and label and store the CDs in a safe place.

Harvesting on farm trials

Organize the research co-operator to be there the day of harvest with a laptop with the manufacturer's software.

Harvest the trial with a single harvester, if possible.

Before you start harvesting check the monitor is working. Place the card in the co-operators PC and check everything is there.

After the trial is stripped: stop, remove the PC card, copy the data to the co-operator's laptop. Do not delete the files on the PC Card.

Place the card back in the header. Continue stripping.

That evening carry out the normal backup procedure.

3.3.2 Yield map analysis

(Originally published in PrecisionAgNews - Volume 2, Issue 2, Winter 2004, SPAA)

Author: Rupert McLaren, farmer, Barmedman, New South Wales

Some very reasonably priced software is now available to farmers for integrating and analysing yield and other data sources. I use the AFS software package, Case's bundled software that is now produced by AgLeader. At the time of writing this is virtually the same as 'SMS Basic' which has become highly regarded due to its open architecture www.agleader.com/support.php?Page=smsnewsletter

The statistical package I mainly use is called 'JMP' that was developed by the SAS Institute www.jmp.com/

Kriging is carried out by a package called Vesper that was developed by the Australian Centre for Precision Agriculture at the University of Sydneywww.usyd.edu.au/su/agric/acpa

GEOD is the name of the projection altering program www.lands.nsw.gov.au/Records/Surveying/GDA/GEODSoftware.htm

Analysis steps

Yield data are analysed as follows:

1. Export yield data from the manufacturer's software as text.
2. Clean data and alter projection.
3. Place data on grid.
4. Load data into spreadsheet or statistical package.
5. Analyse data.
6. Export analysis back to manufacturer's variable rate software.

Exporting yield data

Once yield data have been imported into the manufactures software a yield map can be generated (see Figure 3.3.2.1). This map is of limited use because it cannot be compared objectively with other data sources or yield maps for that paddock from previous years. The first step to over-coming this problem is to export the yield data as a text file. In the new AFS software and SMS basic this is carried out by right mouse clicking on the file tree on the left hand side of the screen, 'Export' is then selected from the pop up menu.

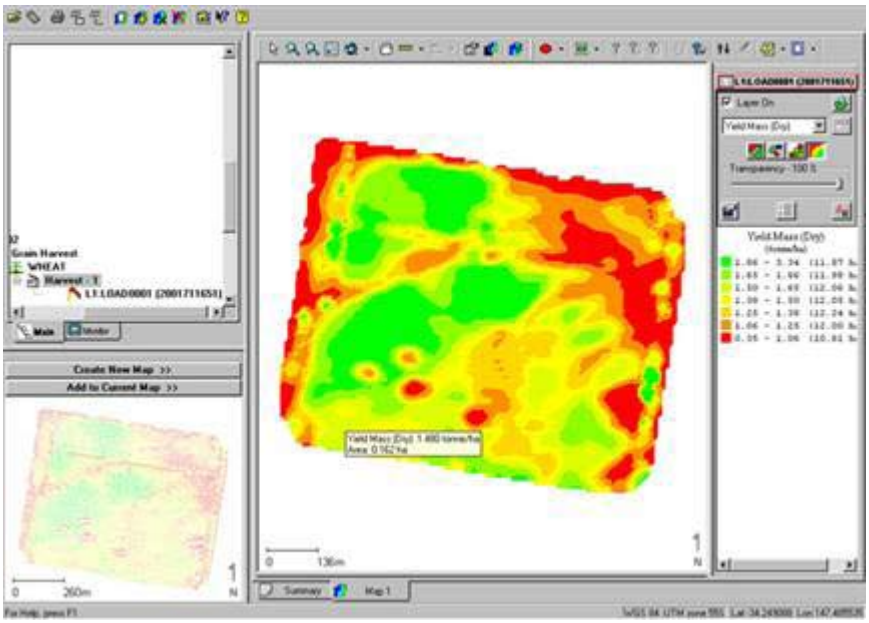


Figure 3.3.2.1. Yield map as seen in AFS software.

Select the option to export the data as comma delimited text file and then select the data columns you need. I choose Yield Mass, (Dry), Elevation and Track.

Clean data and alter projection

Many of the exported data points are erroneous. Every time the comb is lifted to turn at the end of a row and lowered to start a new row, a number of low values are recorded. If less then the full swath width is taken, errors occur in the map. If a single incorrect low point is recorded the kriging process usually smoothes it out. If there are numerous erroneous points aligned along a headland, for example then this pattern will show up in the final map. There are also usually a number of high yield points generated when the header slows. These are easily selected and removed. Lower points are usually more difficult to select because some low points are where the crop yielded poorly and some are harvest artefacts.

To overcome this I use Track (compass bearing in degrees). Most of the low harvest artefact values coincide with where the header has turned. By taking the difference between in track and subsequent points, the points where the header is turning can be isolated and removed. This is all carried out within JMP. I use Version 4, which allows scripting so this task can be automated. Figure 3.3.2.2 shows all the recorded yield points while Figure 3.3.2.3 shows the cleaned dataset.

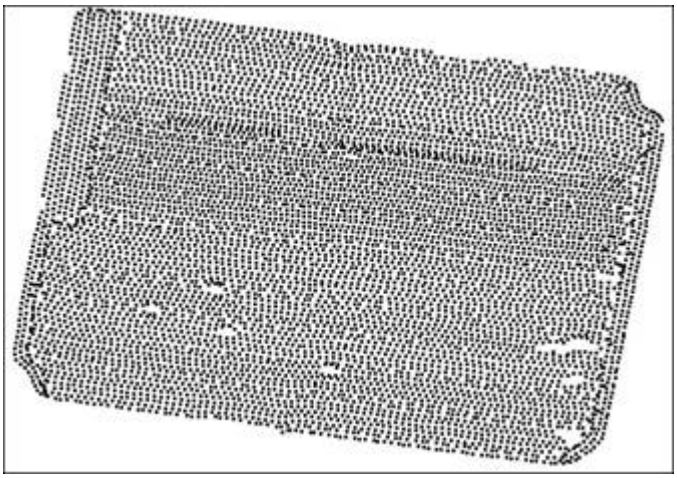


Figure 3.3.2.2. Complete data set.

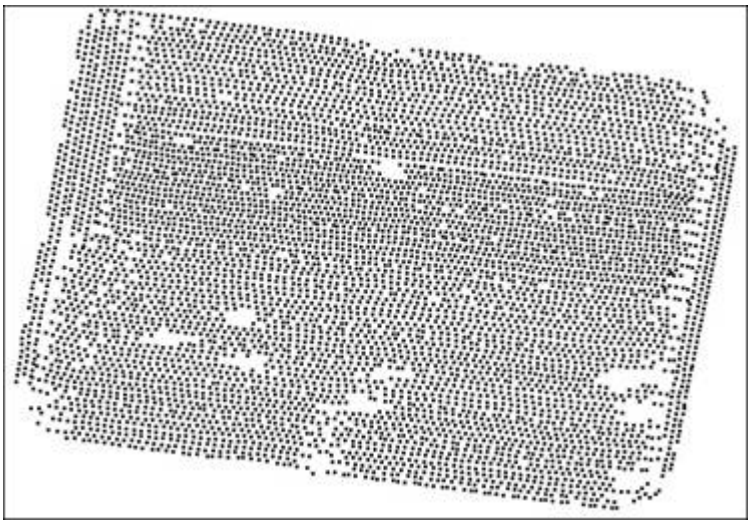


Figure 3.3.2.3 Data set minus low end values and overlaps.

Having cleaned the data the projection needs to be changed. Yield monitors identify each point using Longitude and Latitude, for which the units are degrees. The numbers are not easy to use and 'Vesper' the program used to krig your yield data on to a grid requires you to have your coordinates in Universal Transfer Metacor (See section 3.2.2 Coordinate systems and map projections) a system that has the world divided into sections and the covered with

a grid divided up into meters referred to as eastings and northings. The program to carry this out is 'GEOD'. The projection your data is most likely to be in is WGS84. This is for all intent and purposes exactly the same as GDA in GEOD. Having cleaned your data in 'JMP', save the file as a '.txt' file.

This file is then imported into GEOD and converted from Longitude Latitude to Easting Northing. Unfortunately when GEOD writes the new file it puts a little bit of text at the top of the new file telling you what it has done. This has to be removed before kriging can take place. I just open it in 'Wordpad' and delete that information

Placing data on the grid.

Initially I purchased a program called 'Surfer' to carry out my griding, however, 'Vesper' is a superior program at a fraction of the price. Particularly useful is the block kriging option that allows errors in the data to be smoothed. I krig my data onto a 10 meter grid and find this gives me more than enough detail to generate application maps, while not creating huge files that are difficult to work with.

Load data into a spreadsheet or statistical package

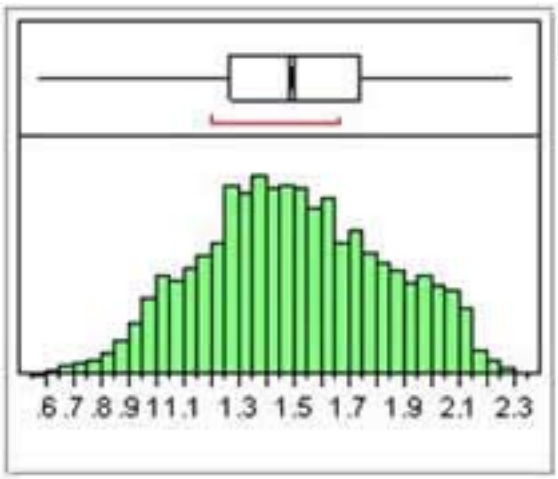
The 'Vesper' output file is a 'txt' file. This can be easily imported back into 'JMP' or spreadsheet programs such as 'Excel'. Because the same grid is used for a particular paddock, each layer of data that has been kriged has exactly the same number of points. Before the data layers can be pasted into a single spreadsheet the points must be sorted based on the Easting and Northing columns. Once this is done each column is copied and pasted into a single spreadsheet (Table 3.3.2.1).

Easting	Northing	Can 99	Whe 00	Can 01	Whe 02	EM 38	NDVI 02	Ele ft
544540.768	6210144.5	0.7932	5.53812	0.8987	1.04672	96.53561	0.106097	888.6852
544540.768	6210154.5	0.88374	5.36833	0.93764	0.95129	97.8977	0.0819301	890.4153
544540.768	6210164.5	0.8272	5.23574	1.26825	0.93012	100.7406	0.0837996	890.5671
544540.768	6210174.5	1.26448	5.20426	1.1409	0.914163	102.4316	0.0636005	890.6669
544540.768	6210184.5	0.64847	5.2612	0.9437	0.970903	105.9439	0.0556852	890.7592
544540.768	6210194.5	0.67052	5.56759	1.01534	1.02259	104.9849	0.0582117	891.154
544550.768	6210124.5	0.9444	5.71955	1.52715	1.24286	102.3748	0.147697	890.161
544550.768	6210134.5	1.02138	5.73388	1.76155	1.14592	96.75648	0.156241	889.6953

Table 3.3.2.1. Layout of part of the data ready for analysis (in this example the paddock was in canola in 1999 and 2001, and in wheat in 2000 and 2002; there are also EM38 ECa, Biomass {NDVI} and elevation data shown.

Analyse data

The aim of any analysis is to determine if yield is variable and then to classify that variability into management zones. Table 3.3.2.1 also contains EM38 values that are a good determinant of soil type and can be useful in determining causes of variability. The first step I always undertake when I add a new column to the file is to carry out a simple statistical procedure called a frequency table. Figure 3.3.2.4 is a frequency table for the 2002 wheat crop column in Table 3.3.2.1.



Quantiles			Moments	
100.0%	maximum	2.2993	Mean	1.5002456
99.5%		2.2178	Std Dev	0.3327956
97.5%		2.1140	Std Err Mean	0.0037303
90.0%		1.9742	upper 95% Mean	1.5075581
75.0%	quartile	1.7413	lower 95% Mean	1.4929332
50.0%	median	1.4857	N	7959
25.0%	quartile	1.2672	Sum Wgts	7959
10.0%		1.0573	Sum	11940.455
2.5%		0.8853	Variance	0.1107529
0.5%		0.7226	Skewness	0.0357498
0.0%	minimum	0.5719	Kurtosis	-0.605001
			CV	22.182739

Figure 3.3.2.4. Frequency table for the 2002 wheat in Table 3.3.2.1 showing the distribution of recorded yields and their statistical analysis.

The graph represents the number of points with a given yield value. From the moment column it can be seen that the mean or average yield value was 1.5t/ha. In the graph the highest bars are around the mean with the height of the bars denoting the number of points. These bars reduce in size as they move towards the yield extremes 0.5t/ha at the low end and 2.3t/ha at the high end.

The yield in the paddock was variable; this is supported by the CV figure (Coefficient of Variation), which is derived by dividing the standard deviation (a measure of variation) by the mean and multiplying by 100 to convert it to percentage. As a rule of thumb if the CV is greater than 10 then there is sufficient variation to divide the paddock into more than one zone. If the CV is less than 10 the paddock yield was very even and it is going to be relatively pointless to divide the paddock into different management zones.

Therefore, from Figure 3.3.2.4 it can be seen that the wheat in 2002 was quite variable and could be divided into several zones.

But when making input decisions a single year's data is insufficient to make an application decision. One of the phenomena seen by many farmers who have begun yield mapping is that of mirror imaging. That is from one year to the next a similar yield patterns occurs but the high and low areas are reversed. This is sometimes called the 'FlipFlop' effect. The relationship between different years can be summarized using a scatter plot analysis, created using 'JMP' as shown in Figure 3.3.2.5.

Multivariate

Correlations

	Whe 00	Can 01	Whe 02
Whe 00	1.0000	0.6992	0.5678
Can 01	0.6992	1.0000	0.6904
Whe 02	0.5678	0.6904	1.0000

Scatterplot Matrix

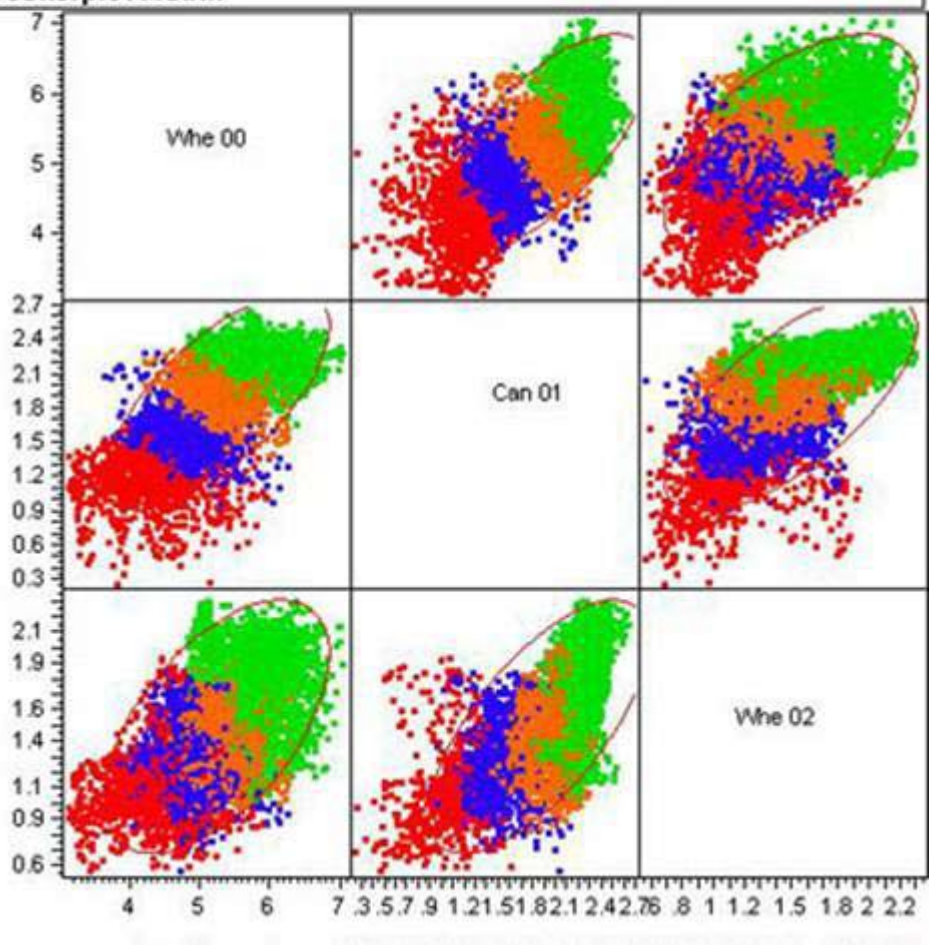


Figure 3.3.2.5. Scatter plot matrix created using J MP, with the paddock set to be divided into 4 zones .

In Figure 3.3.2.5, 3 years of yield data are compared. The colours represent different zone based on cluster analysis. The paddock has been divided into four zones.

Zone 1 represented by green dots is where the paddock yields extremely well.
Zone 2 denoted by the orange dots is where the paddock produces better than average.
Zone 3 denoted by blue is where the paddock produces less than average.
Zone 4 denoted by the red dots is where the paddock performs poorly.
There is a good correlation in all of the 3 years shown. If there was any mirror imaging, the points in one of the windows of the matrix would slope down from left to right and there would be a negative number in the correlations display. The scatter plot matrix shows that this particular paddock has the same yield pattern from year-to-year.

The next step is to divide the variation into management zones. To do this I have been using K means clustering in 'JMP', with the number of clusters being determined by the amount of variability and its spatial arrangement. Typically I have been classing paddocks into 2-4 zones. Figure 3.3.2.6 shows the spatial arrangement of the zones for the example paddock.

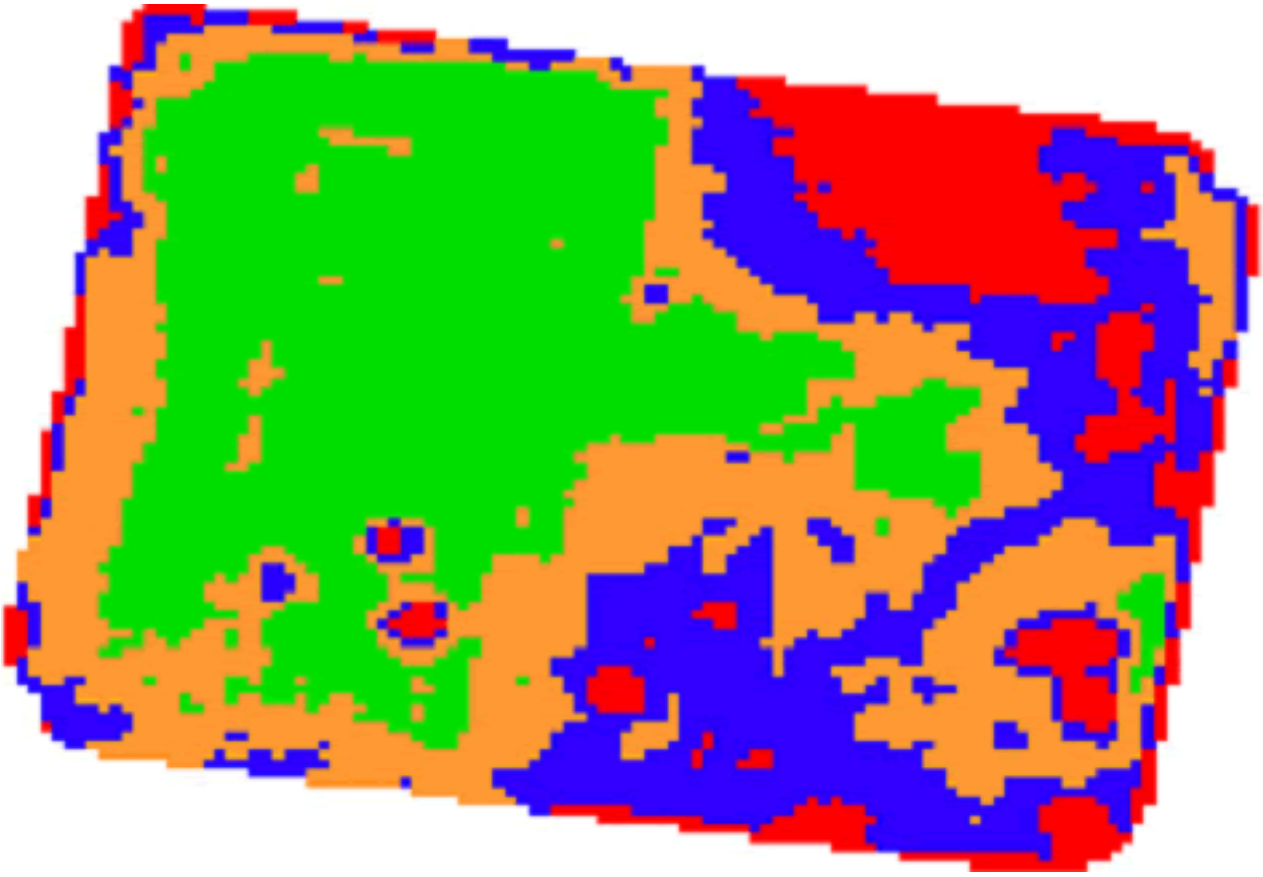


Figure 3.3.2.6. Spatial arrangement of zones. Key red=least productive>>blue below average>>orange above average>>green most productive.

The next step is to determine which factors have caused the zones and what treatment that zone should receive. There is no single answer to these two questions. They are, in fact, questions that any farmer, regardless of whether he has been collecting yield data or not, is asking him or herself. The advantage the PA farmer has over a conventional farmer is they are working on a subpaddock zone scale and can remove some of the in-paddock variability. That is the PA farmer can target soil tests and trials to regions within the paddock, while the conventional farmer is taking samples from all over the paddock and then batching them to achieve a paddock average.

This is how I would approach the above example in Figure 3.3.2.6.

I would try and explain the zones in terms of my local knowledge. For example, the low yielding areas around the outside of the paddock are tree effects. I reduce the fertiliser going onto these areas.

I look for soil type differences using an EMI map. Maybe the variation is intrinsically related to the soil type. I have found EMI maps a very cost-effective way of determining in-paddock zone boundaries. The EMI map in this paddock is shown in Figure 3.3.2.7. While the correlation is not perfect it can be seen that the large high producing area of the paddock is associated with an area of higher EMI values indicating that there is more clay in this portion of the paddock.

The most disappointing part of this paddock is in the north-east corner and why this is I cannot explain. The area of lowest yield seems to cut across soil type boundaries and can be traced into the paddock to the north of this one. At this point in time I resort to soil testing. In this situation I initially conducted a soil test for macro nutrients. This test did not really explain the poor crop health. It did however, show up that phosphorus was accumulating in the non-productive area (Colwell P 75 mg/kg) while it was reasonably low in the better yielding areas (Colwell P 16 mg/kg). The problem was not for the lack of phosphorous. Thus the initial course of action was to adjust the fertiliser application until the problem could be solved. I suspect now that it may be a copper issue, as similar soil types in the area are responding to the application of copper. Tissue testing will be used in the future to try and identify underlying differences.

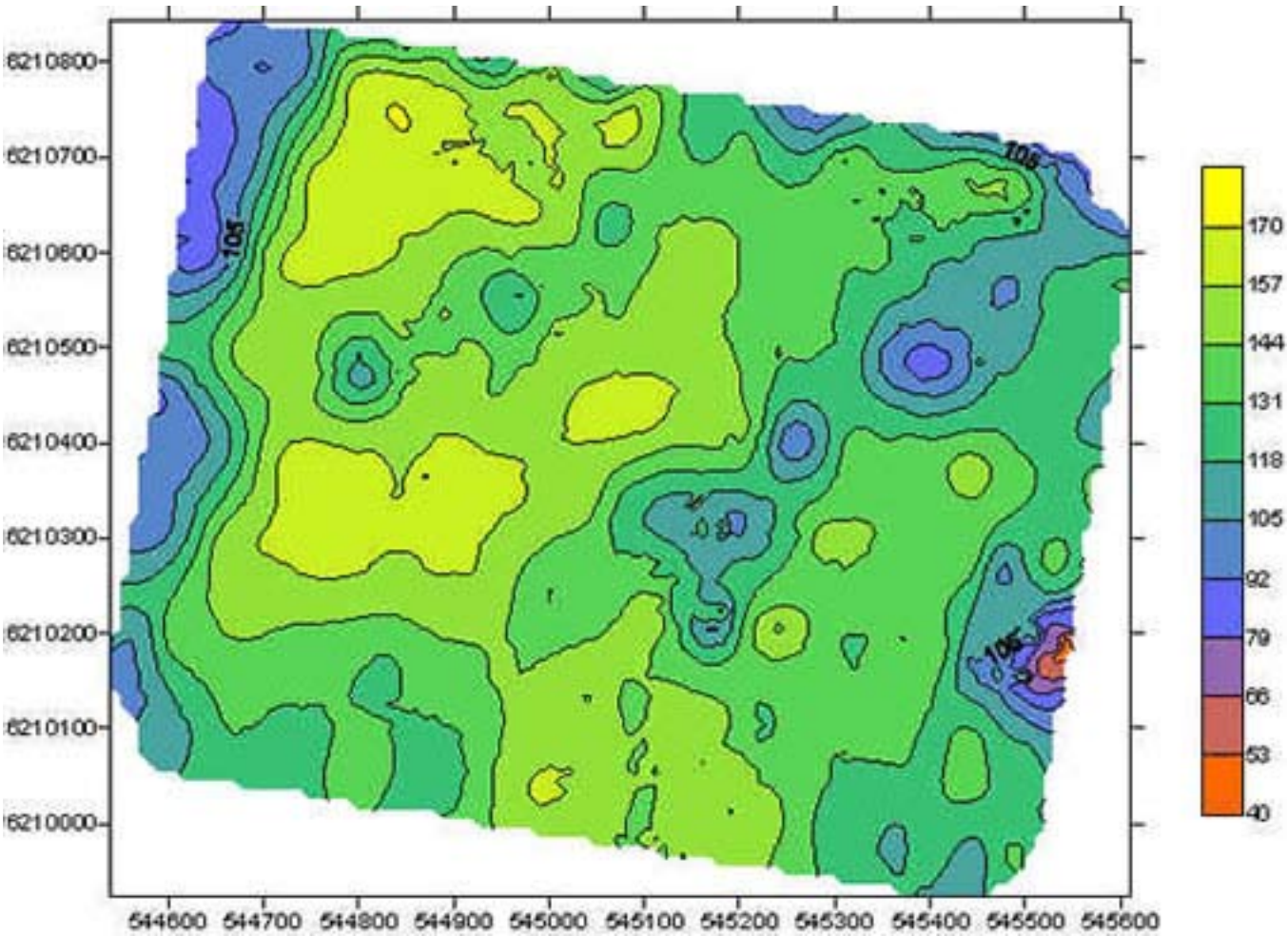


Figure 3.3.2.7. Electromagnetic induction map, scale= millisiemens/metre.

Having carried out the above steps I assign a fertiliser rate to each zone using 'JMP'. The new file is saved as a text file.

Export analysis back to manufacturer's variable rate software

The text file is imported back into the manufacturer's software and the rate column used to generate a map, which in turn is used for a template for a rate map. In the SMS Basic software this is quite a simple step. The end result is shown in Figure 3.3.2.8.

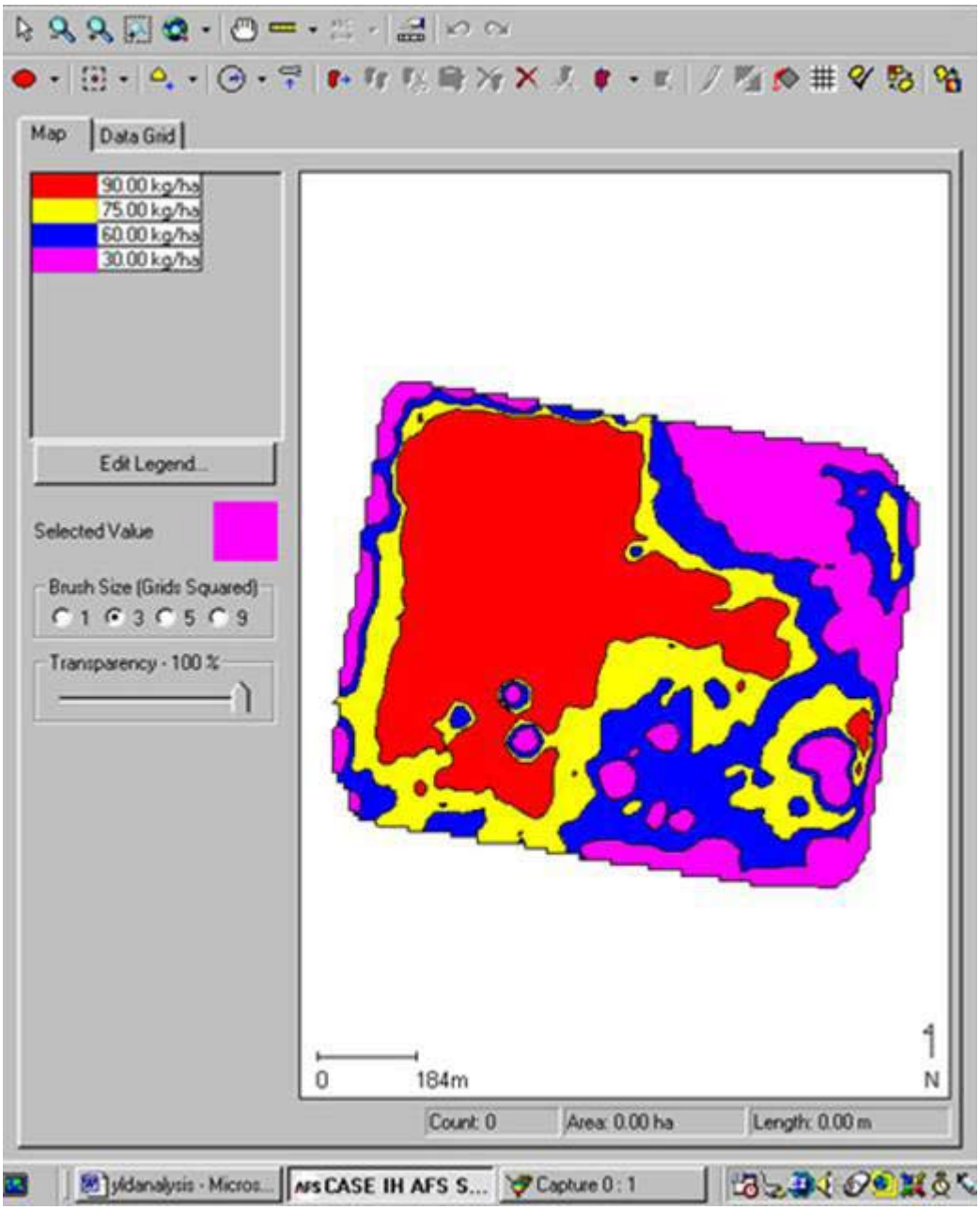


Figure 3.3.2.8. The finished variable rate map for MAP (mono ammonium phosphate) fertiliser application.

3.3.3 Preparing a gross margin map

Authors: Ian Maling, Silverfox, Matthew Adams, Satellite Remote Sensing Services, WA Department of Land Information, Brett Whelan, Australian Centre for Precision Agriculture, and Mike Wong, CSIRO Land & Water

Once a map of paddock yields is available, this can be converted into a gross margin (GM) map using the net price received for grain less the growing costs. A GM map is a valuable tool for growers as it can show which parts of a paddock (or farm) are most important in generating profit, and which are marginal (or in some cases making a loss), at least under current management. Crop modelling can then be used to map the potential gains in GM to be made in different parts (zones) of the paddock by improving management, for example by better adjustment of inputs according to season and use of variable rate technology.

Figure 3.3.3.1 is an example of a GM map constructed using grain yield, moisture and protein data gathered by on-harvester sensing systems. The calculation of premium/discounts were made using the 2004 final AWB pool matrix at 5% screenings and these were applied at each point in the paddock where yield was measured. This provides a map that shows how each part of the paddock performed rather than an averaged production assessment.

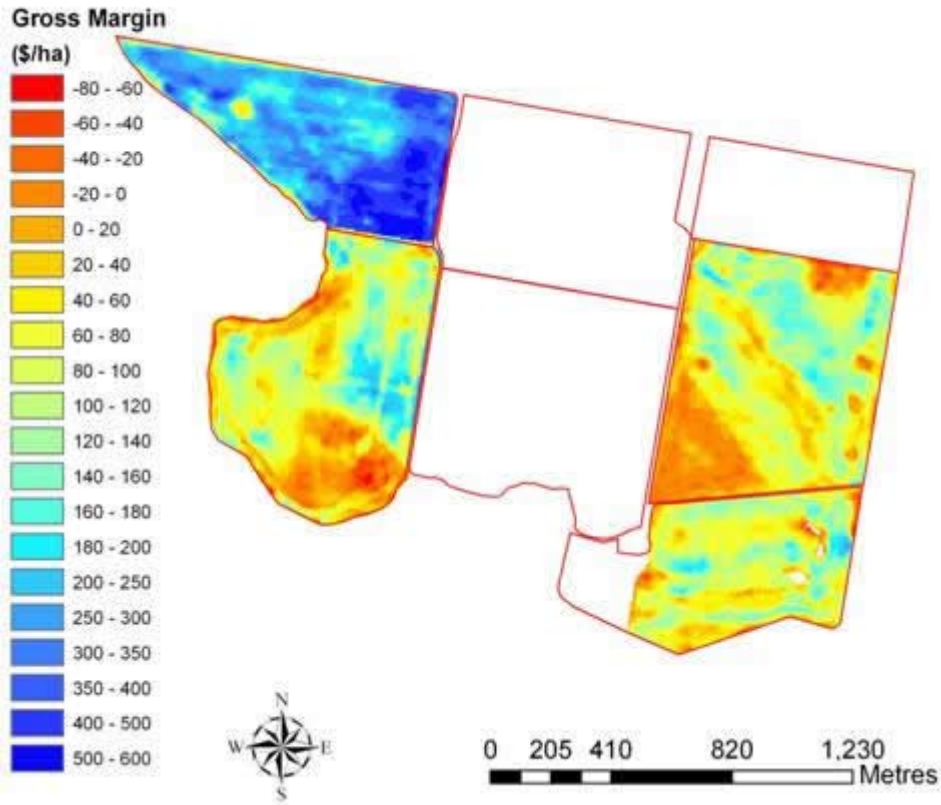


Figure 3.3.3.1. A gross margin map produced from grain yield, moisture and protein data gathered by on-harvester sensing systems.

Figure 3.3.3.2 illustrates a GM map for the 5 years (1998-2002) produced from averaged data to show loss and profit making areas in a paddock in Western Australia. The Three Springs paddock had a wheat-lupin rotation since 1998 (wheat year). GMs were calculated for each year from yield maps. For wheat, the current APW price of $150/t (AWB data) was used with a production cost of $175/ha (data taken from Department of Agriculture WA Gross Margins Calculator). For lupin a current price of $160/t and production cost of $125/ha was used.

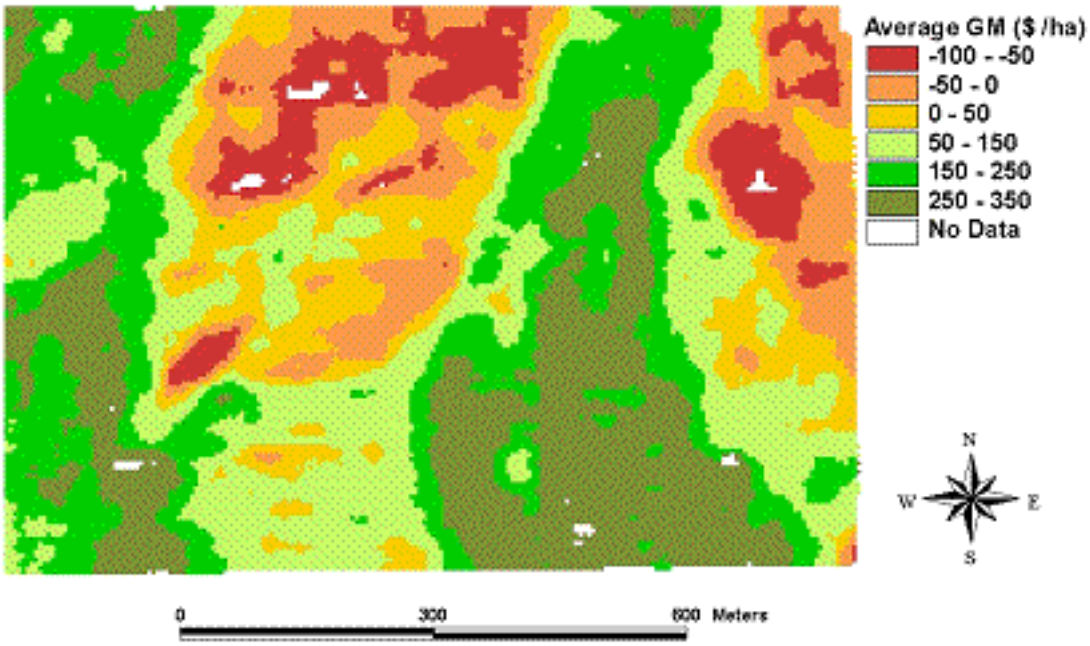


Figure 3.3.3.2. A paddock gross margin (GM) map based on 5 years of averaged data.

The actual size of the loss and profit making areas vary from paddock-to-paddock, and from year-to-year. In this example, from Three Springs in WA, the loss making areas were mostly due to soil type. In another example from a much larger paddock near Buntine in WA (Figure 3.3.3.3 below), GMs were averaged over 1998 (lupins), 1999 (wheat), 2000 (canola) and 2002 (wheat). This showed that areas of the paddock that performed poorly financially were mostly those with shallow soils over superficial compacted gravel layers.

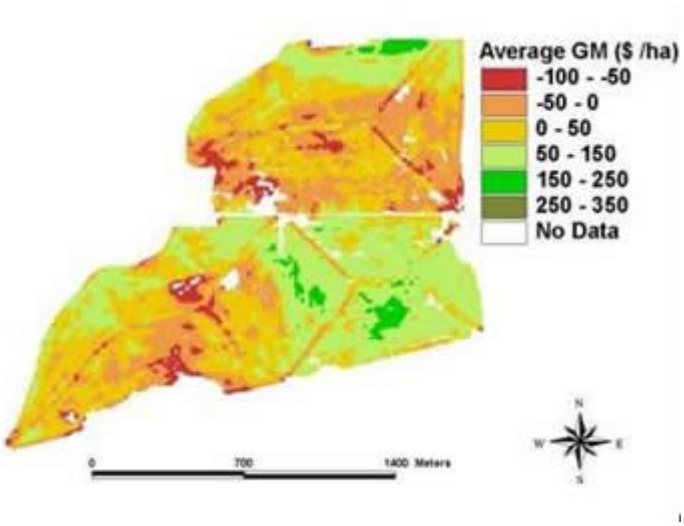


Figure 3.3.3.3. A gross margin (GM) map for 4 years of wheat-lupin rotations.

In the absence of very coarse textured soils or superficial gravel layers, many paddocks may not have any loss making areas at all. Figure 3.3.3.4 is the GM map for wheat and lupin grown on about 2000 ha at a farm in Wongan Hills for the year 2000. The soil on the farm is typically the deep Wongan loam with some locations affected by salt. Several paddocks on this farm were entirely profit making.

In the absence of very coarse textured soils or superficial gravel layers, many paddocks may not have any loss making areas at all. Figure 3.3.3.4 is the GM map for wheat and lupin grown on about2000 ha at a farm in Wongan Hills for the year 2000. The soil on the farm is typically the deep Wongan loam with some locations affected by salt.

Several paddocks on this farm were entirely profit making.

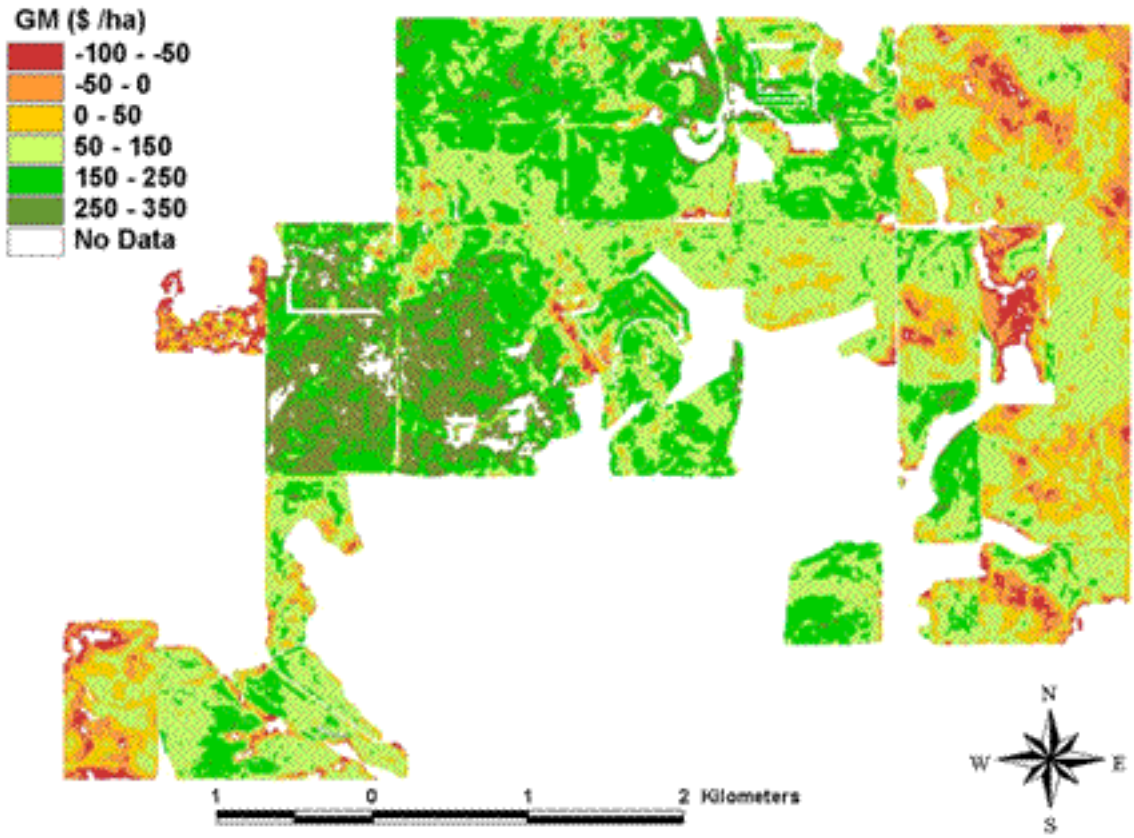
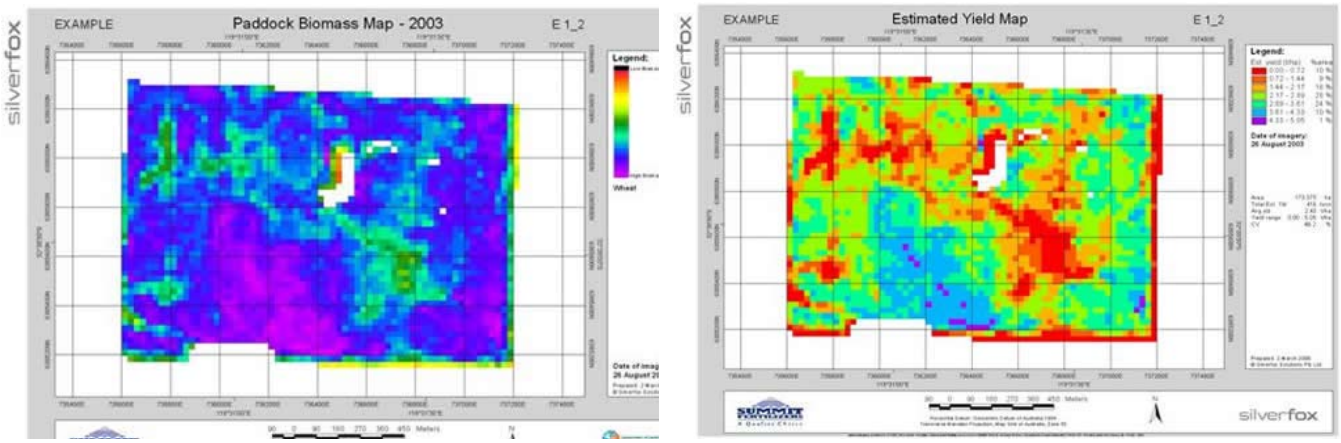
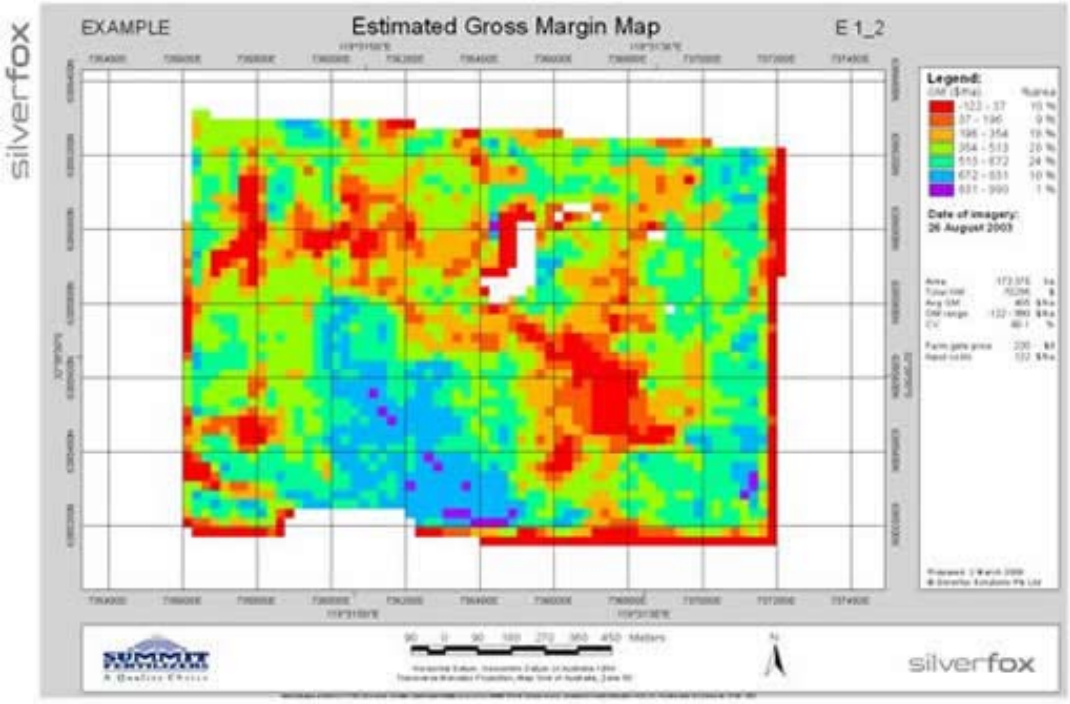


Figure 3.3.3.4 A gross margin (GM) map for wheat and lupin grown on 2000 at Wongan Hills in 2000.

GM maps allow growers and advisers to identify where most profits come from historically and to identify and manage loss making areas. To help future planning further, spatial crop growth simulations allows growers to anticipate where profits are likely to come from based on knowledge of the paddock and anticipated weather and crop management scenarios.

An example of a map of estimated GM, and a paddock yield-zone map (with proposed sites for soil sampling to help uncover the reasons for variable yields), both developed from biomass imagery, is shown in Figure 3.3.3.5.





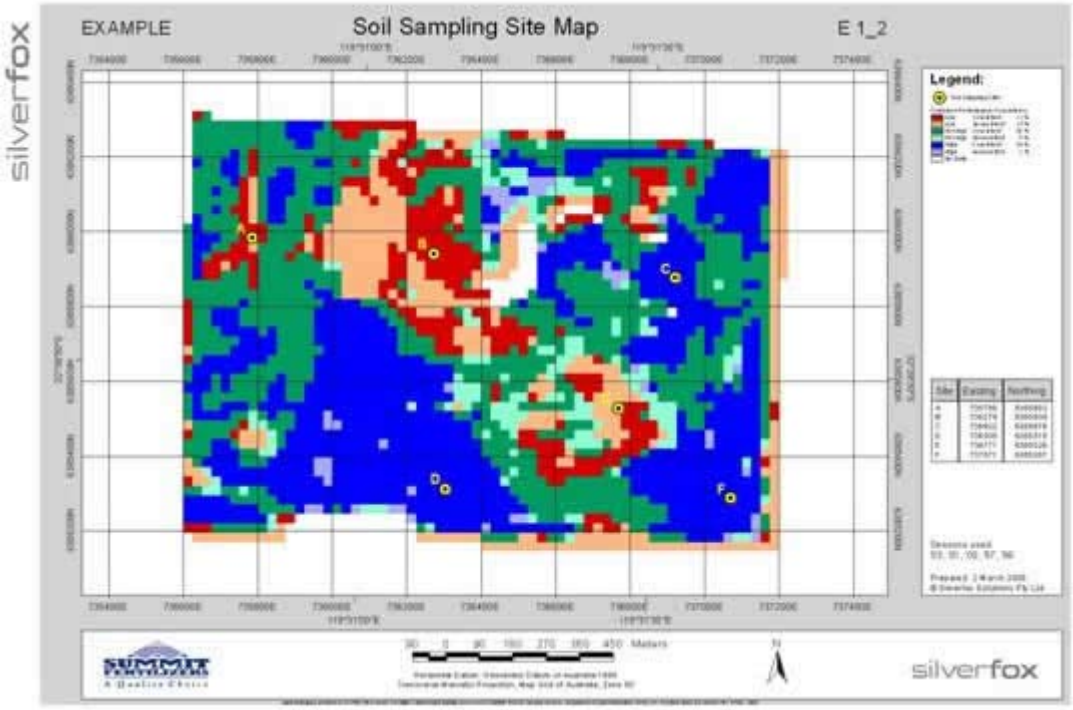


Figure 3.3.3.5 An estimated gross margin (GM) map, and map of paddock yield zones, developed from biomass imagery (source: Silverfox Solutions Pty Ltd).

4. Managing Variability

4.1.1 Putting precision agriculture into action
4.2.1 Choosing and using precision agriculture machinery
4.2.2 Data storage
4.2.3 Combining precision agriculture with Controlled Traffic Farming
4.2.4 Managing spatial variability - a decision framework
4.2.5 Creating paddock management zones
4.2.6 Use of variable rate technology
4.2.7 Using precision agriculture to manage post-emergence agronomy
4.2.8 Using precision agriculture for on-farm research
4.2.9 Potential management classes at the whole-farm and catchment scale
4.2.10 Value of precision agriculture post-farm gate for QA/QC and EMS
4.3.1 Linking seasonal forecasting with precision agriculture
4.3.2 Is long-term management of spatial variability warranted?
4.3.3 Is spatial variability worth managing differently for tactical decisions?
4.3.4 Managing spatial variability for tactical decisions when zones are unstable in size and location

4.1.1 Putting precision agriculture into action

Based on current technology and research there are several ways in which precision agriculture (PA) can be used in grain production, and in on-farm and farming systems trials. Figure 4.1.1 provides some general steps in the implementation of PA systems.

A global positioning system (GPS) alone can be used for the accurate location of tracks in the paddock for controlled Traffic Farming, and in Raised Bed Cropping. It can also be used to return to the same sampling position.

Autosteer using GPS enables longer working hours through less fatigue and working at night. It also allows, when combined with GPS with 2 cm accuracy, sowing into the inter-row and accurate inter-row management (e.g. for herbicide application).

Yield and quality monitors, linked to GPS units, enable the collection of detailed spatial data which can be communicated to appropriate mapping software.

Crop and soil data can be combined to identify paddock or farm management zones for differential cropping (e.g. in relation to pH or disease), to manage for seasonal risks (e.g. waterlogging, areas of low PAWC) or for segregated harvesting.

On-the-go sensors can identify areas where a specific input is required.

The combination of advanced electronics into tractors, controllers, air carts and spray rigs is allowing variable rate application of inputs to different management zones.

	Objective	How PA tools and techniques can be used
1	Optimise average crop management and increase farming efficiency	GPS location and recording for crop scouting and soil sampling, and simple paddock experimentation (e.g. new varieties or pesticides). Vehicle guidance and autosteer to increase efficiency (e.g. reduced overlap), establish controlled traffic or raised bed systems, sow into inter-row, shielded spraying etc.
2	Determine the location and magnitude of spatial and seasonal variability	GPS linked to yield quantity/quality monitors and soil sensors, and geo-referenced remotely sensed data, used to develop maps of variability. Gross margin maps prepared based on yield and quality. Maps can be compared across seasons and crops to identify areas of stable relative yield or margin.
3	Determine causes of spatial variability and optimal management response	Combine several seasons of PA data layers to identify likely causal factors, followed by targeted field investigation (e.g. soil profile sampling) to confirm. Use climate data with crop and financial models to test alternative management responses (e.g. avoid, reduce inputs, grow tolerant crop or ameliorate).
4	Optimise production input/output ratio for grain quantity and quality. Maximise gross margin and minimise environmental footprint.	Use PA data layers to delineate management zones at a paddock or farm scale; use these to base crop decisions (e.g. type and variety) and prepare input application maps for VRT using variable rate controllers. Use yield monitors and financial analysis to check results and underpin further adaptive management.
4	Improve grain quality control and product marketing	Use GPS with grain quality monitors and segregation tools to meet quality requirements and achieve price premiums. Electronic information tagging of field operations and grain loads, and downloading into Environmental Management Systems, provides data to support marketing and quality control/assurance.
5	Increase on-farm experimentation/trials	Use PA maps to design on-farm trials, with GPS to enable accurate lay-out and yield monitors to record the results.

Figure 4.1.1. Generalised steps in the adoption of precision agriculture (PA)

4.2.1 Choosing and using precision agriculture machinery

Authors: Rohan Rainbow, Southern Precision Agriculture Association (SPAA), and Bindi Isbister, Department of Agriculture WA

Since the mid 1990s there has been considerable expansion in the type and range of PA equipment and agricultural machinery developed for use with PA systems. The driving factor has been the development of harvester yield monitors, which have highlighted the variation in productivity that can exist across a paddock.

The use of PA equipment on agricultural machinery can be divided up into the following categories:

- Position: raw GPS or differential GPS (dGPS);
- Guidance: marker arms, GPS visual or light bar, GPS autosteer;
- Variable rate: rate controllers for airseeder boxes, spreaders, boomsprays; and
- Sensors: yield monitors, protein monitors, crop sensors.

Central to the system is the task controller (computer) and monitor (virtual terminal). The task controller gathers information from the GPS and sensors on variable rate machinery and initiates the response through the smart controllers and the mechatronic systems.

These technologies can be used on their own such as GPS for guidance or in combination for PA. For example, yield mapping requires a GPS, a sensor data logger and software to compile a yield map, while variable rate technology (VRT) requires a GPS, a variable rate controller and an implement with variable rate capability.

The challenge facing many growers is choosing the right equipment to complete the task they require and making sure the equipment from different manufacturers is compatible. Incompatible equipment is a major limitation to the adoption of PA techniques identified by a GRDC national survey on PA, Southern Precision Agriculture Association (SPAA) survey and a needs analysis by the WA PA Steering Group link to CANbus. It is important to be aware of compatibility, and ask questions up front to save time and money later when applying the technology on-farm.

When buying PA equipment some key questions to ask the dealer or manufacturer are:

- Is this system compatible with existing machinery and PA equipment? If the answer is yes, ask the provider for an example of where it is working successfully.
- What specification computer and or software are required for the storage and manipulation of data?
- For VRT can the controller on the airseeder box or spreader be linked to another brand of GPS? If a GPS system is already owned ask about linkages between that specific brand and model.
- What after sales support services are available for learning how to use the system and for technical problems? Is there 24 h on-farm support?

4.2.1a GPS and dGPS

Before choosing PA equipment growers need to know what operations they want to use it for. This will determine the level of GPS accuracy required (see Table 4.2.1a1). (See section 3.2.1 Global Navigation Satellite systems).

Application	Minimum GPS accuracy
Yield monitoring, variable rate controller	Raw GPS signal, 4-15 m
Visual or automated guidance- spreading and crop spraying	Sub-1 m
Visual or automated guidance - seeding and accurate spraying controlled traffic farming	±10-20 cm
Autosteer - automated guidance, inter-row seeding, inter-row spraying, harvester autosteer	±2 cm

Table 4.2.1a1. Minimum GPS accuracy required for different broadacre operations.

The accuracy of guidance and autosteer systems should be determined based on the requirements for a particular operation and the potential financial return (See section 1.2.3).

Basic GPS receivers

A basic GPS receiver is able to provide a position with some degree of error. These devices are generally inexpensive, provide on-screen tracking and are usually hand-sized. A basic GPS is now capable of sub-20 m accuracy. There are a range of manufacturers including Garmin, CSI, Trimble and Magellan.

Differential GPS (dGPS) receivers

Many systems have been developed to minimise Selective Availability, the international error that in the past was added to satellite systems to prevent hostile parties using GPS, and to improve positional accuracy to between 2 and 5 m. Although these devices are more expensive than basic GPS devices and may require a well-placed antenna to receive the differential signal, they provide real-time qualitative information and can be programmable. The differential signal is calculated from a GPS located on a known site capable of correcting any selective availability or atmospheric errors. The correction factor is transmitted to the dGPS via a number of methods. The main correction systems currently available in Australia, or that could become available, are described briefly below, and the advantages and disadvantages of each are listed in Table 4.2.1a2.

- Maritime radio beacons have been established by the Australian Maritime Safety Authority &along the coast, particularly adjacent to the Great Barrier Reef, to broadcast the correction signal for ships. The accuracy of the transmitted signal declines with distance from the station (usually about 1 m error per 150 km).
- A correction service is available, through subscription, from AUSNAV via FM radio stations (e.g. Triple J). The differential correction signal is weaker than the FM radio station broadcast. Therefore, the ability to pick up the radio station does not necessarily mean the differential signal can be obtained. Coverage is limited by the ability to pick up the FM broadcasts, which can decline in quality with weather or topography. Coverage includes from the Sunshine Coast to Adelaide via Melbourne.
- An annual subscription to a specialised GPS operator, such as OmniSTAR or John Deere Starfire enables the correction signal to be broadcast via satellite. GPS receiver manufacturers include CSI, Leica, RDS, OmniSTAR/ Fugro, Novatel, Ashtech, John Deere Starfire and Trimble. Accuracy is typically ±1 m for OmniSTAR VBS (Virtual Base Station) and Starfire I. Accuracy is typically - ±10 cm for OmniSTAR HP and Starfire II.
- A system known as WAAS (wide area augmentation system) has been well used in the USA to improve accuracy of GPS devices. It appears unlikely that Australia will receive this system due to the installation price, however the aviation industry is moving into a LAAS (local area augmentation system) for enhanced accuracy. A further system in development is MSAS (MTSAT satellite-based augmentation system) which will provide a free Australia-wide satellite-based differential correction system.
- RTK (Real Time Kinematic) base station differential GPS. This option gives the greatest degree of correction accuracy, ±2 cm, but requires the owner to purchase or pay for access to a local privately owned dGPS signal transmitter and power supply. Ideally the base station should be mounted in a fixed position on a building or

mounted on a pole set into the ground to maintain differential correction for high accuracy operations such as inter-row sowing. Range is limited to 10 km to maintain correction accuracy. This option could be owned jointly by several farmers.

Purchasing GPS equipment

Emerging technologies are integrating hand-held computers with GPS devices for mobile mapping applications.

Some suggested questions to ask the dealer when buying GPS equipment:

- What is the accuracy of the GPS system? Ask for this in terms of accuracy over 24 h and pass-to-pass. Accuracy over 24 h is important, as high repeatability of the GPS signal is required to allow the operator to return to the same position.
- Is there an annual satellite subscription fee?
- Can the system be easily upgraded to a more accurate system?
  Is the system suitable for all tasks, for example yield mapping, variable rate control, electromagnetic induction (EMI) surveying? If not, is it compatible with other systems that have those capabilities, and with which ones is this system compatible?

	Advantages	Disadvantages
Marine beacon	Free signal Cheap receivers	Less accurate away from coast No signal over 400 km from nearest beacon signal
FM broadcast	Cheap set-up costs, GPS receiver and FM receiver required	Annual subscription fee Limited coverage
Satellite	Total coverage across Australia and across locations Accurate (sub-1 m) to very accurate (± 10 cm)	Receivers can be expensive Annual subscription fee
RTK base station	Highly accurate (± 2 cm) No dGPS subscription	Range limited to 10 km Expensive

Table 4.2.1a2. Advantages and disadvantages of different methods of signal correction for dGPS.

4.2.1b Equipment compatibility

There continues to be major advances in PA technologies. With an increasing range of tractor electronics such as autosteer systems, sprayer, seeder and implement controllers from different manufacturers, problems have arisen, particularly with regard to product compatibility. Many of the early and current PA controller systems were developed to use RS232C data communication systems, each with their own controller protocols. This has lead to many product compatibility issues.

CANBus ISO 11783 is the upcoming standard in the agricultural area for electronic system network components used in agricultural machinery, including:

- Task controllers;
- Virtual terminal (VT);
- Electronic control unit (ECU);
- Implement Bus - cabling, connectors and electronic signals; and
- Defined protocols and data file formats.

CANBus ISO 11783 is sometimes referred to as the generic CANBus or more specific Isobus. This standard forms the backbone of the autonomous agricultural machine system. CANBus which stands for Controller Area Network, plus a Bus or data path shared by many devices, was originally developed in Germany by Bosch primarily for use in the automotive industry. Since the 1980s there have been many different standards of CANBus developed, some are used universally and some are proprietary.
The international CANBus ISO 11783 standard, which has been widely accepted for agricultural applications, consists of 13 documents ranging from definition of the transmission medium (physical layer) to application of the entire spectrum of serial communications based on CAN.

Why do we need CANBus ISO standards?

Many farmers currently run a mixed tractor fleet and require equipment standardisation for ease of transferability between machines and to reduce hardware costs. There is a need for fitting and signal standards that will help ensure different types and make of equipment can 'talk' to each other, as illustrated in Figure 4.2.1b1 below. Standardisation will improve cab ergonomics, and reduce connector and cable clutter thus reducing terminal damage. It will also simplify support and training for these devices.

Figure 4.2.1b1. Examples of the types of equipment that need to be linked electronically. (source: Rudi Bartels BeeLine Technologies).

The CANBus ISO 11783 standard will emerge as the dominant standard for agricultural electronic control systems and PA. It will gain greater industry recognition with the introduction of ISOBus approval stickers on compatible equipment (Figure 4.2.1b2). The CANBus ISO 11783 is becoming the predominant standard in agricultural tractor controller systems, particularly in the original equipment manufacture market, however there continues to be many proprietary CANBus standards used by a number of manufacturers.

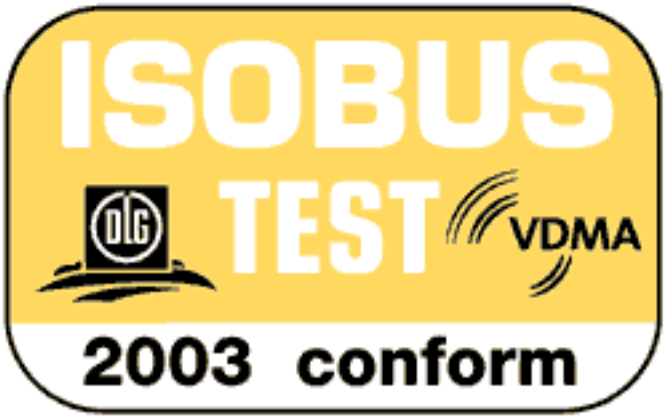


Figure 4.2.1b2. Electrical components that are ISO 11783-ready will be indicated by an ISOB us approval label (source: ISOBus website www.isobus.net).

Task controller and virtual terminal

This task controller is responsible for managing the tasks, and determining which task has control of the virtual terminal (VT). The task controller, which is often integrated with the VT, is responsible for standardised data logging and data import, and data export via compact flash cards or discs and USB drives.

The VT provides the user interface. Typically the VT has a screen and keys for the output and input of data, and it must satisfy a large number of requirements from purely technical to ergonomic. For example minimising screen glare has been a major challenge to VT manufacturers.

The VT is a dumb terminal that displays screens as defined by the electronic control unit (ECU) and communicates appropriate user input to the ECU. Based on the ISO standard, any ECU will have a similar look on any VT to which it is connected.

The VT concept is based on the idea that all of the nodes in a network can share one or more VT, from which they can then interact with the user. From the perspective of the ECU, the VT is exclusively available to each node. Masks are defined for the output and input of data, and these can be displayed on the VT. This information is provided by the ECU and not by the VT.

Figure 4.2.1b3 illustrates how all the components of guidance and PA communicate.

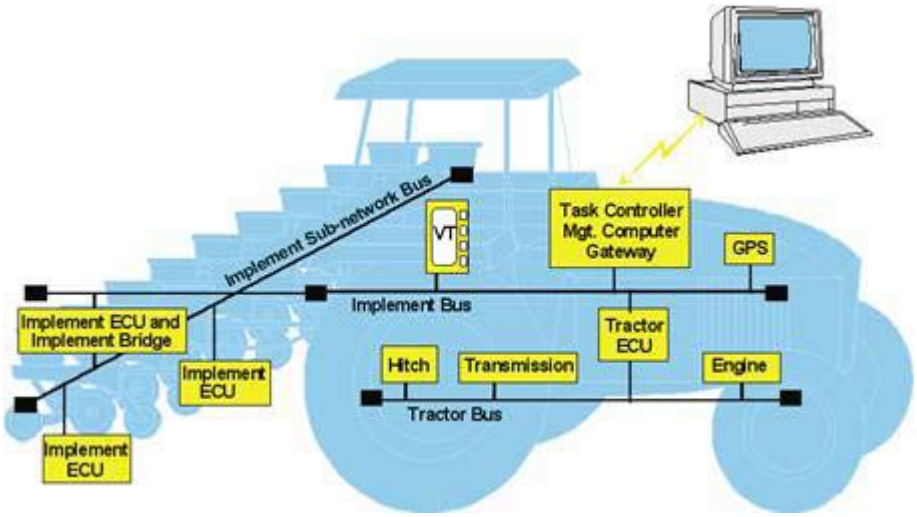


Figure 4.2.1b3. Diagrammatic representation of the relationship between guidance and precision agriculture components (source: ASAE Distinguished Lecture Series).

Electronic control units (ECU)

The implement ECU is essentially the main computer or the 'brains' of the variable rate system. It provides the user interface to/from the VT and performs low level control functions such as valve actuation for variable rate controllers and reading yield sensors and transferring this data to the Bus.

Auto on-off switching for spray controllers and airseeders has been developed using paddock mapping software in combination with guidance and autosteer systems. Spray systems have become more sophisticated with smart systems technology such as the Weedseeker® system, which can sense green weeds in summer fallow. The CASE IH AIM Command system gives full electronic control of spray droplet size and flow rate. Airseeder technology has improved substantially with innovations such as ultrasonic depth control sensors, blocked head monitors and electronic control of seed and fertiliser application rates.

The tractor ECU represents the communication interface between the implement Bus and tractor Bus (see Figure 4.2.1b3). Consequently the tractor ECU assumes a central role in tractor-implement communication. A communication interface was needed because no uniformly defined interfaces existed for the tractor Bus.

The tractor ECU provides a gateway for information from critical tractor systems to/from the Bus including engine speed, vehicle speed, hitch status etc. This ECU is typically a heavy-duty externally mounted unit with a single automotive connector.

Tractor and implement Bus

The tractor and implement Bus is a series of cables and connectors that link the tractor ECU, implement ECUs, VTs and task controllers together. It includes one or more externally mounted connectors to interface to externally mounted ECUs. The implement Bus has defined protocols and electrical characteristics.

There is a standard external breakaway connector for all ISO-compatible tractors. The connector will 'break away', to avoid cable/socket damage if an operator forgets to remove it. The connector design is part of the ISO 11783 standard. This external breakaway connector also provides access for external ECUs.

The challenges of precision agriculture technology progress

The computer industry has faced some transitional issues in technology development such as the demise of the RS232C port and 3.5" floppy drive on many computers and now the agricultural industry is facing similar issues. Many farmers have experienced significant redundancy of RS232C-based GPS signal communication systems when upgrading tractor and harvester equipment which uses the CANBus ISO 11783 standard. This can add significant cost to an upgrade of agricultural equipment. Some harvesters for example allow the input of GPS signal data in both the RS232C and CANBus ISO 11783 formats, but many do not. In time, most agricultural equipment manufacturers will standardise on the newer CANBus or ISOBus standard, making much of today's existing RS232C-based equipment incompatible.

Growers should be aware of this issue and clearly discuss this with the manufacturer or dealer before purchasing new equipment. Questions to ask are:

- Is the equipment CANBus ISO 11783 compliant or is the CANBus system another ISO standard or a non-standard proprietory CANBus system?
- Does the equipment have dual inputs for RS232C and CANBus ISO 11783 dGPS receiver hardware?
- Is the equipment hardware ISO 11783 compliant and/or will a software upgrade make it ISO 11783 compliant?
- Is an optional RS232C/CANBus ISO 11783 interface upgrade available for the particular piece of equipment, this often involves considerable programming by the manufacturer?

Mechatronics

The area of mechatronics, or the mechanical interface with the PA controller, has developed rapidly in agricultural systems. Many manufacturers have designed tractors with electronic over hydraulic control systems, which make the fitting of original equipment manufacturer and after-market autosteer systems much simpler. Until recently, most autosteer systems on the market required an additional hydraulic block to be fitted that can be controlled electronically. This required tapping into the existing hydraulic system and has had some issues with tractor manufacturer warranty.

Sprayer solenoid reliability has improved substantially in recent years and most current systems use a motor controlled mechanical ball valve. There is a slight time lag in the switching by this system, but more sophisticated auto-switching systems can be calibrated to account for this lag. More recent advances in spray controllers such as the CASE IH AIM Command system and the Weedseeker® system now enable the spray to be immediately switched off at the spray nozzle. This has many benefits for drift control into sensitive areas, particularly near waterways.

Electronic airseeder controllers have been available for many years. The main difference between them is in how the air cart metering system is driven and controlled. There are effectively three main types of airseeder metering motor control systems all of which are capable of variable rate applications:

- **Electric drive:** requires a steady battery voltage supply and can draw significant current. Often farmers have had to improve alternator capacity to drive these systems, particularly when operating at night with many operating lights. Many farmers have reported a high failure rate of drive motors due to high loads and wear rates on the motor.

- **Electronic control over hydraulic:** overcomes the issue of high torque requirements on drive motors, particularly on large air carts. This does require a significant amount of hydraulic oil capacity and is best suited to high flow rate, closed centre hydraulic systems. Many farmers with older tractors with low hydraulic flow rates have lacked sufficient hydraulic capacity to continue driving the hydraulic motors when lifting the machine hydraulics, or turning with the tractor steering system
- **Electronic over mechanical:** this system has been popular, particularly with older tractors with low hydraulic flow rates. It uses a linear actuator which is essentially a linear electric motor that adjusts a mechanical arm on a variable rate mechanical gearbox. Generally this system can be retrofitted to existing seeders with a variable rate gearbox.

Many farmers have utilised their airseeder cart fitted with variable rateapplication technology in combination with an air-application urea distribution boom. This enables farmers to better utilise their capital expenditure on air seeding equipment and variable rate infrastructure for post-seeding nitrogen application, rather than purchasing additional variable rate controller hardware for a separate urea spreading unit.

Sensor systems

The use of sensor systems or crop monitors such as yield monitors on harvesters has become commonplace. The reliability of these sensors has improved substantially, particularly in hilly harvesting conditions, however a significant change in slope can affect readings with most harvesters. Yield monitors need some maintenance, in particular to check that the sensors are clear of dust, grain or other contaminants such as snails. The introduction of other sensors that can potentially give an estimate of grain protein will give additional data on spatial grain yield quality.

Recently visual sensors such as that used in the ROBOCROP have been developed that track between existing green crop rows and provide a signal to a hydraulic controller to provide some minor adjustment to the tractor implement. This improves the accuracy of operations such as inter-row cultivation and spraying.

The development of the Yara N-Sensor has given farmers the abilityto determine crop health and nitrogen by reading crop greenness and biomass using near infrared sensor technology. This gives a measure of crop nitrogen requirement with real-time response to a fertiliser spreading system. This technology has been widely adopted in Europe, but is still in the research and evaluation stage in Australia.

For more information about sensing systems and methods see Section 3.1.1

4.2.2 Data storage

Authors- Rob Bramley and Susie Williams, CSIRO Sustainable Ecosystems and CRC for Viticulture

PA is fundamentally about data - lots of it! To consider crop yield or quality, or soil or landscape factors, with sufficient resolution to characterise spatial variability, large amounts of data need to be collected and managed. Indeed about 30 % of time spent on GIS-related matters is actually spent simply managing data.

Yield monitor data files often contain information about yield at several thousand points in a single paddock, and if these data are mapped properly (See sections 3.3.1 and 3.3.2) the results are grids comprising many thousands of pixels. As a consequence, the typical PA practitioner ends up with many large data files that can be easily confused if they are not logically named and stored.

The following information on data storage is based on our experience of managing GIS data; it is not the only way of managing data, and it may not be perfect in all situations.

4.2.2a Some golden rules

Keep all raw data and key files

Besides being very organised and structured in such a way as to be able to find a particular data set when required (see below), it is essential that all important pieces of data are kept. As a general rule, in addition to our final yield grids, we keep the original raw data (the harvester/yield monitor files), and any files which contain the major data manipulation steps required in map production.

An example might be a file in which yield as recorded by the monitor has been adjusted to that delivered to the weighbridge. A spreadsheet program such as Excel is useful for such manipulation. We import yield monitor files into Excel in order to check the data - (Does it look sensible ? Was the GPS receiving the differential signal ?), and to trim out very high and low values (See section 3.3.2). It is essential that the resulting Excel file is kept. Such files enable tracking back to determine exactly what was done to produce the yield map, and preserve the information needed to reconstruct the map following one of those fatal computer glitches that strike from time to time.

Construct a logical directory structure

Being organised and structured, so that data can be easily found, is essential. The way that our directory structure is set up is with the first 'tier' divided into separate folders for each focus site or region; eg mid-North, Yorke Peninsula etc. In the more typical case of a single farm or property this might be the names of the paddocks, eg Tudors, Westies, Paddock 1, Paddock 2 etc (see Figure 4.2.2a1). Under each of these main areas, is the second tier of files. Here we keep a folder of 'BlockData', for paddock GPS points, boundaries, imagery and the grid that we want to project all other maps onto. At the same level within the directory structure, we split all our yield data on the basis of its year of collection, so '2002' will house our yield map for the 2002 harvest along with any other data that helped to produce that map. Another folder at the same level within the directory structure - 'Soils' - will be made up of sub-directories (third tier) in which any soil maps, spreadsheets containing soil test data or the location of inspection pits may be stored. The number of second tier folders will depend on the number of other data layers collected.

Some of the commercial PA software does not help in the logical storage of data. We have seen many examples where a program installs itself into the Windows 'Program Files' directory (very sensible), but then puts data into this directory too (not at all sensible). We suggest that the 'Program Files' directory should be just for programs, and that data should go somewhere else, preferably in a directory structure such as that shown in Figure 4.2.2a1. We do not recommend the use of 'My Documents' because this is also the default storage location for many software programs which may or may not be relevant to PA.

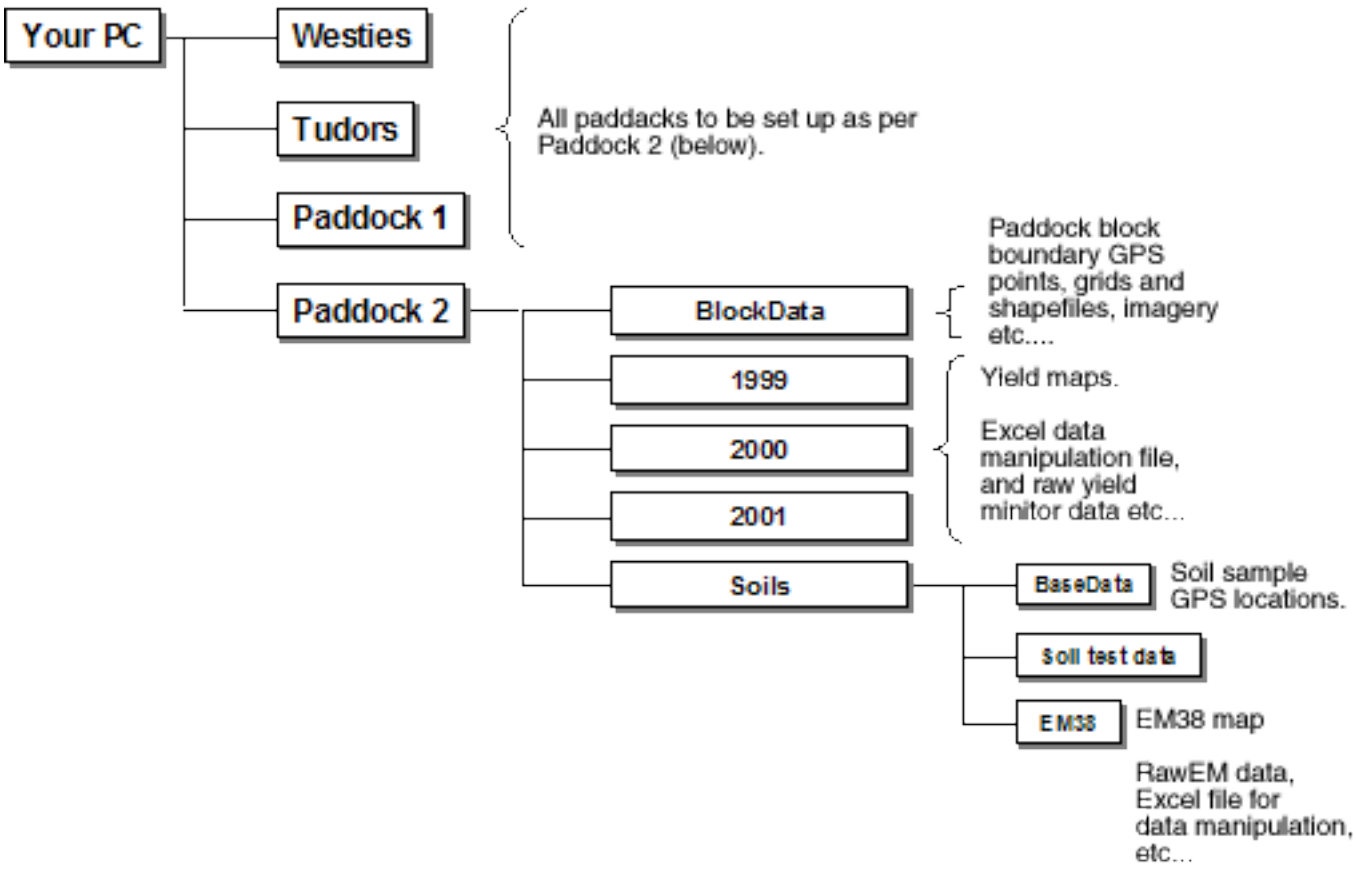


Figure 4.2.2a1. A possible directory structure for storing PA-related data on a farm computer. This example shows a three tiered storage structure.

Use meaningful names and a standard naming convention for data files

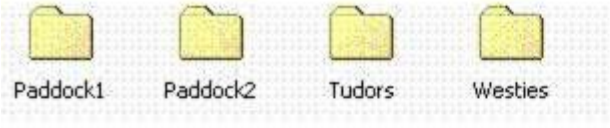
The other data management issue to keep in mind is the naming of files. Try and stick to the same naming conventions all the way through. By doing this files names can quickly be related to their content. For example, we run our yield data through the VESPER kriging program. So all our input files for VESPER have names which end in '_ves'; for example, 'yld01_ves.txt' would be the VESPER input file for the 2001 yield map. We name the corresponding VESPER output file, containing the kriged data, so that it matches up - for example, 'kr_yld01.txt'. This may sound trivial, but when dealing with hundreds of files, being able to identify the right one first time makes life much simpler.

In summary, if a good directory structure can be set up from the beginning, and the naming conventions can be turned into a habit, then data management becomes easier, and you can save a lot of time as a result.

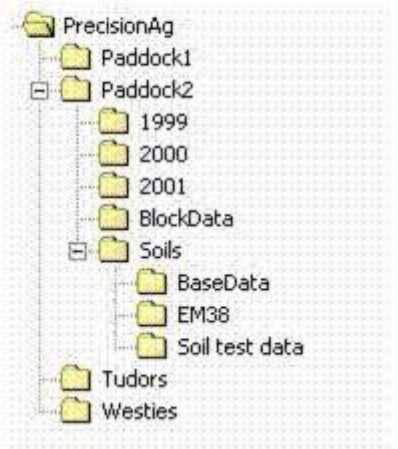
4.2.2b Make the computer do what you want, not what Bill Gates wants it to do

It is a fact that a computer will only do what someone has told it to do. The occasional 'big freeze' whilst producing the year's most important map might make this hard to accept, but it is true. However, the more recent editions of Windows have tried to take some of the decision-making control away from the computer user, supposedly to make life easier for them. Whether or not some of these 'benefits' are realised is really down to the personal preference of the user. However, the recent use of icons in Windows Explorer (formerly File Manager) does not help with PA data management in our view. We therefore recommend that rather than using the now-standard icon-based view (Figure 4.2.2b1), the old view is used (Figure 4.2.2b2), this is turned on by going to the 'View' menu and selecting 'details'.

4.2.2b1 Windows standard view (icons)



4.2.2b2 Old-style view (details)



Two possible views in Windows Explorer - A case of old being better than new

Acknowledgments

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4.2.2c Data integration and interpretation

Authors: Ian McGowen, NSW Department of Primary Industries, and Matthew Adams, WA Department of Land Information

The integration and interpretation of purchased data can be undertaken by a contractor/GIS specialist, negating the need for a large expenditure on equipment and software. For simple display and basic analysis, a computer with low to moderate processing capacity is sufficient. For analysis of spatial data and imagery, a higher level computer is recommended. Computer speed and specifications change rapidly, as do the requirements to run high level GIS and image processing software. The most up-to-date versions will often exceed the specifications of a 3 year old computer, and usually require the most up-to-date operating system.

Choice of a microprocessor depends on the applications used. In the past, processor clock speed (in MHz or GHz) was used as a guide to performance and processor choice. However, it is not necessarily a reliable guide for comparing processors, as performance is also strongly influenced by the amount of cache on the chip, its architecture (i.e. design, including support for multi-threading and 64 bit applications, or the presence of a single/dual core) and front side bus speed. Both Intel and AMD, the major processor manufacturers, now use a special rating scheme for comparing their own processors. As a general rule, when choosing between two processors from the same company, a processor with a higher 'rating' will be more advanced. A more advanced processor will generally perform better, even if it has a slower clock speed than a less advanced processor, due to larger cache size or other enhancements. However, rating is not a direct measurement of performance.

The desktop computer specifications detailed below are intended as a guide only, and are applicable as at December 2005. They are also only intended as a guide for computers using Microsoft operating systems. Once the Microsoft Windows Vista operating system becomes available and supersedes Windows XP, the specifications will alter. In particular, there will be an increase in the minimum RAM level, base processor type and speed required. It is essential to seek expert advice for system and software requirements before purchasing equipment.

Basic desktop computer specifications (display and basic analysis only, Windows operating systems)

Note that computers with these specifications, particularly at the lower end of the processor range, are suitable for displaying data but will be unable to run any but the most basic analysis software; they may be inadequate for many PA applications:

- Intel Pentium II 450 MHz, Pentium III 1 GHz or AMD K6-III 450 MHz, Duron 1 GHz, Athlon 1 GHz or better processor.
- Windows 98, Windows ME, Windows 2000 Service Pack 2, or Windows XP Home or Professional Service Pack 2. Note that Win NT 4.0 with Service Pack 6a can be used, but is not compatible with some programs and that Windows XP is only suitable for the faster processors.
- Desktop or mid-tower case
- 256-512 MB RAM
- 20-40 GB hard disk drive for storage of applications and data
- CD-RW or CD-RW/DVD-ROM or DVD ±RW drive (preferred). This is essential for data backup. Alternatively, an external USB hard disk drive can be used in a similar capacity
- 1.44 MB floppy disk drive
- 2 serial, 1 parallel port
- 2-4 USB 1.0 or 2.0 ports
- 4-5 PCI (Peripheral Component Interconnect) slots
- 250 W power supply or better
- Network interface card (NIC) 10/100 Mbit/s (fast Ethernet) - optional
- 15-17” Cathode Ray Tube (CRT) or Thin Film Transistor (TFT) monitor. For CRT monitors, an aperture grille flat screen is preferred, with a dot pitch of 0.25 mm or less. For TFT monitors, brightness should be a minimum of 200 cd/m2 (‘nits’), contrast ratio 500:1 or more and response time less than 12-15 ms
- 4-8 MB 2D/3D AGP (Advanced Graphics Port) 2x-4x graphics card capable of 1024 x 768 pixel resolution with 32,768-65,536 colours (15-16 bit display). Graphics cards built into the motherboard are not recommended as they share system RAM
- Fax modem (external or internal)
- Basic colour inkjet printer
- Surge and spike protector with an RJ45 modem/fax socket (a basic 350-500 VA uninterruptible power supply with an RJ45 modem/fax socket is strongly recommended for rural areas)

Minimum advanced desktop computer specifications (display and advanced analysis, Windows operating system)

- Intel/Celeron D 2.80–3.33GHz to Pentium 4/Pentium 4HT 3.0–3.6GHz, or AMD Sempron 2600+–3400+ to Athlon 64 3200+–3800+ or better processor. Note that Intel and AMD now have advanced and dual core processors (Pentium D/Pentium EE and Athlon 64 X2/Opteron) for high end desktop use. Additional special processors are available for workstation or server level computers
- Windows XP Professional Service Pack 2
- Desktop or mid-tower case (preferred, with at least 3 x 5¼” bays, 2 x 3½” bays)
- 512 MB–2 GB DDR (Dual Data Rate) RAM (DDR2 for advanced systems). 1GB or more is preferred for advanced software
- 80–250 GB hard disk drive for storage of applications and data
- 8–16x dual layer DVD+/-RW drive (essential for data backup). Alternatively, an external USB, Firewire or Serial ATA hard disk drive can be used in a similar capacity
- 1.44 MB floppy disk drive
- 1 serial, 1 parallel port
- 6 (minimum) –8 (preferred) USB 2.0 ports
- 1 Firewire 400 port (optional)
- 1 PCIe (PCI Express) 16x slot, 1–2 PCIe (1x – 4x) slots, 3 PCI slots
- 350–400 W power supply
- Network interface card (NIC) 10/100 (fast Ethernet) or 10/100/1000 Mbit/s (Gigabit Ethernet)
- 17” –19” CRT or TFT monitor. For CRT monitors, an aperture grille flat screen is preferred, with a dot pitch of 0.25 mm or less. For TFT monitors, brightness should be a minimum of 200 cd/m2 (‘nits’), contrast ratio 500:1 or more and response time less than 12–15 ms and preferably 8–10 ms.
- 64–256 MB 3D PCIe 16x graphics card capable of 1028 x 1024–1600 x 1200 resolution with 16.7 million–4,295

million colours (24–32 bit display). Avoid graphics cards built into the motherboard, as these share system RAM
Fax modem (external or internal)

- Mid range to advanced colour inkjet printer with USB 2.0 interface
- A4 colour scanner with USB 2.0 interface (optional)
- Basic uninterruptible power supply (UPS) with an RJ45 modem/fax socket, 500–650 VA or better capacity.

Software

There is a wide variety of software programs available at different levels of complexity, cost, sophistication and compatibility that will allow you to manage and interrogate data, and to derive prescription maps for a variety of controllers.

These software programs can be divided into three levels: introductory, mid level and advanced. Examples of each level available are provided in Table 4.2.2c1. The introductory packages are designed to allow data stored on cards to be retrieved, archived and presented in simple maps. This level of software is being increasingly designed with additional database features that allow tabular summaries of harvests over paddocks, farms, and years to be performed. In general, introductory packages do not allow multiple layers of data to be integrated, but can accept data gathered by other systems and present these as maps. A few introductory packages may also allow the export of a machine-ready VRT file either as an 'out of the box' function (e.g. New Holland or SMS Basic) or by purchasing a license code to access the additional functionality (e.g. JD Office).

The mid level software programs are packages that generally have been designed and developed by third parties (relative to the machinery manufacturers) to suit the needs of growers and consultants in the PA industry. These packages can read multiple yield data formats, import soil test data, create machine-ready VRT application files, and combine different data layers either through clustering or by map algebra.

Advanced software programs have substantial display and analysis capabilities, but they are not designed necessarily for ease of use in PA applications. An example is ESRI's ArcView 3.x. ArcView 3.x is a GIS development platform. It has the capability to import and process most types of files (although not yield files in their binary format), but the process of doing so may not be easy or intuitive. However, the SST Development Group has customized ArcView 3.x to allow much easier use of the capabilities of ArcView 3.x within a PA environment. Note that ArcView 3.x is not fully Windows XP compliant, it runs with several limitations (refer to http://www.esri.com/software/arcview/about/sys-reqs.html). Versions 3.0 and 3.1 are less compliant than versions 3.2a and 3.3. ArcView 3.x has been superseded by the more advanced ArcGIS 9.x.

Category	Software	Indicative cost
Advanced software	ArcGIS	Starting from A $3000
	MapInfo	
	Geomedia	
	Manifold Professional/ Universal	US$245- 545
	TNT View	US$500
Mid level	AGIS	US$49
	SST Toolbox	A$9000
	PAM	A$4000
	FarmWorks	US$1000
	Agleader SMS Advanced	US$1500
	Mapshots	US$995
Introductory	JD Office	Starting from $20
	Agleader SMS Basic	Free
	CASE AFS	Free with equipment purchase

Table 4.2.2c1. Examples of different levels of software currently available; arrow shows decreasing cost.

4.2.3 Combining precision agriculture with Controlled Traffic Farming

Authors: Bindi Isbister, Department of Agriculture WA, and Don Yule, and Tim Neale, CTF Solutions Pty Ltd

Controlled traffic farming (CTF), also called tramline farming, is a method of PA that provides a 'backbone' for precise and targeted placement of inputs. The 'backbone' is constructed using a guidance system to repeatedly run the wheels of heavy cropping machinery on permanent tramlines to minimise compaction and overlap, maximise access to the paddock, and improve crop yield. An ideal system has all equipment working up and back, with all machinery operating widths and track widths matching.

CTF allows some basic improvements in farm efficiency due to improved soil management practices, including reduced compaction and no-tillage. Once established these benefits could be refined using other PA techniques and sources of information to gain future improvements in farm production and management by matching inputs to yield potential.

4.2.3a Benefits of CTF to farm production

Benefits of CTF can be broadly separated into two categories, improved crop production and better farm efficiency.

Improved production

Confining the wheels to permanent tramline lanes minimises soil compaction by traffic, as the crop is grown between the tramlines in un-compacted soil. Research has shown yield increases of 515% depending on soil type and assuming residual compaction is removed (Tullberg et al. 2001; Ellis et al. 1992, Blackwell 1999-2000). The yield increase may occur over time as soil structure improves from increased organic matter, better root growth, no re-compaction and more earthworm/biological activity (Tullberg 2005). Doubling of annual crop production on Queensland and New South Wales farms is common with fully operational CTF systems, including no-tillage.

Effects of past management are often a cause of within-paddock yield variation. Adopting CTF can help minimise some of these effects. For example, in an up and back layout, traffic turns at the end of the run, to minimise traffic this could be made into an access track wide enough for traffic to turn without running on the crop. In round and round operations, the double sowing of corners often reduces yield which can be seen in a yield map or on an aerial photograph.

Better farm efficiency

Reduced overlap results in input savings, for example savings in fertiliser and herbicides can range from 3 to 30%, depending on the accuracy of the guidance system used. With one marker arm the saving is about 3%, while with 2 cm GPS autosteer the saving can be up to 30%. Other savings include improved farm planning, more efficient grain handling with chaser bins on adjacent tracks. Running on firm tramlines can also reduce fuel use by 25-50% (Blackwell et al. 2004).

Tramlines allow easy in-crop access for post-sowing operations including fertiliser top-up, and spraying of herbicides and fungicides. They also improve the accuracy of pre-sowing fertiliser spreading, spraying, deep banding lime and make night spraying possible. Firm, compact tramlines may allow for timely in-crop access in wet conditions where machinery would get bogged in conventional farming systems.

The use of an accurate GPS guidance system with CTF allows for precise/targeted placement of inputs including fertiliser placement, sowing into old crop rows or sowing between old crop rows for better stubble handling. Other agronomic benefits from guidance are inter-row shielded spraying or cultivation, deep ripping between crop rows and relay planting.

In a CTF system, tramline layouts must be designed to achieve maximum traffic efficiency and incorporate surface

water control principles to minimise the risk of land degradation, erosion and waterlogging. Information sources useful for PA such as aerial photographs, elevation maps, soil type and farmer experience are used to determine safe layouts, however obtaining professional advice is strongly recommended.

On-farm trials made easy

In a complete CTF system, where all equipment runs on 3 m wheel spacing (determined by the header), on-farm trials can be easily established based on tramlines and using a yield monitor. Using a simple trial design where each seeding run is a trial plot, changes in agronomy can be tested before implementing changes across a whole paddock or farming program (See Designing your own on-farm experiments: how PA can help).

4.2.3b Setting up a CTF system

Each farming system is different, therefore it is hard to prescribe a system that fits all. There are many options for developing a CTF system; the one chosen must suit the farm priorities its equipment and budget.

There are five considerations when designing a CTF system

1. What are your priorities?
2. What direction do you want to work in (paddock layout)?
3. What guidance system would you like?
4. What machinery widths and tracks do you want to base the system on?
5. What tramline type is suitable?

A CTF system can be developed over a number of years according to your circumstances (see Figure 4.2.3b1 for some CTF options). CTF systems can range from an inexpensive round and round system, to one that includes up and back autosteer (2 cm accuracy) for maximum efficiency.

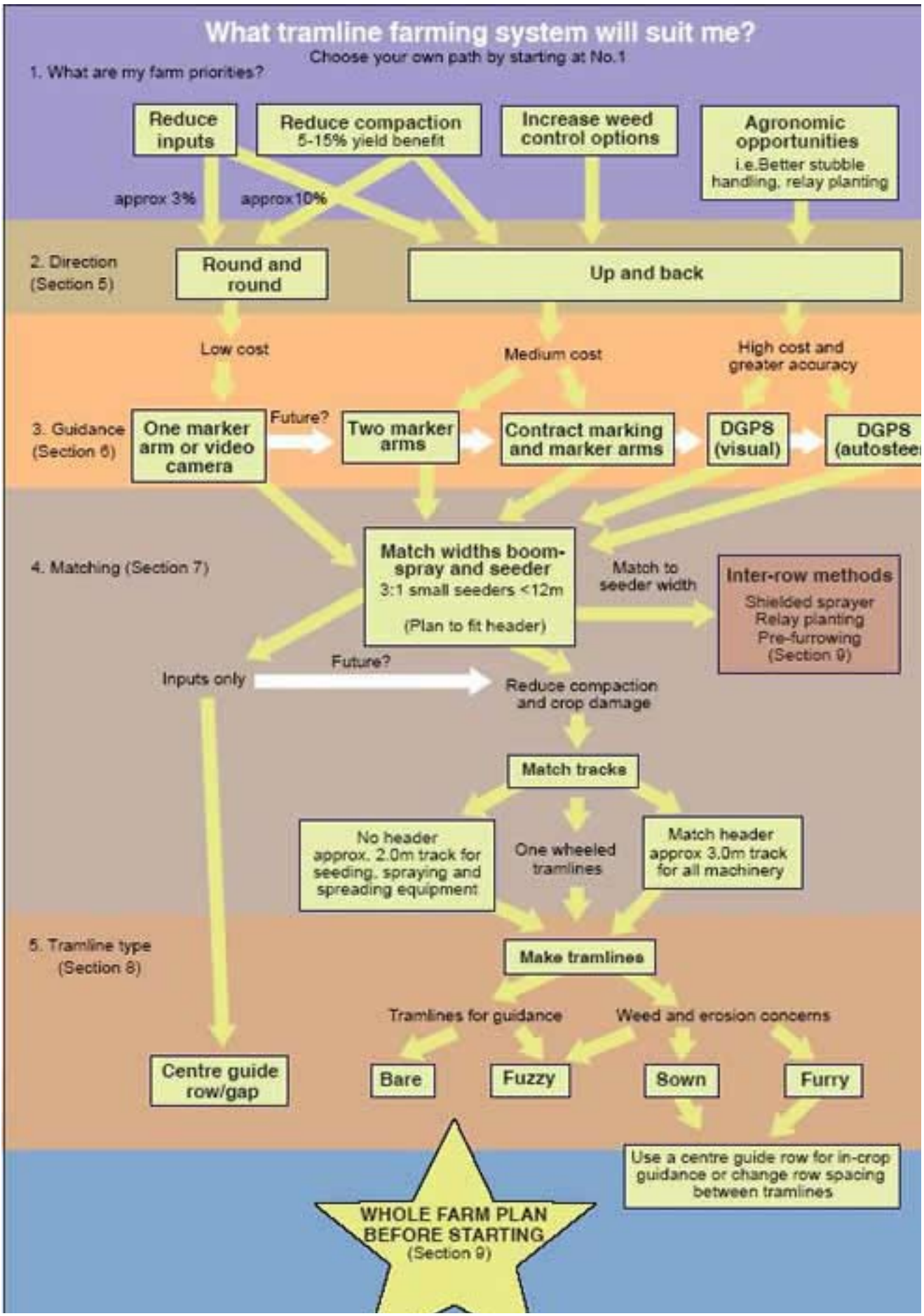

Figure 4.2.3b1. Options for tramline farming systems. (source: Webb et al 2004).

4.2.3c CTF and PA

CTF works to its full potential when wheel traffic is controlled by high accuracy (2 cm) GPS autosteer guidance system as this minimises overlap and ensures guess rows are accurately spaced. The guess row is the gap between one pass of the seeding bar and the next; ideally it should be the width of the tine spacing. The wider the tine spacing, the more critical the accuracy of the guess row.

CTF allows for PA technology to work more accurately. For example each pass of the header represents a full comb width, which in turn allows for an accurate record of the yield coming into the yield monitor. If the crop coming into the comb is only 80% of the swath width programmed into the yield monitor then the yield monitor software is underestimating the yield of the crop.

Economic analysis has shown that using GPS autosteer with CTF provides large financial benefits at no risk, compared to PA (zone management) which has low returns at high risk (Stone 2004). The autosteer will return benefits from the reduced overlaps whereas the benefits of zone management/variable rate are still unclear, particularly where yield is unstable. The financial benefits gained from improved efficiency due to the use of CTF are gained in any soil type. Yield increase will be dependent on soil type (yield potential, constraints) and farm management practices.

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4.2.4 Managing spatial variability - a decision framework

Author: Mike Robertson, CSIRO Sustainable Ecosystems

Managing spatial variability is dependent on the type of management being considered. For strategic or longer-term management decisions, understanding and responding to spatial variability is usually more important than worrying too much about seasonal variation. In contrast, for tactical management decisions that result in a response in the current growing season, understanding and responding to the season at hand is both more important and a precondition for making spatial management decisions.

Strategic management might start with the question 'How much does yield or quality vary from year-to-year?'. To answer this question effectively, several years of maps of spatial variation or proxies such as yield maps, satellite images, mud maps or test results are required. Usually one is looking for zones that are relatively fixed in size and location.

For longer-term strategic management, such as treating acidity using lime, or phosphorus deficiency using superphosphate, seasonal variability may not be a major concern. This is because, if one is looking at long-term responses to treatment some of the seasonal variation can be averaged and decisions can be focused on spatial variation. Even if there is not a benefit every year, there's a chance that the benefit will occur in enough years to pay for itself. Hence there is not the emphasis on needing to be seasonally responsive in management.

Since potential management zones cannot be precisely located most of the time, there is often the need to take the 'precise out of PA. Instead, it is probably most helpful to concentrate on better targeting management to match seasonal conditions and their impact on spatial variability. This is tactical management.

With tactical management, the key question is 'Given that the season looks like this, are there opportunities for spatial management of the crop?' For short-term or tactical management, such as nitrogen application or other factors that do not usually have long-term responses, seasonal variability is likely to be of major concern. By definition, tactical management involves responding to the current season - it is all about temporal variability and its effect on your crop and your management of it. Consequently, spatial decisions will often be a lower priority for tactical than for strategic management decisions.

Growers may face two types of situation in tactical decision making with PA data. One is when management zones are relatively predictable in size and location from season-to-season, that is their size and location are stable from year-to-year. This can be assessed from experience, yield maps, crop sampling or satellite images. In this case the tactical decision is mainly about determining the level of inputs in response to seasonal conditions.

The second situation is when the size and location of zones are unpredictable from season-to-season, that is, they can flip-flop between years, and particular parts of a paddock or farm can yield above or below the average depending on the season. Growers then need to make some assessment of the probability of a below- or above-average season, perhaps based on timing of the opening rains or the amount of water stored in the soil profile at sowing, and use this to estimate where management zones are likely to lie for the coming season based on past experience and biomass/yield maps.

In both cases seasonal information can be helpful in assessing what decision to take. A seasonal climate forecast, the amount of stored soil water at sowing, the sowing date, and in-crop rainfall leading up to the decision point can all be used to ascertain the yield expectation and hence management response. This information can be used in various models (eg. WUE, APSIM) to derive a yield estimate or target.

The opportunity to benefit from the tactical management of spatial variation increases as the average yield increases. Therefore, in 'good' years the payback from responding to spatial variation will be higher than in 'poor' years. This occurs because the difference between yield or response zones increases as yield increases. Usually, when yields are below about 1.5 t/ha (yield differences required will depend on circumstances), yield and response zones become too close to benefit from differential management.

Case studies suggest that tactical management that ignores spatial variation but correctly manages for that season's

average yield or response will generate about two-thirds of the profit that could have been obtained from perfectly managing both temporal and spatial variation (see section 4.3.3). That is, if perfect tactical management of both temporal and spatial variation was worth an extra $10/ha, then managing to the season correctly and ignoring spatial variation would be worth about $7/ha.

4.2.5 Creating paddock management zones

Authors: Ian Maling, Silverfox Solutions Pty ltd, and Matthew Adams, WA Department of Land Information

A management zone is an area of the paddock that will be managed in a particular way for a specified input. Management zones are currently the most practical way to implement one of the main tenets of PA - the capability to apply the correct or desired amount of input where and when it is needed. Paddock management zones can be used to differentially apply any soil ameliorant, fertiliser, seed, herbicide or pesticide. Management zones derived for variable herbicide application are not likely to be the same as management zones derived for fertiliser management. Indeed different nutrients may require different management zones. How many different zones are required is currently dictated by the feasibility of varying individual inputs. Management zones are not static and should be evaluated and adjusted over time.

4.2.5a The base layer

The basis for all paddock management zones is an accurate farm map. There are many ways of obtaining this ranging from driving around the farm and paddock boundaries and logging key points with a GPS unit, digitising the boundaries from an orthorectified aerial photo or satellite image, or by using yield or EMI maps (See Sections 3.2.3 and Standards for EM mapping for the grains industry).

Comparative costs

The cost of acquiring a farm map varies by source and state. In Western Australia, an orthorectified aerial photo costs between $100 and $200 for a farm of about 1000 ha. The spatial resolution is about 1 m, and the image will have been acquired sometime in the past 3-5 years. The spatial error should be no more than 5 m.

The cheapest orthorectified satellite image in Western Australia costs $180 per property. The image is captured from the Landsat satellite and has a spatial resolution of 25 m with an error of ±25 m. The images are acquired each year either in February or between July and September, and are available for nearly all years since 1993.

Satellite images with higher spatial resolutions, 1 m or less, are available, but there is a requirement to purchase a minimum 100 km 2. The cost is about $600.

However, a high resolution satellite image purchased for the purposes of a farm map or management zones may also be used to identify management issues related to plant growth as the satellites have additional spectral bands that a standard aerial photo lacks. If purchasing a high resolution satellite image for management zones, 6-12 weeks after sowing is often a suitable time to determine within-season nitrogen application. For weed or pest detection, the best time to acquire an image is when a pest or weed problem is thought to be occurring.

4.2.5b Identifying paddock management zones

When identifying paddock management zones the first question to ask is ‘What aspect of paddock management is to be influenced?” The answer will determine what information needs to be gathered in order to derive paddock management zones. For example, for targeting aphid control a recently acquired image (either - kite, balloon, airborne or satellite) coupled with an on-ground survey to confirm infection levels would be appropriate. Management zones for post-sowing application of urea may use some soil test results combined with a seasonal climate forecast and interpretation of historical yield maps or imagery.

Sources of information that may help in the creation of meaningful management zones for a variety of purposes are listed in Table 4.2.5b1

Management zone	Remote data	On-ground data
Nutrient application	In-season satellite or aerial photo Gammaradiometric maps EM31/38, Veris maps	Paddock and farm boundaries Yield map Soil tests Topographic maps Plant test results Tiller counts Knowledge of unusual/ anomalous areas Seasonal climate forecast maps Historical rainfall records
Spray	In-season satellite or aerial photo	Paddock and farm boundaries Pest and weed scouting information Topographic maps In-season climate data

Table 4.2.5b1. Sources of data that can be used to produce zones for different management applications.

There are two different opinions on the identification of management zones. One prioritises the zones based on plant measurements (e.g. yield, biomass maps etc.), the other prioritises zones using soil data (e.g.EMI, soil analysis etc.). The case studies included on this disc provide examples of how both methods have successfully been applied on-farm.

4.2.5c Combining data layers

Combining data layers is generally beyond the capabilities of the software supplied with precision farming equipment. Before layers are combined it is important to use data only from years where the key constraint causing variability had an effect. For example if waterlogging is the main causal factor, it may not be observed every year, or acidity may have increased over time. Layers can be combined either manually or by a computer-based method. Both are described below. (See also section 3.3.2)

Manual

One of the simpler techniques for combining data layers is to use an orthorectified aerial photograph, satellite image or yield map and draw on zones based on colour or tonal contrasts in the image. This technique has been used effectively in the United States and Western Australia due to the correlation of key soil properties with soil colour (e.g. see Fleming et al. 2000, JPAg 2:201-215). Multiple data layers can be roughly combined by overlaying these zoned maps with maps of yield or other properties printed on acetate sheets. The weakness of this method is the ability to take the aerial photograph or acetates with zones marked on them and convert them into an electronic format that can be uploaded into a VRT controller.

Computer-based

Before data can be combined using computer-based tools it must be transferred to a regular grid of specified spacing - this is achieved by interpolation. Traditionally yield data have been grided at 5 m spacing. The justification for this spacing was that 5 m grid spacing represented approximately half the width of a header and it seemed reasonable to interpolate between two header rows. It is also a convenient multiple of the resolution of many common forms of satellite imagery (250 m for MODIS, 25 m for Landsat, 20 m for SPOT 2 and 4, 10 m for SPOT5).

There are several packages that use one or more interpolation techniques (inverse distance weighting, minimum curvature, kriging etc.). No single technique is better than another. Often a technique that works well for certain paddocks and situations will not work well in other paddocks or even a different situation within the same paddock.

Many of these techniques can be found as either freeware or shareware. One shareware package that will interpolate data is the Australian Centre for Precision Agriculture's (ACPA) Vesper package available from their website [http://www.usyd.edu.au/su/agric/acpa/]. This package uses kriging to interpolate raw data onto a regularly spaced grid.

Another consideration when combining multiple datasets is having all of the datasets at the same grid spacing and same grid locations.

Researchers continue to debate the best options of combining multiple datasets when one set of data is collected at one line spacing or resolution and additional data is collected at a different resolution. An example is satellite data acquired on a 25 m grid spacing, EMI data acquired on 20-m line spacing with a sampling interval of 5 m along the line, and yield data acquired on approximately 10 m line spacing with a sampling interval of about 5 m along the line.

Some researchers believe that the coarsest dataset should dictate the size of all grids, in this example all data would be interpolated to a 25 m grid spacing to match that of the satellite data. Others believe that it is appropriate to either subsample or interpolate the coarser dataset down to the finer one, in this example all data would then be on a 5 m grid to match the generally used 5 m grid for yield data.

Researchers are continuing to explore the implications of the two options. They are questioning how well the interpolation method (IDW, kriging, minimum curvature etc.) represents the underlying processes. If the interpolation method captures the nature of the spatial variability exactly, then there should be no difficulty interpolating a coarser dataset to a finer resolution.

The counterargument is based on statistical considerations. Some researchers argue that arbitrarily increasing the data density is making it easier to find statistical differences between two datasets when in fact there are none present. This comes about by an increase in the number of 'pseudo observations' entered into a statistical model. The larger the number of observations, the smaller the standard deviation becomes and the easier it is to find statistical differences.

4.2.5d Delineating management zones

Classifying a continuous dataset

A more complicated set of techniques relative to the manual one described above divides data into several classes, determined by the operator using one of several methods. These methods include Jenks' natural breaks, standard deviations, normalising, standardising and percentiles. These methods are found in many GIS packages. However, these techniques are generally applied to a single dataset (eg one year's yield map, image, EMI map etc.). These may or may not represent 'true' management zones.

Using more than one dataset

The next level of analysis is to incorporate more than one dataset into the determination of management zones. Such an analysis falls into two categories: those that mathematically combine datasets, and those that divide the datasets up into areas with common attributes. The latter type is referred to as cluster analysis or unsupervised classification. If the location of zones is known from a subsample of data, the remainder of the data can be classified by discriminate analysis (also referred to as supervised classification). If a subsample of known data is not available, the data can be classified by a collection of techniques that fall under the general category of cluster analysis.

There are many tools available on the Internet that can combine several data layers by using cluster analysis. Among the most common product is FuzMe (Fuzzy k-Means with Extra grades) which is available from ACPA. This is one of a suite of programs that perform cluster analysis. Detail on how FuzMe works can be found on theACPA website http://www.usyd.edu.au/su/agric/acpa/fkme/FkME.html.

Another freeware package is Management Zone Analyst 1.0, available from MPAC at http://www.fse.missouri.edu/ars_software/mza_reg.asp and described more fully at http://agron.scijournals.org/cgi/content/abstract/96/1/100

There are other packages available in farm GISs, available from the USA, that have the capacity to delineate management zones. None of the mainstream paddock management software packages commonly used in Australia (e.g. PAM, Backpaddock, iFarm) currently have image algebra or clustering algorithms built into them. Such features could be incorporated in future versions if there was sufficient demand from the agricultural community to justify the development costs.

To perform high end analyses using different algorithms to those available in freeware, a higher end, purpose-built

GIS or image processing program may need to be considered. These are designed to manipulate large, multiple datasets.

It is possible, however to perform mathematical analyses in, for example Microsoft Excel, providing the number of rows multiplied by the number of columns does not exceed 65,536 (limit to the number of rows in Excel) if column-based calculations are being performed, or 253 columns x 65,536 rows if calculations are sheet based.

4.2.5e How many zones?

There is no set number of zones that need to be identified. For some uses, for example fertiliser application, equipment can vary rates every few metres, although this is generally not practical or justifiable except perhaps in experimental situations. Alternatively, uniform management of a whole paddock (i.e. one management zone) may be more appropriate in other situations (e.g. lime spreading over a uniform soil type). In practice, between one and five management zones may be established for a particular farming operation, with one, two or three being the most common (Figure 4.2.5e1). Width of machinery, paddock size and how the paddock is worked will also affect the feasible number of zones, mainly because large equipment cannot be turned on small areas.

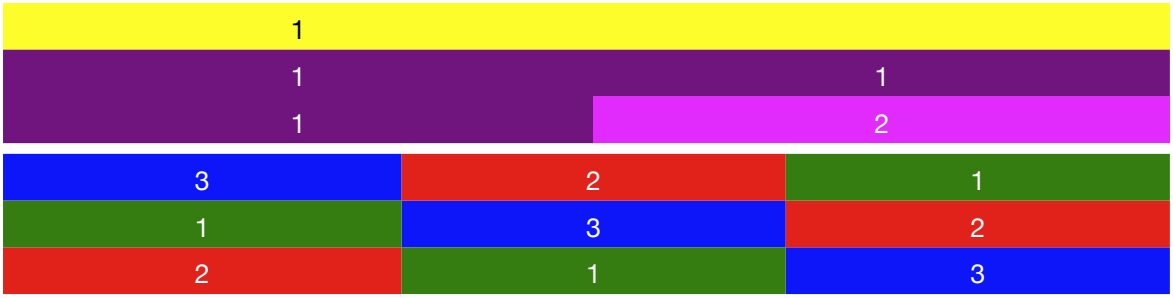


Figure 4.2.5e1. Diagrammatic representation of a paddock with one to three management zones. One management zone is equivalent to uniform management. Two management zones are generally equivalent to splitting a paddock into above and below average in a measured attribute (e.g. yield, Veris, EM38 readings of soil ECa). Three management zones are equivalent to splitting a paddock into below average, average, and above average in a measured attribute. The relative sizes and location of yield zones can vary from season to season.

4.2.5f Some zone management options

Once a paddock has been divided into management zones, it is possible to treat the zones differently either every year or, providing the causes of crop variability are known, in those years when a factor(s) is considered likely to occur. The differential management applied, whether strategic or tactical (See section 4.2.4) will depend on the size of the yield differences and the causal factors. At one extreme, the grower may decide not to crop sections of the paddock where a gross margin map consistently shows negative returns. Or a different crop type may be selected, for example triticale rather than wheat, in areas with soil pH below 4.5 where aluminium toxicity is a problem under wet conditions. In areas of low elevation where yield maps suggest periodic lack of grain, a later-flowering variety could be sown to avoid a 'frost window'.

Areas with known pest or weed populations can be located and sprayed, and/or a different mix or level of pesticides used during normal spraying operations. If pre-testing suggests the presence of soil disease organisms at levels where there is risk of damage and yield loss, a pesticide seed dressing may be applied, perhaps only in the higher-yielding zones where greater potential profit and risk justifies the additional expense.

Seeding rate and fertiliser application amount are inputs that are commonly varied between zones. Profit may be increased by reducing inputs on low-yielding areas, partly because the expected yield does not require the average and high level of input, and also because nutrients may have built up to higher than needed levels over the years of uniform application due to low crop removal. Increasing inputs on the high-yield zone may also be very profitable if nutrient is limiting.

Amelioration of factors limiting grain yield may be financially justified in some cases, for example with ripping, lime

4.2.6 Use of variable rate technology

Authors: Matthew Adams, Satellite Remote Sensing Services, WA Department of Land Information , Ian Maling, Silverfox Solutions Pty Ltd, and Troy Jensen, Queensland Department of Primary Industries and Fisheries

Variable rate technology (VRT) allows rates of inputs, for example fertiliser, seed, chemical and operations such as tillage, to be varied within a paddock. The rate is changed either based on predetermined management zone (See section 4.2.6b) or information gathered on-the-go by sensors.

The greatest benefits of VRT are seen in paddocks with high variability in soil fertility, weed growth or soil compaction. Instead of applying a single rate of input throughout an entire paddock, the input rate can be adjusted to match the potential yield of the management zone or to tackle infestations of pests. Savings of over 80% have been reported for some sensor-based selective spray systems (http://www.ntechindustries.com/rowcrop.html).

Cost savings on fertiliser, seed or pesticide inputs are not the only benefit. Limiting the amount of fertiliser or pesticide to only the amount needed by the crop can have a beneficial effect on the environment.

VRT integrates well with PA, however benefits can still be gained if precision farming is not practised.

4.2.6a Key factors influencing whether VRT will pay -

See section 1.2.2

- Size of the enterprise: the bigger the enterprise, the greater the area/return to offset cost of equipment.
- Size of paddocks: smaller paddocks tend to exhibit less variation. Experience from Western Australia indicates that variation in paddocks under 60 ha is generally too low or in too small an area to make VRT pay. However, if a property consists of many small paddocks VRT may pay across the entire cropping enterprise.
- Size of the variation in the paddock: in Western Australia practitioners have found that unless a yield variation of more than 1.0-1.5 t/ha exists between management zones VRT is unlikely to be cost effective (exceptions do exist), hence yield maps become important.
- Stability of variability: if variability is driven by spatial rather than seasonal factors it is likely to be relatively stable and more appropriate for VRT.

Work conducted in Western Australia suggests that when considering VRT the proportion of the total paddock area that shows consistent variability is very important; that is, the stability in the size and location of yield zones across seasons, provides a crucial benchmark.

- Marginally suited: greater than 55% of the total paddock area is consistently in one type of yield zone through time. More suited if a large proportion of the high performing area is consistent.
- Well suited: in excess of 65% of the total paddock area is consistent through time.
- Very suitable: in excess of 75% of the total paddock area is consistent through time
- Exceptionally suited: in excess of 85% of the total paddock area is consistent through time.

When the highest level of stability is present, in terms of location and size, and high and low performing zones, it is not imperative to understand in detail the causes of good or poor yield. Proven stability over time gives confidence that VRT can be applied for the current season; the relative inputs to different management zones can be determined based on past results, although the absolute amounts may be varied according to season.

4.2.6b Zone or sensor based VRT

Zone based VRT involves creating application zones that describe the varying amounts of input needed across a paddock. Application zones are produced from yield, topography, soil, nutrient or weed maps that have been 'ground-truthed' to give specific details of inputs required across a paddock. The application zones are interpreted by variable rate controllers, also called electrical control units (ECU), run by small computers, that increase or decrease the amount of input according to the map (see Figure 4.2.6b1 for an example of zone based VRT).

Zone based VRT allows decisions to be made based on information gathered in the paddocks independently of the application or the operation. Zone based VRT gives precise control over how much of a given input is applied to specific areas within any paddock. However, it does involve data collection and processing; the greater the amount of data collected and over longer time periods, the more accurately the zones can be defined.

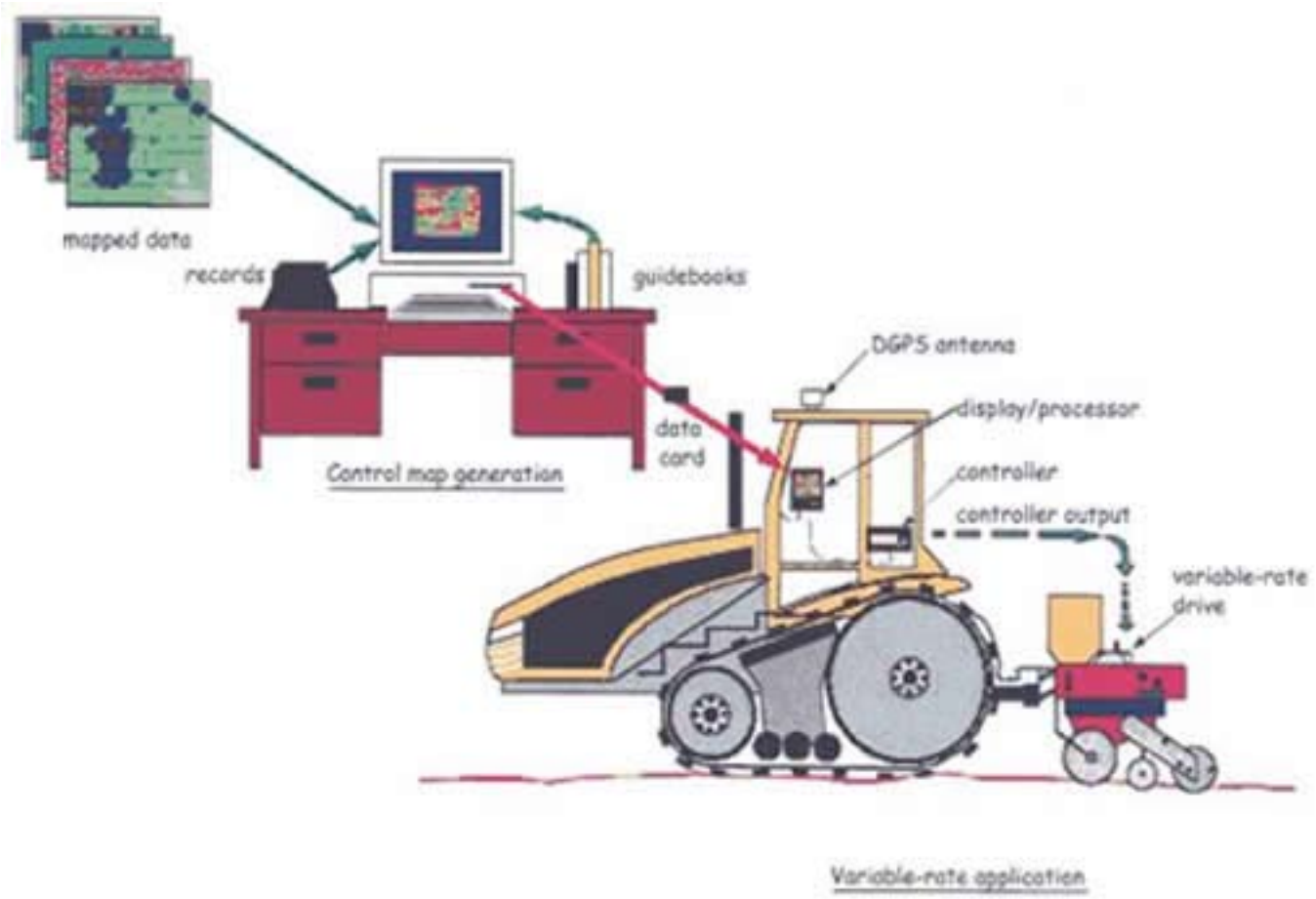


Figure 4.2.6b1. An illustration of a zone-based variable rate system (source: Purdue University's Site Specific Management Centre).

Sensor based VRT uses sensors to collect data, such as soil properties or crop characteristics, on-the-go and relays this information directly to a variable rate controller, which responds by varying the input (see Figure 4.2.6b2 for an example of sensor based VRT). This technology does not require detailed maps or extensive decision making prior to application.

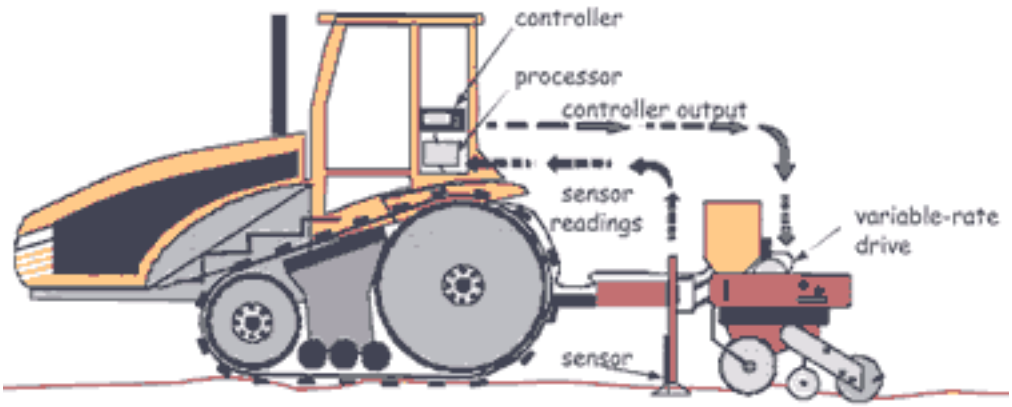


Figure 4.2.6b2. An illustration of a sensr-based variable rate system (source Purdue University's Site Specific Management Centre).

Sensor based VRT is readily included into any farming system, without the need for any data records or detailed maps. Sensor based VRT can be used with or without precision farming practises although benefits will be reduced.

Sensor based VRT is highly specific. One piece of equipment will only apply pesticides and another will be needed to apply fertiliser, however, each piece of equipment is self contained so there is no need to buy several components. The specific nature of the equipment is driven by the different sensors needed and the different processing required by each input. Weedseeker®, N-Sensor® and Greenseeker® are all examples of sensor based VRT applications.

4.2.6c Converting zones to VRT fertiliser maps

There are two main approaches to determining fertiliser rates, one that looks at fertiliser optimums based on predicted response curves and economics, and the other that chooses to replace, at least, the nutrients removed by a crop. The response curve model works well in responsive situations and where soil test calibrations exist. The fertiliser replacement model is more common in fertile environments where the crop is relatively non-responsive to fertiliser but the farmer wishes to at least replace the nutrients that are removed by the crop (i.e. to avoid mining their inherent fertility and/or avoid over fertilising poor production areas).

Given an understanding of the productive potential of different paddocks or different areas within a paddock, either approach can be used to develop different paddock rates or variable rates within a paddock. The response curve approach is readily evaluated for the economic outcome of such an approach and its return to investment. The replacement approach is a life choice decision based on how much a farmer is willing to invest in variable rate equipment to deliver more fertiliser to high performing areas of a paddock and less fertiliser to the poorer performing areas.

In the response curve approach, by using a simplistic model (for example one that has been derived for Western Australian conditions), the predicted grain yield in a paddock is calculated as a function of achievable yield and nitrogen uptake. Achievable yield in this instance is the water-limited potential yield, discounted for weeds and diseases. The water-limited potential yield of a crop is determined by the interaction of the climate (solar radiation, rainfall, temperature) with soil properties (particularly hydraulic conductivity as it varies with depth). Soil properties have been shown to vary widely across a single paddock. Therefore, water-limited potential yield may also vary across a paddock.

A crop of a certain potential yield has a certain demand for various nutrients. For example, a 1 t/ha crop has a lower requirement for nitrogen and other nutrients than a 5 t/ha crop. The soil will be able to supply variable levels of nutrients according to a range of factors. For example, a soil with an organic carbon content of 1% will supply less nitrogen to a crop during the growing season than a soil with an organic carbon content of 4%.

The difference between a soil's ability to release nutrients for plant growth and the demand for those nutrients by a crop with a given potential underpins the practice of applying less nutrients where the yield potential is low and more nutrients where the yield potential is high. Adams et al. (2000) demonstrated that using variable estimates of achievable yield within a paddock was better for deriving nitrogen recommendations than using a paddock average. Providing a variable estimate of nitrogen supply did improve recommendations, but only slightly.

Based on the above experience, agronomists in Western Australia apply the following zoning for fertiliser. Areas that are stable and high performing are zoned for high fertiliser rates and variable high performing areas are zoned average unless the client overrules. For example, they may note that variation is observed only one year in five and wish to treat the variable area as 'high potential' and therefore a high fertiliser input zone. Poor areas, whether stable or unstable, are zoned poor and receive reduced inputs.

In Western Australia a three-tiered fertiliser overlay based on seasonal (temporal) variation is also applied. If the autumn break is before the end of the first week in May it is considered to indicate potential for an above average year and an overall higher input regime is selected. A season where sowing starts in June is considered a lower potential season and an overall lower fertiliser regime is chosen. The third option is when sowing starts between the two and this is treated as an average year. Thus there are three zones by three seasonal options, which are determined based on the break. Most states have an equivalent system, in some cases based on stored soil moisture.

There is one last interaction between potential yield and fertiliser zoning that is worth noting. A farmer in the eastern wheatbelt of Western Australia in a good year might grow a 1.8 t/ha crop, in an average year a 1.4 t/ha crop and in a bad year about 0.8 t/ha crop. Therefore, in the poor year it will be very unlikely that a yield variation of 1.5 t/ha between high and low yielding parts of the paddock will occur, making zoning and VRT unrealistic.

In a year with a late autumn break the most profitable decision in marginal environments is often not to sow a crop. However, if a farmer decides to sow in such a year, then PA information allows high risk paddocks or zones (seasonally very unstable) to be identified and sown last or not at all in a poor year. The high-risk paddocks or zones may be sown with no or a minimal amount of starter fertiliser and without using VRT, the more fertile areas could be sown first but again with little or no fertiliser.

Therefore, based on current experience, VRT would only be used in a good or above average year where the crop potential warrants the variable application.

4.2.6d Assessing the payoffs to variable fertiliser management in the context of PA

Author: Michael Robertson, CSIRO Sustainable Ecosystems

The following information is based on work in progress

One of the key selection criteria for the use of zone management over uniform management for fertiliser application is the economic advantages gained. There are many claims arising from single season experiments done in commercial situations that purport to show large economic advantages to zone over uniform management.

From first principles it would be expected that the dollar per hectare advantage to zone management would be a function of how different the various zones in a given paddock were in terms of average yield and area, the shape of the yield response to varying rates of the fertiliser, and relevant costs and prices that were applied.

This analysis can be done from first principles by deriving response curves of the dollar advantage of zone versus uniform management as a function of the yield differences between zones, as well as overall yield level, zone areas, and costs and prices. The analysis described below is for a single nutrient (nitrogen, N) on wheat, a crop-nutrient response situation about which we have considerable knowledge and can simulate with crop models.

In order to make this analysis as generic and therefore transportable as possible, the following (questionable) assumptions were made:

- That if the asymptotic yield with respect to fertiliser input is known, then it is possible to derive the Mitsherlich curve of yield versus fertiliser, ignoring the contribution from soil sources and assuming that yield=0 when fertiliser=0 (see Figure 4.2.6d1). The form of the curve is Y = Ymax - Ymax[exp(-c*N)], where N is the rate of fertiliser, Y is yield and c is the curve shape parameter. One can derive a family of response curves for Y of wheat versus rate of nitrogen across a range of soil types and seasonal conditions, and find that the parameter c is quite conservative and can be predicted as a negative function of Ymax. The ability of being able to generate a curve of Y versus N if Ymax is known, means that Y can be predicted for any value of N. This analysis also assumes that haying-off-type responses are uncommon or unimportant and that the Mitsherlich response covers most situations.

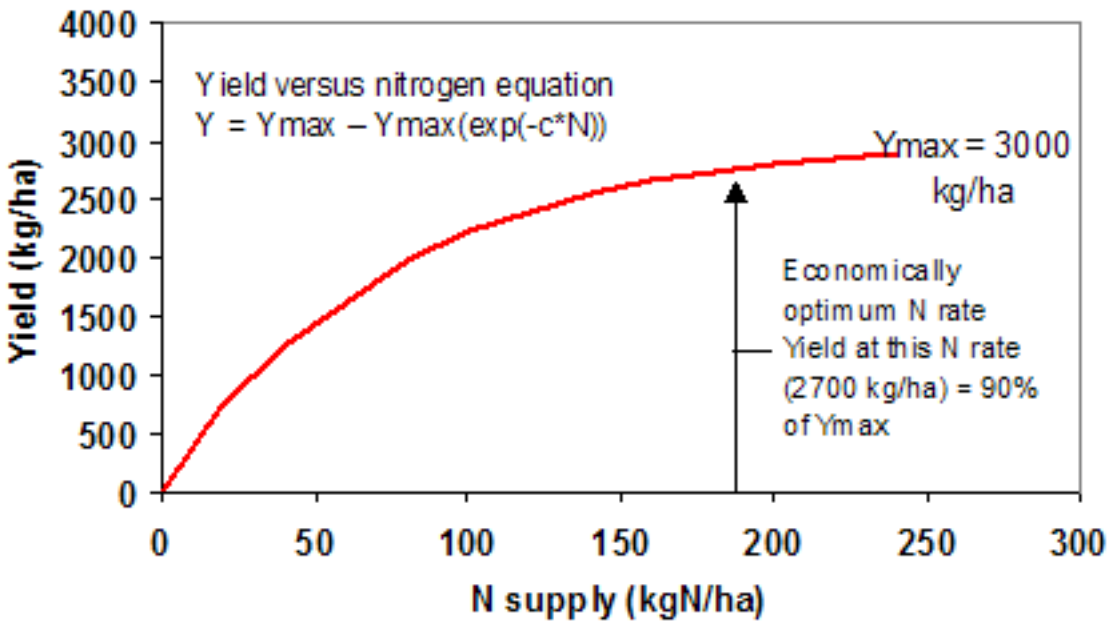


Figure 4.2.6d1. Example of a nitrogen (N) versus yield response curve for wheat used in this analysis. In this example the yield potential (Ymax) is 3000 kg/ha, the economically optimum N rate is 180 kg N/ha and the yield at the economically optimum N rate is 2700 kg/ha.

- That the yield at the economic optimum rate of nitrogen is a constant fraction of the biological maximum yield (Ymax). For given prices (wheat $250/t) and costs (urea $1/kg N), the yield at the economic optimum nitrogen rate is about 90% of Ymax. For a combination of extreme prices ($150/t) and costs ($1.5/kg) this percentage shifts to 80%.

Therefore, if Ymax is known, then the nitrogen rate at the economic optimum can be predicted using these first two assumptions.

- Protein considerations are ignored in this example.
- Other variable costs of production are ignored in this example (e.g. harvesting), but can be accommodated by considering the commodity price as net of variable costs.
- A management zone in a paddock can be represented for management purposes as having an 'average' yield and a given area.

Applying these assumptions, for the case of nitrogen fertiliser on wheat, given the area of each zone and its average yield (and therefore the economic optimum nitrogen rate) it is possible to calculate:

- The dollar return from fertilising the whole paddock at the economic optimum using the spatially weighted paddock average.
- The dollar return from fertilising each zone to its economic optimum, therefore the dollar advantage in each zone to zone management over uniform management.

This analysis yields the following responses for a paddock that has three zones of equal size, wheat price is $250/t, nitrogen cost is $1/kg (pink line in Figure 4.2.6d2). Yield of the lowest yielding zone is either 0.5, 1 or 2 t/ha and the difference between it and the highest yielding zone ranges from 1 to 4 t/ha. The yield of the middle zone is assumed to be the average of the high and low zones.

The response shows that the dollar advantage varies from $1/ha to $35/ha, which corresponds to the range of figures quoted recently from GRDC SIP09 studies. Advantages to zone management greater than $10/ha will only occur if the high and low zones differ by at least 2.5 t/ha. These correspond to gross margin increases of about 3%.

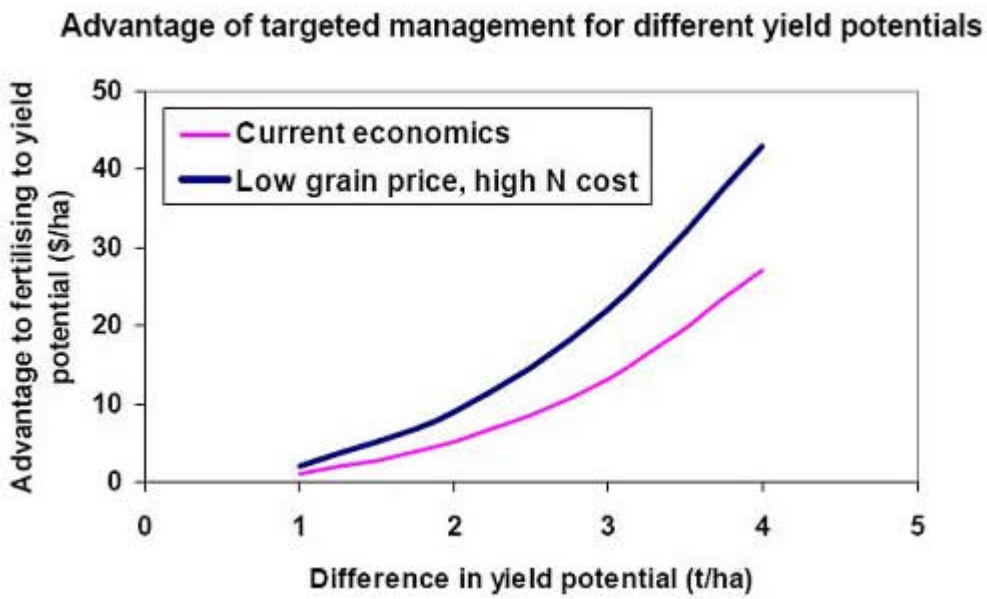


Figure 4.2.6d2. A higher difference in yield potential between zones, and higher growing costs in relation to grain prices, both make use of PA/VRT more attractive financially.

In contrast, the dollar advantage was greater when prices and costs where more marginal for cereal production (the blue line in Figure 4.2.6d2 - $150/t and $1.5/kg N, respectively). Under this situation only a 2 t/ha difference between high and low zones is required to rise above $10/ha.

It must be emphasised that this analysis only considers one nutrient (nitrogen) on wheat. Clearly, if multiple nutrients are being considered then the advantages to zone management over uniform management will be greater that those indicated here.

4.2.7 Using precision agriculture to manage post-emergence agronomy

Authors: Ian Maling, Silverfox Solutions Pty Ltd, and Matthew Adams, Satellite Remote Sensing Services, WA Department of Land Information

The three main post-emergent applications of PA are in nutrient, weed and pest management.

4.2.7a Nutrient management

The in-season management of nitrogen is the main post-emergent application of PA in relation to crop nutrition. However, foliar application of micronutrients may have application in some situations.

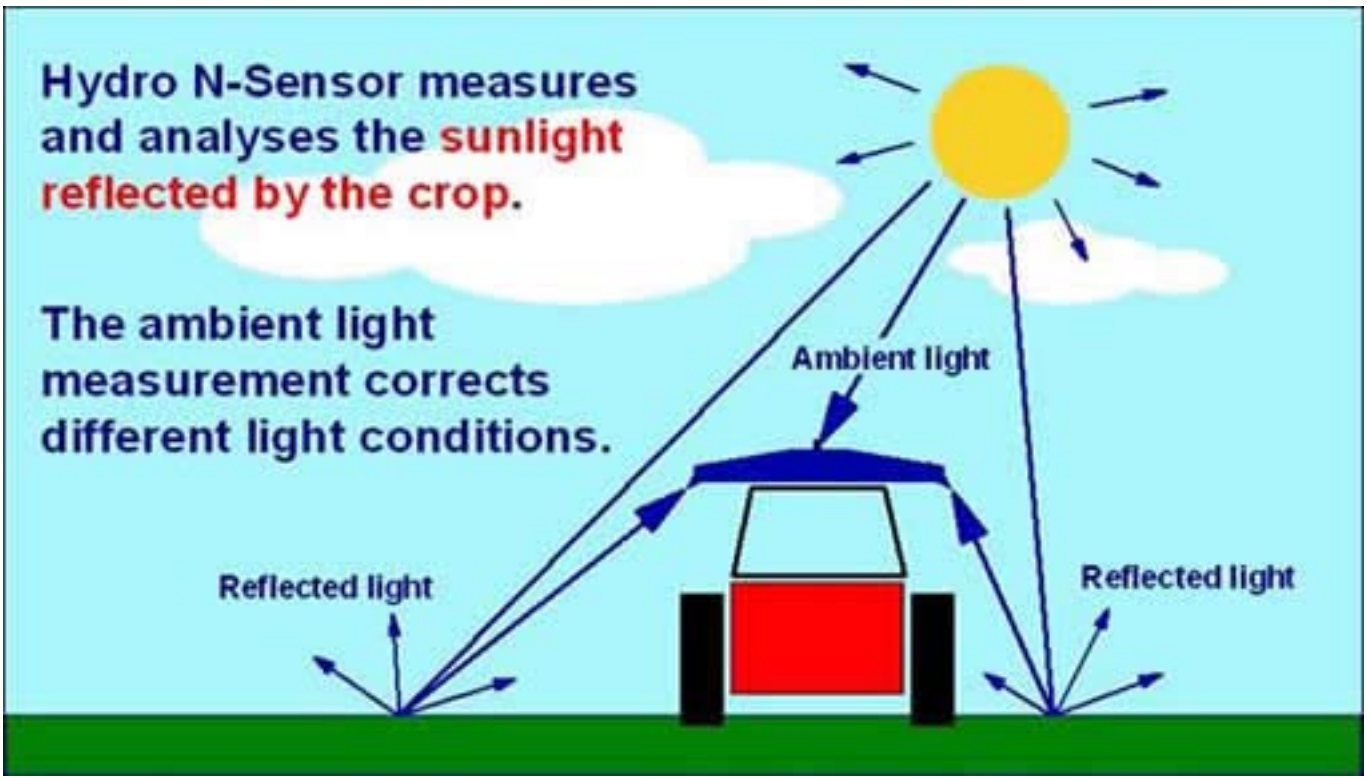
There are two general nitrogen management methods being trialled in Australia. The French system Farmstar®, marketed in Australia as AgriView® (http://www.terrabyte.net.au/agriview.htm), provides in-crop nitrogen application maps. Presently, calibrations for Australian conditions are being developed. This system uses satellite or airborne imagery coupled with estimates of potential yield for different zones, derived from intuition or climate forecasts and/or soil tests to estimate whether sufficient nitrogen is present to supply a crop at a given yield potential at that point in the season. A nitrogen fertiliser map is derived from this analysis and delivered to the grower. This can be updated through the growing season as condition change.

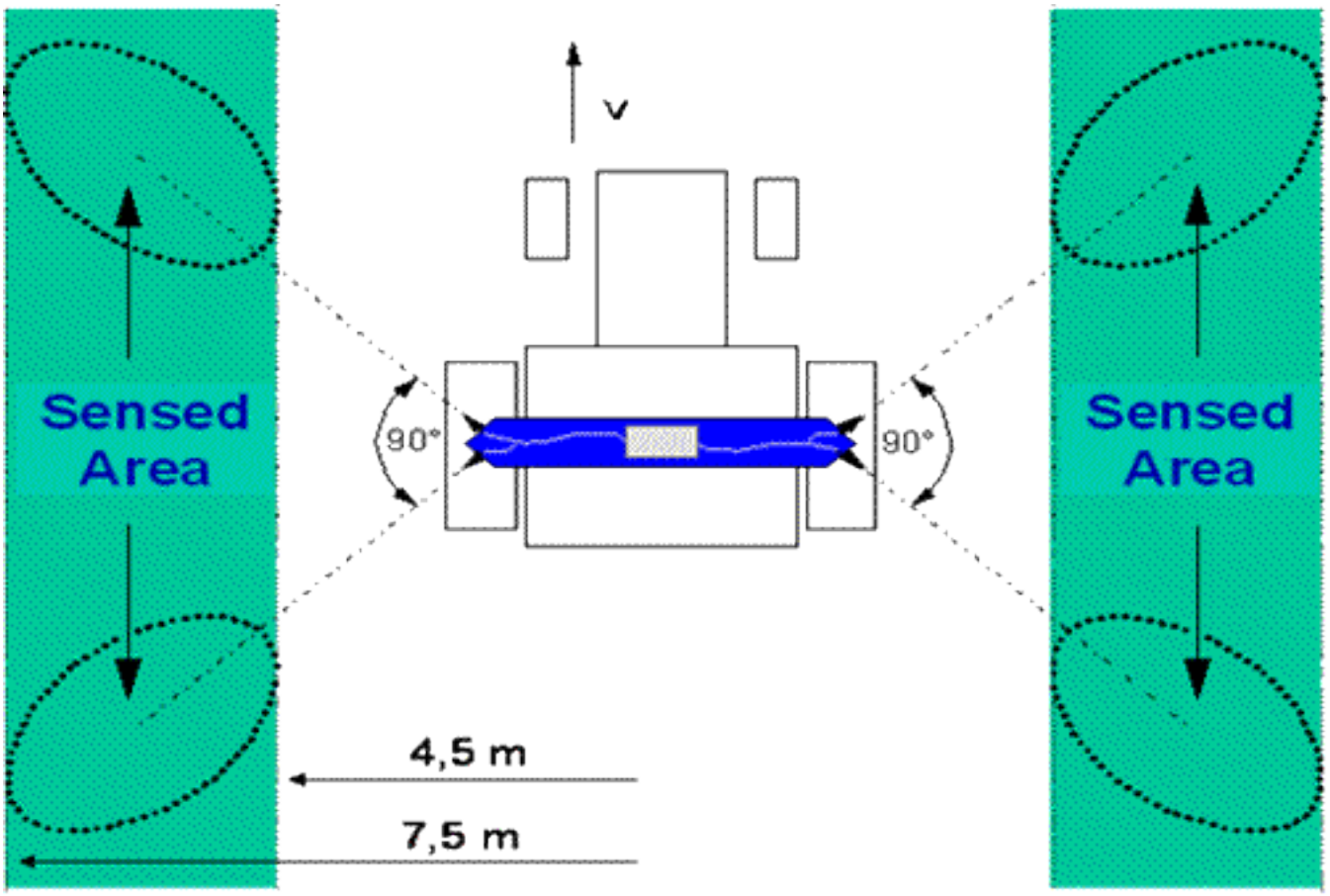
The other nitrogen management method being trialled uses an on-the-go sensor to determine nitrogen rate at the time of application. Greenseeker® (http://www.greenseeker.com/greenseeker_faqs.html) and N-Sensor (See section 4.2.7a) are examples of this method. Essentially these systems compare the normalised difference vegetation index (NDVI) of the crop in front of the tractor to the NDVI of a check plot that has received adequate nitrogen or of a relatively uniform part of the crop (selected by visual inspection). Based on this calibration, nitrogen rates are altered. This system is in the early trial stage in Australia, but is likely to be most applicable where nitrogen is the key limiting factor affecting production. Currently, the system cannot identify an area that has a low NDVI due to a subsoil constraint versus one that has a low NDVI because it is truly deficient or low in nitrogen. It is conceivable that future developments will allow for 'exceptional' circumstances.

Using an N-Sensor to vary in-crop nitrogen applications

Author: Allan Mayfield, Allan Mayfield Consulting

The Southern Precision Agriculture Association (SPAA) is trialling an N-Sensor to determine whether a variable rate of nitrogen produces a higher yield than a constant rate when used post-emergence in cereal crops. This N-Sensor, developed by the European company Yara, is used commercially in Europe by 350 growers and contractors, but is currently not commercially available in Australia.
Fitted to the roof of the tractor, it scans crops and automatically regulates the rate of nitrogen fertiliser spread according to the greenness and biomass of the crop (see Figure 4.2.7a1).
Yara





The N-Sensor scans an area of 50 m² each second

Figure 4.2.7a1. Principle of the N-Sensor system (source: Yara).

This multispectral scanner measures the light reflectance properties of the crop canopy in the range 450-900 nm.& In the visible wavelength range (400-700 nm) the reflectance is indicative of leaf chlorophyll content and hence, the crop nitrogen status.& In the near-infrared region (700-900 nm), higher reflectance indicates greater crop biomass (see Figure 4.2.7a2).

The N-Sensor unit consists of two diode array spectrometers: one spectrometer collects the crop reflectance data on both sides of the tractor; the second spectrometer measures the irradiance conditions at the same time, in order to correct the reflectance signal due to changes in sun angle and cloud cover. Normal operating time is from 1000 to 1600 hours. The system is controlled through a terminal that displays current system information and logs crop and GPS data on a flash card to produce a paddock map (see Figure 4.2.7a4).

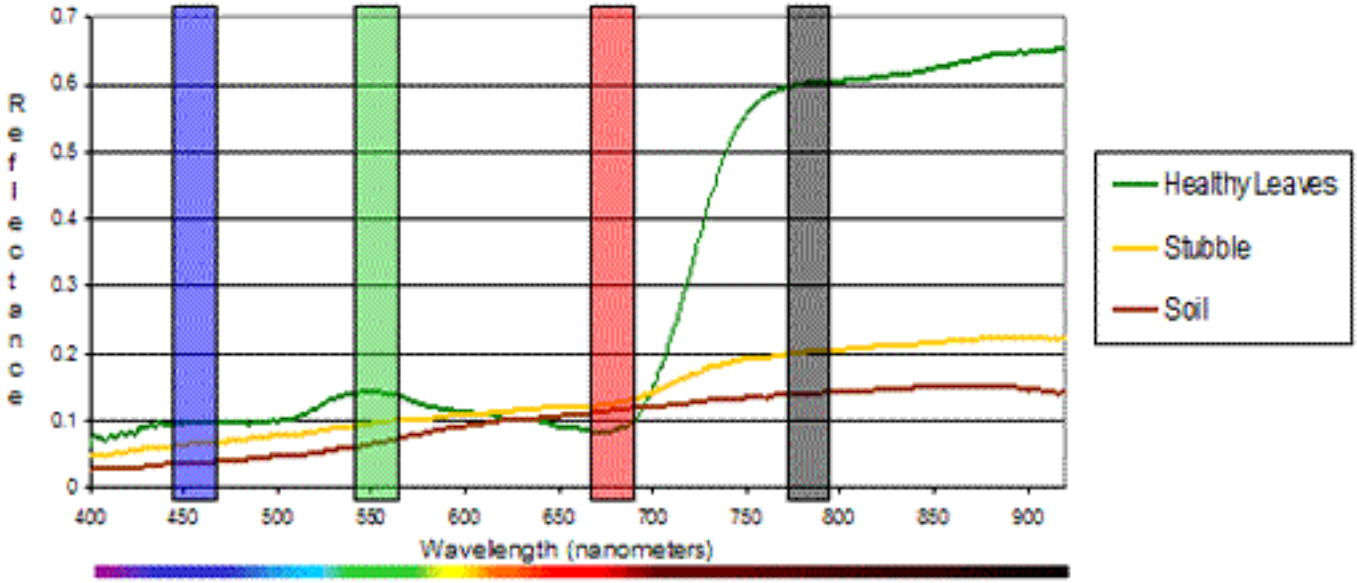


Figure 4.2.7a2. Spectral resolution of the N-Sensor. Vegetation spectral reflectance (lines) and standard reflectance bands (bars) (source: Yara).

A pre-determined fertiliser rate is set in the control box after scanning a small part of the crop. Thereafter the fertiliser rate will vary around this value. Where the crop is a paler green a higher rate is applied, and where the crop is a darker green a lower rate is applied. This can also be reset to apply more nitrogen fertiliser to darker green areas and less to paler green areas, for example to increase protein in the better areas of the crop. Alternatively, crops can be scanned earlier, for example when spraying herbicide. Crops can then be checked to identify causes of yellowing before applying the fertiliser.

There is also a low biomass 'cut-off' setting which prevents excessive amounts of fertiliser being applied to parts of the crop which may be thin due to other factors, such as poor emergence or pest damage (see Figure 4.2.7a3).

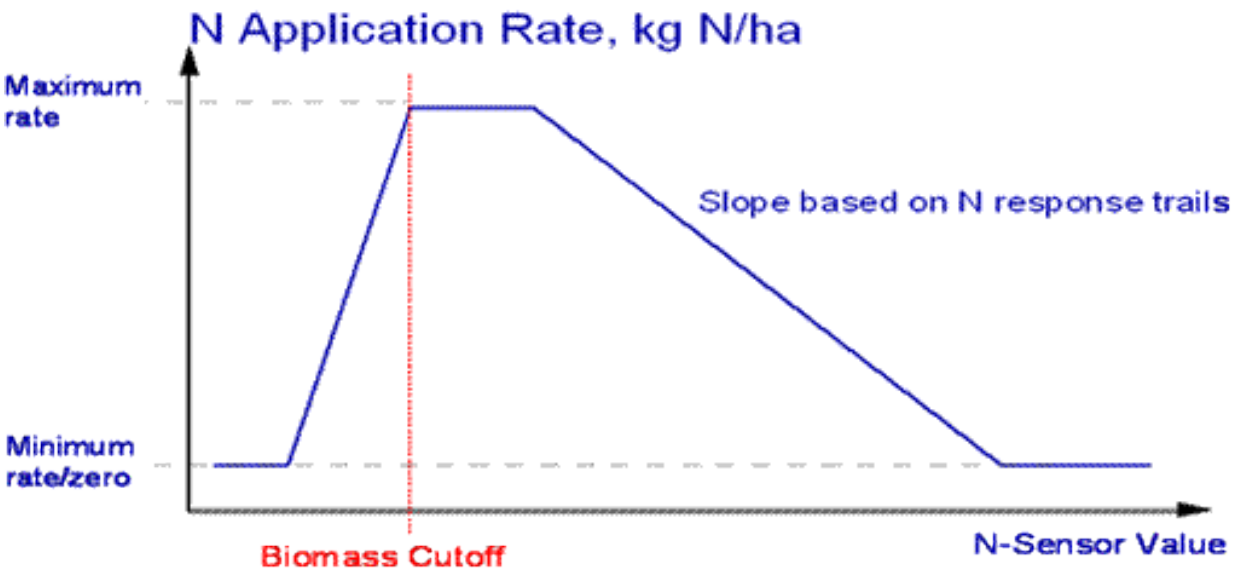


Figure 4.2.7a3. The principle of how the N Sensor readings are converted into a nitrogen application rate (source: Yara).

To test the value of variable rate application of post-emergence nitrogen, the N-Sensor is being used to apply strips of nitrogen fertiliser at a variable rate and then at a constant rate alongside (using the same total amount of fertiliser). Examples of paddock maps of crop biomass and nitrogen application rates generated by the N-Sensor set at a variable rate are shown in Figure 4.2.7a4.

The SPAA trials will be repeated in the 2006 winter cropping season In preliminary trials at three sites in South Australia in 2004, wheat yield increases with a variable compared with a constant rate ranged between 0 and 4%. In the 2005 trials, yield change (variable versus constant rate of nitrogen application) varied from -1.5 to +5.7%. The average increase in yield reported from trials in Europe is about 3%. Grain protein in the European trials was also slightly higher with variable rate application.

The N-Sensor is also being used to map variation across crops in New South Wales, Victoria and South Australia in the SIP09 research program. This information is used with other crop and soil details to better define zones for differential management across paddocks.

In Europe, the N-Sensor is being trialled for other possible uses. These include variable rate desiccation of crops with herbicides and variable rate application of fungicides according to differences in the crop biomass across the paddock, that is, higher rates are being applied to thicker parts of the crop and lower rates to thinner parts.

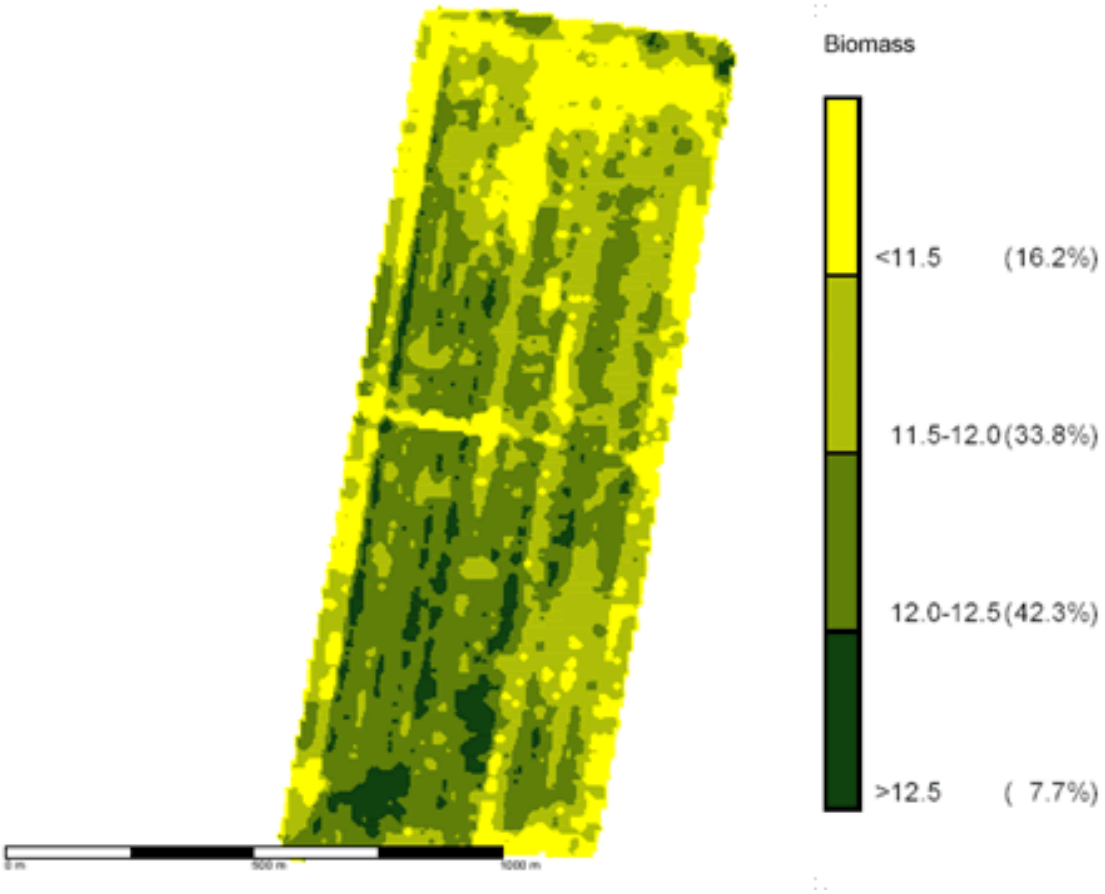


Figure 4.2.7a4. Examples of crop biomass and nitrogen application maps produced by the N-Sensor (source: Allan Mayfield Consulting).

4.2.7b Pest management

Weeds

Targeted herbicide application is another opportunity for using PA for in-season agronomy. The two main approachesare 'on-the go' or zone based which is derived from crop scouting or in-season airborne images.

One commercially available 'on-the-go' system is the Weedseeker® from NTech Industries, the same company that produces the Greenseeker™ system. Weedseeker® is designed for use with shielded inter-row spray systems.

It uses NDVI to identify plants that are growing in the inter-row, where they should not be, and triggers herbicide to be applied only when plants are identified. Growers are also using this technology in fallow paddocks where weeds may be scattered at a low density across a paddock.

Other systems are being designed to be capable of discriminating broadleaf weed, within grasses, for example radish in a wheat crop, using image pattern recognition technology and applying selective herbicide only when needed.

Diseases and insects

Fungicides and insecticides may also be applied at different rates in management zones that have been derived for these purposes. In Australia research in this area is continuing, and results show that across a paddock there is more variation in disease than there is with soil factors such as pH or nutrients.

PA is being used to manage soil diseases such as crown rot. Rather than defining disease management zones, auto steer with 2 cm accuracy is being used to achieve inter row seeding. Researchers in South Australia and New South Wales have observed that root diseases are lower in the inter-row than under the previous year's crop, and increases in yield have been achieved from sowing in the inter-row.

4.2.8 Using precision agriculture for on-farm research

'Designing your own on-farm experiments: How precision agriculture can help' is a publication from GRDC and CSIRO. Chapters include experimental designs with and without VRT and methods for evaluating and analysing data.

4.2.9 Potential management classes at the whole-farm and catchment scale

Authors: Madeline Florin and Brett Whelan, Australian Centre for Precision Agriculture, the University of Sydney

Information on variability in resources and risks should eventually be available across whole-farm enterprises and assimilated into tactical and strategic planning. This is being driven by a greater desire of land managers to understand the causes/effects of the variability in their systems and therefore operate more efficiently. Research is now being undertaken to extend the management class or zone concept from individual paddocks to whole farms. This is an important step in the perpetuation of practical PA research and uptake. Extension from farms to catchments will be an equally important process.

There are a number of reasons why describing management classes across whole farms can be valuable. They should provide:

- The ability to prioritise areas for site-specific crop management (SSCM). In reality, SSCM may not be appropriate everywhere on every farm and a whole-farm perspective can aid in locating paddocks that are suitable for further site-specific exploration. At this scale economic considerations can be more comprehensively incorporated into the analysis
- A holistic viewpoint to integrate environmental goals. At the paddock-scale, environmental impacts may be difficult to segregate and, between paddocks at any one time, there may be operations undertaken that are based on competing farm objectives. The whole-farm scale should make it easier to analyse and make decisions that are more relevant to the whole enterprise

The main challenge in this area of work is the establishment of methods to delineate production classes across whole farms. Currently, the costs associated with collecting adequate information for deriving management classes are large and consequently inhibit application across whole farms.

A method that would enable researchers to infer suitably fine-scale information across whole farms in an efficient way is required. One way of achieving this is to utilise a combination of data layers at different spatial resolutions and extents. The idea here is to undertake a coarse-scale whole-farm assessment using a continuous sensing system such as airborne EMI or gammaradiometrics. This data would be used to choose a small number of paddocks which cover the extent of the variation observed. These paddocks would be studied in fine-scale for site-specific crop management and the relationships between the fine and coarse-scale data used to predict management class properties over the whole farm.

Another challenge associated with this work is developing new ways to use potential management classes within a whole-farm perspective for sustainable farm outcomes. One idea relevant to both farm and catchment scale is the consideration of alternative land uses. Understanding the nature of potential management classes in terms of yield potentials and potential to perform environmental services or disservices can be used to decide suitable combinations of land use. Mosaic farming is an application of this concept where land uses (annual crops, pastures and deep-rooted perennials) are matched in space to soil and landscape characteristics.

4.2.10 Value of precision agriculture post-farm gate for QA/QC and EMS

Author: Miles Dracup, Water Corporation WA (formerly Department of Agriculture WA)

Environmental Management Systems (EMS) are designed to help businesses manage their impacts on the environment. They focus on the production process and provide a structured framework for achieving continual improvements in environmental performance, using the management cycle of Plan-Do-Check-Improve. The EMS of a business can be aligned with an accreditation standard and audited against it to access environmental performance benefits, such as in the market place or acceptance in a supply chain.

There are many potential benefits of having an EMS. Although not yet well developed, they include: increasing profitability and operating efficiencies, meeting market/supply chain requirements, reducing legal liability, altruism, and building community confidence.

There are a number of potential synergies between EMS and PA:

- EMS fosters implementation of management practices to achieve better environmental performance by a business. PA can be an effective tool to achieve this, particularly where environmental performance issues are related to spatial variability.
- PA can help integrate profitability and conservation, particularly through targeted use of inputs and increased efficiency of use.
- EMS can provide a framework for integrating PA into farm business planning, structuring the identification of land management objectives and priorities, appropriate practices and monitoring of benefits.
- EMS can enable a farm to access benefits of PA that are contingent on environmental outcomes.
- Data collected for PA, such as for variable application of fertilisers or pesticides, can be used to assess whether EMS goals are being achieved.

Spatial management tools

PA tools developed to focus management on spatial variability will find a logical home in farm-level EMS. An EMS requires identification of the important environmental impacts and of where and when they occur and/or their source(s). Although spatial management tools for PA focus on identifying variability in performance, the management of that variability focuses on applying appropriate treatments and rates to maximise efficiency and use of inputs and manage the land appropriately. Ideally, this simultaneously increases profitability, eco-efficiency and resource protection.

Tools such as biomass imagery, yield monitoring and gammaradiometrics (See section 3.1.1)provide cost effective means of visualising spatial variability and thus targeting management action and monitoring the benefits. Decisions on how to manage the variability require diagnosis of causes, and assessment of their importance, as a basis for prioritising action. This enables appropriate and targeted management of priority sources of variability, and ideally the benefits are monitored and evaluated. PA should therefore be a central plank in a farm's EMS.

Site-specific management

Site-specific management (PA) can take a number of forms, all likely to lead to cleaner and more efficient production systems and can therefore help meet the objectives of an EMSas well as components of QA and QC programs.

Land use planning aims to match land use with capability and PA data can help to achieve this. For example, gross margin analysis might identify non-profitable areas for cropping, which might be better managed (from both environmental and economic perspectives) as perennial vegetation.

Productivity maps can be used to identify areas with high and low input responses, which can be used as a basis for spatially targeting inputs. For example, over fertilising non-responsive areas could pollute aquifers or water courses and

waste expensive inputs, whereas matching fertiliser application to needs would improve efficiency of use and profitability.

Maps of productivity limitations can be used to target soil management. For example, maps of harvest index or soil moisture at harvest can potentially identify areas of incomplete soil water extraction, indicating possible soil constraints, such as compaction layers and acidity. These lead to reduced uptake of water, the most widely limiting input. Poor water extraction also contributes to groundwater recharge. Targeting soil amelioration to areas of greatest need can improve its cost effectiveness and likelihood of implementation.

Diagnostic approaches relating spatial variability to causes will facilitate issue specific management, whether it is, for example, input limitations, subsoil constraints or soil limitations. Similarly, integrated modelling will help match inputs with needs. Limiting inputs such as pesticides to only those areas of a farm or paddock where they are required, and limiting the amounts applied to only what is required, provide a method that will assist growers with both QA and QC programs.

PA equipment also has the potential for automatic and spatially-registered recording of all paddock operations, something that may in future become important in providing information required by food processors and value chains. This potential of PA is yet to be realised, but could become an important driver for adoption.

4.3.1 Linking seasonal forecasting with precision agriculture

Authors: Daniel Rodriguez Agricultural Production Systems Research Unit (APSRU), Queensland Department of Primary Industries and Fisheries, Miles Dracup, Water Corporation WA (formerly Department of Agriculture WA), and David Tennant, Department of Agriculture WA

For most Australian agro-ecological regions, there are key decision points within the growing season when a range of tactical decisions, such as variable rate nutrient applications, can be made or modified according to seasonal conditions. Stored soil water, rainfall and rainfall distribution are key factors determining yield potential, so weather to date and outlooks for the rest of the season are important factors to consider.

Farmers apply seasonal forecast information to improve planning and implement decisions. Most planning decisions (e.g. crop, variety, predrilled fertilisation and area to be planted) are made before the growing season starts. These decisions are likely to benefit from good seasonal forecasts, providing there is adequate lead-time. Thereafter, tactical decisions, for example whether to apply more fertiliser or sprays or de-stock, can also be supported by quality intra-seasonal and seasonal forecasts and crop yield outlooks.

A number of studies have indicated that increases in profit (5-20%) and/or reductions in risk (up to 35%) (i.e. proportion of years of negative returns) can be achieved by adjusting crop nitrogen inputs and tuning cultivar maturity with the use of existing seasonal forecasting tools.& Benefits from conserving resources including more efficient use of water and less soil loss have also been mentioned in these studies (Hammer et al. 1996; Nelson et al. 2002; Lythgoe et al. 2004; Anwar et al. 2006).

One of the most important causes of seasonal variability in Australia is the El Niño Southern Oscillation (ENSO) phenomenon, which can provide the basis for predicting season types. However, the indices commonly used to predict ENSO do not have a consistent predictive capacity during early autumn, the time when farmers in Mediterranean environments are making some of their important decisions. Growers are therefore not confident in using the currently available indices in making cropping decisions. Seasonal forecasting is a rapidly evolving area and considerable advances have been made in recent years, providing farmers with a growing number of seasonal outlooks. Some of these providers can be found on the Internet, for example Bureau of Meteorology (www.bom.gov.au), the European Centre for Medium Range Weather Forecasts (www.ecmwf.int), Experimental Centre for Climate Prediction (www.ecpc.ucsd.edu), QDNR Long Paddock site (www.longpaddock.qld.gov.au), and the International Research Institute for Climate and Society (www.iri.columbia.edu). Outlooks for rainfall and temperature are usually published over sliding 3-month periods using a variety of methods ranging from statistical correlations with sea surface temperature (SST), or the Southern Oscillation Index (SOI), to global climate models.

The monitoring of higher frequency events like the Madden-Julian-Oscillation can also provide useful risk management information to decision makers. The Madden Julian Oscillation (MJO), also known as the 40-day wave, is a large scale oscillation (wave) in the equatorial region. The MJO originates over the Indian Ocean and travels east at 800 km per day (10 m/s). It has been shown that the location of the MJO, or phase, is linked with patterns in Australia's rainfall. This validates anecdotal evidence about the effect of the MJO recognised by many in the rural sector. The MJO website (www.cpc.ncep.noaa.gov/products) can show when and where regions of Australia may experience enhanced (suppressed) rainfall conditions, based on the phase of the MJO. Other synoptic factors ultimately determine rainfall, but these results can help farmers to forecast the increased (decreased) chance of rain as an MJO traverses the tropics.

Agricultural production systems in Australia are dynamic and diverse. Numerous interactions occur between soil, crop and climate, which are often difficult to identify and manage. Management decisions that relate to climate are also made at different times of the year and with different levels of significance for different farming systems. This is why the use of crop simulation models (See section 2.3.1) has been identified as essential to integrate and quantify processes and factors that interact across the different dimensions of the production system, the soil, the climate, the crop and its management. The Agricultural Production Systems Simulator (APSIM) has the capability to simulate the effects of interacting resources and agronomic inputs. Its modular format allows simulation of a large number

of different crop types as well as the major inputs that affect yield such as soil water at sowing, nitrogen availability, plant density etc.

Two important decision support tools that can provide objective assessments of management alternatives for specific crops and locations, the Web-based Yield Prophet ® and the WhopperCropper computer database, have been derived from the APSIM simulation framework. These decision support tools are subscription based, and can be used easily to combine results derived from the APSIM simulation framework with outcomes from seasonal climate forecasting systems.

Yield Prophet ® is an on-line point-based crop production model that provides grain growers with real-time information about the crop during growth. Its primary output is the forecast of yield probabilities based on the simulation of crop production from pre-sowing until harvest and the outcome of several seasonal climate forecasting tools. Yield Prophet ® is presently being commercialised by the Birchip Cropping Group in South Australia, Victoria, New South Wales and Western Australia.

WhopperCropper is a database of pre-run simulations with the APSIM model, that uses the outcomes from the five SOI phase seasonal climate forecasting system to produce probabilistic outlooks of crop yield production at a regional level. The pre-run scenarios are very quickly displayed and can be easily graphed in a number of formats. WhopperCropper training and distribution is now available through the company Nutrient Management Systems.

In agricultural areas with a Mediterranean-type of climate, knowledge of stored soil water is a useful basis for decision making at the start of the season, when the greatest decision making opportunities occur. Thereafter, further management decisions can be tailored to the season and forecasts as they unfold. These are the underlying principles behind other simpler alternative approaches to crop yield forecasting. In Western Australia a simple agro-climatic model (STIN) is used to produce wheat yield outlooks at the shire level. STIN predicts shire wheat yields, assuming yields are a function of soil water at sowing and the timing and amount of rainfall during the growing season. A similar approach has been recently developed for sorghum in Queensland. The seasonal sorghum outlook is based on the integration of a simple shire level agro-climatic sorghum stress index model, which is sensitive to (i) water deficit or excess during the growing season, (ii) actual climate data up to the forecasting date and (iii) projected climate data after that date. The projected data are drawn from historical analogue years based on similarity to the prevailing phase of the SOI.

Rules of thumb, such as relationships between April/May rainfall and growing season rainfall have been developed and used by farmers in southern Australia for some time to guide their management decisions.

Several tools are available to cover aspects of season tracking, to help with decisions at critical times. Information can be generated relating to stored soil water at or near sowing (PYCAL and STIN), relationships between early season rain and growing season rain (SOWHAT and Climate Variability Calculator), seasonal development (PYCAL and Climate Variability Calculator) and nitrogen fertiliser levels (SYN and SPLAT). Many of these tools have been developed by or are available from state departments, for example the Department of Agriculture WA and the Queensland departments of Primary Industries and of Natural Resources. Some other simple and popular tools include:

Rainman contains historical monthly and daily rainfall for 3800 locations and monthly and daily streamflow data for nearly 400 locations across Australia . Worldwide, Rainman contains monthly rainfall records for some 9500 locations across the world. This software can be used to analyse these records for individual locations for seasonal, monthly and daily patterns, forecast seasonal rainfall based on the SOI or SST, group locations for spatial analyses, import monthly and daily rainfall and streamflow data, and print results as tables and graphs or maps.

HowOften? is a program that explores long-term rainfall records to find how frequently rainfall events occur. Some examples of its applications include finding: how often planting opportunities occur? This can be used to evaluate the risk associated with opportunity cropping.

HowWet? is a computer program which uses farm rainfall records to estimate how much rain has been stored as plant available water, how much nitrogen has been mineralised in the soil, and how much erosion was caused by runoff water during the fallow period.

HowMuch? is an educational tool which uses rainfall records to estimate crop yields from crop water use efficiency and the plant available water capacity (PAWC) of a farmer's soil. With HowMuch? farmers can find relationships between planting dates and rainfall patterns, investigate which part of the planting window coincides with the best 'average' rainfall, try to match flowering date to a period of high rainfall, and determine whether flowering dates

coincide with periods of high probability of rainfall.

ChoicesChoices is a computer-based tool for developing a framework for calculating average gross margins for crop sequences or rotations.

Other sources of information on climate risk management can be found from:

CRIMFA (Climate Risk Information Management Farmer Association) provides timely seasonal climate risk information support to primary producers, advisors, researchers and interested parties.

The Long Paddock website is provided by the Queensland Government. It supplies decision-support information services to help clients better manage climatic risks and opportunities particularly those associated with the ENSO phenomenon.

The Managing Climate Variability Program (MCVP) focuses on research and development activities on improving climate prediction, providing better access to climate information, developing tools for tactical decision making and further adapting agricultural and natural resource management practices to Australia .

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4.3.2 Is long-term management of spatial variability warranted?

Author: Michael Robertson and Lisa Brennan, CSIRO Sustainable Ecosystems

In some cases, zones in a paddock are stable in their size and location. Under these conditions it is possible to take an approach to management where inputs are adjusted by zone but not by season, with the rate for each zone determined from the average long-term yield response.

Although stable in size and location, each zone will still have year-to-year yield variability. Therefore the input would be applied assuming that every season will be an average season, even though we know that that will not be the case.

Given this type of approach the conditions under which it is worth managing zones differently versus managing the paddock uniformly can be assessed. To do this, three things must be known:

1. The relative sizes of zones. This information can be gained from yield maps of the paddock, biomass images, aerial photographs or eyeball estimates.
2. Costs of inputs and prices for outputs that are relevant for the season under consideration, including the likely range of these if they are subject to short-term change
3. The biophysical response to inputs in each zone. In plain terms, for example, the fertiliser response curve. (See section 4.2.6d)

Given these three pieces of information, a spreadsheet calculator has been developed that can allow you to estimate the value of zone management versus uniform management.

Some general insights gained from this exercise include:

Many biophysical responses in agriculture generate an economic response that is flat around the optimum - the consequence is that there is only a relatively small loss of income from not applying the optimum rate of input.

The flatness of economic response curves means that their optimum or near-optimum input levels are more likely to be similar with those in other zones in the paddock even though they may have quite different yield levels. If the optima of economic responses for different zones overlap then returns to zone management, over uniform management, will be limited.

If the zone dominating the area of the paddock has a broad economic optimum then returns to zone management are reduced because it does not matter if the precise amount of fertiliser is applied to maximise return in all zones, versus just applying the amount that will maximise it for the whole paddock - returns in both cases will be similar being on the broad economic optima part of the curve.

If zones that dominate the area of the paddock have ‘pointy’ optima (i.e. associated with large reductions in income by applying above or below optimum rates) then returns to zone management are enhanced because there is more chance of economic losses

The marginal gain from zone management compared to uniform management is sensitive to prices and costs, particularly the ratio of the input cost to the output price.

Refer to Economics of zone management spread sheet [Excel doc, 90.5kb]

4.3.3 Is spatial variability worth managing differently for tactical decisions?

Authors: Michael Robertson and Lisa Brennan, CSIRO Sustainable Ecosystems

The response to managing stable zones differently within a paddock versus managing the paddock as a uniform management unit is confounded greatly by seasonal variation. Seasonal variation impacts on the performance of zones by varying the timing of management events (e.g. sowing, topdressing, harvesting) and varying crop yield and quality. Thus in a wet year zones may respond quite differently to each other and to inputs (e.g. fertiliser), whereas in a drought year zones may yield similarly because water is more limiting than nutrient supply.

Continuing the example of precision fertiliser application it is difficult to apply a consistent strategy to zones because in some seasons a zone may be over fertilised, while in another season it may be under-fertilised. With some idea of the likely seasonal prospects at the time that the input is applied (e.g. nitrogen fertiliser at sowing) it may be possible to maximise the benefits of zone management by not over-fertilising the low-yielding zones in poor years and not under-fertilising the high-yielding zones in the good years. However, since a farmer does not have perfect weather information at the time of applying fertiliser, it is not possible to know if the economically optimal rate is being applied.

Section 4.3.4 Managing spatial variability for tactical decisions when zones are unstable in size and location describes how to manage seasonal variation when zones are unreliable in their size, location and ranking.

So how important is it to predict the season correctly versus applying accurate spatial management?

We have conducted analyses on this question for fertiliser nitrogen management in wheat for both the Western Australian and northern New South Wales environments. The answer is similar in both cases, so for simplicity here we give a summary of the New South Wales analysis.

We compared scenarios for nitrogen fertiliser applied to wheat at sowing for four management situations over several seasons:

- Perfect management: economically optimal nitrogen rates were applied to each zone and adjusted for each season, based on full knowledge of the in-season climatic conditions. A farmer will never actually experience this situation because all currently-available seasonal forecast are not perfect. So, this option gives the upper limit of what is possible with seasonal and spatial management combined.
- Seasonal management: uniform application of nitrogen across a paddock (no zones) with the economically optimal nitrogen rate seasonally adjusted using perfect seasonal knowledge.
- Zonal management: management by zones, but rates in each zone were not seasonally adjusted. In each year, the economically optimal nitrogen rates for each zone in the average year were applied in all years.
- Uniform management: no spatial or seasonal adjustments were made to the nitrogen rate for this option. The economically optimal nitrogen rate for uniform nitrogen management in the 'medium' year was applied in all years.

Fertiliser rates for each strategy are summarised in Table 4.3.3.1.

Management	Zone	N fertiliser applied (kg/ha)		
		Good year	Medium year	Poor year
Perfect	1 (shallow)	114	24	7
	2 (medium)	130	55	21
	3 (deep)	148	82	54
	4 (extra deep)	165	99	78
Seasonal	1 (shallow)	142	70	42
	2 (medium)	142	70	42
	3 (deep)	142	70	42
	4 (extra deep)	142	70	42
Zone	1 (shallow)	24	24	24
	2 (medium)	55	55	55
	3 (deep)	82	82	82
	4 (extra deep)	99	99	99
Uniform	1 (shallow)	70	70	70
	2 (medium)	70	70	70
	3 (deep)	70	70	70
	4 (extra deep)	70	70	70

Table 4.3.3.1. Nitrogen (N) rates (kg/ha) applied to each zone in three season types for four nitrogen management strategies (perfect, seasonal, zone and uniform). The four zones varied in soil depth from shallow to extra deep and hence in plant available water capacity.

The seasonal management option has the effect of under-fertilising the good zone and over-fertilising the poor zone within each season, sometimes resulting in a yield decline associated with the crop 'haying-off' with too much nitrogen.

The zone management option under-fertilised in the good years and over-fertilised in the poor years. The economic significance of nitrogen excess was minor compared to nitrogen deficits because the price of nitrogen is low relative to the value of the crop.

Over the period tested, the 'seasonal management' strategy generated a greater proportion of the potential 'perfect management' returns than the 'zone management' and 'uniform management' options. The failure of the 'zone management' option to match the returns from the 'seasonal management' option, and even the 'uniform management' option, in the good year was its inability to exploit the potential yields of the good year with sufficient nitrogen.

The penalty for ignoring the season in the nitrogen management decision (failing to adjust rates to account for seasonal variation) was, in this case, greater than the penalty for ignoring spatial variability.

Management		Paddock returns by zone ($)			
	Zone	Good year	Medium year	Poor year	Total
Perfect	1 (shallow)	8514	1887	663	
	2 (medium)	13,495	5645	2790	
	3 (deep)	13,637	8247	6650	
	4 (extra deep)	17,220	10,192	8840	
	Total	52,866	25,971	18,943	97,781
Seasonal	1 (shallow)	8052	1125	-202	
	2 (medium)	13,153	5227	2230	
	3 (deep)	13,137	6350	4161	
	4 (extra deep)	10,368	7137	4121	
	Total	44,710	19,839	10,311	74,859
Zone	1 (shallow)	580	1887	388	
	2 (medium)	3182	5645	1873	
	3 (deep)	4981	8247	5925	
	4 (extra deep)	6967	10,192	8210	
	Total	15,709	25,971	16,395	58,075
Uniform	1 (shallow)	3937	1125	-967	
	2 (medium)	4284	5227	964	
	3 (deep)	4177	6350	6230	
	4 (extra deep)	4695	7137	7951	
	Total	17,094	19,839	14,178	51,111

Table 4.3.3.2. Paddock returns ($) by zone for each nitrogen (N) management strategy under three season types. This example is for a 100 ha paddock and a wheat price of $250/t and fertiliser of $1/kg N.

Further analyses have suggested that the economically optimal rates for each zone for the good season were also applied by growers in the medium seasons. Farmers have some confidence in being able to anticipate a poorer season at the time of applying nitrogen, for example, from a late sowing, low starting soil water and/or negative SOI at the time of the nitrogen application decision. Thus if nitrogen rate is only reduced in the poor seasons and one deliberately fertilises for a good season in all other years, then this improves returns over the zone management strategy and even better than the seasonal management strategy.

In summary

It is more important to predict the season correctly, even if the spatial distribution is then incorrect, than vice versa. Seasonal variation is much more significant financially, and hence adjusting target yield and inputs for seasonal conditions is crucial. Spatial variability can then be overlaid on the seasonal adjustment for the best result.

4.3.4 Managing spatial variability for tactical decisions when zones are unstable in size and location

Authors: Michael Robertson and Lisa Brennan, CSIRO Sustainable Ecosystems

Often zones in paddocks are unstable in their size, location and ranking from year-to-year. High yielding parts of the paddock in one year may be low yielding in other seasons, and vice versa.

As a result it is difficult to apply a consistent strategy to zones because in some seasons a zone may receive more input, fertiliser for example, than is required, while in another season it may be under-fertilised.

We have suggested that for this type of situation it may be possible to adopt the following tactical approach that involves adjusting fertiliser (especially nitrogen) within the season as the type of season and the location of the zones becomes apparent as the season unfolds.

The steps involve:

1. Start the season with low inputs of nitrogen at or before sowing
2. Estimate average paddock potential yield based on plant available water in the soil profile or rainfall received and/or forecast rain probability; together with experience, past yield records for the paddock, or some type of modelling to convert rainfall into a yield expectation
3. The average paddock yield can then be used to calculate the different yield levels occurring in various proportions of the paddock area (See section 4.3.4a). The exact location of these areas will be determined for that season in the step 4.
4. Locate points of the distribution in a paddock using in-season biomass imagery (See section 3.2.4i).. For winter cereal production this may involve an image in July or August where early growth differences are starting to become apparent but not so late that the biomass image has 'saturated'.
5. Manage inputs to meet expectations in each zone. The relationship between fertiliser nitrogen, for example and yield expectation, can be assessed using experience, past yield records for the paddock, or some type of modelling where fertiliser rate is converted into a yield in relation to the potential yield expectation.
6. Update potential yield estimates using in-season rainfall figures.

If steps 6 and 2 differ sufficiently, return to step 3

The value of this type of system is that:

- No prior knowledge is needed of the size and location of zones - this is indicated by the in-season biomass image.
- The updating of the seasonal yield expectation means that you will respond to the season as it evolves.

The approach does not rely on one method for estimating yield expectation, or the response of yield to inputs - anything from experience to past yield records for the paddock, or some type of modelling (e.g. water use efficiency or APSIM) can be used.

4.3.4a Partitioning of spatially averaged paddock yield expectations amongst zones

Author: Mike Robertson, CSIRO Sustainable Ecosystems

In PA, analysis of yield maps has concentrated on defining zones within a paddock that maximise the difference in average yield between zones. This leads to the expectation that widely differing zones should benefit from different management.

In such analyses it is helpful to know, for a given season, what proportion of the paddock is below or above a certain yield level. This enables inputs to be varied to match the yield expectation in each zone.

A consistent relationship has been found between the average yield in a paddock and the spread of yields across all individual points in the paddock. This means the yields follow what is called a normal (or bell-shaped) distribution (see Figure 4.3.4a1).

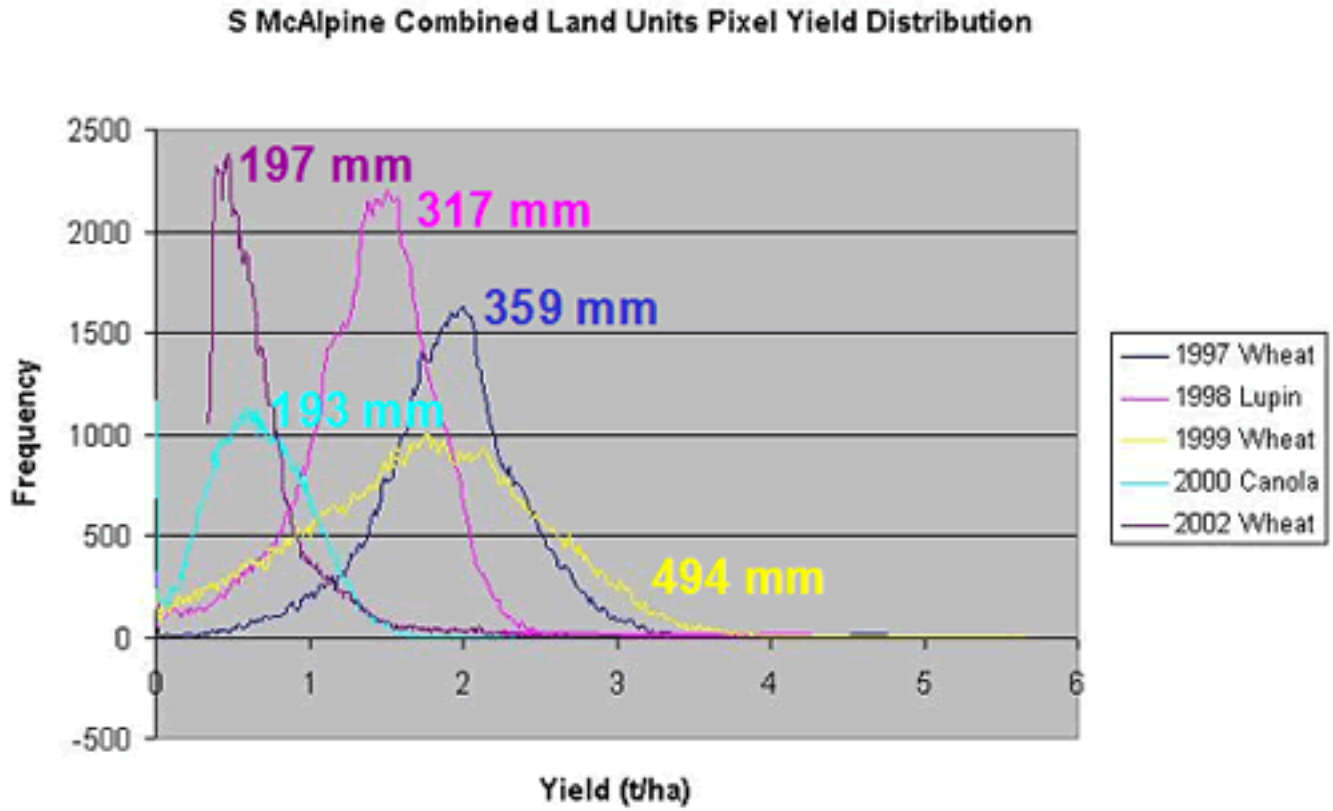


Figure 4.3.4a1. Yield distributions from different crop species and seasons from a paddock in Western Australia.

While Figure 4.3.4a1 shows consistent yield distributions for a paddock in Western Australia, research by a CSIRO team has found this to occur in other paddocks around Australia. The generality of this observation needs to be tested more widely before it can be used routinely. The method outlined in this section should only be considered provisional. Therefore, it is proposed for the purposes of simplicity that the bell-shaped distribution can be linearised into a triangular simplification.

This knowledge is very powerful because if the paddock yield is known or can be estimated (e.g. from rainfall records) then the proportion (%) of the paddock that will produce above a certain yield level (t/ha) can be estimated (see Table 4.3.4a1). For example, if average paddock yield is 2 t/ha then 13% of the paddock will yield less than 0.5 t/ha, and 75% of the paddock will yield less than 3 t/ha. It is important to note that this information does not identify the location of yield variability. To do that requires analysis of past yield maps. If the location of zones is known to change within a paddock, from season-to-season, then current season satellite imagery (e.g. NDVI) can be used to help annually specify locations in a paddock.

	Percent of								
Average paddock yield (t/ha)	0.5	1	1.5	2	3	4	6	8	12
0.5	50	100	100	100	100	100	100	100	100
1	25	50	75	100	100	100	100	100	100
1.5	17	33	50	67	100	100	100	100	100
2	13	25	38	50	75	100	100	100	100
3	8	17	25	33	50	67	100	100	100
4	6	13	19	25	38	50	75	100	100
5	5	10	15	20	30	40	60	80	100
6	4	8	13	17	25	33	50	67	100
7	4	7	11	14	21	29	43	57	86
8	3	6	9	13	19	25	38	50	75

Table 4.3.4.a1. The proportional area of a paddock with yields below the specified value for a range of average paddock yields. This analysis assumes that individual yield points in the paddock follow a linearised estimate of what is called a normal (or bell-shaped) distribution.

Within the GRDC PA research initiative, new tools are being developed and released progressively that link measures of seasonal variability, the scale of spatial variability, the relative stability of paddock yield zones, and the area cropped, to provide a more comprehensive tool that advisers and growers can use to determine whether PA will be a financially sound investment in particular situations.

Case Studies

Introduction

Michael and Bev Smith

For the past 10 years, Michael and Bev Smith, farmers from Moree, NSW, have developed their PA system; it now includes variable rate fertiliser and chemical applications, yield and protein monitoring, and autosteer. They are continually looking at new applications for PA technology to help improve the profitable management of their farm. Recently they have tested zone sampling for insects.

Andrew and Rodney Weidemann

As a family the Weidemanns have always aimed to keep up to date with the latest information and technology to help make their farm more profitable. Farming in the Wimmera, Victoria, Andrew and Rodney Weidemann started yield mapping in 1996. Ten years later PA technology plays a key part in all their farming enterprises, throughout the year.

Photo: Andrew Weidemann, courtesy of Grain Business

Ian Carter

Ian Carter knows that PA has evolved rapidly over the past 15 years but believes it still has a long way to go before it is widely adopted. He accepts that PA equipment is increasingly becoming just another part of the machinery budget with many items coming as standard, but before investing in non-standard items he needs to be sure there will be a benefit. For this reason he is using autosteer, precision spraying and yield mapping but is still gathering data before he moves into variable rate applications.

Mark Branson

Mark Branson is passionate about the possibilities PA technology has to offer, and since 1997 has been evolving his PA system that now includes variable rate seeding and fertiliser application, and autosteer.

Colin Stoeckel and his father Adrian

With three Zynx systems, autosteer on three tractors, two headers, and two yield and two protein monitors, Colin Stoeckel and his father Adrian have invested heavily in PA equipment to crop 7000-8000 ha of low rainfall Mallee country near Swan Reach, South Australia. They calculate that the majority of the equipment has paid for itself in the year of purchase.

Adam Inchbold

Investigating the potential for variable rate management has helped Victorian grower Adam Inchbold improve his understanding of the soil factors that influence his productivity.

David and Christina Forrester

Having observed considerable variability across their paddocks David and Christina Forrester adopted yield mapping and then variable rate nutrition. They have seen some incredible differences in productivity and profitability from applying PA to their nutrient program.

Rob Taylor

Darling Downs cropper Rob Taylor has been a practitioner of controlled traffic farming since the mid 1990s. However, the production of a whole-farm yield map in 2003 convinced him that he needed to completely change his farm layout in order to maximise water flow through his 2200 ha of cropping land.

Michael and Bev Smith

For the past 10 years, Michael and Bev Smith, farmers from Moree, NSW, have developed their PA system; it now includes variable rate fertiliser and chemical applications, yield and protein monitoring, and autosteer. They are continually looking at new applications for PA technology to help improve the profitable management of their farm. Recently they have tested zone sampling for insects.

In 1996 the Smith's purchased a new header and thought it would be good to have a yield monitor included so they could start yield mapping. They bought an AgLeader 2000 yield monitor, hired a GPS unit and by the end of harvest produced yield maps that showed considerable variation across the 1255 ha of winter cereals.

The Smith's soils are black basalt over sandstone. The depth to the sandstone layer varies across the farm. They suspected the yield variation was due to differences in soil depth and consequently water availability to the crop. Michael set-up the GPS and yield monitor on a quad bike and using a metal push probe measured moist soil depth, recorded the location and therefore detailed soil depth across a paddock. If he was starting today Michael would use EMI mapping to gather the soil data which would provide him with elevation data at the same time. Michael reports that aerial and satellite biomass imagery does not appear to have the consistency of relationship with final yield in the north, as much can happen between taking an image just prior to flowering and final grain fill.

Over several years soil depth across the whole farm was mapped and yield data gathered for both the winter cereals and chickpeas, and the summer crops of sorghum and sunflower. Generally a good relationship was seen between yield and soil depth, although Michael reports that in wet years anomalies were found in the chickpea paddocks due to some waterlogging and disease.

Variable rate and paddock zones

By 1998 the Smiths decided they wanted to manage the variation they had identified and purchased a variable rate driver for the airseeder, a Raven 700, two channel controller, and up-graded the yield monitor to an AgLeader PF3000 capable of variable rate control. They now have a John Deere Greenstar yield monitor/controller which is used in the JD 9660STS header and JD 8220 tractor. Greenstar is CANBUS rated, making it compatible with other CANBUS rated equipment; it also has a serial port on the GPS allowing connection to the AgLeader monitor.

Management zones were initially drawn manually based on the yield maps, and Michael and Bev found these to be stable over different seasons. They were also pleased to find that for their farm the zones were accurate when compared with zones produced using analytical software by the University of Sydney. The protein monitoring is still at an early stage but as more data are collected it will be used in the creation of nitrogen zones.

The management zones are programmed into the yield monitor together with a fertiliser rate for each zone. This information plus the location are fed to the Raven controller, which in-turn instructs the variable rate driver on the airseeder and sends details back to the yield monitor of what rate was actually applied. Although the Raven is able to control two inputs, for example seed and fertiliser, the AgLeader only controls one but allows a second to be manually adjusted from the tractor cab.

The change to variable rate nitrogen has resulted in approximately the same amount of fertiliser being applied across the farm but in a more targeted manner. In some paddocks savings of $14/ha have been recorded by more targeted use of urea and a further $6/ha by varying the use of starter fertiliser. If three management zones are used based on an average zone yield of 2.8 t/ha (low), 3.5 t/ha (medium) and 4.6 t/ha (high), urea is pre-drilled at 55 kg/ha (low),

69 kg/ha (medium) and 83 kg/ha (high). MAP or DAP are also applied at seeding to the three zones at similar ratios.

In a good season Michael tested variable rate seeding with the sorghum. His aim was to vary seeding rates to achieve increased germination in the deeper soils and better utilise the stored water; he was pleased with the result.

Software

Michael believes that farmers who would like to adopt variable rate technology need to have some interest in computers as setting-up the variable rate parameters has meant more time in the office. The Smiths use several software packages to manage their PA data. For variable rate they use a USA package called Farmworks, basically because it was the only software package available when they started. JDOffice is used to manage yield data, and JMP for integrating and analysing different sources of data and mapping. Vesper, the University of Sydney statistical program, is used to place all data on the same grid, which is vital if different sources of data are to be integrated.

Autosteer and controlled traffic

Having been driven to distraction with a light bar, the Smiths decided to invest in a John Deere Greenstar AutoTrac autosteer system in 2003. They had already converted to controlled traffic farming (CTF) on 9 m machinery widths, a 9 m grid aligned to the CTF runs is used by the Vesper software; this makes setting-up and analysing trials simpler. With the autosteer system they are able to optimise the advantages of CTF, including reduced overlap, less driver fatigue and the ability to concentrate on operating the machine rather than driving on the tracks in a straight line.

The combination of variable rate application, CTF, and autosteer have allowed Michael to experiment with variable rate spraying for Helicoverpa insects in chickpeas. Sampling highlighted that in the deeper soils insect numbers were above spray thresholds, whilst in poorer areas they were below. The tramlines allowed easy access to the areas of high population where a control spray was applied. This worked well for the first hatching although a more uniform distribution was found in the second hatching which required spraying of the whole paddock.

Words of wisdom for beginners

- Determine what is causing variation in your paddocks before launching into variable rate and try and assess if it is stable from year-to-year.
- Establish what you want to do with PA before investing in equipment and make sure that what you buy can meet your objectives.
- Not all PA technologies are currently equally applicable to all regions.

Colin Stoeckel and his father Adrian

With three Zynx systems, autosteer on three tractors, two headers, and two yield and two protein monitors, Colin Stoeckel and his father Adrian have invested heavily in PA equipment to crop 7000-8000 ha of low rainfall Mallee country near Swan Reach, South Australia. They calculate that the majority of the equipment has paid for itself in the year of purchase.

Farming with their wives Sonya and Dawn, one permanent and one part-time workman, Colin and Adrian Stoeckel run a simple system growing feed and malt barley. In 1999 they started variable rate farming, adjusting seed and fertiliser rates between the sand hills and the shallow flats. The average rainfall is 275 mm, and until recently they have used a constant seed and fertiliser rate resulting in uneven crop yields with crops on the shallow flats burning-off and those on the sand hills running out of nutrition.

Management zones were established in 1999 based on past knowledge and paddock history, and verified by soil testing. Zones were marked out by putting a KEE Zynx controller and GPS receiver in a ute and driving around the edge of the zone while logging them into the Maplink program. This one-off process took about 1 h per 400 ha. Colin admits they could have had many more management zones due to differences in soil type and depth but have managed to settle on between three and five. The zones are fine tuned each year based on yield data but frost and disease, issues that are not always correctly interpreted from yield maps, are also taken into consideration.

Variable rate

Since purchasing the variable rate controller substantial yield benefits and cost savings have been achieved. These combined to provide the rapid pay back for the PA investment. Barley on the flats now finishes fully, producing yields of about 1-2 t/ha compared with 0-1 t/ha before when they burned off. They also save on input cost with only 35 kg/ha seed, 0-5 kg/ha urea and 35-40 kg/ha MAP. On the sand hills yields have increased substantially and are normally now between 0.8 and 1.5 t/ha compared with 0.1-0.6 t/ha previously, with inputs now of 65 kg/ha seed, 40-60 kg/ha urea and 50 kg/ha MAP. Colin continues to experiment with different seed and fertiliser rates.

The Stoeckels run two seeders, each with three boxes. One is a Horwood Bagshaw electric drive airseeder, with a 19 m (62') Scaribar and DBS knife points at 30.5 cm (12") spacing, pulled by a Case STX 450 tractor. The other is linked to a Flexicoil seeder (same width and tyne spacing) pulled by CAT Challenger 95E tractor. Knife points are worked at about a 15 cm (6") depth for disease control and seeding depth is about 10 mm.

Variable rate is now controlled by a KEE Zynx multi channel controller, but they started with a KEE seedrate controller run through a laptop. No compatibility issues have occurred with the current set-up. With the Flexicoil seeder, the Zynx controls the Flexicoil monitor for variable rate application.

In addition to being able to vary the rate of application from each box (i.e. seed and two fertilisers), this controller is also able to regulate water rate for the spray rig mounted on the seeding bar.

A Dosatron injection unit allows the Stoeckels to mix water and herbicides in-line. Glyphosate and trifluralin are sprayed in front of the tyne, which Colin says works well in these soil types. Water rates are varied based on weed spectrum, weed size and spraying conditions.

Autosteer

In 2005, the Stoeckels invested in KEE autosteer, the base station gives them 2 cm accuracy where before they had only sub-1 m accuracy. In future they plan to sow between last years stubble rows with the hope of improving the environment for the emerging seed and to seed into an area with a lower concentration of root disease. If this produces benefits they will be on top of the savings autosteer has already provided. Colin calculates that eliminating overlap has saved them about 300 ha worth of inputs, seed, fertiliser and chemical, not to mention fuel and time. At harvest autosteer, which is in both the Case 2388 headers (AFS yield monitors had to be upgraded to work with 2 cm accuracy), allows the two headers to work in close proximity and by skipping a row, with an empty box, unloading on the go can be undertaken in any direction, which saves time. Autosteer on the headers also makes it very easy for the chaser bin driver to keep on line.

For the past two harvests Colin and Adrian have been testing a protein meter that uses NIR technology. Despite some early teething problems this is developing into a very useful tool that allows them to blend malting barley on the go.

Colin and Adrian are passionate about the advantages that PA technology has bought to their farming business. They have achieved solid financial returns from PA without spending hours in front of a computer. All members of the team are able to use the PA equipment, although Colin programs in all information that is required.

Words of wisdom for beginners

- When purchasing new equipment Colin tries to avoid mixing and matching systems and is particularly pleased with the KEE Zynx system as it can perform multiple tasks and everything he needs can be run off one monitor.
- For those moving into PA he suggests they try and establish all their current and possible future uses of PA before purchasing equipment.

Andrew and Rodney Weidemann

As a family the Weidemanns have always aimed to keep up to date with the latest information and technology to help make their farm more profitable. Farming in the Wimmera, Victoria, Andrew and Rodney Weidemann started yield mapping in 1996. Ten years later PA technology plays a key part in all their farming enterprises, throughout the year.

Photo: Andrew Weidemann, courtesy of Grain Business

With a Microtrak yield monitor fitted to the JD 9500 header and agronomic support from Pivot fertiliser company, Andrew and Rodney Weidemann first ventured into yield mapping in 1996. Their objective was to use the maps to identify locations to sample soil and build a database of soil characteristics across their farm. However, they ended up with many more questions than answers.

Today yield maps, EM38 soil surveys, satellite imagery and on-the go sensors are used to evaluate yield data and soil types in a paddock and make decisions on nitrogen applications in the crop. The average paddock size is 80 ha. The combination of technologies gives them a quicker understanding of the differences between soil types and the soils' capacity to hold nutrients and moisture to better target fertilisers to crop need. However, it was the addition of autosteer that has revolutionised their cropping program.

PA equipment

The Weidemann's run two StarFire 2 guidance systems (10 cm accuracy). This system is based on a subscription that costs $1250 a year for each of the two units.

They are happy with the 10 cm accuracy this system gives as in their self-mulching grey clays machinery does not trail accurately. Reliability/repeatability from year-to-year is of more importance to the Weidemanns than 2 cm accuracy. However, if a community base station where available they would consider subscribing to it, especially as they are interested in adopting inter-row seeding.

Andrew notes that most of the farm is on returned soldier settlement acreages, which were established as very square blocks. This provides an excellent guide when setting up for PA as they can set up on either 0 degrees or 90 degrees depending on the paddock direction, instead of using the normal A-B line required as a baseline for PA operations in each paddock.

One of the StarFire 2 systems is located on a John Deere 9760 header for yield monitoring and autosteer; the other system is on a John Deere tractor and is used for autosteer and variable rate control of the airseeder, guidance for spraying or guidance for spreading fertiliser.

A KEE Zynx rate controller is used to vary fertiliser output on the Simplicity seeder. Data are managed using PAM Farmstar software, Pocket PAM and JDOffice.

The total set-up cost for the current system was between $60 and 70K.

Autosteer

The Weidemanns work up-and-back, and aim to match machine working widths and wheel tracks to produce a full controlled traffic system. Currently the seeding bar is 11 m and the boom spray is 33 m but the header comb is only 9 m. Matching machinery will bring the benefits of reduced compaction and crop damage by wheeling, while autosteer immediately reduced overlap and allowed wide row crop spacing to be adopted.

A minimum 5% saving in seed, fertiliser and fuel costs is estimated since the introduction of autosteer which is a substantial annual saving across 2000 ha of crops. In cereals similar savings in herbicide and fungicide usage have been recorded but the savings in pulse crops have been even greater.

Autosteer has allowed chickpea and Aqua Dulce broad bean crops to be sown as paired rows, on 1 m row spacing. The autosteer helps ensure the row spacing is maintained accurately across the paddock, and allows a shielded sprayer to be used with non-selective herbicides for in-crop weed control. Detailed cost savings have not been calculated for herbicides, but for fungicides chemical use has been reduced by 50%.

A yield benefit was also recorded that may be due to better water use efficiency and improved weed control, especially of resistant ryegrass. In 2004 the district average for both crops was 1 t/ha, whilst the Weidemanns produced 1.4 t/ha of chickpeas and 1.75 t/ha of beans.

Management zones and variable rate nutrition

Andrew used a combination of information from yield maps and EM38 soil maps to produce management zones with their PAM Farmstar software.

In one paddock an EM38 survey identified significant differences in soil characteristics across the paddock. Soil testing within these different areas identified a correlation between available phosphorus in the areas defined by the EM38 survey. For example, phosphorus levels ranged from 54 mg/L (luxury amounts) to 17 mg/L (deficit). The Weidemanns are now experimenting with varying phosphorus inputs at seeding within these management zones. Rates vary from 25 kg/ha to 100 kg/ha depending on the type of fertiliser used.

However, zoning for nitrogen may take longer to achieve as zones have been found to flip-flop between high and low yield depending on the season. This may be due to the impact of a good crop removing more soil moisture in the previous season but more research is required to confirm this.

Satellite imagery is being evaluated as a means of determining in-crop nitrogen application zones. An on-the-go N-sensor that is able to vary nitrogen rates based on crop greenness is also being tested.

Disadvantages or limitations

Record keeping is a big issue with many aspects of PA. The Weidemanns found themselves on a steep learning curve when it came to computerised record keeping. A particular frustration is that much of the available yield monitoring software is not compatible with farm recording programs. They are happy with JDOffice but want to achieve more with it and hope the local support can help them.

Another problem has been the difficulty in finding expert advice for support and service. When buying PA technology they believe growers should ensure they know what hardware and software support is available and whether it is local or remotely based. The Weidemanns subscribe to a John Deere 24 h hotline; this is based in the USA and costs US$400 per year. This is not ideal but has been sufficient until now. They hope that the larger agricultural machinery manufacturers will start to offer a better level of support and service for their software and application.

Analysing yield data and producing yield maps is time consuming, and a further limitation is that PA can turn you into a computer nerd with the savings in time and fatigue from driving being substituted with hours working on the computer!

Words of wisdom for beginners

- Do not become hung up about accuracy, 10 cm is currently fine for all of our autosteer situations. For yield mapping and variable rate we feel 1 m accuracy is sufficient.
- Watch out for expensive, high level software that requires much learning. Also if you have old yield data, check that it can be read by newer software, for example our pre-2000 maps were on a Microtrac yield monitor held as .dat files and only expensive programs such as Farmstar can access this information.
- Ensure that any equipment and software purchased comes with high quality, preferably locally based, back-up.
- Think about computer record keeping at the start. Develop a logical system that allows easy retrieval.

Adam Inchbold

Investigating the potential for variable rate management has helped Victorian grower Adam Inchbold improve his understanding of the soil factors that influence his productivity.

Adam Inchbold farms 2250 ha with his parents at Yarrawonga. Each year about 55% of the farm is cropped under a rotation of wheat-canola-wheat-triticale or barley. The remainder is under pasture for 4 years and supports the self-replacing breeding and finishing beef herds. Rainfall is winter dominant with average growing season rainfall of 280-300 mm, and an average wheat yield of about 3.8 t/ha. Adam's objective is to optimise production from every hectare.

This objective has been hampered by the large variation in performance across a paddock. In 2003, four trial paddocks were established and an EM38 survey plus background data were used to delineate potential management zones. The EM38 survey cost about $5/ha. This was followed in 2003, 2004 and 2005 by extensive in-zone ground truthing of: topsoil depth and type, deep nitrogen, crop performance, yield mapping, and soil moisture using Gopher capacitance meters.

This work identified that the topsoil remained similar across most of the area surveyed. However, the properties of the subsoil changed significantly down the slope from the tops of the hills through the mid slope, both dominated by duplex soils, often clay loam over a sodic clay or stony subsoil, to the points of lowest elevation which tended to be heavier clay. These differences provide a key to identifying when and where the crop runs out of available soil water in drier seasons, and areas of superior drainage in wetter seasons.

This project is being undertaken by the Riverine Plains Farming Systems Group in collaboration with Brett Whelan at the Australian Centre for Precision Agriculture, University of Sydney , as part of the GRDC PA Initiative.

PA equipment

Adam has been yield monitoring since 2000. In 2004 he purchased an autosteer system (Autofarm/GPS Ag) and with an on-farm base station is achieving 2 cm accuracy. The system required an investment of about $50K but Adam believes it is the best and will provide substantial cost benefits over its life, not just from reduced inputs but also from improved yields generated by the accurate placement of inputs.

The autosteer system is moved between the spraying/spreading tractor and the harvester. The autosteer is also used to gather quality elevation data. A Trimble 4100 provides the GPS data for yield monitoring and variable control of the airseeder. In 2004 a protein monitor was fitted to the header.

Adam uses SMS Advanced for the PA side of the business. The program is user friendly, and yet has the capacity to handle relatively advanced analysis of spatial information including clustering of multiple spatial layers to make zones. Being a generic program, information can be imported from and exported to many different brands of hardware.

Linear actuators have been trialled on a Simplicity airseeder with zero max gearboxes for rate control. These work well. This year an Ag Leader Insight controller will be purchased to handle variable rate control of the airseeder and spreader.

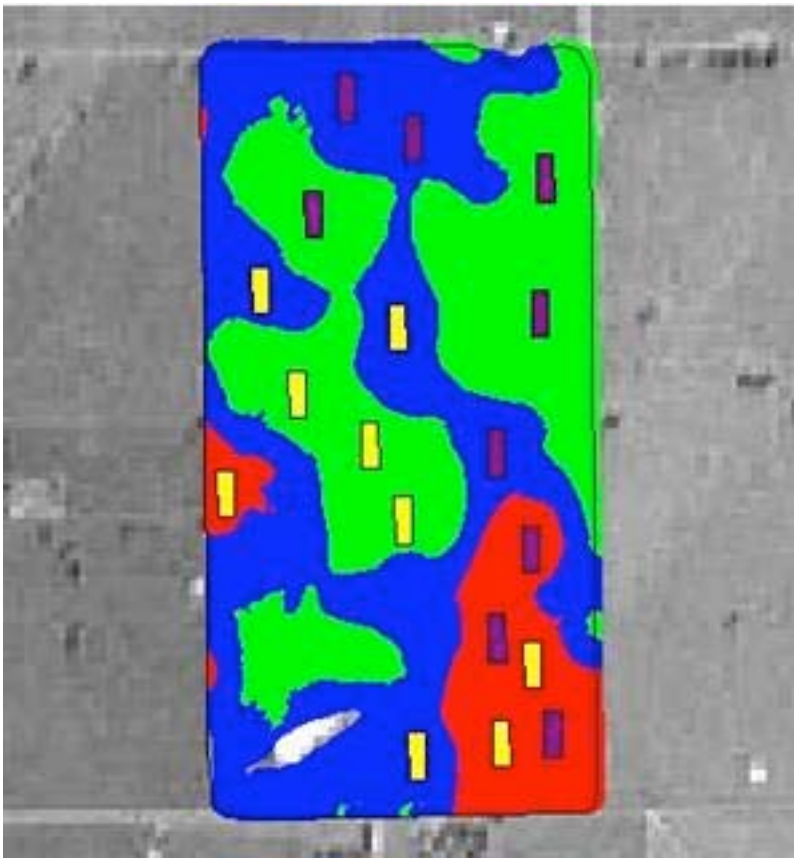
In a previous header, a Garmin hand-held GPS unit, costing about $400, was used to make yield maps. This unit is now used as a tool to assist logging and locating points of interest around the farm

A Gopher meter, costing about $500, has been used to monitor soil moisture throughout the growing season. Data loggers have also been used in the project to give automatic readings.

Variable rate

Deep soil nitrogen tests taken at 90 locations, within each of the three management zones in one trial paddock, in 2003 identified a range of available nitrogen from 31 to 320 kg N/ha. Based on these results, a nitrogen response experiment was run with the paddock sown to canola. Three nitrogen rates 0, 100 and 200 kg/ha were applied (topdressed) just before bolting in each of the three paddock zones (Figure 1a). The majority of the paddock received 100 kg/ha.

(a)



(b)

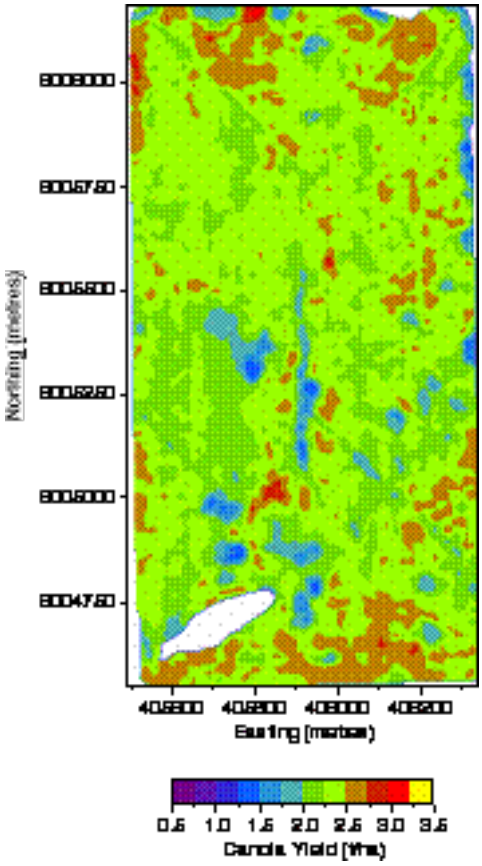


Figure 1. (a) Urea fertiliser application trial-overlaid on the three paddock management zones- yellow plots received 0 kg/ha, purple plots received 200 kg/ha, the remainder of the paddock received 100 kg/ha. (b) Canola yield map for 2003

The yield map (Figure 1b) showed a generally uniform pattern across the paddock with most of the paddock producing 2-2.5 t/ha. However, an economic examination of the response data shows that the output from the different zones could have been optimised by applying different average rates in each. The urea rate for maximum yield and economic optimum for each zone using a marginal rate analysis is shown in Table 1.

By applying variable rates of fertiliser based on management zone, the average gross margin for the paddock would have improved by $38.95/ha.

However, nitrogen responses have been found to be very reliant on season. In a dry finish (2004) the blue zone with a medium EM38 reading gave the poorest response to nitrogen applications of 50 kg/ha or more, whilst in a wetter season (2005) it responded well to higher nitrogen inputs.

	Urea rate for maximum returns (kg/ha)	Urea rate for maximum yield (kg/ha)
Class 1 (red - high EM)	0	0
Class 2 (green - low EM)	169	237
Class 3 (blue - medium EM)	72	151

Table 1. Urea rates to achieve maximum yield and economic optimum per management zone.

In variable rate phosphorus trials it was the zones with high conductivity readings (red) that gave the greatest response to higher phosphorus inputs.

Across the rest of the farm Adam is applying gypsum and lime based on pH management zones. For example areas with pH 5 or lower receive 2.5 t/ha of lime whilst areas with pH 5.5 or more receive 1.25 t/ha or no lime depending on the point in the rotation. This is generating a substantial cost saving without any detrimental impact on grain yield or quality. Also, it has the advantage of being able to address more pH issues in a given year with a limited quantity of lime.

Disadvantages or limitations

Variable rate does not always produce financial advantages, and it takes a considerable amount of time to gather all the background information. However, this has helped Adam gain a much better understanding of the soil factors that may be influencing his production across the farm. He feels tools such as Yield Prophet will play a role in developing robust yield potentials by management zone.

On Adam's property the yield potential of the zones flip-flops a little. More research is required to help growers understand what is driving the flip-flop and how big a difference is required to justify variable rate.

There are many potential sources of data to choose from but which is the most cost effective remains to be confirmed. Adam has tried using NDVI satellite data to estimate in-crop nitrogen requirements. At $3-4/ha this is potentially a cost-effective tool, providing the data are delivered on time, but at standard prices he has found it too expensive for the value it provides to the current cropping system.

Adam has also found that PA technology is not perfect - hardware failure, dodging trees when on autosteer and the occasional software glitch all add to the challenge of adopting PA.

Words of wisdom for beginners

- Do not spend too much money on things you may want to change later.
- Streamline your system so you need the least number of hardware items to do a range of different operations.
- Critically evaluate the positives and negatives of the many different technologies that are available. Are they really useful for your system?
- Start by simply breaking a paddock into a couple of smaller management zones and apply existing decision-making techniques to each zone rather than the paddock as a whole; then move on from there.

Ian Carter

Ian Carter knows that PA has evolved rapidly over the past 15 years but believes it still has a long way to go before it is widely adopted. He accepts that PA equipment is increasingly becoming just another part of the machinery budget with many items coming as standard, but before investing in non-standard items he needs to be sure there will be a benefit. For this reason he is using autosteer, precision spraying and yield mapping but is still gathering data before he moves into variable rate applications.

Photo: Ian Carter, courtesy of The Land

Cropping 3000 ha at Quirindi, NSW, Ian farms with three permanent workmen and also uses contractors at harvest. The rainfall is summer dominant and officially averages 650 mm/year but in summer 2005/06 only 51 mm was received. Despite this sorghum crops were only a little below the 6.5 t/ha average, supported by the moisture stored in the black basalt soils.

Winter crops include bread wheat (average yield 4.7 t/ha) and feed barley, and summer crops are corn and sunflowers.

Autosteer

Ian's system has evolved from controlled traffic farming (CTF) in the early 1990s to 10 cm accuracy autosteer in 2003. The CTF layout was set-up using elevation data from a grid survey conducted using a 2 cm vertical accuracy GPS. All equipment is on 3-m wheel centres and wheel tracks are not cultivated or sown. PA equipment has gradually been upgraded to increase accuracy. In 1998 he purchased a yield monitor and GPS unit for guidance and yield mapping, and a light bar was used for spray guidance. In 2000 guidance with sub-1 m accuracy was purchased and in 2003 the John Deere autosteer system with 10 cm accuracy was installed. With the addition of a base station this system can achieve 2 cm accuracy.

'If I was starting today I would go straight for autosteer to gain all the benefits', said Ian.

On Ian Carter's farm green is the colour as he runs all John Deere equipment. Due to problems moving the displays and control units between the header, self-propelled spray rig and the tractor that pulls the Excel double disc planter, three units have been purchased.

'Having the same system in each machine is very useful for all members of the team, and the fact the system is based on one monitor makes learning how to use it much simpler.'

More education on the use of PA equipment is one area that Ian would like to see the industry develop. He feels most farmers using PA today have learnt by their own experience and then trained their employees. Having an experienced local dealer is invaluable.

Precision spraying

The GPS antenna on the self-propelled sprayer is not only vital for autosteer but also for precision spraying. Many of Ian's paddocks have irregular shapes and even with CTF overlap on edges and headlands could not always be avoided, especially when using the 27 m boom. The boom is in five sections and Ian has purchased a Rinex auto-section controller, this switches off any boom section that is covering an area already sprayed.

'Basically the GPS continuously registers the location of each section of the boom, if that location has already been logged the controller switches off the overlapping section(s).'

Since adopting no-tillage in the 1980s all operations have been run up and back. The addition of the spray controller means there is no need to switch off the boom when turning, as it will automatically register that the headlands have already been sprayed. This allows the operator to concentrate on turning, eliminates misses and overlaps. Autosteer has also helped increase the accuracy of night spraying.

Yield maps

Although Ian has not used yield maps to create management zones he still finds the maps a useful management tool. As well as harvesting with his own machine he uses one or two contracted headers, all of which run the same yield monitor and software. Having the same systems means the data can easily be integrated and mapped using JDOffice. Ian finds these maps especially useful to assess areas of the paddock where he did not reap.

'I use yield maps to assess trials and differences in management. For example, in an area of the paddock burnt by a neighbour's fire, we recorded a yield reduction of 2 t/ha, most likely due to the loss of moisture by evaporation without the stubble cover. Without a yield map we would not have quantified the impact of stubble removal.'

Ian believes one of the biggest changes that is required for wider adoption of PA is in the area of software. He would like to see software that offers pre-operating check wizards and also that is more 'Windows' based. He would also like to see the creation of PA schools to provide employers and employees with an opportunity to learn how to strategically maximise the value of PA rather than learn by mistakes.

David and Christina Forrester

Having observed considerable variability across their paddocks David and Christina Forrester adopted yield mapping and then variable rate nutrition. They have seen some incredible differences in productivity and profitability from applying PA to their nutrient program.

In the 1990s the Forresters started experimenting with the use of potassium and increased fertiliser rates to try and improve yields on their poorer performing lighter soils. Some positive results were recorded for the potassium but little benefit was gained from the additional fertiliser. It was then that they turned to yield mapping as a means of defining their poor and high performing areas.

The Forresters farm 3400 ha at Mullewa in the northern WA grain belt. About 2600 ha are cropped each year and the yellow sand plain and white sand over gravel or clay soils are under a 6 year wheat-lupin rotation, with the occasional crop of canola or barley. This is followed by a 3-year pasture phase of Cadiz clover. Their average growing season rainfall is 336 mm and average wheat yields are about 3 t/ha.

One year of yield mapping was enough to convince the Forresters that they should manage to the yield potential of an area and not try to lift the yield of poorer performing areas. The initial zones were based on one year of yield maps. Usually several years of yield maps and other data are recommended for the production of management zones but the Forresters were eager to adopt PA and have found their zones remain relatively stable from year-to-year.

The zones are now re-assessed every few years and David uses a combination of experience, yield mapping, site-specific soil samples and biomass imagery to establish the zones. For the Forresters, the management zones are generally associated with changes in soil type; high performing zones tend to be on the yellow sand, the low performing zones on the white gutless sands, and the medium performing zones where the two soil types interface.

PA equipment

The Forresters started with and continue to use two Rinex Farmtrax systems that give them 10 cm accuracy. This level of accuracy is sufficient for their needs (yield monitoring and variable rate application) as they are not using autosteer. The guidance signal is from Omnistar and over the 8 years of use the units have performed well with only small problems with compatibility and DGPS dropouts.

One Rinex system is either in the John Deere 9320 or 8320 tractor. It is either connected to a Farmscan 22C1 controller to regulate fertiliser output from the Simplicity airseeder box or it controls the Marshall spreader when topdressing fertiliser or to guide the boom spray.

The other unit is mounted in the John Deere 9760STS header connected to an AgLeader yield monitor.

This equipment was selected because it was the best on the market at the time of purchase and is suited to guidance, yield monitoring and site-specific soil sampling. The Rinex software is used on a PC to draw up the zone maps and record paddock data. David uses a commercial company to produce the yield maps so he does not have to spend time ‘polishing’ the yield data.

Set-up costs

In 1998 the cost of setting-up to yield map with one Rinex system was $28,000. The second Rinex was brought for $24,000 as part of a funded project. The Farmscan controller and wiring loom cost about $5000. David pays an annual subscription to Omnistar for the DGPS signal - this is a farm licence and covers the two units for $2970 (including GST) each year.

The cost of the investment is spread across the 2600 ha cropped and used for variable rate and guidance both of which produce cost benefits, therefore the payback on the investment has been satisfactory.

Variable rate

All fertiliser applications, excluding lime and dolomite, are applied using variable rates based on the management zones.

The Forrester's total fertiliser bill has not changed significantly over the 8 years, however what has changed is the efficiency of use and the gross margin for strategic application. Where an average rate of fertiliser was spread across the whole paddock a large proportion of fertiliser was being wasted by the poorer performing areas. With variable rate technology the high performing areas receive the most fertiliser.

Originally rates were varied by about 20 kg/ha between zones, now the Forresters vary rates by up to 100 kg/ha depending on the zones in a paddock and the crop. Table 1 contains the current fertiliser rates by zone for a paddock in a specific year. The rates may change every year based on a nutrient budget but the relative difference between the rates for low, medium and high zones will be similar.

Zone potential	Low	Medium	High
DAP Zn (kg/ha)	69	90	120
Potash (kg/ha)	60	80	100
Urea (kg/ha)	50	90	120

Table 1. An example of fertiliser rates varying by product and yield potential of a management zone.

Since 1992 the Department of Agriculture WA, in conjunction with the Forresters, has been running trials to establish the cost benefit of variable rate nutrient management.

A simple large-scale trial design using test strips of different fertiliser rates across the production zones has been applied in several paddocks. Each strip is 12 m, the width of the Forrester's seeder bar.

In 2002 the trial plots were harvested using a small plot harvester and David's header, and the results were analysed by John Blake and his colleagues. The small plot results showed that matching inputs to productivity potential zones, that is applying low inputs to the low production zone, for example, was more profitable than applying a medium rate across all zones (Table 2). Analysis from the broad-scale strips using David's header (1 km long runs across the three productivity zones) confirmed the small plot results. From Table 2 it can be seen that as yield potential increases, the greater the yield, protein and financial benefit from increased fertiliser inputs.

&Input	Low potential			Medium potential			High potential		
	Yield (t/ha)	Protein (%)	$GM/ha	Yield (t/ha)	Protein (%)	$GM/ha	Yield (t/ha)	Protein (%)	$GM/ha
Low = 33N/11P	1.54 (a)	9.3	105	2.1 (b)	8.3	248	2.45 (b)	9.2	254
Med = 56N/17P	1.68 (a)	9.6	38	3.56 (c)	11.1	303	3.62 (c)	9.8	320
High = 75N/23P	1.67 (a)	12.7	-26	3.69 (c)	11.3	238	4.26 (d)	12.2	398
Same letter indicates the yield is not significantly different; Yield LSD 0.17 t/ha.									

Table 2. Changes in gross margin (GM) due to adjusting nutrient inputs on wheat in three yield potential zones (Blake et al., Department of Agriculture WA).

Analysis of the broad-scale strips harvested by the Forrester's header in 2002 showed a net improvement of $9054 in the profit return for the test paddock (Table 3) (Blake et al. 2003).

Treatment		Low potential zone ($net/zone)	Medium potential zone ($net/zone)	High potential zone ($net/zone)	Total net return ($)
One rate	1109		13,345	26,108	40,563
Variable rate	3516		13,592	32,509	49,617
Net improvement ($)					9054

Table 3. Whole-paddock net return of variable rate zone management compared to one rate application for David Forrester's Dam paddock. Total paddock area 160 ha; average yield 3.1 t/ha; grain price $178/t.

This approximate $55/ha improvement is representative of what was being achieved in other paddocks on the farm in the same year. The improvement was gained by better allocation of inputs and increased quantity and quality of grain (higher protein and less screenings). However, results do vary from paddock to paddock and farm to farm, and of course are influenced by the differential between fertiliser cost and grain price.

Disadvantages or limitations

David does not think that there have been any disadvantages to adopting PA and variable rate nutrition. The biggest issue the Forresters encountered was coming to terms with how much the fertiliser rate can be varied. They felt the first year was wasted because rates were only varied by 10 kg and no differences were observed physically or financially.

The Forresters have only one workman, who knows and understands the system but relies on David if changes need to be made or alarms start ringing. Initially David would drive the first lap of every paddock to make sure the system was working. He advises on carrying out thorough pre-seeding tests to make sure the system is working properly and that all operators are familiar with its operation every year.

One challenge in the future may be to upgrade the equipment because it has limited compatibility with other systems (other controllers and machines).

Words of wisdom for beginners

- What always works on my farm does not always work 20 km away so do your own trials.
- Start with a couple of paddocks at a time.
- Do not be scared of the technology - I was computer illiterate when we started but you can learn to use computers and there is back up available.
- When buying new machinery make sure it can do everything you want it to do as they are not always compatible with other equipment (controllers, monitors, tractors etc.).

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Mark Branson

Mark Branson is passionate about the possibilities PA technology has to offer, and since 1997 has been evolving his PA system that now includes variable rate seeding and fertiliser application, and autosteer.

Mark, Nola, Deane and Jennifer Branson farm 1200 ha near Stockport, South Australia. About 80% of the land is cropped each year to canola, CCN wheat, faba beans, peas, durum wheat and malting barley. The remainder is sown to pasture for the self-replacing merino and prime lamb flocks. Average growing season rainfall is 350 mm and the average wheat yield is 4 t/ha. However, with soils ranging from red brown earths to heavy cracking clays, undulating topography and variation in rainfall across the farm, Mark tries to avoid talking about averages.

Mark's aim is to manage variation to optimise the production from an area and if the average yield is considered then he feels it makes it harder to focus on the potential output. For example, his high yielding zones produce 8 t/ha wheat, double the farm average. His interest in trying to manage variation started in the 1980s when he was at agricultural college, but it was not until he bought his first yield monitor in 1997 that he started on the path to managing variability.

In 2006 the whole farm will be sown using variable rates of seed and fertiliser for the first time.

PA equipment

In the CASE header Mark runs a CASE AFS yield monitor and has upgraded the software so that it provides elevation data and is compatible with 2 cm accuracy guidance. The Trimble base station and receiver provide guidance, giving 2 cm horizontal accuracy and 6 cm vertical accuracy. The receiver is easily transferred between the header and the tractor.

Mark runs a KEE Zynx X10 autosteer on his John Deere tractor. This also is his variable rate controller and airseeder and spray controller.

Mark chose this equipment as he felt it was the best on the market for his needs and there is excellent local back-up.

Yield map data are processed using the CASE AFS software, and then imported into Fairports PAM Farmstar software for long-term storage. The yield maps are also imported into KEE's Maplink program for the production of the variable rate maps for phosphorus replacement, seeding rate, nitrogen and chemical applications. Analysis of data from the management zones is either done by a consultant or as part of a research program.

Mark runs Fairport's PAM software for general mapping and paddock record keeping.

The total investment in PA technology is about $65K with the yield monitor coming as standard equipment on the header.

Variable rate

In 2002, as part of GRDC's PA Initiative, Brett Whelan of the University of Sydney created high, medium and low yield zones for Mark across two paddocks on the farm. These were produced by combining information from aerial photographs, yield maps, elevation and an EM38 survey; the latter provided soil and elevation data. Trials have been run across many parts of the farm and this information was used in working out why there are differences in the zones. Mark is pleased to report that these zones have remained relatively stable over the 4 years of use.

Since then Mark has zoned up many more paddocks for use in his PA program.

For 3 years Mark has been experimenting with variable rates of phosphorus at seeding. Rates across each zone have been increased or decreased by a third from the paddock average recommendation. For example, for a wheat crop the base rate would be 120 kg/ha DAP, with rates tested varying from 80 to 160 kg/ha. For the first 2 years no difference was seen but by the third year the soil P reserves had been mined and differences started to show. Mark will continue this work to establish how extreme the variation in phosphorus rates can be.

Phosphorus rates are now based on crop nutrient removal calculated from yield maps instead of on soil tests and projected yields; so Mark is achieving a cost saving in inputs.

In-crop, variable rate nitrogen applications are also being assessed. Mark has experimented with biomass imagery produced as infrared photographs and trials with the N-sensor have been carried out on the farm.

Results from the biomass imagery, the Farmstar system and the nitrogen recommendations from the Yarra N-sensor are currently being compared.

In the N-sensor trials, a 4% yield improvement was recorded where nitrogen applied at stem elongation was varied based on crop greenness, compared to using a fixed nitrogen rate.

The next big step with variable rate technology is variable rate seeding, using higher rates on known patches of ryegrass to provide greater crop-weed competition. Mark uses last year's biomass imagery, ideally taken at late tillering, and yield maps to determine where the problem patches are located. He targets higher seed rates at patches where a high biomass coincides with a low yield after these patches are confirmed by ground-truthing.

Autosteer and CTF

For the past three years Mark has used autosteer with 2 cm accuracy. Initially he matched his equipment widths for controlled traffic farming (CTF) - the seeding bar and gypsum spreader at a working width of 10 m, and the urea and spray booms at 30 m; all wheels are on 2.2 m centres. Wheel spacing was determined by the fixed chassis design of his trailed boom spray.

Mark was pleased with the transition to CTF but found that in his undulating country crop damage from wheel tracks was still 1 m of crop in every 30 m. This was particularly detrimental to yield when applying of nitrogen and fungicides later in the season.

The addition of 2 cm accuracy autosteer to the system cut the crop damage in half, with only 50 cm trafficked per 30 m. The combination of reduced crop loss and savings on inputs due to even better accuracy of placement has resulted in the investment in the autosteer being paid-off in 2.5 years.

Mark has found the added bonuses from autosteer are: less compaction, which is an issue across all of Mark's soil types; less operator fatigue; and the ability to concentrate on the operation rather than driving straight.

Much of the sowing tractor work is done by Mark's father and workman, and they have both found the system easy to learn and operate.

Disadvantages or limitations

Mark is passionate about PA and the potential the technology has for managing his cropping program. However, he has found that adopting PA technology does require some new skills in terms of computer use. These can be minimal for the operator but can be considerable for the person analysing, manipulating and storing data. In future more third parties are likely to offer this service.

Working out the economics of variable rate is challenging. Mark sees this as a disadvantage and believes it is limiting growers' confidence in PA technology and slowing down adoption. But he considers that by looking at the drivers of yield variation in more detail he has become a better agronomist.

Words of wisdom for beginners

- Know what you want to achieve before buying equipment and think to the future to ensure that what you buy has the flexibility to execute additional tasks. For example, protein monitoring is just around the corner.
- Set paddocks up correctly for controlled traffic farming, once set-up, changes need to be avoided, as cultivating compacted tracks is hard work.
- Good back-up is essential and should definitely be part of any buying decision.
- Only upgrade if the upgrade is offering something you need, that is unless the upgrade is free!

Rob Taylor

Darling Downs cropper Rob Taylor has been a practitioner of controlled traffic farming since the mid 1990s. However, the production of a whole-farm yield map in 2003 convinced him that he needed to completely change his farm layout in order to maximise water flow through his 2200 ha of cropping land.

Farming near Macalister , Queensland , Rob Taylor has established that variability across the farm is driven by topography and its impact on the overland water flow. His soils are all black vertosols, with the majority being Bongeen clay and the remainder the slightly lighter and more fertile Waco soils. Annual rainfall is 680 mm of which 70% should fall in the summer, but as with many areas in this region summer falls have ranged from less than 100 mm to only 300 mm. Good water flows across the property, from isolated storms, has helped to sustain the sorghum yield at about an annual average of 5 t/ha. Other summer crops include corn and mungbeans, while between 10 and 20% of the farm is sown to winter crops of wheat, barley or chickpeas; the proportion is totally dependent on how much stored soil water is available.

Rob Taylor adopted no-tillage in the early 1990s, this was shortly followed by laying out the farm for controlled traffic farming (CTF), with permanent unsown tracks and all equipment modified to 3 m wheel centres. The farm layout was based on previous property history with the tracks measured out using marker arms. Stuart Cannon, Rural Property Design, introduced the concept of topographical maps using survey grade GPS, this was carried out but use of the data was put on hold.

These changes revolutionised their approach to farming. No-tillage incorporating CTF greatly reduced compaction and with good stubble cover improved water infiltration resulting in greater volumes of stored soil water. The ability to store more water has increased production. CTF has enabled management efficiencies of reduced overlaps, improved operational timing and greater cropping frequency, and it has also improved natural resource management.

In 1998 a yield monitor and GPS unit were purchased and yield maps were produced for the first time.

‘The paddock yield maps showed there was variation but like many we did not really know what to do about the variation; I also felt we needed several years of data before we made any decisions’, explained Rob.

However, in 2003 consultant Tim Neale produced the first whole-farm yield map and Rob was struck by the relationship between topography and yield. When the mapped topographic information was combined with the yield data Rob was quickly convinced that the whole farm layout needed to be changed.

‘The whole-farm map indicated the reduction in yield in areas affected by water logging as well as yield increase where water was allowed to flow unhindered. Changing the layout offered the ability to distribute heavy rainfall in one part of the farm by overland flow to another part, in essence as irrigation water.’

Stuart Cannon was commissioned to redesign the farm layout using the new topographical data. Rob had already successfully experimented with running tracks up and down the slope against the convention of working across the contour. With appropriate headland design such a layout had proved to be better at controlling water flow and caused less soil erosion. Consequently tracks running up the slope were incorporated in the new layout.

Rob uses 18 m grassed headlands as turning areas, roadways, and areas that spread water slowing down its flow before it enters or as it leaves the tracks. The management of water as it enters and leaves paddocks is of the highest priority in order to prevent soil erosion.

In addition to maximising water flow Rob wanted to maximise efficiency by minimising the number of odd shaped paddocks. The new layout resulted in only two triangular paddocks, compared to the previous layout that had many non-rectangular paddocks that were inefficient to work and in which overlap was difficult to eliminate.

It took a couple of years to complete the change in paddock layout, especially where old tracks were moved from running east-west to north-south as the land needed to be levelled. However, the main delay was that Rob held off applying the new layout until 2 cm accuracy autosteer guidance was purchased. The John Deere Starfire system was purchased with a new John Deere 8420 tractor in 2005.

If marker arms are all that can be afforded for the creation of CTF tracks they can do the job, but with 10 years of experience Rob Taylor has found that even tracks that appear straight at first gradually become more and more crooked as any small wiggle becomes exaggerated over time.

With RTK GPS and 2 cm accuracy, achieved from the shared based station, Rob finds the new tracks are considerably straighter. Currently the autosteer is only on the tractor but Rob reports that the header stayed on the new tracks so well he hardly had to steer. Guess rows are accurately spaced and the chaser bin is always the correct distance from the header for unloading. Benefits from improved accuracy, reduced fatigue and better water flow are all having a positive impact on the bottom line.

Investment in PA technology has been about $80K for hardware, including the AgLeader 3000 yield monitor and GPS antennae on the Starfire system. Tim Neale collates, analyses and maps all Rob's data.

Rob believes farm layout is crucial in many areas and should be high on the list when considering the reasons for investing in PA technology - that includes purchasing hardware or employing contractors. If he was starting today and the budget allowed he would go straight to autosteer.

Rob is waiting on more information to come from the imagery, yield and protein data assessments gathered on his farm as part of PA research. Ultimately he anticipates he will go to variable rate but is still assessing which technology to buy.

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Glossary

Accretions	External deposits on soil surfaces deposited from soil water.
Active Sensing Systems	Remote sensing systems which measure the characteristics of a reflected signal generated from an object bombarded with a signal from the sensor (e.g. radar).
Aerial Photography	Remote sensing technique in which either an orbital satellite or aircraft records a photograph of a portion of the Earth's surface.
Archive	The storage of historical records and data collected over a number of years (e.g. Landsat data archive stored since the 1980s).
ASCII	American Standard Code for Information Interchange. A standard coding system used for identifying alphanumeric characters within a computer.
Aspect	The horizontal direction that a slope faces.
Attribute Value	A numerical measure of a spatial element.
Band	A discrete interval of the electromagnetic spectrum between two wavelengths measured by remote sensing systems.
Baud Rate	A measure that describes how rapidly single digital elements are transmitted over a communication line.
Bit	An abbreviated term for binary digit, the smallest unit of computer data.
Block Kriging	A spatial interpolation method used to predict unknown values at unsampled sites by appropriately weighting the known values at sample sites based on grid cells.
Byte	A unit of computer storage of binary data usually comprising eight bits, and equivalent to a character.
Carrier	An encoded radio frequency signal in which information is transmitted.
Centroid	The position at the centre of an entity. Usually the middle of a two-dimensional object such as a polygon.
Channel	The necessary circuitry for a GPS receiver to receive signals from a single GPS satellite.
Choropleth Map	A map that shows regions or areas that have the same characteristics, such as a yield map, where quantitative spatial data is depicted by different colour variations of yield ranges.
Classification	The process of assigning individual pixels of a digital image to classes based on spectral reflectance.
Coarse Acquisition (C/A)	A unique code for each GPS satellite that is accessible by the public for single and group use.
Continuous Management	A management system in which agricultural inputs are applied to a field on a point-by-point basis.
Contour Line	A line drawn on a map connecting a set of points all of which have the same value.
Controlled Traffic Farming (CTF)	A farming system in which most or all wheeled traffic runs on a set of permanent tracks in order to restrict soil compaction to only those parts of the paddock. An ideal system has all farm equipment having matching wheel tracks (widths).

Datum	A datum is a reference surface. For mapping there are two datums, one is horizontal, the other vertical. A geodetic datum defines an ellipsoid, an initial location, an initial azimuth, and the distance between the geoid and the ellipsoid at the initial location (or locations).
Decision Support System (DSS)	A system that is capable of integrating diverse data sources with expert knowledge and decision models to aid in the making of strategic decisions.
Differential Correction	The correction of the GPS signal to make it more accurate. This requires a secondary GPS receiver, called a base station, placed at a point of known position. The base station then measures bias errors that are used to correct bias errors at the location of interest. The three common ways to access a correction signal from a base station are from a: marine beacon; commercial FM radio station with frequency supplied by AUSNAV; and satellite provided by a specialised GPS operator.
Digital Elevation Model (DEM)	A digital representation of the continuous variation of elevation over space.
Digital number (DN)	The digital number or 'brightness value' (BV) is a number recorded for each pixel of a remotely sensed image in each band of the image. The brighter the reflectance of a target in a particular band, the higher the digital number will be in the pixels covering the target. The range of the values is dependent on the radiometric resolution of the sensor. For an 8-bit image, the range of digital numbers will be 0-255 (i.e. 28 = 256 values).
Electromagnetic Radiation (EMR)	Energy that is reflected or emitted from objects in the form of electrical and magnetic fields.
Electromagnetic Spectrum	All the wavelengths of electromagnetic energy including visible light, infrared light, ultraviolet light and radio waves.
Ellipsoid	An ellipsoid is a solid for which all plane sections along the axis are ellipses or circles. If any two of the three axes of an ellipsoid are equal, the figure becomes a spheroid (ellipsoid of revolution). If all three are equal, it becomes a sphere.
Enhanced Thematic Mapper (ETM)	A passive sensor carried on Landsat&7.
Expert System	A computer program that uses techniques normally associated with a human expert such as knowledge, heuristics and inference to solve a narrowly defined set of problems.
Extrapolation	The prediction of the value of a variable outside the measured range or an inference of the value of a variable.
Gammaradiometric	Gammaradiometrics is the measurement of natural gamma ray emissions of radioactivity, primarily from the top 30 cm of soil or rock. Often, this can provide information about the parent material of the soil that can be related to soil types across the region or paddock.
Geocode	A code representing a spatial element that describes its location incorporated into a GIS.
Geographic Data	Data which records the shape and location of a feature as well as associated characteristics which define and describe the feature
Geographic Information System (GIS)	A computerised database designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information.
Geoid	An equipotential surface (i.e. a surface that is perpendicular to the direction of gravity at all points). This is influenced by variations in density of the crust and mantle. For practical applications a spheroid is a good approximation.
Georeferenced Data	Spatial data that pertains to a specific location on the Earth's surface.

Georeferenced System	A coordinate system keeping track of specific points on the Earth's surface. An example of such a system is the Universal Transverse Mercator (UTM) system.
GIS	Geographical Information System. Computer software to present, compare and analyse spatial data.
Global Positioning System (GPS)	A network of 24 radio-transmitting satellites developed by the US Department of Defence to provide accurate geographical position fixing.
Greenwich Meridian	A line that runs due north-south through the Royal Observatory in Greenwich , England . Running from pole to pole this line was adopted as a zero line for longitude by the British in the seventeenth century and became the official Prime Meridian for the world in 1840.
Grid	A data structure that uses a set of grid cells forming a regular, or nearly regular, tessellation of a surface to represent an area like a field.
Ground Control Point (GCP)	An easily identifiable feature with a known location that can be used with other ground control points to geometrically correct an image.
Ground Truth	The collection of information on the Earth's surface at the same place and time as a remote sensor gathers data. This permits the interpretation and calibration of remotely sensed data sources such as yield maps.
Guess Row	The gap between one pass of the seeding bar and the next (ideally it should be the width of the tine spacing).
Guidance System	A system of equipment for automatically guiding the path of a vehicle.
Hyperspectral Sensor	A sensor capable of simultaneously measuring hundreds of individual wavelengths of the electromagnetic spectrum.
Image Rectification	The process by which an image or grid is converted from image coordinates to real-world coordinates.
Interpolation	The process of predicting unknown values between neighbouring known data values.
Inverse Distance Weighting	A spatial interpolation method that assigns greater influence to known samples closer to a desired location.
Kriging	A method that interpolates data from a known set of sample points to a continuous surface by assigning a set of weights to the samples based on a semivariogram model, the locations of the samples relative to each other and to the point or block being estimated.
Landsat (Land Satellite)	A series of unmanned earth-orbiting satellites used to study the Earth's surface.
Latitude/Longitude	A polar coordinate system that specifically describes a position on the Earth. Latitude is the north to south position. Longitude is the east to west position. Locations are described in units of degrees, minutes and seconds.
Map Projection	A systematic transformation of locations on the spherical globe to locations on a flat plane while maintaining spatial relationships.
Map-based Variable-rate Application System	A system that adjusts inputs based on a pre-made electronic map of the input using a differentially corrected positioning system to determine the applicator position in the field.
Mean	The average of a set of data in which the values of all observations are added together and divided by the number of observations.
Mosaic	The process of joining database files for adjacent areas into a single file or image.
Multispectral Sensor	A sensor that obtains imagery from several different portions of the electromagnetic spectrum at one time.

Near Infrared (NIR)	Portion of the electromagnetic spectrum lying near the red end of the visible spectrum. Wavelengths around 700-3000 nm.
Nearest Neighbour	A spatial interpolation method whereby the predictions of attributes at unsampled points are provided by the single nearest data point.
Noise	Random variations or error in a data set.
Normalised Difference Vegetation Index (NDVI)	A common means of analysing remotely sensed imagery for vegetation health, vigour and greenness. The index is created by subtracting the value of the red band of the imagery from that of the near infrared, and then dividing this by the sum of the red and near infrared bands. Red light is strongly absorbed for photosynthesis and near infrared light is strongly reflected in healthy plants, so a high index value relates to high health and greenness. The NDVI is the most commonly used vegetation index.
Off-nadir	Nadir imagery is imagery captured directly below the sensor (i.e. vertically downwards or on-track). Many modern satellite systems also have off-nadir capacity to reduce revisit time. Off-nadir imagery is imagery captured at an angle, that is not vertically below the sensor. This is achieved by orienting the sensor to point either side of its normal track (or even in front or behind in some cases). Imagery captured at an extreme angle suffers distortion problems.
Orthophoto	An aerial photograph that has been orthocorrected. Orthocorrection involves the removal of all geometric distortions such as variations in scale and relief. It requires a digital version of the aerial photograph, a digital elevation model, high quality 'ground control point' of known location, and the calibration information for the camera used to capture the photograph. An orthophoto can be used to measure distance and area accurately. Ortho means 'correct', 'true' or 'straight'.
Panchromatic	A film sensitive to all or most of the visible spectrum, between 400 and 700 nm . Landsat 7 has a panchromatic band.
Passive Sensing System	Remote sensing systems which receive the naturally emitted and reflected signals from sensed objects.
PCMCIA Card	A removable card that is able to hold large quantities of data and able to withstand the harsh environmental conditions used by most yield monitors.
Pixel	A term used in remote sensing which is an abbreviation for 'picture element'. A pixel is simply the smallest picture element of a digital image. The smaller the pixels, the higher the resolution of an image.
Polygon	A multisided figure that represents areas on a map that, for example, have the same category of yield, land use or soil type.
Precise (P) Code	A confidential pseudorandom code transmitted by GPS satellites.
Principal Components Analysis (PCA)	A means of compressing the information content of imagery with a number of spectral bands into two or three principal component bands. This is useful when dealing with imagery with many spectral bands, as adjacent bands are often highly correlated. It is often used as a first step for classifying the image (e.g. into different vegetation or land use classes).
Pseudo Range	A measurement of the true distance of a GPS receiver from a satellite.
Pseudorandom Noise (PRN)	A regular binary sequence of code that has noise-like properties. It measures the distance to a satellite.
Raster Format	Images that are represented by a matrix of row and column data points whose values which when taken together, describe the display of an image on an output device.
Real-time Correction	The practice of correcting the GPS signal by immediately sending the differential correction information to a mobile receiver in use.

Real-time Kinematic (RTK)	A procedure where carrier-phase corrections are transmitted in real-time from a reference receiver to a user's receiver.
Rectification	Referencing to the Earth's surface.
Remote Sensing	The collection of information about an object, series of objects or landscape without being in physical contact with the object or event.
Scale	The ratio or fraction between the distance on a map, chart or photograph and the corresponding distance on the ground.
Selective Availability (SA)	Adopted by the US Department of Defence to introduce some error into the GPS satellite signals to reduce their accuracy for civilian users. This policy was discontinued in May 2000 and is now turned off.
Semivariance	A measure of how much neighbouring data points differ in value. Equal to one-half of the squared difference between the points, it is used in the spatial interpolation technique of kriging.
Semivariogram	A line fit to a graph plotting the semivariance against distance for kriging.
Sensor-based Variable-rate Application Systems	Systems which create application maps by processing field data collected from real-time sensors as the implement moves through the field to alter an input on-the-go.
Site-specific Crop Management (SSCM)	A management system that takes into account the variability of crop and soil parameters to make decisions on the application of production inputs.
Spatial Prediction	Any prediction method that incorporates spatial dependence.
Spatial Resolution	Refers to the size of the smallest object on the ground that an imaging system, such as a satellite sensor, can distinguish.
Spatial Variability	The variation found in soil and crop parameters (e.g. soil pH, crop yield) across an area at a given time.
Spectral Resolution	The capability of a sensing system to distinguish between electromagnetic radiation of different wavelengths.
Spheroid	A geometrical three-dimensional figure used to represent the Earth. It is formed by the rotation of an ellipse about its minor axis.
SPOT	A series of French satellites used to study the Earth's surface.
Standard Deviation	A statistical term that tells how spread out numbers are from the average, calculated as the square root of the average of the squares of the deviations from the mean.
Temporal	Pertaining to time, such as temporal variation (variation over time).
Temporal Resolution	The time taken for a satellite to revisit the same location.
Temporal Variability	The variation found in soil and crop parameters within a given area at different measurement times.
Ternary	In PA a Ternary Image is a three-colour image derived from the three main gammaradiometric layers - red = K, blue = Th, green = U, (although some people swap the blue and green channels). Using this imagery, areas with high K and low in Th and U will appear red; low in everything is black; high in everything is white).
Thematic Map	A map depicting selected kinds of information relating to one or more specific themes such as yield or soil type.
Thermal Band	The infrared wavelengths of the electromagnetic spectrum.
Tramline Farming	Another name for Controlled Traffic Farming.
Universal Transverse Mercator (UTM)	A commonly used planar coordinate system that uses a set of transverse mercator projections to divide the globe into 60 zones, each covering 6 degrees longitude.

Unsupervised Classification	An automated computer classification of digital imagery, where the computer groups pixels based on their similarity across the spectral bands in the imagery (spectral homogeneity). The number of output classes and the spectral similarity limits are set by the operator. The operator then examines the original image and attempts to aggregate the classes into 'information classes' based on statistical and geographic adjacency.
Variable-rate Application (VRA)	The adjustment of crop production inputs such as fertiliser to match spatially-variable conditions within a field.
Variable-rate Technology (VRT)	Equipment that can vary the application rates of fertiliser, pesticides and seed as it moves across a field.
Variance	A measure of dispersion of a set of data points around their mean value. The square root of the variance is the standard deviation.
Vector Format	A format where positional data is represented in the form of points, lines and polygons where each of these units is composed of a series of one or more coordinate points.
Yield Monitor	A system that gathers georeferenced yield data by measuring the mass or volume of a harvested crop per unit area, by location, within a field.
Zadoks Growth Stage (GS)	The Zadoks decimal code is a description of the growth stages of cereals. A useful website detailing the Zadoks code is at: http://www.lethamshank.co.uk/gs.htm. A document relating Zadoks code to timing of cereal herbicide application can be found at: http://www.agric.nsw.gov.au/reader/record/Zadoks_growthchart3.pdf
Zone Management	A management system in which a paddock is divided into different zones based on potential production. Zones may then be used to guide the application of agricultural inputs.

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