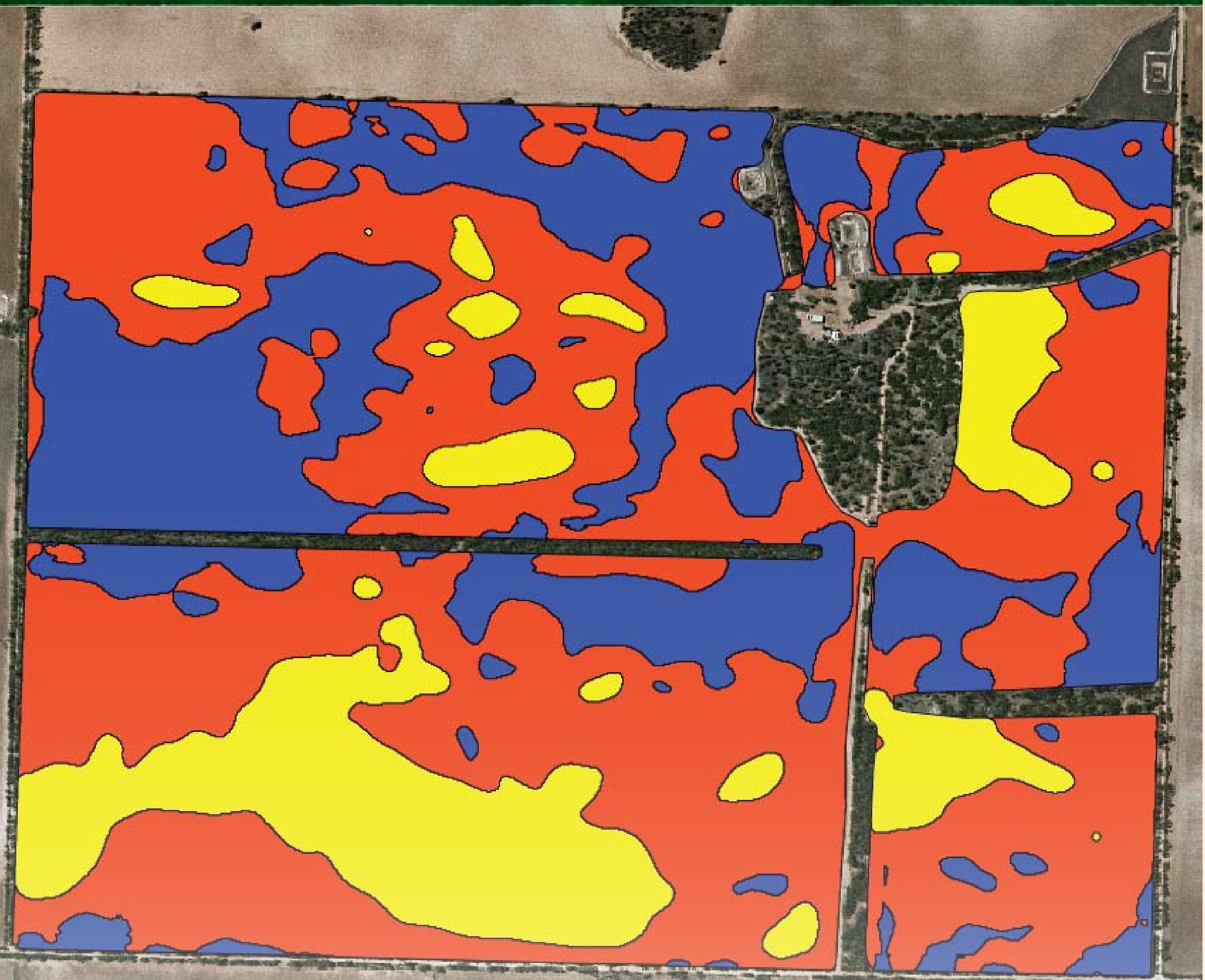
PA in Practice

grain growers' experience of using variable rate and other PA technologies



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SPAA Southern Precision Agriculture Association

GRDC Grains Research & Development Corporation

Australian Government
Department of Agriculture, Fisheries and Forestry
National Landcare Programme

Learning from experience – PA in Practice has been produced by SPAA as part of a project funded by the Department of Agriculture Fisheries and Forestry under the National Landcare Program. As part of the same project eight PA groups have been established in South Australia and Victoria. More details of these groups and how to be involved is found on the SPAA website.

Southern Precision Agriculture Association

GRDC Grains Research & Development Corporation

Australian Government Department of Agriculture, Fisheries and Forestry National Landcare Programme

BCG shared solutions

CSIRO

SAGIT

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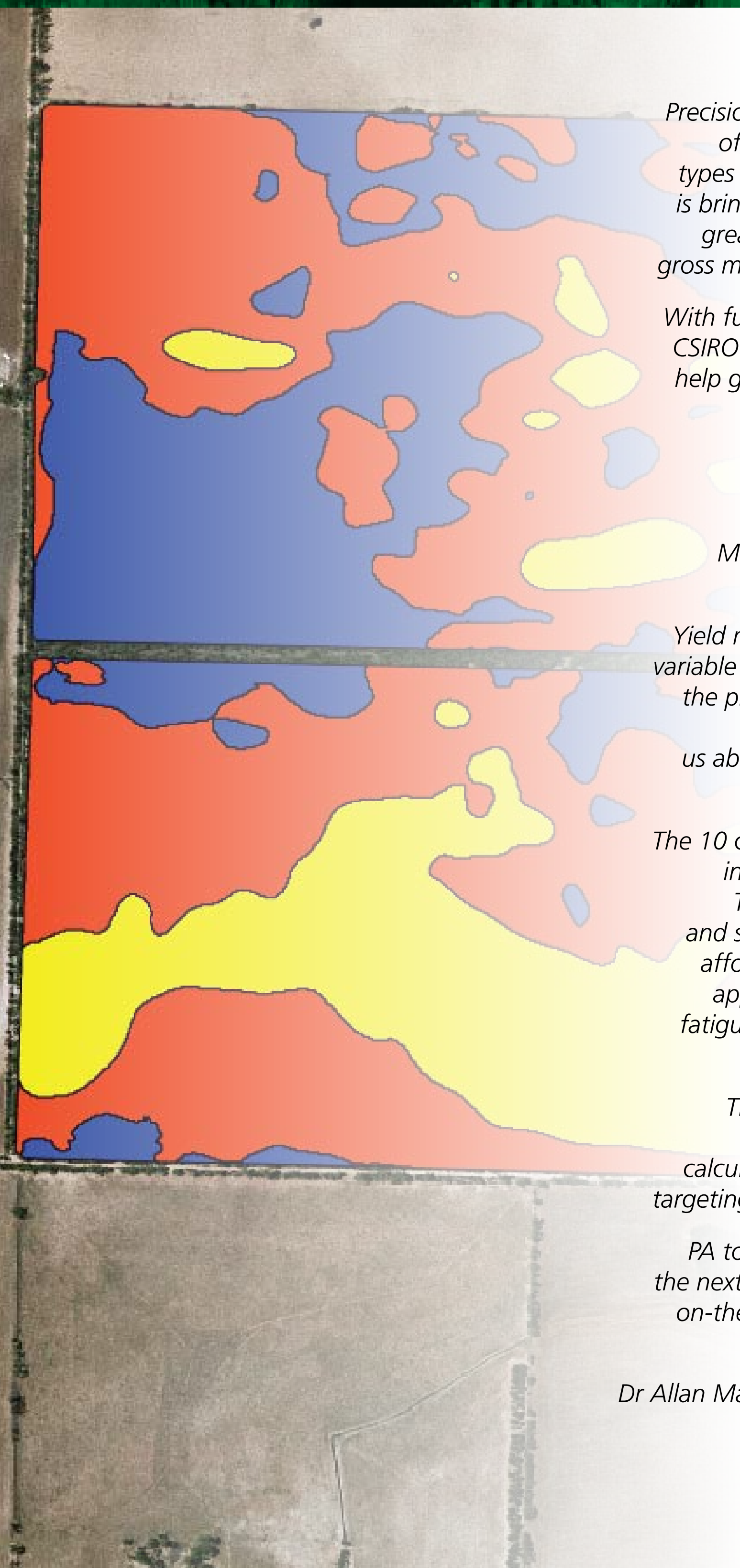
PA in Practice

"PA is making my farming more challenging and more interesting."



Precision Agriculture (PA) in Australian broadacre cropping has come of age. Producers in a range of cropping environments and soil types are now able to demonstrate the benefits that investing in PA is bringing to their businesses. Benefits range from less fatigue and greater efficiency to yield increases and cost savings that increase gross margins and can result in PA investments being paid off rapidly.

With funding from GRDC, DAFF and the National Landcare Program, CSIRO and SAGIT, PA in Practice *brings together 24 cases studies to help growers learn from other growers who between them average over eight years of PA experience.*

PA in Practice *is divided into three sections – YIELD MAPPING, PA CASE STUDIES AND ECONOMICS OF PA; the case studies are produced by Matt McCallum, McCallum Agribusiness Consulting, researchers from CSIRO and Cherie Reilly, Birchip Cropping Group.*

Yield maps form an important data layer when zoning paddocks for variable rate (VR) applications. To assist with gathering yield data and the production of useful yield maps, PA in Practice *contains step by step guides on these processes. Yield maps can also teach us about factors limiting crop production in paddock zones such as nutrient levels.*

The 10 case studies in section two demonstrate how these producers' investments and use of PA have evolved over the past 10 years. They illustrate the range of starting points in PA, the hardware and software available and how many of these have become more affordable over time. The case studies also show the range of PA applications in current use, from autosteer reducing overlap and fatigue to zone mapping and variable rate applications for fertiliser, gypsum and lime and management of different land classes.

The third section provides 14 case studies that were specifically produced to look at the economics of PA; values have been calculated for the cost savings and benefits of reduced overlap and targeting inputs by zone, and for payback periods for PA investments.

PA tools are dynamic; advances in technology are now opening up the next stage in Australian PA, this centres on the use of sensors and on-the-go rate changes not only for fertiliser but also for pesticides.

Dr Allan Mayfield, SPAA Research Coordinator, Allan Mayfield Consulting

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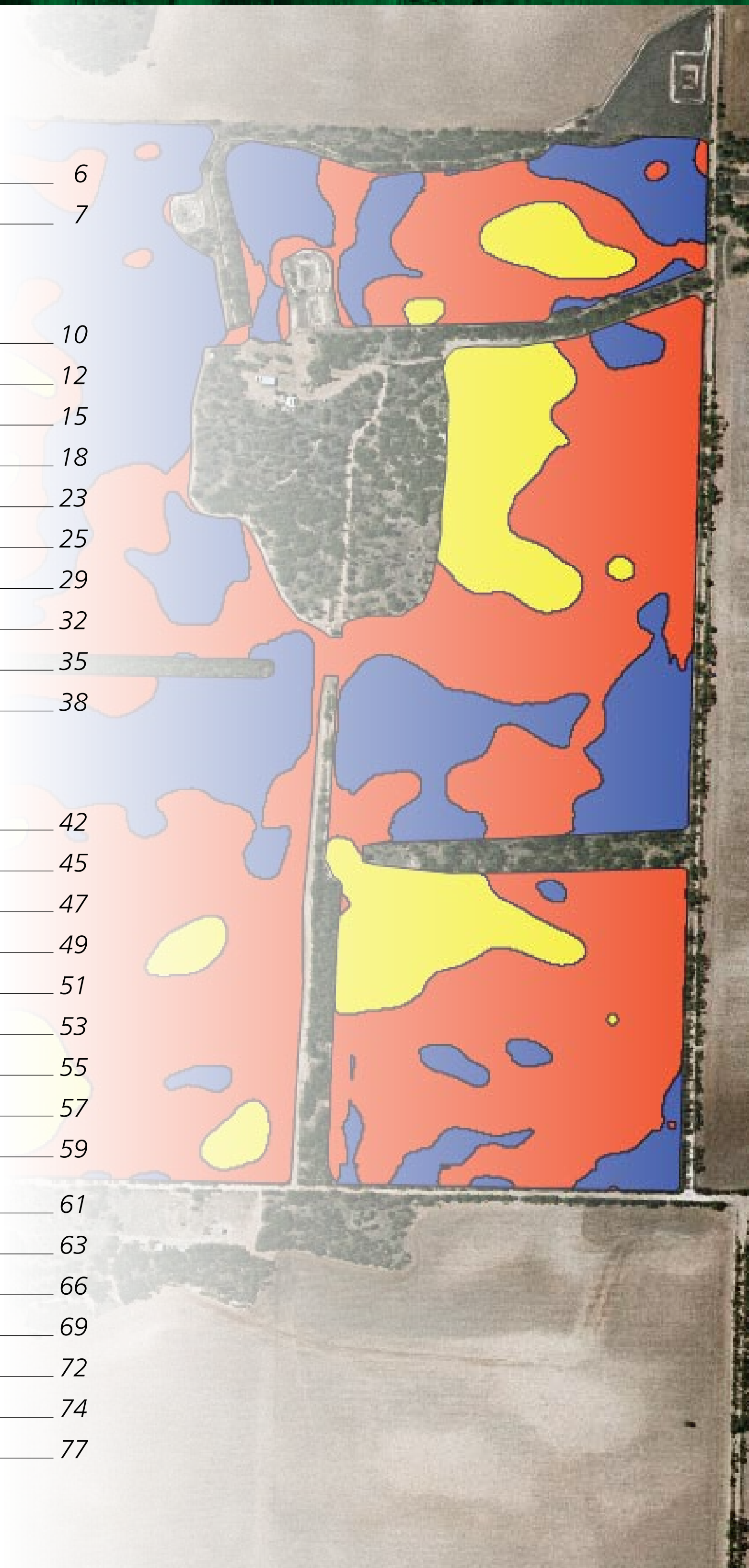


Section 1 Yield mapping

Section 2 PA case studies

Section 3 Economics of PA

SECTION 1

Yield mapping

PA in Practice - grain growers' experience of using variable rate and other PA technologies

Collecting yield data

Harvest is the only opportunity to map how your crop has performed. The following simple steps can help you save much time and heartache after harvest.

Start with an empty data card – save a copy of any data from previous years and then clean the card before starting harvest.

Naming – use the same name for a paddock each year. Enter the paddock/area details into the yield monitor before starting to harvest. If details are already set-up make sure you load them, so the yield data is saved to that paddock. This will save considerable time when sorting data later.

Check the flow and moisture sensors – if these are not working properly then everything that follows is a waste of time.

Check the flow sensor detector plate for wear and tear; they are not supposed to have holes in them. Check there are no objects jammed behind the plate and that cables are not damaged and are connected properly. Flow sensors may need cleaning during harvest – especially in paddocks with large numbers of snails.

Moisture sensors are best cleaned with alcohol based solvent so no residues are left on the shiny sides.

Calibration – Each year, calibrate the flow sensor for different grains - eg. cereals, canola, and different legumes. Aim for an accuracy of 5% or better, which may require several calibration loads. Avoid recalibration within a paddock unless it is clear that something has affected the performance of the monitor. More generally, it is a good idea to regularly check the calibration and if necessary, make any adjustments. However, where the need for recalibration occurs, it is essential that good records are kept of where and when the adjustment was made, and of what has been adjusted. The mapping software can then be used to fine-tune calibrations.

Whilst accommodating these changes in calibration is much easier the fewer you have, it is important that the yield monitor is as well calibrated as possible. This is especially important when you have more than one harvester working in the same paddock because they will each have different calibrations that will need to be accounted for when assembling all the data into a single map. Refer to your yield monitor manual for details on calibration

Cutter bar width – for grain harvesting, the cutter bar width, ie the width of the harvester comb must be set-correctly. If harvesting windrowed crops this is the width of the windrower comb.

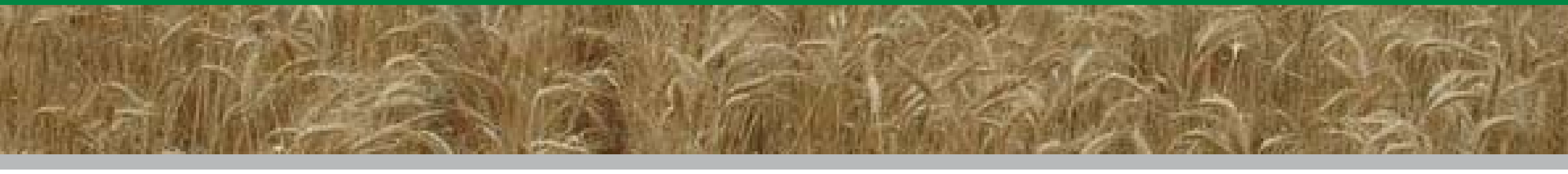
Keep data clean – no this is not about dust, it is about avoiding logging data where there is none or it is incomplete. Minimise overlap, avoid cutting less than a full cutter bar width, lift the comb when you reach the end of the swath and harvest up and back. All these will help improve data quality and save time when processing data into maps. If using autosteer you may need to reconfigure the GPS settings on your receiver to ensure the GPS information is delivered correctly to the yield monitor.

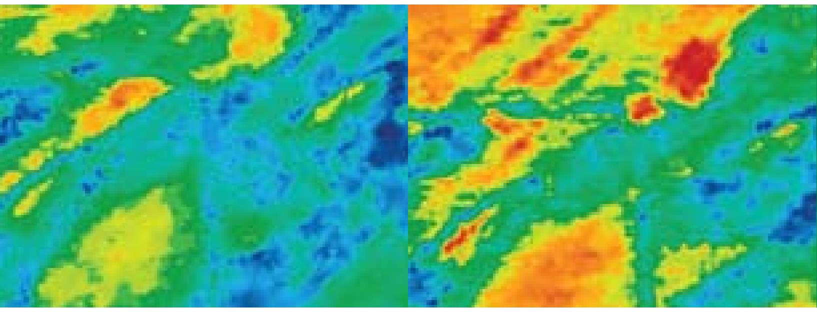
GPS and guidance – an uncorrected GPS signal, is sufficiently accurate for yield mapping in grains. If you have an RTK signal it is worth using as elevation data will be gathered at the same time.

Card check and back-up – if the yield monitor does not create an on-the-go yield map on screen, you MUST load data onto your mapping software to confirm data is being logged correctly.

Ideally data should be downloaded and stored daily – once a season is definitely not often enough. Create a new folder for each year's files (See data storage page 7). Regularly back data up to an external hard drive, CD or DVD. It is a good idea to copy to back-up before it is processed by the mapping software. Your yield mapping software should have a back-up function.

*More information on collecting good yield data is found in previous issues of SPAA publications available from **www.spaa.com.au**, and in the GRDC PA Manual via **www.grdc.com.au***





Making yield maps

Accurate yield maps can provide data for improved farm management decisions now and in the future. Examples of their use include estimating nutrient removal, gross margin and water use efficiency, as well as for the delineation of management zones.

The following information has been written primarily for grain growers but is of relevance to all crop types.

The production and storage of accurate yield maps follows five steps:

1. collecting accurate yield data;
2. data storage;
3. data cleaning - removal of erroneous data points;
4. changing the GPS projection to easting and northing; and
5. interpolating (producing a smooth map surface) data.

At the completion of these steps the yield map should be an accurate representation of the paddock's production and is ready for use.

Software supplied with yield monitors is gradually becoming more sophisticated, with many packages able to produce yield maps from yield data at the touch of a button. However, the supplied software generally uses less exacting statistical methods to interpolate the data; that is, to turn the yield data collected at points into a smooth continuous map surface. Software that uses 'kriging' rather than inverse distance weighting (IDW) is recommended for producing more robust maps.

If using the yield mapping software supplied with your yield monitor, you will only need to complete the first three steps, referring to your instruction manual for information on how to clean yield data. However, if you want to produce representative yield maps that you can integrate with other sources of mapped data, such as EM38 or elevation, follow all five steps. In general, the map derived from yield monitor software is regarded as a quick overview but for applications other than a quick look, production of a more robust, representative map is strongly recommended.

Step 1 – Collecting accurate yield data

See page 6.

Step 2 – Data storage

Before starting the mapping process make sure all previously collected yield data has been transferred from your data card to your computer. Make a back-up copy of all the raw data files onto a CD.

On completing each of the steps three, four and five, data will need to be saved. Following a common naming theme will help when relocating files in the future.

File names should contain paddock name, crop type (eg. wheat, canola), year collected and data type (eg. raw, trimmed, interpolated).

Examples: a raw yield file containing wheat data from House Paddock harvested in 2007 would be named

House_wheat_07_raw.txt

If the data was trimmed (abbreviated to tr) and converted into MGA coordinates (easting and northing) then the new file may be named House_wheat_07_MGA_tr.txt

If the data had been interpolated by kriging (abbreviated to kr) then the new file may be named

House_wheat_07_MGA_kr.txt

A hierarchal filing system (Figure 1) is suggested to assist in the rapid retrieval of the correct data.

With this system many paddocks can be stored under 'Farm', and multiple years under 'Paddock' and several data types (yield, soil, crop biomass, etc.) under each 'Year'. It is recommended that raw data is stored in a 'Raw' data folder, and any subsequent files that have been altered are saved in the 'Manipulated' data folder.

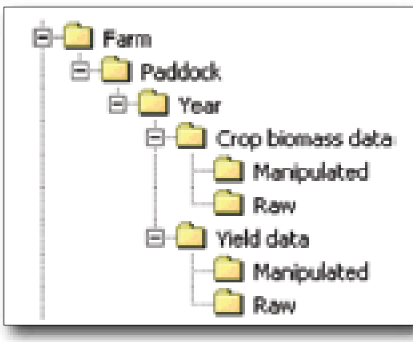


***Figure 1.** An illustration of a logical yield data file structure that allows easy retrieval of saved data.*

Further detailed discussion on this issue is available in the GRDC PA Manual and Precision Ag News Vol 2 Issue 3 – Summer 2004.

Step 3 – Data cleaning

Not every data point is appropriate for mapping; some may be misplaced due to GPS signal error, others are low or even zero readings at the start and end of rows when the comb is not at full capacity or abnormally high when the harvester slows, or when there is a blockage in the system. All of these erroneous data points need to be removed.

Firstly, yield monitor calibration accuracy should be checked. This can be done by comparing total deliveries (do not forget stored or grain kept for seed) with the total yield recorded on the yield monitor. This is best done for each grain type. Yield adjustment can be made in the yield mapping software to correct for any discrepancies at any point denoted by (i) in the equation below.

If the calibration is not accurate, yield maps still identify areas of higher and lower yield but this will not be sufficiently accurate for making nutrient removal, gross margin or water use efficiency maps.

If data is to be cleaned with the yield mapping software then refer to the yield mapping software manual or help guide. If alternative software is used the data will need to be exported as "comma separated values" (.csv) or "text" (.txt).

Incorrect data can be removed in a spreadsheet such as Excel. Specific recommendations for cleaning grain yield data are described in Precision Ag News Volume 1 Issue 2 October 2002.

Alternatively, for grain growers a software program like Yield Editor can be used; this is free to download from www.ars.usda.gov/services/software/download.htm?softwareid=20. Yield Editor allows incorrect data to be removed using a number of filters. For grain data, use 'filters' for maximum and minimum yield, standard deviation, start and end pass delay (ie. when pulling in and out of the crop), maximum and minimum speed, and changes in speed (ie. to remove points where the harvester has stopped or started rapidly). Manual deletion of points is also possible.

Yield Editor will only import data saved in an AgLeader Advanced txt file format. With FOViewer (a free program www.mapshots.co/FODM/fodd.asp) data from most yield monitors can be read.

For grape yield mapping, Dr Rob Bramley, CSIRO recommends the removal of any data recorded when the GPS was not receiving a differential signal. This would also be a wise strategy for grain growers.

Irrespective of the crop being grown, Dr Bramley also recommends the trimming of the top and bottom 1% of yield values from the dataset. Guidance on how to do this is available at www.cse.csiro.au/client_serv/resources/protocol_supp1.pdf.

Step 4 – Changing the GPS projection to easting and northing

GPS data is generally gathered based on longitude and latitude on decimal degrees using the WGS84 American standard. However, mapping software requires it to be in eastings and northings with units of metres. To make this change the software will require your Universal Transverse Mercator (UTM) zone; Australia is covered by UTM zones 49 to 56 (Figure 2). Geod is a free program able to convert Australian coordinates available at www.lands.nsw.gov.au/survey_maps/geodesy/gda/geod_software

Yield Editor can convert the GPS projection to eastings and northings, which bypasses Step 4. However, it is important to note that, as Yield Editor is American software it locates data on the standard datum (WGS84) rather than the Australian datum (GDA94). There is approximately a 70cm difference between the two

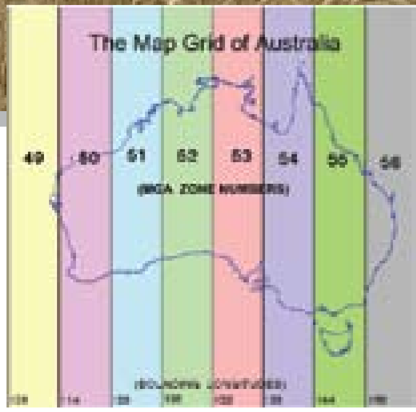


Figure 2. *Australian Universal Transverse Mercator – source www.environment.gov.au/erin/tools/mga2geo-gda.html*

but as most broadacre equipment takes several meters for rates to change this is not of major concern.

Ideally the datum should be converted as recommended in Step 4.

Step 5 – Interpolating data

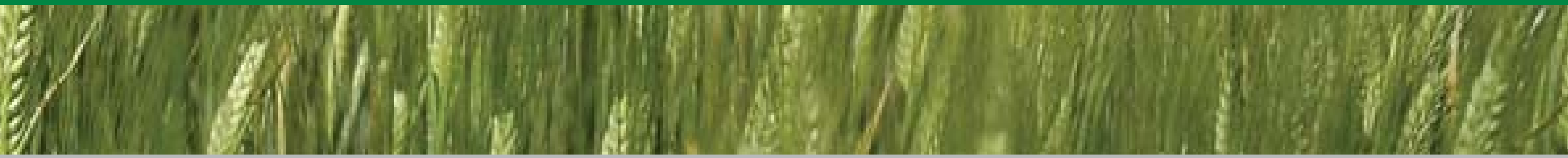
To turn all the data points and spaces between them into a yield surface the data needs to be interpolated. VESPER is a shareware program ($55 from www.usyd.edu.au/su/agric/acpa/pag.htm) that kriges the data and places it on a standard grid. Kriging produces a smoothed map surface and allows yield data to be layered with data from other sources, eg. EM38, which has been placed on the same grid. Creation of a grid is a key step. For each paddock, always use the same grid (same size and location). Ideally, the grid will be derived from a differential GPS survey of the paddock boundary.

For grain crops a 5 to 10 metre grid is appropriate. For block kriging grain a 25 to 30 metre block is recommended.

After yield map interpolation, the results need to be displayed. Ideally, this is done using GIS software eg. ArcGIS, AGIS, PAM and SMS Advanced among others. They vary in price, functionality and user friendliness, so seek advice before purchasing. However, some yield monitor software will allow the processed data to be imported back in for map display. The yield map should now be an accurate display of the actual yield variation observed in the paddock.

More information on yield mapping is found in back issues of Precision Ag News available at ***www.spaa.com.au***

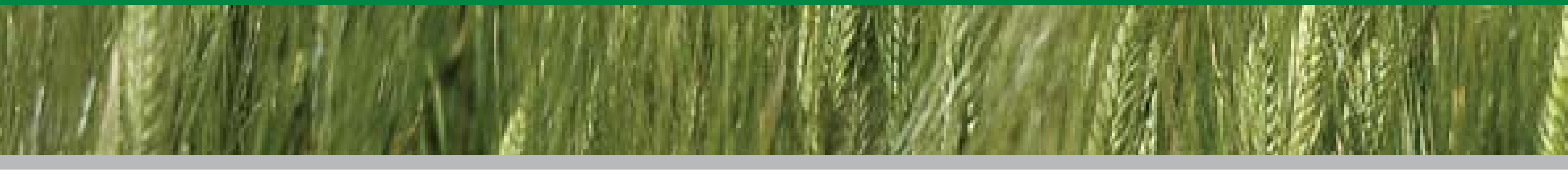
$$\text{Adjusted yield (i)} = \frac{\text{measured yield from the yield monitor (i) x total tonnes delivered}}{\text{total tonnes harvested by the yield monitor}}$$



SECTION 2

PA case studies

PA in Practice - grain growers' experience of using variable rate and other PA technologies




To date Dean Bagshaw has used a local contractor to spread P fertiliser variably across the paddock prior to seeding, based on a prescription map.

VR pays dividends on variable soil types

Dean Bagshaw suggests his farm is ideal for variable rate as he has some of the best and worst soil in the State along with the biggest rocks.

PA Timeline

Guidance	Yield mapping	Autosteer	Variable rate (VR)	Inter-row seeding	Direct injection spraying	Shielded spraying	On-farm trials
2003	2003		2005				2007

Farm profile

Farming personnel	*Dean Bagshaw*
Farm location	*Malinong, Upper South East, SA*
Annual rainfall	*450mm*
Soil types	*Sandy loam flats, deep sandy and rocky rises*
Farm area	*1300ha*
Topography	*Undulating*
Enterprises	*Wheat, barley, canola*
Average wheat yield	*3t/ha*
SPAA member	*Yes*
PA consultant	*Felicity Turner, Swan Brothers*
Agronomy consultant	*David Brown*

PA equipment

In 2003, the purchase of a New Holland TR89 harvester fitted with an Agleader yield monitor marked the start of Dean Bagshaw's use of PA. The addition of a GPS receiver, data card and New Holland's own Precision Farming software ($1,100) enabled Dean to start yield mapping. Precision Farming Software is based on SMS basic, an Agleader program from the USA and distributed by gps-Ag in Australia. Dean has found both the yield monitor and software easy to use.

In 2003, when upgrading to a new boomspray an Outback-S lightbar guidance system was purchased for use on his spray tractor ($9,000). The cost was partially offset by the reduced price of the boomspray, because the foam marker ($5,500) was not ordered. The lightbar system uses an autonomous correction signal called E-diff, and has a pass-to-pass accuracy of 10 to 30cm. Dean chose the Outback-S unit for ease of use and because he felt it to be a better investment than a new foam marker.

In 2006, another Outback-S unit was purchased for the sowing tractor ($3,000). Since adopting GPS guidance for sowing, Dean has measured a reduction in overlap of 8 to 10%, which he estimates to represent a saving of $10 to 13/ha.

Full VR in 2005

Dean adopted VR over his entire cropping program in 2005, based on two years of yield maps and knowledge of soil type productivity. Farming in a relatively reliable area with 450mm rainfall and cool ripening conditions, his crop yields are closely linked to soil type.

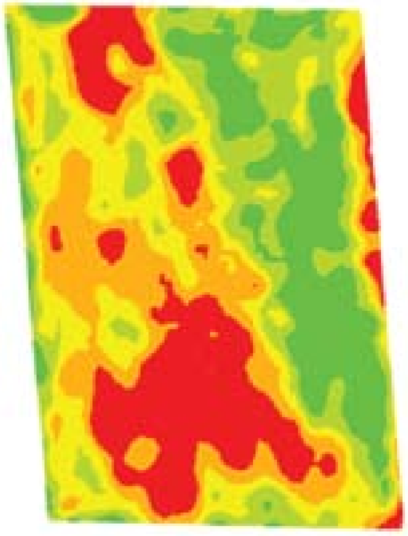
The sandy loam flats are the most productive and regularly yield 3 to 5t/ha. Rises consist of deep sand and/or limestone and consistently produce low yields of 0 to 2t/ha.

Before VR, Dean applied a blanket rate of fertiliser per hectare (30kg nitrogen, 15kg phosphorus) across his paddocks. Soil tests revealed this strategy was building soil phosphorus (P) on the sandy/rocky rises (30ppm), while the levels of P fertility were low on the more productive flats (10ppm).

Since 2005, Dean has applied more P to the flats (20kgP/ha) and less to the unproductive sandy/rocky rises (10kgP/ha). In 2007, this strategy saved Dean up to $25/ha in some paddocks. A standard rate of nitrogen (N) fertiliser is applied at sowing (20kg N), but varying the rates of post-sowing N is being considered.

Dean's air-seeder cart is not capable of VR so a local contractor is used to spread P fertiliser in front of his sowing operation. For variable rate applications a spreader fitted with Farmscan Farmlap system, using a corrected Omnistar GPS signal (approximately 10cm accuracy) linked to a Comspread controller 1 is used.

P rates vary based on prescription maps developed with his PA consultant Felicity Turner.



	Average Yield t/ha	DAP applied kg/ha
	5.0	100
	4.0	80
	3.0	80
	2.0	50
	1.0	50

Figure 1. *In 2007, targeting phosphorus to the more productive sandy loam flats, saved $25/ha in some paddocks.*

During summer Felicity and Dean review his yield maps and develop prescription maps for P using a combination of:

- yield maps from the most recent harvest;
- yield maps from previous years to check consistency;
- knowledge of soil types and production potential.

Prescription maps are produced using SMS basic, and exported as a shape file. The SMS shape file is converted through the Farmscan DataManager software where rate bins are created and data is converted to a file format that can be read by the Farmlap system. This process is relatively straightforward.

Potassium (K) response

In conjunction with SPAA, Dean conducted a K fertiliser trial on one paddock in 2007. In the past, K was found to be required for the successful establishment of lucerne on sand hills. The trial aimed to determine if there was any response to K in wheat.

Soil tests taken at the start of the trial, indicated that K levels in the top 10cm were low, but not critical.

In the trial paddock three rates of muriate of potash, 0kg/ha, 50kg/ha and 100kg/ha, were applied. Each treatment was three seeder widths and runs the entire length of the paddock.

Tissue tests and yield were measured. No yield response occurred in this season but treatment effects will be monitored over subsequent seasons.

Future plans for VR

To enable him to manage his own VR program, Dean plans to have a variable rate controller on his next air-seeder cart. He plans to include more test strips across paddocks to monitor the profitability of his VR program, and to use site specific soil testing to ensure P levels are being maintained. Dean will also keep experimenting to improve his cropping system and is considering increasing seed rates on sandy/rocky rises to improve crop establishment.

Contact details:
Dean Bagshaw, 0409 679 054, kanbara@bigpond.com

Kym I'Anson is pleased with the benefits in time saving, cost efficiency and improved productivity he has gained since using PA in his cropping system.

Targeted inputs improve soil and crop performance

Strategic use of inputs is helping the I'Ansons improve their soil and crops and reduce their ryegrass problems.

PA Timeline

Guidance	Yield mapping	Autosteer	Variable rate (VR)	Inter-row seeding	Direct injection spraying	Shielded spraying	On-farm trials
	2002	2004	2005	2004		2004	2007

Price, availability of local and 24 hour support and transferability between vehicles, influenced Kym I'Anson's PA equipment purchases for his integrated PA program.

Kym started yield monitoring in 1999 with John Deere equipment ($6,000) for his JD 9510 harvester. Yield mapping commenced three years later in 2002, when a JD GPS receiver, JD processor and JD Office software were negotiated in the price of a harvester upgrade (JD 9650 STS). Yield maps are downloaded using JD Office software.

A further investment for a tractor steer kit ($6,000) linked to the JD GPS receiver and JD processor equipment allowed Kym to sow using autosteer.

Farm profile

Farming personnel	*Kym, Murray, Katie and Ann I'Anson*
Farm location	*Saddleworth, Lower North, SA*
Annual rainfall	*400-500mm*
Soil types	*Heavy red clay, shallow grey shale and deep black soil*
Farm area	*1250ha*
Topography	*Undulating*
Enterprises	*Wheat, barley, oaten hay, canola*
Average wheat yield	*4t/ha*
SPAA member	*Yes*
PA consultant	*Sam Trengove*
Agronomy consultant	*Allan Mayfield*

Kym uses the StarFire2 (SF2) correction signal ($1000/year), which he finds provides reliable and repeatable 10cm autosteer. The newer JD GS2600 GreenStar display and mobile processor was purchased in 2005 ($17,000). This is now used for autosteer on two tractors, and for yield monitoring and yield data collection in the harvester.

Prior to autosteer, Kym adopted a controlled traffic system with bare, permanent wheel tracks in 2003. Controlled traffic resulted in a reduction in overlap of 5%.

The I'Anson family operate an 11m Ausplow DBS seeder on 260mm spacings, purchased in 2004. By lifting hydraulic tynes bare wheel tracks are left every 33m to provide permanent guidance for the boomspray.

The addition of autosteer further improved accuracy reducing overlap by a further 3% and has enabled inter-row sowing to be adopted. The combined reduction in overlap of 8%, equates to a saving of $25/ha on variable inputs of seed, chemical, fertiliser and fuel.

Kym finds that inter-row sowing is successful with his 10cm system, providing he takes the time to reset his AB lines each year. To inter-row sow, Kym returns to a permanent wheel track and uses the nudge function in the GreenStar to re-centre the AB line that was laid down when autosteer was adopted. The AB line is stored by the GreenStar software. The result is the tynes are positioned between last year's crop rows.

The I'Ansons consider no-till, controlled traffic, autosteer and inter-row sowing as a whole package that has helped them retain more stubble, create an ideal environment for crop establishment and growth, and increase yields on their more challenging soil types. Weeds in tramlines are an issue in some paddocks and these are controlled by herbicides dispensed from a purpose built shielded sprayer.

Another key piece of PA equipment on the farm is the handheld iPAQ coupled with a Garmin GPS receiver and Farm Works software (total cost $1500). This equipment is used to map soil zones across the farm and enabled a VR program for gypsum and lime applications to be implemented.

Soil mapping and VR

Acidity and sodicity limit productivity on a large proportion of the I'Anson's properties, which are characterised by three reasonably distinct soil types. During the past five years the I'Ansons have manually mapped the soil types in each paddock.

Paddock maps were loaded into the Farm Works software, which draws a grid across the paddock and pinpoints where each hectare should be soil sampled. Using these locations and soil colour approximately 30 soil tests were taken per paddock. The results from these soil tests have been used to create zones for the application of lime and or gypsum.

Heavy red clay soils

These soils are sodic and acid ($pH_{(CaCl)}$ 4.0 to 5.5) and make up 70% of the property. Yield monitoring revealed that crops grown on these soils were yielding 30% less than the other soil types. The addition of lime (2.5t/ha) and gypsum (3t/ha), in conjunction with stubble retention has greatly improved the yield potential on these soils. Kym reports the substantial improvement in crop competition has drastically reduced ryegrass on these soils.

Lime and gypsum are spread using a Marshall belt spreader and VR is all manual at this stage using the Garmin, drums and pegs to mark out soil zones in each paddock.

Shallow grey shale

These soils make up 20% of the property and are mostly located on the tops of hills. They are acid ($pH_{(CaCl)}$ 5.2) but not sodic, and therefore, only require lime (2.5t/ha).

The use of controlled traffic with autosteer has resulted in a combined reduction in overlap of 8%, equating to a saving of $25/ha on variable inputs of seed, chemical, fertiliser and fuel. Weeds in tramlines are an issue in some paddocks and these are controlled by herbicides dispensed from a purpose built shielded sprayer.

Soils types vary within paddocks; across the farm 90% of soils need lime but only 70% need gypsum. By zoning soil types, a variable rate spreading program has been developed that saves $22/ha compared to the use of a blanket application rate of lime and gypsum across the farm.

Deep black soil

The remaining 10% of the farm consists of a deep, free draining black soil that is neutral ($pH_{(CaCl)}$ 6.0 to 7.0). These soils do not require lime or gypsum. In fact, the addition of lime to these soils could make them alkaline leading to problems with Group B herbicide residues.

At this stage the program is to apply lime every four years and gypsum every five years. At a cost of $25/t for each product the VR program saves Kym $8,000 in lime and $20,000 in gypsum by not putting product on soil types that do not require amelioration. This combined saving equates to $22/ha across the farm.

VR trials for improved hay productivity

Farming in a high yielding but low nitrogen (N) status region Kym is using between 30kgN/ha and 70kgN/ha applied as urea, to maximise grain and hay yields.

Blanket applications of nitrogen at seeding have resulted in the productivity of some hay crops being radically reduced due to lodging and reduced hay value. Lodging can result in 40% of hay not being baled and the price being downgraded by approximately $50/t.

In the past, Kym has conducted deep N soil tests in different zones, with results varying between 80kgN/ha to 250kgN/ha (0-60cm) within the same paddock. These results suggested there was considerable scope to implement a VR – program for N fertiliser as a means of reducing lodging and producing a more even hay crop across the paddock.

Kym sees a future in using PA technology in conjunction with deep N soil tests to help him fine-tune his N fertiliser strategy.

Trials have been conducted by Dr Allan Mayfield and colleagues that assessed the use of variable rate N in the hay crops. Seeding N rates were slashed from 60kgN/ha to 30kgN/ha and a Yara N Sensor was used to identify parts of the paddock that required additional nitrogen during the growing season.

The Yara N Sensor uses optical sensors to measure the level of crop greenness and this information is used to develop a biomass image. This image can then be used to create N fertiliser application maps targeting N rates to crop requirement. In Europe these biomass images are also used to vary the application rates of plant growth regulants and fungicides.

The biomass images taken in July/August identified areas that were N deficient or had abundant N and were likely to lodge before cutting. Based on the biomass data a fertiliser map was produced and additional nitrogen was only applied to parts of the paddock. When averaged across the paddock the total N applied to the hay crop was 45kgN/ha, a saving of 15kgN/ha. Kym reports that lodging was markedly reduced, paddock yield increased and no price downgrades were experienced.

Future plans for PA

Kym is yet to analyse and use his yield maps. The major barrier has been the lack of an affordable, farmer-friendly software package capable of processing and analysing yield map data. In future Kym may work with his PA consultant to analyse yield data. Automating his VR program for lime and gypsum spreading, and using PA tools to help him fine-tune his N fertiliser strategy are plans for the future.

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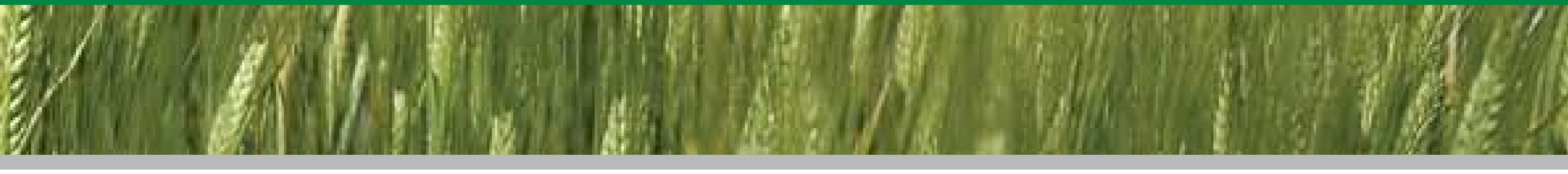
Lodging can result in 40% of hay being left unmown. The use of biomass maps to create variable rate fertiliser application maps has resulted in a saving of 15kgN/ha, improved yield and no price downgrade due to the impact of lodging on hay quality.



Graham and Brendon Johns have been pleased with the benefits gained from their VR phosphorus program.

Yield maps help save fertiliser inputs

While adopting variable rate seed and fertiliser programs has not been totally hassle free, Brendon and Graham Johns are pleased with the results.

PA Timeline

Guidance	Yield mapping	Autosteer	Variable rate (VR)	Inter-row seeding	Direct injection spraying	Shielded spraying	On-farm trials
2003	2005	2003	2007				2005

PA equipment

The first venture into PA for the Johns family was with an Accutrak from gps-Ag in 2003 ($14,000). The Accutrak is a 10cm autosteer unit fitted to their spray tractor, and the benefits of 5% less overlap and fatigue were immediate. They have been satisfied with the accuracy and reliability of the unit. They report one of the biggest advantages is the ability to spray summer weeds at night when the Delta T* is at its lowest. Effective summer weed control is vital in years when crops have to grow and fill grain on stored moisture.

In 2006, they purchased a Farmscan RT4000 autosteer system with Topcon receivers ($45,000), which was fitted to the tractor used for seeding. A corrected RTK GPS signal is provided by a base station. The main reasons for buying the Farmscan unit was the price and the fact that variable rate could be integrated into the system at a later date. The Johns have been disappointed in the reliability of the autosteer system, which should achieve 2cm repeatable accuracy. The Farmscan RT4000 controller is also fitted to their harvester for autosteer. For this purpose, Brendon sourced a second steering

Farm profile

Farming personnel	*Brendon, Graham, Denise & Margaret Johns*
Farm location	*Warnertown, Upper North, SA*
Annual rainfall	*340mm*
Soil types	*Sandy loam and clay loam*
Topography	*Gently undulating dune/swale sandy loam soils, and clay loam flats*
Enterprises	*Wheat, barley, peas and vetch green manure*
Average wheat yield	*2.2t/ha*
SPAA member	*Yes*
PA consultant	*Sam Trengove*
Agronomy consultant	*Allan Mayfield Consulting*

kit from Western Australia and fitted it himself at minimal cost.

Brendon and Graham have been yield mapping for the last three years with a monitor that came as standard with their John Deere STS harvester. Yield maps are downloaded using JD Office software (approximately $150).

In 2007, Brendon decided to go VR and purchased electronic actuators to vary the rates of grain and fertiliser automatically from his Simplicity air-seeder. These actuators, controller and wiring looms cost $7000, and Brendon fitted them himself. Farmscan DataManager software was supplied with the actuators.

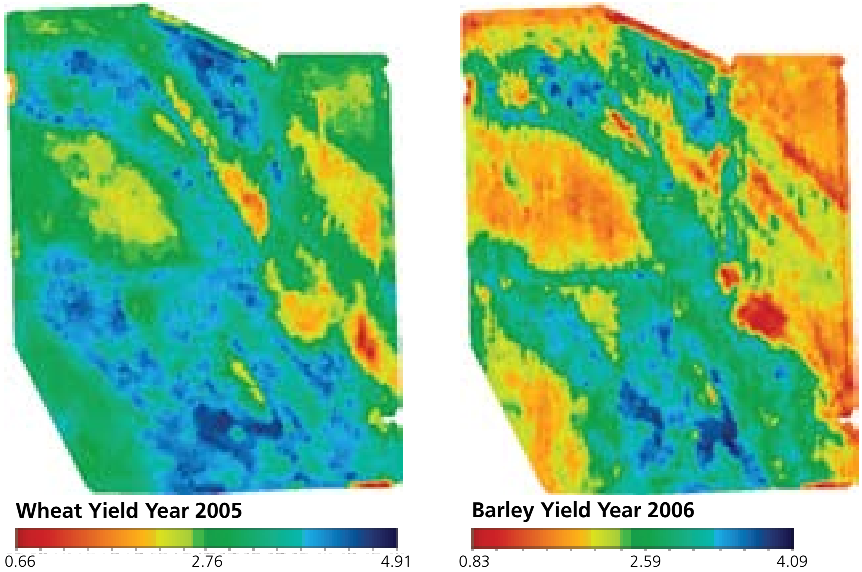
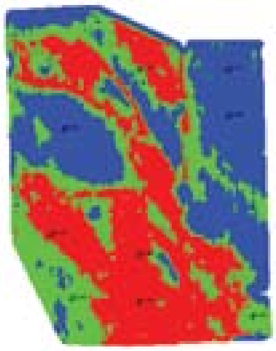


***Figure 1.** Wheat (2005) and barley (2006) yield maps where used with soil data and farmer knowledge to develop the three management zones seen Figure 2.*

Full VR program in 2007

Brendon engaged PA consultant Sam Trengove to develop in-paddock management zones based on yield maps from 2005 and 2006. His objective was to redistribute his fertiliser and seed to improve overall paddock performance.



Cluster	Area (ha)	Relative area	Barley Yld 06 (t/ha)	Wheat Yld 05 (t/ha)
1	57	0.37	3.07	3.92
2	45.5	0.29	2.28	3.32
3	51.8	0.34	1.82	2.57
95% CI	154.3		0.17	0.19

		0-10cm		0-60cm						40-60cm
Cluster	Area (ha)	Soil P (ppm)	Soil K (ppm)	Nitrate N (mg/kg)	Ammonium N (mg/kg)	Total N (kg N/ha)	Sulphur (mg/kg)	Sulphur (kg/ha)	Moisture (%)	Boron (mg/kg)
1	57	27	417	6	1	64.6	4.6	35.98	6	0.5
2	45.5	33	586	10	1	85.8	6.7	52.36	9	1.8
3	51.8	32	657	11	1	93.6	7.4	57.72	13	4.3

***Figure 2.** A strong relationship between soil type and yield underpins the three zones created in this 154 hectare paddock.*

Yield data was cleaned and kriged. These yield maps were laid on top of each other (known as overlaying) and vertical analysis segregated the data into yield classes using a process called supervised k-means clustering (Figure 1and 2).

A combination of soil samples taken from yield zones and farmer knowledge were used to assess the zones. For example for the paddock in Figure 2:

- high yielding red zones were located on the lighter textured dunes and overall were lower in nitrogen (N), phosphorus (P) and sulphur (S);
- low yielding blue zones were overall higher in nutrients (N, P, S), and are located on the heavier textured flats and boron is higher in the subsoil;
- intermediate yielding green zones are located on the mid-slopes between the red and blue zones.

The zone maps were then exported from Viewpoint to Farmscan DataManager software as a 'shape file' in order for Brendon to create prescription maps for variable rate seed and fertiliser applications. The zone and yield maps were converted into P replacement maps by allocating 4.5kgP (cereals) or 6.5kgP (legumes) per tonne of grain removed from the zones averaged over the previous two years.

In some paddocks only 2006 yield map data was available. This information was imported straight from JD Office into DataManager and transformed into a P replacement map based on 2006 crop yields using the same figure of 4.5kgP (cereals) and 6.5kgP (legumes) per tonne of grain removed.

Brendon also adjusted sowing rates on particular soil types. On non-wetting sands seeding rates for wheat were increased by 50% because establishment on these soils has been a problem in the

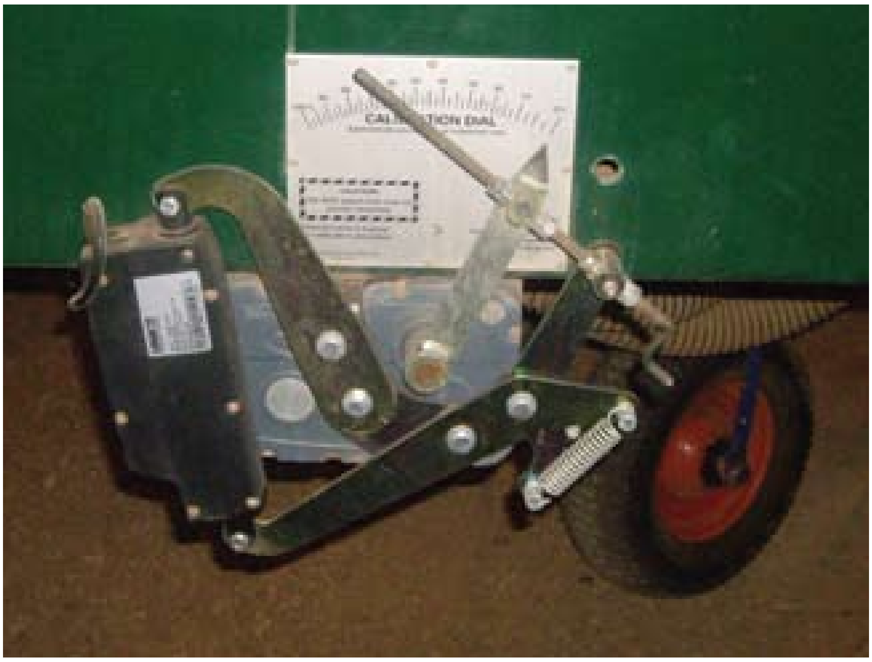
Autosteer is controlled by the Farmscan RT4000 unit. Currently VR seed and fertiliser is contolled by a 3500 CanLink.

past. Conversely, barley seeding rates were reduced by 20% on the heavy clay loam flats because these flats often run out of moisture in spring.

VR results in 2007

The sowing program in 2007 went smoothly and all equipment worked. However, there were two minor problems with the prescription maps. Firstly, boundaries on some prescription maps needed to be adjusted because yield map data was collected using raw GPS signal and the sowing tractor used a corrected RTK GPS signal from a base station. Secondly, where prescription maps were solely based on yield data small areas contained blank spots where no data was recorded. Receiving no information on what rate of seed or fertiliser to apply the air-seeder rate controllers shut down and placed zero seed and fertiliser in these areas. All data was cleaned and processed as recommended and why these blanks occurred has not been resolved.

Brendon's VR fertiliser plan was not to reduce the total amount of product used but to redistribute it according to historical production. However, allocating fertiliser based on zones and P replacement, to his surprise resulted in a 20% reduction in fertiliser used compared to the previous years. This saving was enough to pay for his VR equipment in one year.



Brendon fitted the linear actuators that enable automated VR to his Simplicity air-seeder for a cost of $7000.

Increasing the sowing rate of wheat on non-wetting sand hills was a big success resulting in the best establishment on these soils in years.

One of the key lessons Brendon has learnt in relation to PA is the importance of keeping copies of data and settings. A malfunction in the RT4000 caused by shutting the controller down incorrectly resulted in the loss of the AB line data for each paddock. Brendon now stores multiple copies on his computer and on USB drives. He also down loads all application data daily as this provides the rates of inputs actually applied. Farmscan have added an independent battery back-up to the controller and an alarm now signals if the unit has switched to this power source.

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** Delta T (ΔT) is the difference between the wet and dry bulb temperatures. It is used to measure the relationship between temperature and relative humidity. ΔT is one of the parameters that should be considered when assessing the risk of spray drift and pesticide performance. Ideally the ΔT should be between 2 and 8°C.*

SPAA Southern Precision Agriculture Association
Australian Government
Department of Agriculture, Fisheries and Forestry
National Landcare Programme
SAGIT

In low rainfall cropping country Peter Kuhlmann is using PA to identify input rates and where in the paddock these will produce the best gross margin.

Trials determine cost effective input rates

Eyre Peninsula farmer Peter Kuhlmann has used PA to conduct on-farm trials that have helped him develop a variable rate seed and fertiliser program.

PA Timeline

Guidance	Yield mapping	Autosteer	Variable rate (VR)	Inter-row seeding	Direct injection spraying	Shielded spraying	On-farm trials
2000	2003	2004	2005	2005			2005

PA investment

Abandoning the foam marker and purchasing an Outback lightbar with an Omnistar signal giving 10cm accuracy, ($11,000) in 2000, gave Peter Kuhlmann a taste of the potential benefits of PA.

A boomspray upgrade in 2002 allowed the incorporation of a Farmscan Farmlap monitor, which also used the Omnistar signal. Up and back driving using an AB line, autoboom shut-off and the addition of autosteer two years later, all combined to make Peter's spraying operation more precise and night spraying much easier.

Agleader yield monitors came as standard equipment in Peter's New Holland TR99 harvesters purchased in 2002, but it was a year later when SMS software was purchased ($1500), that yield data was downloaded and mapped. SMS was chosen because it is produced by the same company as the yield monitors. This software is also fully compatible with the Agleader Insight variable rate controller that Peter purchased later.

Farm profile

Farming personnel	*Peter Kuhlmann, Jock Rynne, Andre Eylward*
Farm location	*Ceduna, Eyre Peninsula, SA*
Annual rainfall	*290mm*
Soil types	*Predominantly grey calcareous sandy loam*
Farm area	*8800ha*
Topography	*Undulating dune/swale system*
Enterprises	*Wheat, barley, sheep*
Average wheat yield	*1t/ha*
SPAA member	*Yes*
PA consultant	*Ed Cay, gps-Ag*
Agronomy consultant	*Andrew Bates*

To complete his PA equipment, Peter invested in a 2cm autosteer ($55,000) in 2005 and VR system ($21,000) from gps-Ag in 2006. Compatibility amongst his existing GPS equipment and software, and back-up support were contributing factors in Peter's choice of equipment.

The gps-Ag equipment consisted of a single frequency 2cm AutoFarm providing autosteer on the seeding tractor and one harvester, an EZ-steer with Omistar signal providing autosteer on a second harvester (10cm accuracy), and an Agleader Insight controller capable of variable rate. The Agleader Insight is set-up to vary two granular products and one fluid product. Set-up was a relatively straight forward process, with technical support provided by gps-Ag. There are no major compatibility issues between the Agleader Insight, the Morris air-seeder cart and the Burando Hill fluid fertiliser cart.

Peter has two permanent staff members who both find the PA equipment easy to use following some basic training. Peter reports the company support and advice on setting-up the seeder for inter-row sowing and data analysis of yield maps for variable rate have been valuable.

PA trials

Large strip trials varying the rates of fertiliser and seed across paddocks were established in 2005 and 2006. The main aim of the experiments was to determine the most cost-effective levels of seed and fertiliser inputs (fluid phosphorus and granular urea) across whole paddocks in an 'average' season. This information would then be used to set a paddock's nutrient baseline. Yield maps would be used to calculate nutrient replacement rates above and below the baseline.

The trial strips were up to 1.5km in length and the average yield was

Table 1. *Paddock 26, Krichauff wheat 2005. Results in order from highest gross margin (GM) to lowest. Key: P=phosphorus, N=Nitrogen, Scr=screenings.*

Treatment	Seed (kg/ha)	P (kg/ha)	N (kg/ha)	Yield (t/ha)	Protein (%)	Scr. (%)	GM ($/ha)
Standard rates	60	4	12	1.59	11.2	4.5	171
Low seed	40	4	12	1.51	11.4	4.5	165
High input	40	8	19	1.79	11.5	5.5	164
Low seed, no N	40	4	3	1.42	11.2	5.5	163
High P	60	8	13	1.65	11.3	6.1	163
High seed	80	4	3	1.46	11.6	5.4	154
High N	60	4	16	1.48	11.3	5.2	153
High seed, no fert.	80	0	0	1.28	11.5	3.3	150
Low seed, no fert.	40	0	0	1.15	11.7	5.2	150
High P, no N	60	8	5	1.41	11.2	6.3	140
No P	60	0	9	1.19	11.1	4.9	136

Table 2. *Paddock 22, Yitpi wheat, 2006. Results in order from highest gross margin (GM) to lowest.*

Treatment	Seed (kg/ha)	P (kg/ha)	N (kg/ha)	Yield (t/ha)	Protein (%)	Scr. (%)	GM ($/ha)
No N	60	5.5	0	0.89	13.5	0.9	170
High seed, no fert.	80	0	0	0.80	13.4	1.0	164
No fert.	60	0	0	0.76	12.9	0.9	158
Standard rates	60	5.5	10	0.82	13.6	0.8	143
High seed	80	5.5	10	0.78	13.4	0.8	129
High P	60	7	10	0.77	13.6	0.8	126
Very high P	60	9.5	10	0.78	12.5	0.9	116
High N	60	5.5	15	0.66	13.8	0.8	102

Table 3. *Paddock 42, Yitpi wheat, 2006. Results in order from highest gross margin (GM) to lowest.*

Treatment	Seed (kg/ha)	P (kg/ha)	N (kg/ha)	Yield (t/ha)	Protein (%)	Scr. (%)	GM ($/ha)
Standard rates	60	5.5	6	0.49	14.1	1.2	71
No N	60	5.5	0	0.43	14.4	1.4	65
Very high P	60	9.5	6	0.51	13.8	0.9	63
High P	60	7	6	0.47	13.3	1.2	62
Low P	60	4	6	0.40	13.9	1.1	58
High fert.	60	7	9	0.45	14.3	2.8	52
No fert.	60	0	0	0.26	13.6	2.4	45
High N	60	5.5	9	0.38	14.1	1.7	44
High seed, no fert.	80	0	0	0.18	14.0	2.2	25
High seed	80	6	8	0.19	13.8	2.8	-5

measured with one full width of the harvester from the yield monitor and compared to the standard strips either side. Yield maps can be analysed using SMS software. Using this software, a box can simply be drawn around each strip and the yield is automatically calculated for that area. Grain samples were taken from each strip for quality analysis by the local silo. Results for these experiments are outlined in Tables 1, 2 and 3.

The difference in the pattern of rainfall between the two seasons was pronounced. Despite a late start to the season in 2005, with wheat sown in late June, an above average spring produced slightly above average yields. In 2006, after the season break in May, wheat was sown in early June followed by average rains in June and July. However, virtually no significant rain was recorded after mid July and crops finished the season solely on stored moisture.

The key findings from these trials were:

- the standard rates of seed, P and N were the most profitable in two out of the three paddock trials, despite contrasting seasons;
- increased P and N rates did not improve gross margin over the standard rates in all three trials;
- the response to adding a standard rate of P was between 0.1 to 0.4t/ha;
- in these seasons the value of N fertiliser was questionable in some paddocks.

Peter considers these experiments easy to conduct when using PA tools. The results from these trials helped him confirm the baseline fertiliser requirements and the yield data illustrated how yield varied across the paddock. To start managing inputs to production zones Peter decided to analyse his yield maps to help develop a VR program for the whole farm.

Yield map analysis

Peter employed the services of Ed Cay, gps-Ag to analyse his yield maps from 2002 to 2006. Data from 2002, 2003, 2004 and 2006 was used to create a multiyear average yield map for the whole farm (Figure 1). 2005 yield maps were not used because the wet spring produced yields that did not reflect the plant available water content (PAW) for the different soil types.

The yield data was normalised against the mean to reduce the bias of a particular year, for example a drought or high yielding year. This analysis highlighted (Figure 1):

- the most consistently high yielding areas are the longitudinal dunes in the central and northern areas of the farm;
- the most consistently low yielding areas are the heavier, clay loam alkaline swales, which have subsoil limestone closer to the surface and some areas have higher levels of boron and salt;
- there was up to an 80% correlation between elevation and yield, with the exception being severe sand blown dunes and rocky outcrops in paddocks;
- for the southern area of the farm, which consists of jumbled limestone outcrops, the yield maps varied with the depth of topsoil.

A multiyear gross margin map based on the yield maps and input costs was also produced (Figure 2).

In this example from paddock 18, the:

- consistently high yielding zone (6% of the paddock) returned a gross margin of $111/ha ($1607 per annum);
- higher yielding zone (41% of the paddock) returned a gross margin of $69/ha ($6260 per annum);
- lower yielding zone (37% of the paddock) returned a gross margin of $31/ha ($2536 per annum);
- consistently poor yielding zone (16% of the paddock) made a loss of $37/ha (-$1309 per annum).

Full VR in 2007

For Peter the objective of VR is to maximise the dollar return from his fertiliser and seed inputs.

At the beginning of 2007 Peter and Ed Cay developed a VR program for the whole farm to meet his objective. Paddock zones were developed using SMS software from yield maps, gross margin maps and most importantly Peter's own knowledge of the farm. Landscape images from Google Earth were used to help reference the location of paddocks.

No fertiliser was allocated to the consistently poor yielding zones but instead was reallocated to the consistently high yielding zones. The end result was the total amount of fertiliser applied in the paddock was unchanged but it was distributed according to historical production.

Prescription maps were put on a data card and directly imported into the Agleader Insight, a process made easy because all equipment and software is manufactured by the same company. During sowing there were no problems with the VR system.

To measure the success of his VR approach, Peter in conjunction with Jonathon Hancock from PIRSA included control strips of standard fertiliser rates across three paddocks.

As the season was so poor grain yield had to be estimated by hand cuts as it was too low to register on the yield monitor. The main conclusion was, in such a dry season, VR benefits were predominantly seen on the poorer soils, where reduced inputs resulted in thinner crops without compromising yield (Table 4).

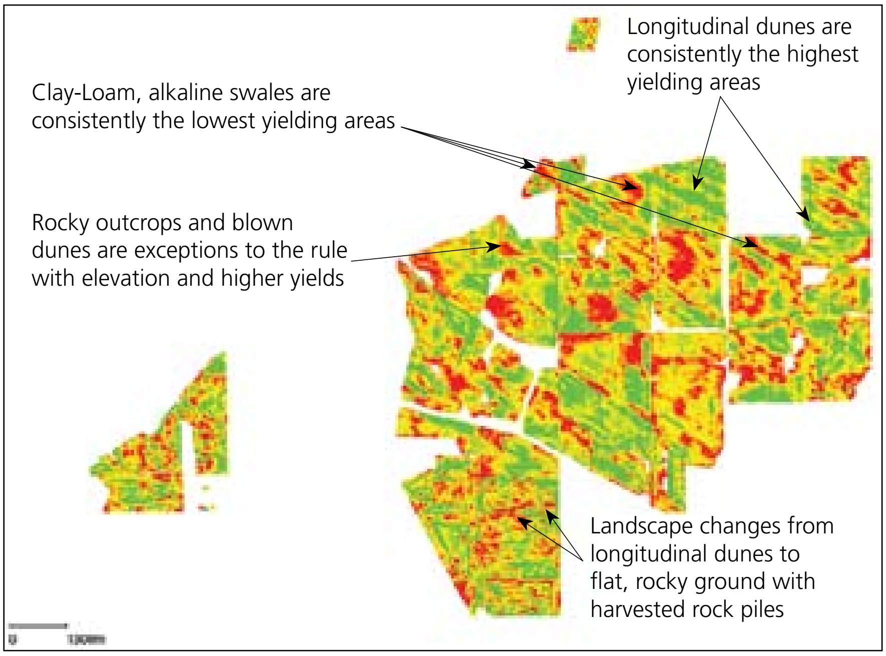

***Figure 1.** A yield map based on four years of averaged yield data, for Peter Kuhlmann's whole property. Green is high yielding and red is low yielding.*

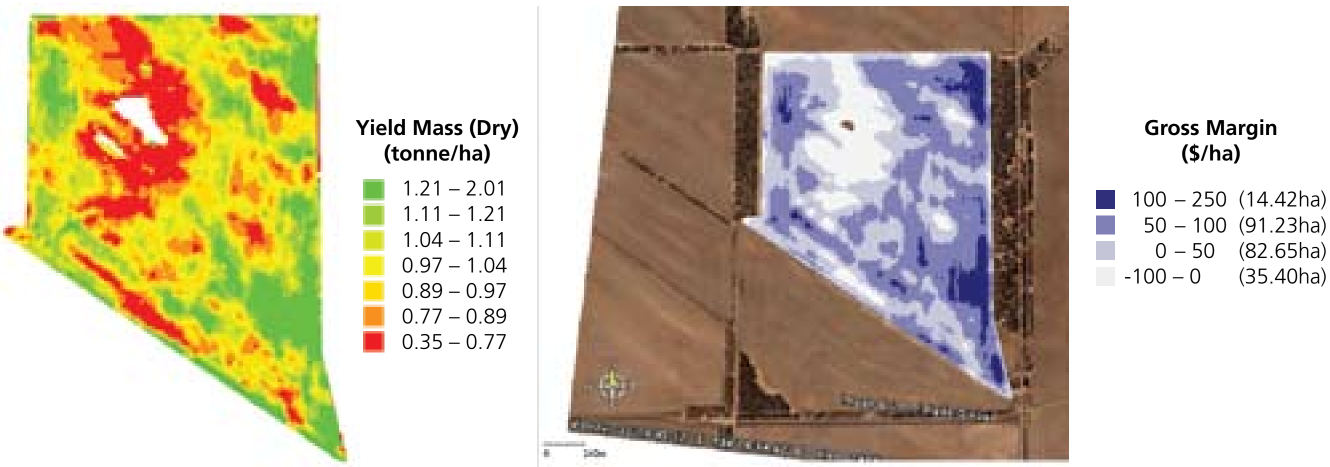

***Figure 2.** A multiyear yield and gross margin map of Paddock 18 shows that zones range in gross margin from +$111/ha to -$37/ha.*

Table 4. *Sowing inputs, grain yield, grain quality and gross income for treatments in paddock 41 Wyalkatchem wheat, 2007.*

Paddock Zone	Paddock Area (%)	Treatment	Seed Rate (kg/ha)	P Rate (kg/ha)	N Rate (kg/ha)	Grain Yield[1] (t/ha)	Protein (%)	Screenings (%)	Gross Margin[2] ($/ha)
Good	40	Prescription	60	6	9.2	0.69	12.2	1.2	241
		Standard	60	4.7	6.9	0.66	11.9	1.0	238
Medium	50	Prescription	60	4	5.5	0.61	12.5	2.2	220
		Standard	60	4.7	6.9	0.62	12.0	1.9	218
Poor	10	Prescription	40	0	0	0.49	12.6	3.2	194
		Standard	60	4.7	6.9	0.45	13.4	2.6	149

[1]Grain yields for poor paddock zone estimated from hand harvests, adjusted for harvesting losses.
[2]Gross Margin is yield by price (with quality adjustments) less seed and fertiliser costs delivered to AWB No.1 pool at Thevenard

Inter-row sowing benefits emerging seedlings but research suggests that in a season with a dry start where the inter-row is generally drier than the soil in last year's furrow, inter-row seeding should be avoided.

Inter-row sowing

Peter has been inter-row sowing for the last two years with his 17.6m Morris 9000 bar on 250mm row spacing. He estimates that the bar tracks between the rows about 70-80% of the time. He has found that sowing between the rows has three main benefits:

- the new seasons cereal crop is kept away from take-all and crown rot inoculum from the previous years stubble rows;
- standing stubble provides valuable wind protection for newly emerged seedlings;
- weed seeds in last years furrow are concentrated and buried under a band of trifluralin with inter-row sowing and no till.

Peter has identified several risks with inter-row sowing. The first relates to sowing away from the fertilised band from the previous crop.

The second occurs in seasons with drier starts when the seed is sown into the ridge of the last crop.

This area of soil is drier than the previous year's furrow that has harvested more moisture. In seasons with drier starts crops should be sown on or near the previous year's stubble row to maximise access to soil moisture.

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Yield maps are not only about crops

Low yielding, unprofitable areas were identified from six years of yield maps; these will not be cropped but will be planted to permanent native vegetation.

Stephen Paddick has been pleased with the benefits of autosteer; in the first year the reduction in overlap meant seven tonnes of fertiliser were left in the shed.

PA Timeline

Guidance	Yield mapping	Autosteer	Variable rate (VR)	Inter-row seeding	Direct injection spraying	Shielded spraying	On-farm trials
2001	2000	2004					2007

PA investment

Over the last eight years the Paddick family has spent approximately $40,000 on PA equipment. In 2001, a Zynx unit from KEE Technologies, which used the marine beacon as the correction signal, was purchased for spray guidance. As the marine beacon signal was found to be unsatisfactory with constant 'dropouts', a corrected signal from Omnistar was used to achieve 10 to 30cm pass-to-pass accuracy ($2,500 per annum). For the past four years the John Deere StarFire2 signal (SF2) has been used for all GPS correction; Stephen finds this to be reliable and accurate to 10cm.

In 2004, the Zynx was transferred to the sowing tractor and the autosteer function added, with SF2 used as GPS correction.

Farm profile

Farming personnel	*Stephen, Shane and Brian Paddick*
Farm location	*Wallaroo, Yorke Peninsula, SA*
Annual rainfall	*340mm*
Soil types	*Calcareous loam and sandy loam with low lying areas of high salt and boron*
Farm area	*1700ha*
Topography	*Flat to gently undulating*
Enterprises	*Wheat, barley, oaten hay, peas, chickpeas, canola*
Average wheat yield	*2.3t/ha*
SPAA member	*Yes*
PA consultant	*–*
Agronomy consultant	*Chris Davey*

Stephen has been pleased with this configuration. Benefits were immediate with less fatigue and overlap experienced. In the first year of using autosteer the 5% reduction in overlap resulted in seven tonnes of fertiliser being left over after sowing.

Unproductive and unprofitable cropping land, delineated on yield maps, will be taken out of cropping and be planted with native vegetation.

Initially, for basic guidance during sowing the monitor from the harvester was connected to the StarFire receiver in the seeding tractor. Additional steer kits for the Zynx autosteer have now been fitted to the spray tractor and the harvester. After sowing, the Zynx autosteer system is transferred back into the spray tractor and to the harvester at the end of the season.

In 2006, a GreenStar2 (GS2) unit with autosteer capability was purchased to enable the spray tractor to run autosteer all year round. The GS2 unit replaced the existing yield monitor.

The Paddick family started gathering yield data in 2000 with a Case IH AFS yield monitor, which came as standard equipment in their Case IH 2366 harvester. In 2004, they upgraded their harvester to a John Deere STS and a yield monitor was included as standard equipment.

The Paddicks have tried several yield mapping products. Instant Yield Map software, supplied free by Case IH, was used to download and view maps from 2000 to 2003. In 2004 and 2005, JD Office from John Deere ($150) was used, and for the last two years they have used GreenStar Apex software from John Deere. Stephen says the GreenStar APEX software is a vast improvement on JD Office and he will use it to generate and analyse yield maps.

Decisions on which products to purchase have been based on price, levels of local support and compatibility between systems. In the future it is likely that a second GS2 unit will be acquired when the Zynx needs upgrading. The GS2 unit can be used for autosteer, and as a spray, seed and fertiliser controller.

Wheat variety trial, 2007

Stephen conducted a wheat variety trial to compare Yitpi, Correll and Gladius in the same paddock. Yields were Yitpi 1.21t/ha, Gladius 1.27t/ha and Correll 1.41t/ha. Correll had an economic return of approximately $60/ha greater than the other two varieties.

Stephen found conducting these trials using PA equipment to be simple and accurate. The GS2 unit allows variety names to be entered for different locations within the paddock and the GreenStar Apex software automatically calculates the yields of the different varieties. The varieties were sown across soil types within the paddock and 10cm autosteer on the header ensured a full comb was always cut; both factors improve the robustness of the yield data.

Using yield maps to retire unproductive land

Recently, the Paddick family won a National Landcare Program (NLP) grant to plant native vegetation on unproductive agricultural land. Low lying land that is high in salt and boron will be fenced-off and permanently retired from cropping. Yield maps were used to delineate profitable and unprofitable areas of paddocks over the last six years. Typically, areas that regularly yielded less 0.4t/ha were unprofitable and will now be removed from the cropping program. Removing unproductive land is anticipated to increase whole farm profit because inputs will not be wasted on these areas. The permanent vegetation will reduce the likelihood of the salt areas spreading in the future.

VR plans for 2008

In 2008, Stephen plans to implement a VR program over 10% of his farm. The paddocks targeted for VR have been EM38 surveyed and mapped at a cost of $10/ha. EM38 measures the apparent electrical conductivity of the soil, which is influenced by the soil's salt, moisture and clay content and by soil bulk density.

Generally the EM38 maps corresponded with yield maps and the two sets of information will be the basis for constructing zones within paddocks. Zones will be produced in the GreenStar Apex program.

Targeted soil sampling in low and high yielding zones will be conducted to help devise fertiliser prescription maps. Some preliminary soil testing in low yielding areas has revealed high levels of phosphorus (P) so, a reduction in P fertiliser in these zones is anticipated.

Paddock zones from GreenStar Apex will be exported as a 'shape' file into the Maplink program supplied free from KEE technologies and loaded into the Zynx unit in the sowing tractor. Prescription maps can be easily created within the Maplink program. Stephen plans to use a low rate of nitrogen (N) fertiliser at sowing and vary the rate of N fertiliser in-crop using liquid (UAN).

His GS2 unit, which has VR capacity, will become the spray controller. Prescription maps for UAN will be devised from previous years yield maps, EM38 maps and his own paddock knowledge.

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SPAA Southern Precision Agriculture Association

Australian Government Department of Agriculture, Fisheries and Forestry National Landcare Programme

PA makes farming more enjoyable

PA technology helps Leigh Bryan better understand the potential of each paddock and to make informed decisions; he says PA has made farming more challenging but also increased his enjoyment of farming.

Leigh Bryan is self-taught when it comes to PA data analysis, he enjoys the challenges and reward that PA presents whether he is sourcing new software from the internet or experimenting with satellite images to create nutrient maps for hay paddocks.

PA Timeline

Guidance	Yield mapping	Autosteer	Variable rate (VR)	Inter-row seeding	Direct injection spraying	Shielded spraying	On-farm trials
2003	2006	2005	2007	2007	2006		2005

Farm profile

Farming personnel	*Leigh, Susie, Dale and Sue Bryan*
Farm location	*Swan Hill, Mallee, Victoria*
Annual rainfall	*340mm*
Soil types	*Sandy clay loams to sandy loams*
Farm area	*2400ha*
Topography	*Mallee dune swale*
Enterprises	*Wheat, barley, lentils, field peas, chickpeas, canola, hay*
SPAA member	*Yes*
PA consultant	*–*
Agronomy consultant	*Rick Rundell-Gordon, Elders*

PA investment

The Bryans first started using PA technology in 2003, when they purchased a Zynx X10 ($8,000) guidance system (sub-meter accuracy) to help reduce under and over lap.

In 2005, the Bryans added a Zynx X15 (10cm accuracy) with the facility to control autosteer and variable rate ($40,000). The correction signal is provided by an annual subscription to the Omnistar HP signal. This single screen unit was fitted in a John Deere 9300 tractor. While the Bryans have always sown up and back, the improved guidance assisted in their transition to controlled traffic farming.

In 2007, the two box Horwood Bagshaw air-seeder was converted from a gear to an electric drive, allowing seed and fertiliser rates to be varied on-the-go. The seeding bar has the capacity to switch between a tyne spacing of 225mm or 450mm spacing. The wider spacing is used when sowing barley, canola, field peas and chickpeas. This allows consecutive crops to be sown inter-row and benefit in relation to stubble handling, erosion control and inter-row weed control.

After investing in PA technology the first benefit the Bryans immediately discovered was less driver fatigue.

Soil testing has shown phosphorus (P) rates to be adequate across the farm, so Leigh wanted to implement a fertiliser program based on nutrient removal by the previous crop.

Yield mapping began in 2006, and maps are processed using Case IH AFS software (SMS Basic). Maps are further processed through Manifold GIS to create nutrient balance maps (P applied, minus P removed). These maps are use to budget the following year's fertiliser requirements (Figures 1a-d).

In 2006, Dosatron injectors were fitted to a dual line boomspray ($4,000), to allow two chemicals to be applied at the same time but without mixing. For example, glyphosate is distributed in one boom line across the whole paddock, while 2-4-D amine is in the other line to patch spray hard to kill plants such as skeleton weed.

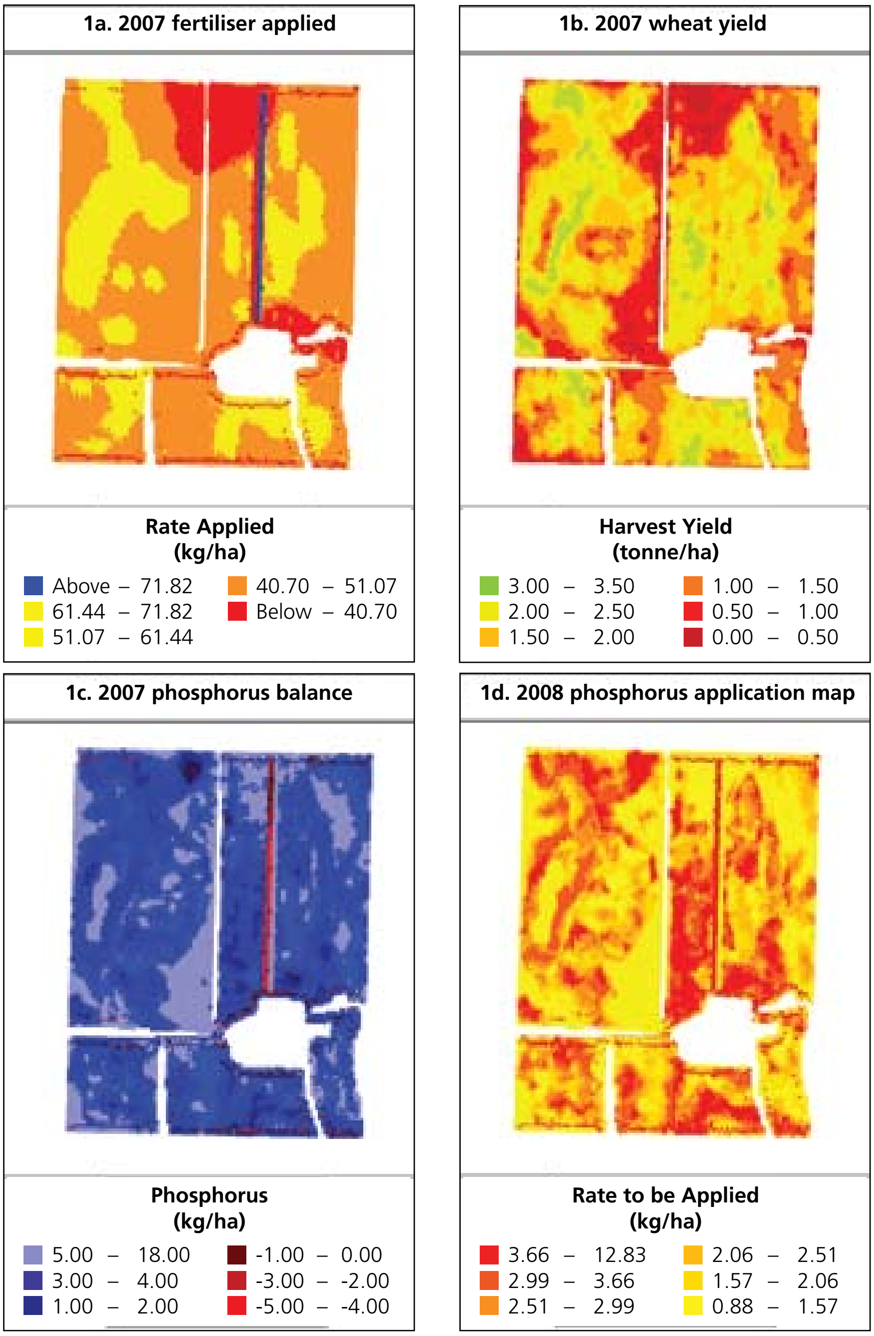
In summer 2006/07, 700 hectares (three paddocks) were EM38 surveyed ($2.20/ha). Only one of these paddocks had useful information that correlated well with yield maps and soil constraints. Leigh has not been convinced of the value of EM38 on his soil types due to unreliable information but he has seen good results with EM38 surveys from farmers on different soils, generally with higher salt constraints.

Upgrades in 2007 included Farm Works software ($1,200). This software provides a suite of fully integrated farm management programs, including in-crop record keeping and the ability to interpret yield and EM38 maps.

In 2007, Manifold GIS (version 8) software was purchased off the internet ($280). This GIS package provides an interactive desktop system for creating, editing and interpreting GIS data layers such as vector drawings, terrain elevation and normalised difference vegetation index (NDVI) images. HyperCube, a free windows based software package that processes digital imagery including multispectral and hyerspectral satellite data, was also used for the first time in 2007.

Largely self-taught in PA data analysis, Leigh produces and interprets all the maps himself. Leigh's choice of hardware and

Figures 1. *a to c illustrate the three maps (Fertiliser applied – 1a, Yield - 1b and Phosphorus balance – 1c) used to create Leigh Bryan's fertiliser application map 1d. Test strips for the variable rate trial can be seen.*



software packages is determined by their ease of use, ingenuity, low-cost and compatibility within his system. Any compatibility problems have been overcome through software upgrades, as well as converting files to different formats.

Yield maps for hay

Because yield data is not collected directly from hay paddocks, Leigh is investigating the use of NDVI satellite images to create yield maps and nutrient replacement maps for paddocks cut for hay and for low yielding legume paddocks where yield data did not register at harvest.

NDVI images taken in late September by the Victorian Department of Primary Industries, were used to estimate yield together with quadrant hay cuts. This timing was immediately before cutting hay and when legumes were at the late flowering stage. The hay paddocks were divided into ten yield zones with zone five representing the average hay yield based on the total paddock production. Leigh is developing this system of spatially estimating hay yield himself, based on indications from research by Victorian Department of Primary Industries.

Fertiliser zones

Two sets of variable rate fertiliser zones are created in different ways; one set is for rates of seed and mobile nutrients nitrogen (N) and sulphur (S); the second is for less mobile nutrients phosphorus (P) and zinc (Zn).

The seed and mobile nutrient zones are based on grower knowledge and on aerial photographs from which soil texture is identified by colour – white sands, red loams and grey clays. N and S are applied in liquid

Table 1. *Yield results (t/ha) for rates of DD Star starter fertiliser (22N,15.7P,1.7S, 0.7Zn) adjusted for soil type compared to a blanket rate of zero or 50kg/ha.*

Rate	0kg/ha	VR	50kg/ha
Sand	1.89	2.2 (50kg/ha)	2.13
Red	1.81	2 (40kg/ha)	2.01
Heavy	1.43	1.55 (20kg/ha)	1.54

Table 2. *The financial benefits of varying rate by production zone is clearly seen for the sand and heavy soil types.*

Difference	Yield (VR vs 50kg) t/ha	Gross Income $/ha	Fertiliser Saving $/ha	GM over flat rate $/ha
White sand	0.07	22.32	0	22.32
Red loam	-0.01	-3.96	5.6	1.64
Heavy clay	0.01	4.68	16.8	21.48

form through the boomspray during the growing season, if required.

The second type of zone, is based purely on nutrient removal as the Phosphorus Buffering Index (PBI) showed all zones have more than adequate P. Yield and the previous year's variable rate fertiliser maps are used to create P and Zn application rate zones for the coming crop. Basically, nutrients removed by the crop are subtracted from the nutrients applied to that crop, to produce a nutrient balance map showing the areas that were under or over fertilised in that year. Leigh then estimates the yield potential for each zone to produce his P application map for the following year (Figure 1a-d).

Fertiliser variable rate trial

Extensive soil testing has been used across the farm to help confirm the zones. In 2007, a variable rate fertiliser trial was run across 2.5 hectare test strips. These test strips can be seen in the maps in Figure 1.

The fertiliser trial compared variable rates of DD Star starter fertiliser (22N,15.7P,1.7S, 0.7Zn) based on production zones (50kg/ha on the sand, 40kg/ha on the red loams, and 20kg/ha on the heavy clays) with a blanket rate of 0kg/ha and 50kg/ha. Tables 1 and 2 detail the yield and financial results of this trial. Normally a blanket rate of 50kg/ha would be applied.

There was no real yield difference but the ability to cut fertiliser rates from 50 to 20kg/ha on the heavy soil without sacrificing yield is evident.

Leigh reports that there was a big visual response to the different rates, but with the extremely dry finish this did not translate into a significant yield difference. The visual response in this trial was considered to relate to the high N content of this starter fertiliser. With adequate P in all soil types, Leigh has not seen a yield response to P fertiliser.

Across the three zones, varying the rate of fertiliser by soil type resulted in an improvement in gross margin of $15/ha compared to a flat rate of 50kg/ha. Seed rate and row spacing trials, also conducted in 2007, helped confirm Leigh's strategies to manage the canopy.

Trials that targeted starter fertiliser rates to the soil's potential resulted in substantial increases in gross margin on two of the three soil types on Leigh Bryan's property.

Future for PA

In 2008, variable rate fertiliser and/or seeding rates will be used across the whole farm with the aim to improve yields and reduce screenings. Leigh's aim is to optimise plant and tiller numbers to produce a canopy and consequently yield that is the potential for that soil type and its plant available water in that season. Plant available water, time of sowing, seed counts and germination tests will all be used to determine seed and fertiliser rates.

Leigh estimates that almost all of his PA investments have paid for themselves within two years. He has also found that PA technology helps him better understand the potential of each paddock and to make informed decisions. For Leigh, PA has made farming more challenging but also increased his enjoyment for farming at the same time.

Leigh believes there are huge benefits to be gained from PA in the Mallee environment due to large in-paddock soil type variability and low rainfall. In the future the Bryans hope to use PA to become even more efficient in grain production. Inter-row and weed seeking sprayers are on Leigh's wish list.

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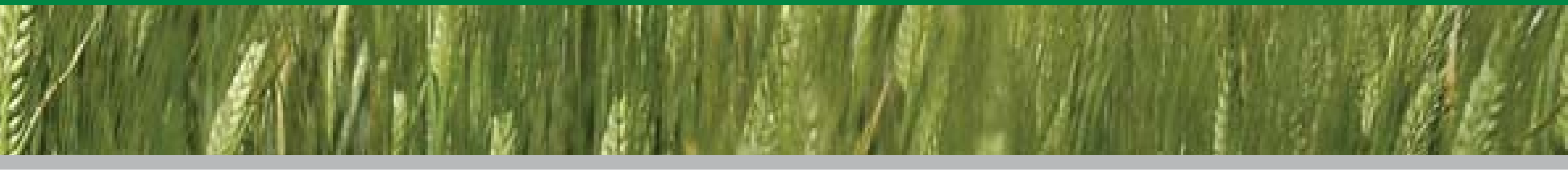
Southern Precision Agriculture Association
Australian Government
Department of Agriculture, Fisheries and Forestry
National Landcare Programme
BCG



Poor seasons have limited Colin Rayson's investment in variable rate equipment but manually changing rates by soil type suggest improvements in gross margin can be achieved from VR.

Yield maps quantify knowledge

The addition of autosteer to Colin Rayson's system has reduced overlap by 7%, while experiments where fertiliser and seed rates are varied manually suggest substantial improvements in gross margin.

PA Timeline

Guidance	Yield mapping	Autosteer	Variable rate (VR)	Inter-row seeding	Direct injection spraying	Shielded spraying	On-farm trials
2004	2002	2006					2007

PA equipment

Price, availability of local support and transferability between vehicles all influenced Colin Rayson's buying decisions for PA equipment.

The purchase of a New Holland TR99 harvester in 2002, fitted with an Agleader yield monitor as standard equipment, plus the purchase of a GPS receiver and software ($3,000) enabled Colin Rayson to start yield mapping. The software is SMS basic, an Agleader program from the USA, distributed by gps-Ag in Australia. Colin finds the yield monitor and software reasonably easy to use to download and view yield maps on his computer. The software has the ability to produce prescription maps for variable rate applications but as yet Colin has not used it for this purpose.

Farm profile

Farming personnel	*Colin Rayson*
Farm location	*Kimba, Eyre Peninsula, SA*
Annual rainfall	*340mm*
Soil types	*Sandy loam, clay loam*
Farm area	*2600ha*
Topography	*Gently undulating*
Enterprises	*Wheat, barley, peas, lupins, canola*
Average wheat yield	*1.6t/ha*
SPAA member	*Yes*
PA consultant	*–*
Agronomy consultant	*Peter King and Associates*

A Farmscan Farmlap guidance system with autoboom shut-off, and a John Deere GPS receiver were purchased in 2004 ($23,000)

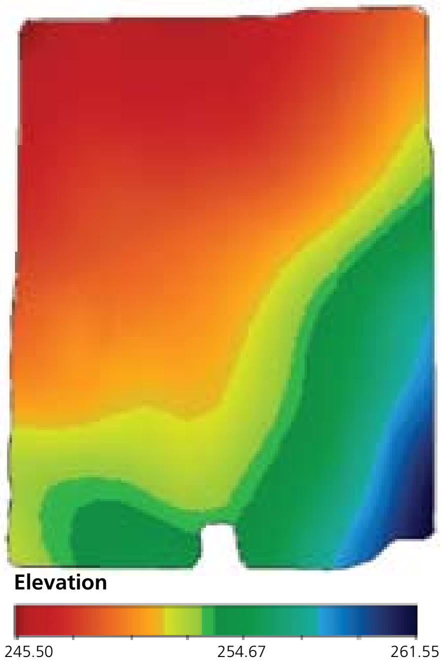


Figure 1. *Elevation data (metres above sea level).*

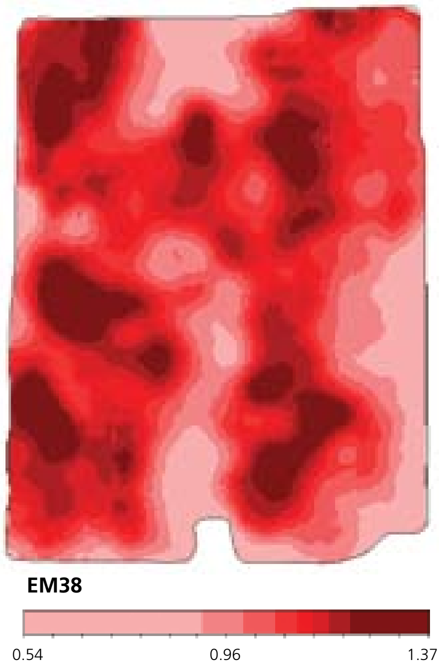


Figure 2. *EM38 survey map (dS/m).*

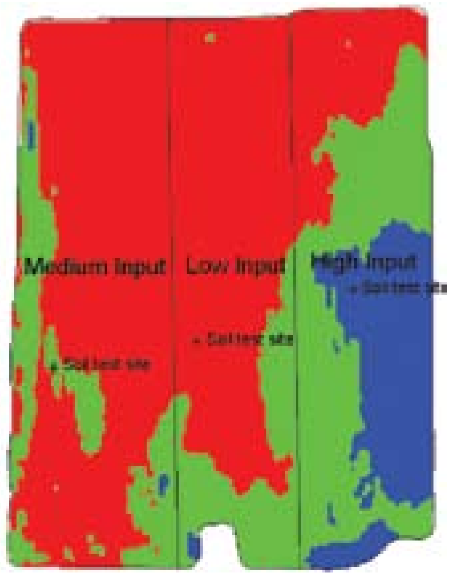


Figure 3. *High (blue), medium (green) and low (red) yield potential zones produced from yield, elevation and EM38 data as part of the PA group project, overlayed with Colin's current input zones.*

for accurate 'up and back' spraying. Initially the StarFire2 (SF2) correction signal was used ($1,000 per year) but Colin has found that the free StarFire1 (SF1) signal is accurate enough for spraying with 30cm pass-to-pass accuracy. Before the GPS, spraying 'up and back' was achieved with moderate success using double sided foam markers. The change to GPS guidance has resulted in less fatigue, a reduction in overlap of 2 to 5% and less missed strips, especially when spraying summer weeds at night.

In 2006, an Agleader EZ-guide lightbar was fitted to the second boomspray unit ($5000).

Before harvest 2006, a John Deere Autotrac autosteer system was fitted to Colin's harvester ($21,000). The system included an electric steering control unit, GreenStar2 (GS2) screen and GPS receiver. After harvest the autosteer is transferred to the main tractor for sowing. SF1 corrected signal is used for both harvest and sowing. Savings in overlap of up to 7% were measured during sowing in 2007, and were most evident with night time work. Total annual savings of $5/ha in variable input costs are being achieved using GPS guidance and autosteer.

Quantifying grower's knowledge

Colin has always been keen on crop monitoring and believes basic crop agronomy needs to be correct before yield maps are used to improve production and/or profit. For him, there is no substitute for

Table 1. *Gross margins per hectare in three input strips between 2002 to 2005.*

Year	Crop	Medium input clay loam	Low input clay loam higher subsoil salt	High input sandy loam rise
2002	Wheat	-$10	-$80	$70
2003	Peas	-$78	-$98	$80
2004	Wheat	-$15	-$15	$82
2005	Wheat	$125	$184	$245
Average		$6	-$3	$119

driving across paddocks to monitor weeds, root disease and nutrition. Having taken these factors into consideration soil sampling is then used in low yielding zones to reveal if soil constraints, such as transient salinity, are limiting yield potential.

Using his knowledge and yield maps Colin has manually varied the rates of seed and fertiliser in three of his paddocks. By creating three input strips that roughly matched the soil types he reduced seed and fertiliser on the poorer yielding clay loam areas and maintained standard rates on sandy rises (Figure 3).

For example:

- Low input strip 30kg seed and 10kg DAP on clay loam soils with high subsoil salt;
- Medium input strip 40kg seed and 40kg DAP on clay loam soils with low subsoil salt;
- High input strip 60kg seed and 60kg DAP on sandy loam soils that are least alkaline in the topsoil.

Yield maps have helped quantify what Colin has known for a long time. The sandy loam rises are consistently the most productive areas, and the clay loam flats are lower yielding because of their susceptibility to spring droughts, especially if a transient salinity problem is also present (Table 1).

While 2005 had a wet spring the other three years suffered from low spring rainfall, consequently the clay loam areas have consistently lost money. Conversely, the sandy loam areas returned a profit in all years.

Changing the seed and fertiliser inputs in the low and medium strips did not significantly affect yield. Analysis suggests that this strategy may increase gross margins by up to $20/ha.

Variable rate trial

A combination of yield maps, elevation data (Figure 1) and an EM38 survey (Figure 2) were used to delineate three production zones in the trial paddock. In Figure 3 the new production zones and Colin's original input strips are marked.

The use of PA data shows that the majority of the medium and low input strips have a low yield potential (red) and a large proportion of the high input strip only has medium yield potential (green). This suggests that the use of on the go variable rate could further improve Colin's gross margin across the paddock.

Future plans for VR

To go automated VR Colin needs to upgrade his seed and fertiliser rate controller. If readily available, he would also employ the services of a PA consultant to help develop prescription maps for his farm. Financial constraints due to a run of poor seasons have been the main reason why VR has not been adopted across the whole farm.

In terms of zoning, Colin would use a combination of yield maps, aerial photographs taken in summer and his own paddock knowledge. He has tried some EM38 mapping, but these do not appear to match up with his own knowledge of paddocks.

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Clinton, Derek and John Tiller (L-R) have pioneered the use of 2cm autosteer and inter-row seeding in South Australia.

Autosteering to improved productivity

Autosteer has delivered a range of benefits to the Tillers, including reduced fatigue, less overlap, the ability to inter-row seed and reduced herbicide damage in sensitive crops such as lentils.

PA Timeline

Guidance	Yield mapping	Autosteer	Variable rate (VR)	Inter-row seeding	Direct injection spraying	Shielded spraying	On-farm trials
	2002	2003		2003		2002	2003

PA equipment

There were only two 2cm systems on the market in 2003, when the Tillers decided to purchase an Autofarm unit from gps-Ag. They were the first farmers to purchase an autosteer system with 2cm accuracy in South Australia and selected the Autofarm system because it was the most affordable 2cm system available, it had an established market in the cotton industry and local support was available.

The unit they purchased was a single frequency 2cm system, and steer kits were fitted to their main tractor, spray tractor and harvester. The Tillers would prefer a dual rather than single frequency version of the Autofarm but this was not available at the time of purchase. Dual frequency enables a quicker 'start up time' and the GPS is less likely to drop out around trees.

Farm profile

Farming personnel	*John, Clinton and Derek Tiller*
Farm location	*Pinery, Lower North, SA*
Annual rainfall	*375mm to 450mm*
Soil types	*Red brown earths, black cracking clay, red loam*
Farm area	*2550ha*
Topography	*Flat to gently undulating*
Enterprises	*Durum, bread wheat, feed barley, lentils, canola, beans*
Average wheat yield	*Pinery 2t/ha, Alma and Stockport 3.5t/ha*
SPAA member	*Yes*
PA consultant	–
Agronomy consultant	*Bill Long, Ag Consulting Co*

Less fatigue was the first benefit experienced with the autosteer, especially during harvest. An estimated reduction in overlap of 2 to 5%, from controlled traffic, which had been adopted in 2001 (1 to 3%) and then from autosteer (1 to 2%), equates to savings of between $5 to $13/ha on variable inputs of seed, chemical, fertiliser and fuel.

Table 1 details the other PA equipment purchased by the Tillers.

Reduced crop damage

Another major benefit of reduced overlap was found when applying chemicals such as Lexone® on sensitive crops such as lentils. Minimising overlap results in considerably less crop damage. The addition of autoboom shut-off further reduced spray overlap by automatically switching-off boom sections when the GPS unit, which is attached to the spray controller, identifies locations that have already been sprayed. This is especially useful when turning and in odd shaped paddocks.

The autoboom shut-off equipment was negotiated as part of the price of a new boomspray and spray controller upgrade in 2005. Increased cost savings with autoboom shut-off are negligible in the Tillers situation with relatively flat square paddocks, but would be more significant in contoured country and paddocks with trees.

Wide rows were adopted as a means of improving yield and reducing spray inputs by targeting herbicides or fungicides only to where they were needed. Here knockdown herbicides are used with a shielded sprayer on the inter-row of canola. Due to reduced efficiency the Tillers no longer use wide row spacing.

Yield mapping equipment purchased consists of a GPS receiver fitted to the AGCO yield monitor; the AGCO GTA (global technology AGCO) software enables the downloading of yield maps. Yield maps cannot be downloaded without the use of this software.

Inter-row sowing and wide row cropping

The 2cm autosteer technology has allowed the Tiller family to experiment and adopt new cropping practises such as inter-row sowing and wide row cropping.

The Tiller family strongly advocate retaining stubble at all costs to protect the soil, conserve soil moisture and build soil carbon. Inter-row sowing is a technique that helps retain stubble.

Inter-row sowing with their 16.5m Conservapak seeder on 300mm row spacing has proved to be reasonably successful with the machine tracking between the rows about 80% of the time. The Tillers will still slash large cereal stubbles (above 4t/ha) to avoid blockages during seeding.

A number of factors that impact on the success of inter-row sowing have been identified.

Table 1. *The Tiller's PA equipment purchases.*

Type	Year	Cost	Purpose
KEE GPS receiver to fit to AGCO R72 yield monitor	2002	$400	Yield mapping
gps-Ag AutoFarm 2cm autosteer	2003	$68,000	Autosteer on main tractor, spray tractor and header
AGCO GTA yield map software	2003	$2,000	Download yield maps
gps-Ag steer kit for new spray tractor	2005	$8,000	Autosteer
KEE Zynx spray controller with autoboom shut-off	2005	-	Autoboom shut-off
Total cost and cost per hectare		$78,400	$31/ha

Experimenting with inter-row sowing in a heavy wheat stubble of 6t/ha, resulted in stubble blockages, so stubbles above 4t/ha continue to be slashed.

The major factors are:

- seeder hitch length should be at least half the width of the machine eg. a 12m machine should ideally have a hitch length of 6m;
- smaller seeders (12m or less) are more successful than larger seeders (16m or greater);
- wider row spacings are more successful (at least 220mm or greater);
- the higher the accuracy and repeatability of the GPS system the better ie. a 2cm system is more likely to be successful than a 10cm system.

An illustration of insecticide applied only on the crop row using a single nozzle mounted above the seeding row.

Research from other parts of Australia indicated that wide row spacing resulted in yield advantages and the opportunity to reduce spray inputs for some pulse and oilseed crops. The Tillers experimented with wide row cropping from 2002 to 2004, growing chickpeas, faba beans and canola on wide rows (0.9 to 1.0m rows).

The wide row cropping equipment cost approximately $20,000; this included a second hand Kinze cotton planter from NSW, a trailing boomspray that was modified for band spraying, and the materials purchased to build a shielded sprayer (shields, controller, nozzles, tank etc).

Wide row crops allowed cheaper knockdown herbicides (eg. Roundup®, Sprayseed®) to be applied on the inter-row using a shielded sprayer and more expensive selective herbicides (eg. Select®) and fungicides to be sprayed just on the row itself. This resulted in cost savings of $30 to $70/ha.

The amount of insecticide used on canola was significantly reduced with their 8.25m cotton planter because only a band of a broad spectrum insecticide was applied on the crop row. This practice saves money, but more importantly protects beneficial insects on the inter-row that would otherwise be controlled by a broad spectrum insecticide.

The Tillers considered wide row cropping to be successful, but very time consuming with small equipment (8m to 16m width, 1000L tanks) and this can reduce overall efficiency of operation on the whole farm. As a consequence wide row cropping is currently not practised, but may be used in the future if ryegrass resistance to selective and pre-emergent herbicides escalates to a state where in-crop inter-row control is required.

Future plans for VR

The Tillers have been collecting yield data since 2002 and experimenting with some VR practices, but a VR program has not been adopted across the whole farm.

Yields maps are created using monitoring equipment that came as standard with their AGCO R72 and R75 headers. Maps are downloaded onto a PC using AGCO GTA software. Yield maps are yet to be analysed for the potential zoning of paddocks. They are not sure whether paddock zoning or a simple fertiliser replacement program based on last year's yield maps is best suited to their farm. The Tillers will seek advice from a PA consultant and their consulting agronomist on this in the future.

The Tillers have observed some potential benefits of VR. Increasing seed rates and N fertiliser on sand hills at Pinery has resulted in a yield increase of approximately 1t/ha. The adoption of this practice across the farm is limited given that sand hills make up less than 5% of their property.

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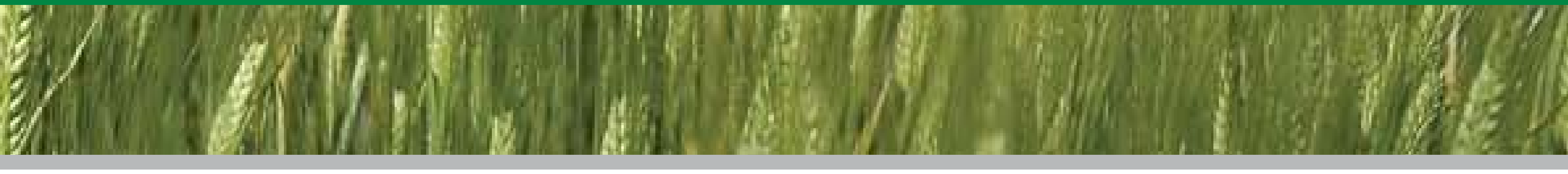

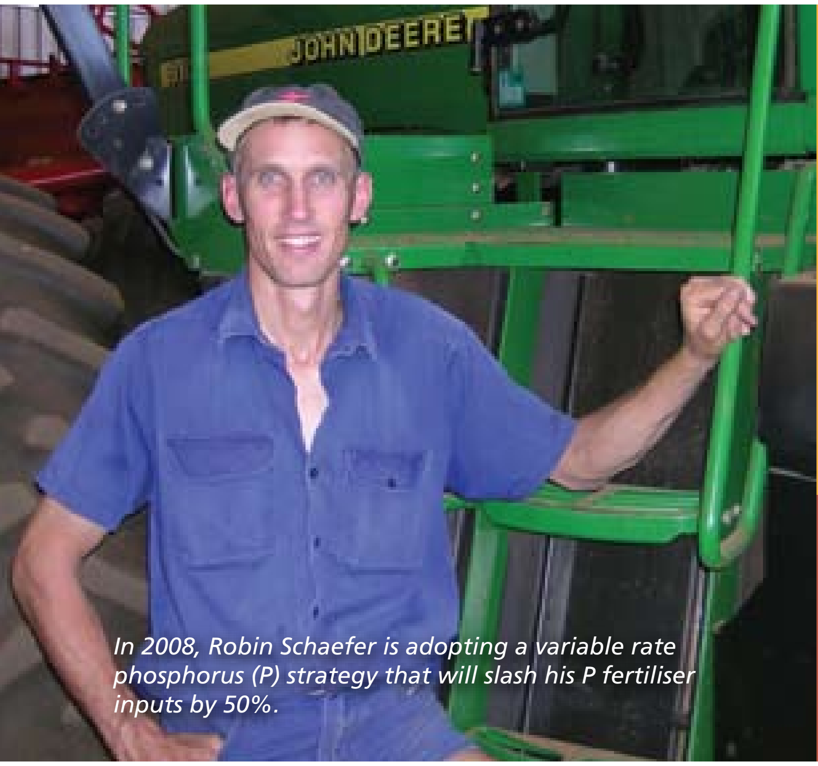

In 2008, Robin Schaefer is adopting a variable rate phosphorus (P) strategy that will slash his P fertiliser inputs by 50%.

Convincing evidence for variable phosphorus

Ten years of trials, combined with his own yield data and a fertiliser feasibility study are helping Robin Schaefer adopt variable fertiliser across his farm in 2008.

PA Timeline

Guidance	Yield mapping	Autosteer	Variable rate (VR)	Inter-row seeding	Direct injection spraying	Shielded spraying	On-farm trials
	2004	2006					2007

PA equipment

Robin Schaefer has been planning the adoption of variable rate (VR) seed and fertiliser for several years. 2008 will be the first year when variable rate phosphorus (P) is used across the entire farm. However, it was back in 2002 when Robin invested in a Horwood Bagshaw triple bin box with electric drives that he was already considering the possibility of using VR. To include these features cost approximately $10,000 more than a standard two bin box with ground drives.

Local company support, ease of transfer between vehicles and the quality of the electric motors were important selling points for Robin.

A Farmscan Canlink 3000 is the seed and fertiliser rate controller, and Farmscan DataManager software was included in the deal.

Farm profile

Farming personnel	*Robin and Rebecca Schaefer*
Farm location	*Loxton, Murray Mallee, SA*
Annual rainfall	*275mm*
Soil types	*Sand and sandy loam soils*
Farm area	*2300ha*
Topography	*Gently undulating*
Enterprises	*Wheat, barley, triticale, canola*
Average wheat yield	*1.4t/ha*
SPAA member	*Yes*
PA consultant	–
Agronomy consultant	–

A yield monitor came as standard equipment with the John Deere harvester purchased in 2004. A Farmscan GPS receiver and antenna ($2,000) were fitted to enable yield mapping. Robin has been yield mapping since 2004, and uses JD Office software ($100) to download yield maps.

Autosteer was fitted to the harvester in late 2006 ($13,000). This price included John Deere GPS receiver and electric steering control unit. The existing yield monitor screen is used for autosteer. The autosteer is transferred between the harvester, spray tractor and sowing tractor.

The free John Deere StarFire1 (SF1) correction signal is used for guidance and Robin has found this accurate enough for his operations (approximately 30cm accuracy). He has even had success with inter-row sowing using this system; the 'nudge button' is used to make corrections along some paddock runs.

Robin was farming 'up and back' with controlled traffic before using GPS equipment, however autosteer has improved the accuracy of the system. The reduction in overlap measured following the adoption of GPS guidance is 2%. This equates to savings of approximately $3/ha on variable inputs of seed, chemical, fertiliser and fuel.

Trials improve knowledge of soil potential productivity

Robin has been able to advance his knowledge of his soil's water and nitrogen dynamics by working closely with the Mallee Sustainable Farming Incorporated on a range of experimental trials, over the past 10 years.

Highlights of the work in relation to PA include:

- yield increases of 0.2-0.4t/ha by deep ripping (50cm) compacted sand hills;
- using the Mallee Calculator to better match crop inputs, particularly nitrogen (N), with seasonally available soil water on different soil types. A trial in 2005 by PIRSA, revealed that profit could be improved by $15/ha if fertiliser N inputs were applied using the Mallee Calculator and VR, compared with a standard blanket rate across the paddock;
- using EM38 surveys to map soil water availability due to changes in soil texture and to subsoil constraints eg. high salt, boron;
- increasing yields by increasing P rates on sand hills.

Robin believes that a sound knowledge of soil types and their production potential is essential if VR is to help improve profit.

Adopting VR P across the farm

Robin plans to adopt a full VR P program on his farm in 2008. He is currently assessing the feasibility of adopting a P replacement program based on last year's yield maps and his knowledge of soil type and crop potential, combined with EM38 maps for 20% of the farm.

Robin's own estimates coupled with a feasibility study of P replacement conducted by Michael Wells, Precision Cropping Technologies, have revealed that P fertiliser rates could be substantially reduced across the farm this coming season. Examples of different P replacement scenarios tested for paddock 22 are in Table 1.

Table 1. *Five phosphorus fertiliser scenarios and their cost based on seven yield zones. Scenario five is the blanket rate that would normally be applied.*

Yield zone	Area (ha)	DAP rates (kg/ha) for five P replacement scenarios				
		1	2	3	4	5
1	7	5	25	9	25	60
2	35	9	25	16	25	60
3	49	15	25	27	27	60
4	63	20	25	37	37	60
5	39	26	26	47	47	60
6	14	32	32	57	57	60
7	1	37	37	66	66	60
Average DAP rate (kg/ha)		19	26	34	36	60
Total DAP needed (kg)		3895	5372	7001	7438	12540
Total cost @ $950/t		$3,700	$5,103	$6,650	$7,066	$11,913

The John Deere autotrac system is transferred between the sowing tractor, spraying tractor and harvester, maximising the use of this investment during the year.

The five scenarios tested are:

1. solely replacing P removed from a low yielding wheat crop (average 0.8t/ha, range of 0.2 to 1.6t/ha) in 2007;
2. putting a base rate of 25kg/ha DAP across the paddock and applying extra P where more was removed in 2007;
3. replacing P removed based on average paddock yield (1.5t/ha) and potential of different zones (range of 0.4 to 2.9t/ha);
4. replacing P removed based on average paddock yield (1.5t/ha) and yield potential of different zones (range of 0.4 to 2.9t/ha) but never applying less than 25kg/ha DAP;
5. blanket rate of 60kg/ha DAP across paddock.

A VR program based on scenario two is the most likely strategy that Robin will use on his farm in 2008. That is, apply a base rate of 25kg/ha DAP across the farm and apply extra P only where more was removed in 2007. For the paddocks that have been EM38 mapped Robin may consider increasing P rates above removal on his more productive areas (mid-slopes and sandy rises). Adopting scenario two would reduce his total fertiliser input by 50% across the farm in 2008, while providing sufficient P in the seedbed for crop establishment.

One risk with using a P replacement strategy is that if soil P levels are low, then yield potential could be limited in an above average year. This is not likely to be the case on Robin's farm because a run of below average years and blanket P applications has resulted in a build-up of soil P.

Future application of PA technology

The lack of user-friendly and affordable software capable of processing and analysing yield map data and developing paddock zones has been the major barrier to Robin adopting VR. Assistance from the PA Groups has helped Robin manipulate his yield data but software incompatibility prevents him from transferring some file formats between systems. Ideally he would like an affordable all-in-one package for yield mapping, advanced data analysis and producing prescription maps.

Robin would like to adopt a full controlled traffic system using 2cm autosteer and all machinery matched on 3m wheel centres. The full benefit of ripping compacted sand hills is more likely to be achieved under this system. His farm will have an evolving VR program that gives the best return on his fertiliser dollar. Robin believes investment in equipment that will enable VR spraying and the production of spray application maps will not only improve productivity but be important for record keeping, especially on farms such as his near horticulture and viticulture enterprises.

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Garth (L) and Colin Aikman have been investing in PA technology since 1999 and are pleased with the improvements in efficiency it has brought to their farming system.

Automatic VR improves efficiency

PA has allowed the Aikmans to move from manual zone management with large areas of headlands within a paddock to on-the-go VR, making the seeding less stressful, faster and more accurate.

PA Timeline

Guidance	Yield mapping	Autosteer	Variable rate (VR)	Inter-row seeding	Direct injection spraying	Shielded spraying	On-farm trials
1999	2007	2006	2005	2006			2007

PA investment

Before investing in PA technology Garth and Colin Aikman sowed the sandy hills and loamy flats separately to enable different levels of seed and fertiliser to be applied to each soil type. This resulted in large percentages of headlands within the paddocks. With PA, the whole paddock is sown in a north-south direction using the variable rate seeder. However, improving the efficiency and accuracy of sprayed chemical applications was the Aikman's PA starting point.

Farm profile

Farming personnel	*Garth, Colin and Diane Aikman*
Farm location	*Underbool, near Ouyen, Mallee, Victoria*
Annual rainfall	*350mm*
Soil types	*Red loamy flats, sandy rises and deep sands*
Farm area	*2900ha*
Topography	*55m to 90m above sea level*
Enterprises	*continuous cropping wheat, barley, lupins, canola, triticale*
Average wheat yield	*1.8t/ha*
SPAA member	*Yes*
PA consultant	*–*
Agronomy consultant	*Liam Lenaghan - John Stuchbery and Associates*

In 1999, the Aikmans purchased a KEE (Topcon) Zynx X15 ($15,000) and fitted this on their spray truck. Initially the Zynx X15 only provided spray guidance with sub-meter accuracy using the marine beacon as the correction signal. The Zynx X15 is now their rate controller, and a software upgrade in 2005 provided auto section control for their six section boomspray.

The use of guidance, rather than foam spray markers and section control have helped reduce overlap, which the Aikmans find particularly valuable when using residual herbicides such as sulphonylureas (Group B). The addition of guidance also helped improve spray application efficiency especially for night spraying summer weeds.

The Aikmans started no-till farming in 2004 and purchased a second Zynx X15 to control seed and fertiliser rates for their triple bin Horwood Bagshaw air-seeder. The seeder was fitted with electronic drives in anticipation of adopting automated VR in the future.

The Zynx X15 has the ability to control on-the-go rate changes based on data from prescription maps. At this time prescription maps were made by driving around each paddock cutting them into zones (hills and flats) using Maplink on the Zynx X15 controller.

Pro-steer auto-steer was added in 2006 with the Omnistar signal providing guidance at 10cm accuracy. This allowed automated VR and inter-row seeding to be practiced. At 270mm row spacing and 10cm guidance inter-row seeding is not perfect but the Aikmans use the nudge feature to improve accuracy and plan to increase to 350mm rows in the future.

The entire PA investment for the seeding system cost approximately $40,000.

In 2007, the Aikmans added a GreenStar2 touch screen monitor/processor ($25,000) to their John Deere 9760STS harvester. This system provides yield monitoring and autosteer control.

Yield and elevation maps will be produced from data gathered by the GreenStar2 and be used to refine existing manually produced prescription maps for seeding.

PA satisfaction

The Aikmans report benefits of reduced overlap, improved timeliness and more appropriate use of inputs from their investments in PA technology. The use of automated variable rate has enabled the removal of in-paddock headlands, which has greatly improved the efficiency of their seeding operation. Autosteer has not only reduced driver fatigue but allows the operator to concentrate on the machine/seeder.

The Zynx controllers were chosen by the Aikmans based on a dealer demonstration, good reports from other farmers using the system, and the fact that one console was able to control multiple operations, cutting down the clutter in the cab.

Garth Aikman recommends that regular software upgrades are factored into the budget as the new features have simplified equipment operation. However, from experience he now saves the main settings before upgrades are conducted as some important settings have been lost during the upgrade process. A written record of settings and sensitivities can save much time and frustration. He also suggests that sending the Zynx back to Topcon for a general check every now and again is worthwhile.

EM38 mapping has not been implemented on the Aikman's property but they can see the benefit of using another tool to increase precision when zoning paddocks, especially as EM38 can help identify subsoil constraints.

Variable rate trial

In 2007, two large plot variable rate trials were conducted on the Aikman property. Each treatment was two widths of the seeder (30m). The objective of both trials was to identify sustainable input rates for phosphorus (P) and for seed.

Trial 1 was a P response trial on Mallee hills and flats. In this trial the four rates of phosphorus were 0, 5, 10 and 15kg P/ha in the form of MAP. Both soil types have a good base level of P and normally

The Aikmans are running variable rate seed and fertiliser trials for five years to try and establish the most suitable rate of inputs on their property.

Autosteer helps to reduce driver fatigue and to cut a full comb width on each pass, this is important for the collection of reliable yield data.

the Aikmans would apply 14.5kg P/ha on the hills and 10kg P/ha on the flats.

In variable rate trials run in 2007 plant height differences were observed between 0kg/ha P (left) compared to 10kg/ha P (right).

The rate of nitrogen was kept constant by adjusting urea rates to the amount of MAP being applied. This information was programmed into the Zynx X15 and rates varied automatically on-the-go. The trial will be run for five years in order to produce an optimum and sustainable phosphorus rate in a continuous Mallee cropping system.

There was a substantial difference in vigour between the 0kgP/ha treatments and the 10kgP/ha, especially on the flats. This suggests seedbed P is required but no visual differences were seen between the other rates. As the Aikmans plan to continue this trial for five seasons they prefer not to assess one year of results.

Trial 2 was to determine the optimum wheat seeding rates on Mallee hills and flats. On the flats seeding rates were 40, 60 and 80kg/ha and on the hills 60, 80 and 100kg/ha. Phosphorus and nitrogen rates were kept constant for all seeding rates, 14.5kgP/ha and 14kgN/ha hills and 10kgP/ha and 7kgN/ha flats.

Future for PA

For 2008, the property will be sown based on four zones - hills, mid slopes, flats and low yielding parts of the flats. Zones will be based on the Aikmans' knowledge of their paddocks, yield maps and soil tests.

Seed and fertiliser rates will be varied by zone to allow inputs to be applied at rates appropriate to the yield potential of each zone. Rates will be based on the results of the trial carried out in 2007.

The Aikmans will continue to run on-farm trials to understand the best use of inputs in relation to different soils on their farm. They also plan to continue to use PA training days to help them maximise the benefit from current and future investment in PA technology.

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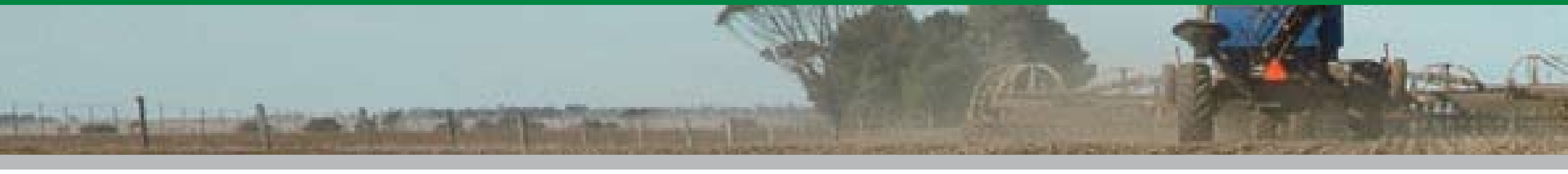
SECTION 3

Economics of PA

PA in Practice - grain growers' experience of using variable rate and other PA technologies



Does PA pay? Part 1

There has been wide scale adoption of autosteer and guidance but the uptake of other PA technologies has been low. One reason for this was considered the lack of evidence that such investments paid.

SPAA, funded by the Grains Research and Development Corporation (GRDC) and the SA Grains Industry Trust (SAGIT), commissioned Dr Matthew McCallum to evaluate the economic implications of investing in PA.

Between harvest 2006 and 2007, eight farm businesses were assessed. The input and grain prices used in these case studies are based on five year averages to 2006 (Table 1). The case studies do not reflect the increased grain prices of harvest 2007.

GPS guidance, autosteer, yield mapping and variable rate (VR) equipment were the main PA technologies evaluated for their financial impact on each business.

It was found that on average $44/ha had been invested in PA technologies with an average annual benefit of $18/ha (Table 2). Autosteer and guidance were found to provide the most rapid payback. However, the payback for VR in this study is extended as some participants invested in this equipment several years before VR was practiced on their farm.

It is hoped this information will provide farmers and advisers with

Table 1. *Location, annual rainfall, farm size, years of PA experience and the year of interview.*

Farmer	Location	Rainfall (mm)	Farm operation (ha)	Years of PA experience	Year interviewed
1	Waikerie	250	3000	7	2006
2	Crystal Brook	400	1600	8	2006
3	Yeelanna	425	2700	2	2006
4	Snowtown	400	2340	10	2006
5	Buckleboo	300	4475	5	2006
6	Stockport	475	1200	10	2006
7	Urania	400	1300	10	2007
8	St Arnaud	400	2400	11	2007

Table 2. *Summary of costs and benefits of PA equipment.*

Farmer	Cost of PA equipment ($/ha)	Annual benefit ($/ha)	Payback period (years)	
			Yield monitor and VR equipment	Autosteer and guidance
1	23	11	1	4-5
2	64	13	10	1-5
3	27	21	-	1-2
4	15	15	6	1
5	12	10	-	5
6	62	37	9	3
7	104	14	-	2-7
8	44	19	-	2-5
Average	**44**	**18**	**7**	**3**

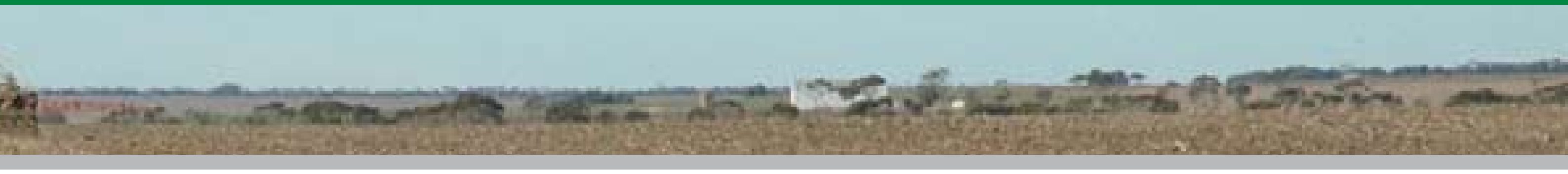


__Table 3.__ Breakdown of source of financial benefit from PA.

Farmer	Annual benefit ($/ha)			
	Savings in overlap	**Fertiliser savings using VR**	**Increased production using VR**	**Other production benefits***
1	4	-	7	-
2	5	5	-	3
3	3	-	-	18
4	5	10	-	-
5	2	-	-	-
6	10	9	-	18
7	14	-	8	-
8	6	-	-	13
Average	**6**	**8**	**7**	**13**

** inter-row sowing, reduced soil compaction, shielded spraying.*

valuable information that will assist them in making informed decisions about investing in PA equipment.

What was done

Eight farmers with an average of nearly eight years of PA experience, from different cropping regions in South Australia and Victoria were interviewed after harvest 2006 or 2007.

Information was collected on:

- area of cropping program, crops grown, crop yields, gross margins, rainfall, soil types;
- variable input costs (fuel, fertiliser, seed, pesticides, machinery, labour) per hectare;
- PA equipment purchases and purpose;
- evidence that PA is working on their farm in regard to less overlap, VR, etc;
- other benefits of PA, eg. conducting own agronomic experiments.

Economic analysis

A relatively simple economic approach was used in this study. The total cost and annual benefit of PA equipment for each farming operation was calculated and expressed as a total dollar value and in $/ha. From this, the payback period was determined.

The payback period is the number of years before the annual financial benefit produced by the PA equipment accumulates to cover the initial outlay for the item of PA equipment, that is the number of years it takes the investment to pay for itself. These calculations exclude the cost of loans used for the purchase. The shorter the payback period, the better the investment.

The total cost of equipment for each farmer was simply calculated from the original purchase price (gst exclusive).

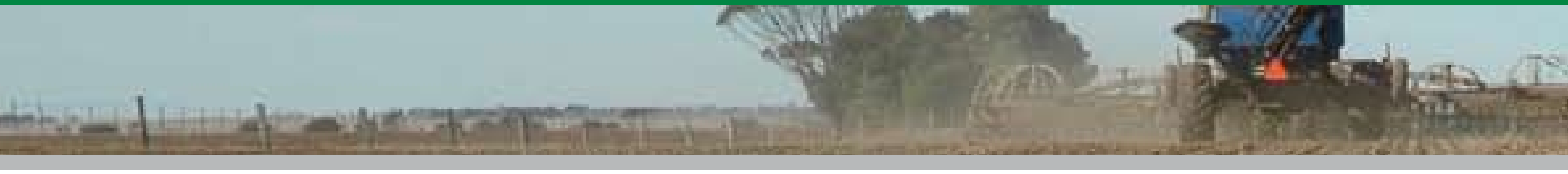
Savings on input costs were based on reduced overlap using PA equipment. This was calculated using the farmers' figures on the individual paddock area that was sprayed, fertilised, etc before and after PA equipment was used (Table 4).

Savings using VR were calculated by comparing variable rate fertiliser application with a previous 'blanket' rate of fertiliser used before PA was employed (Table 5).

Production increases from VR were calculated from changes in yield achieved by varying fertiliser rates by paddock zone. On-farm trial data was used for this purpose. Production increases from inter-row

__Table 4.__ A hypothetical calculation for changes in inputs due to reduced overlap.

	Area ha %	**overlap**
Actual area of paddock	100	-
Area of paddock sprayed, fertilised etc before GPS	105	5%
Area of paddock sprayed, fertilised etc using GPS	102	2%
Saving on overlap using GPS	**3**	**3%**



Benefits of PA including less overlap, reduced soil compaction and matching inputs to crop needs resulted in an average annual improvement in gross margin of $18/ha across eight farms.

sowing were estimated using trial data. Actual farmer data on grain prices and input costs averaged over the last five years, was used in the majority of calculations. Estimates were used when this was unavailable.

Table 5. *A hypothetical calculation of the fertiliser savings achieved on a 100 hectare paddock when a variable rather than a blanket rate is used.*

Blanket rate of DAP	Area (ha)	Total (kg)
Rate (kg/ha) 100	100	10000
VR rates of DAP	**Area (ha)**	**Total (kg)**
Rate (kg/ha) 100	50	5000
Rate (kg/ha) 80	25	2000
Rate (kg/ha) 50	25	1250
Total		8250
Saving in fertiliser		**1750 kg**

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Reduced overlap and improved returns from better use of inputs through variable rate have resulted in Allen Buckley achieving a payback for his PA investments in just under five years.

Allen Buckley

Estimated annual benefit from PA

$11/ha

Allen Buckley crops mainly cereals on his 3000 hectare property at Waikerie, SA. Of this 50% is sown to wheat, 25% to barley and triticale for grain. The remaining 25% is cropped to cereals (barley, triticale, cereal rye) that are used as multi-purpose crops for pasture, hay or grain depending on the weed spectrum, season and commodity outlook. Field peas and canola are grown opportunistically.

Average yields are 1t/ha for all cereal crops. Average annual rainfall is 250mm and April to October rainfall is 160mm.

Allen has two distinct soil types on his farm:

- sandy loam soils on the dunes, 75% of the farm;
- shallow red loam over limestone on the swales, 25% of the farm.

Savings from less overlap

Allen calculates a 3 to 5% saving in variable input costs from the use of autosteer and guidance. With average variable input costs at $105/ha, 4% less overlap equates to $4.20/ha or $12,600 per year.

PA equipment

Table 1. *Details of Allen Buckley's investments in PA equipment.*

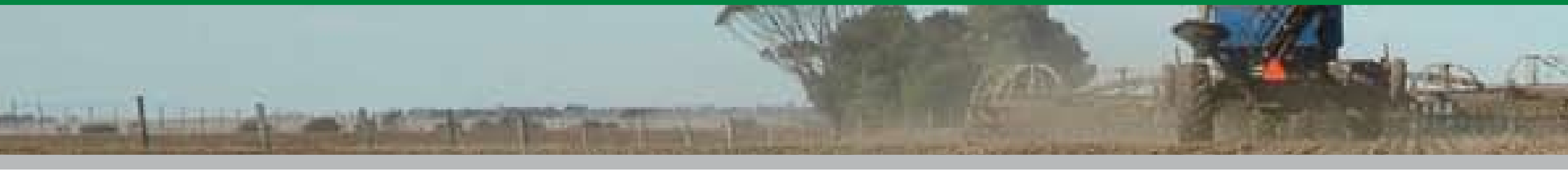
Type	Year	Cost	Purpose
CASE AFS yield monitor	2000	$ 7,500	Yield mapping
Farmscan Farmlap guidance system	2000	$16,000	Spray guidance
gps-Ag AutoFarm 2cm autosteer	2005	$ 45,000	Autosteer on seeding tractor and harvester
Total cost and cost per ha		**$68,500**	**$23/ha**

Note: The AutoFarm is a single frequency unit with base station and steer kits fitted to the seeding tractor and harvester.

Farming to soil type - VR

Allen had been practicing VR without the aid of GPS for a number of years. However, GPS systems make this task more efficient, easier and with less overlap of different crop types within paddocks.

Yields are highest and more consistent on the dunes (1.2-1.5t/ha average) compared to the stony flats (0.6-0.8t/ha average). Soil phosphorus (P) is higher on the flats (20 to 40ppm) than the dunes (13 to 20ppm). In the past, Soil P was as low as 6ppm on the dunes, but Allen has increased the fertility on the dunes by applying 12kgP/ha annually. Only 3.5kgP/ha is applied to the flats. District practice is to apply 10kgP/ha across the whole paddock. There are no savings in



P fertiliser under Allen's system because P is redistributed from the stony flats to the dunes.

Allen's seeding program commences with sowing hard wheat and triticale on all the stony flats using flat shears on his Concord seeder (Figure 1). After this is completed, APW wheat and malting barley are sown with a knife point across the remainder of the farm that consists mainly of dunes. APW wheat and malting barley quality are consistently achieved from cereals grown on the dunes. Consequently, this split seeding program results in less downgrading of grain at harvest time and no delays due to blending grain of differing protein and screenings.

Allen's approach to varying P levels on his dune/swale system has been backed-up by research conducted by SPAA and local PIRSA agronomists. This calculates that in these soil types a 5% increase in yield could be achieved across the farm with variable rate P. Based on Allen's yields a 5% increase in grain yield would equate to a benefit of $20,250 per year or $6.75/ha across the farm.

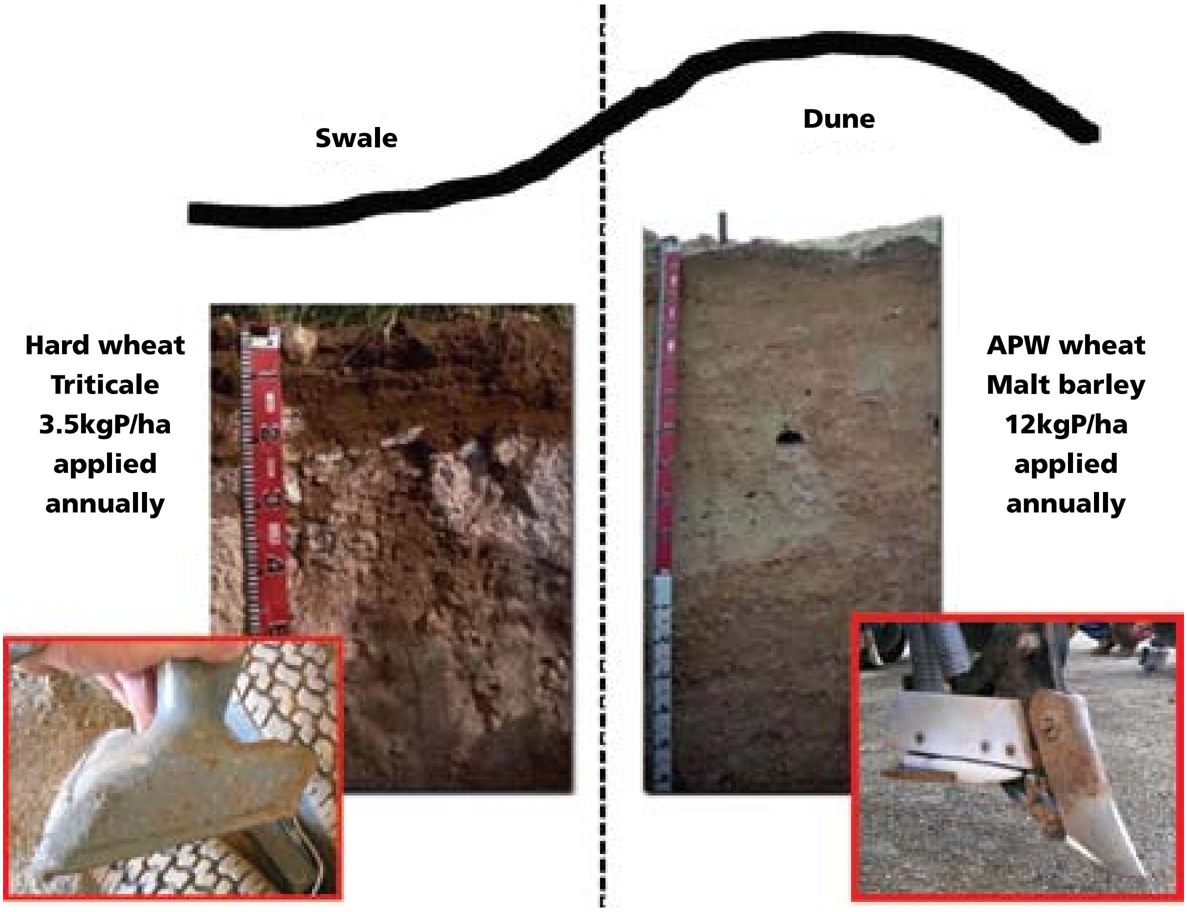


Figure 1. *A synopsis of Allen Buckley's different seeding practices on his two distinct soil types.*

VR in 2007

After trialling an Agleader Insight system from gps-Ag in 2006, Allen used this system to fully automate his VR program in 2007. Cost of this equipment will be approximately $10,000.

Payback period for PA equipment

Based on input cost savings, the calculated payback period for the guidance on the sprayer was 4 years, and 5 years for the autosteer equipment. The use of the yield monitor confirmed that Allen's system of variable rate P is working. Therefore, the payback period for this investment was only 1 year.

Overall economic benefits

The overall annual benefit from PA is estimated to be $32,850 per year or $11/ha on Allen Buckley's property.

Other reported benefits of PA

Allen sells all his grain domestically and quality assurance (QA) is becoming increasingly important. He finds the Farmlap system makes paddock recording in relation to QA simple and this data is easily downloaded onto the home computer.

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Trials on Malcolm Sargent's farm have found that benefits from varying phosphorus inputs are very soil type dependent.

Malcolm and Brian Sargent

Estimated annual benefit from PA

$13/ha

Malcolm and Brian Sargent annually crop 1600 hectares at Crystal Brook, SA of which 70% is sown to wheat and barley and the remaining 30% consists of canola, faba beans and field peas.

Average yields are: cereals 2.5t/ha, canola 1t/ha, faba beans 1.2t/ha and field peas 1.5t/ha. Average annual rainfall is 400mm and April to October rainfall is 300mm.

The major soil types across the farm include:

- sandy loam soils in a dune/swale formation on the northern half of the farm;
- clay loam soils on relatively flat terrain on the southern half of the farm.

Savings from less overlap

Malcolm and Brian calculate a 3% saving in variable input costs from the use of autosteer and guidance. With average variable input costs at $160/ha this results in an annual saving of $4.80/ha or $7,680 per year.

PA equipment

Table 1. *Details of the Sargent's investments in PA equipment.*

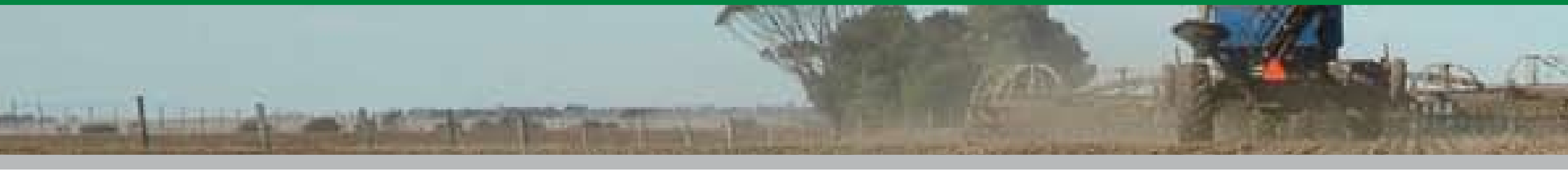
Type	Year	Cost	Purpose
Agleader yield monitor with gps	1999	$21,000	Yield mapping
Agleader lightbar	2002	$ 3,500	Spray guidance
KEE Zynx with VR capacity	2003	$8,000	Variable rate fertiliser
KEE Zynx guidance	2004	$11,000	Spray guidance
gps-Ag AutoFarm 2cm autosteer	2004	$55,000	Autosteer on seeding tractor, spray tractor, self-propelled windrower and harvester
CASE AFS yield monitor	2006	$ -	Yield mapping
Total cost and cost per ha		**$98,500**	**$62/ha**

Note: The GPS receiver from the Agleader yield monitor was used in conjunction with the lightbar for spraying. The AutoFarm is a single frequency unit with a base station and steer kits fitted to two tractors, the self-propelled windrower and harvester. The Case AFS yield monitor came as standard equipment with the harvester.

Savings using VR

The Sargents first started yield mapping in 1999 and conducted VR experiments for nitrogen (N) and phosphorus (P) inputs in 2003, through SPAA and their own trials in 2005. After three years of trials a clear pattern started to emerge.

On the south side of the farm, in the low yielding areas of paddocks soil P concentrations were high (54



to 76ppm) and crops in these areas were not responding to inputs of P fertiliser. In the high yielding areas of the paddock P concentrations were lower (27 to 35ppm) and crops were only moderately responsive to P fertiliser. This was not the case for the northern half of the property where no benefit in VR was measured.

Full VR on the southern half of the farm was implemented in 2006. Paddocks were zoned using a combination of yield maps and a soil variation survey using gamma-radiometrics. Gamma-radiometric sensors measure the natural gamma ray emissions of radioactivity in the soil, mostly in the top 30cm, which provides a soil map of differences in parent material across the paddock. Cereal yields and the soil variation map were strongly correlated.

Savings in P fertiliser from implementing VR on the southern part of the farm averaged $10/ha and vary between $5 and $15/ha, depending on the paddock. Overall savings in P fertiliser on the southern half of the farm (800ha) are $8,000 per year.

Inter-row sowing

A 2cm autosteer system on the seeding tractor allows Malcolm and Brian to accurately sow inter-row 90% of the time. The main benefit is improved stubble handling and crop establishment when barley is sown after wheat in the rotation. Across SA yield benefits of 6 to 9% have been measured in wheat-on-wheat experiments. The Sargents have not conducted their own experiments to quantify the benefits to barley yields but a 2% increase in yield due to better plant establishment, increased herbicide efficacy and reduced impact of root disease is estimated. This equates to an overall financial benefit of $4,500 per year.

Payback period for PA equipment

Based on spraying costs, the calculated payback period for the Agleader lightbar was only one year, and the Zynx guidance was three and a half years. Payback period for the autosteer was five years based on cost savings and benefits from inter-row sowing. The payback period for VR equipment (yield monitor, VR controller) was 10 years because it was seven years before a VR program was implemented.

Overall economic benefits

The overall annual benefit from PA equals $20,180 per year or $12.60/ha across the whole of Malcolm and Brian's property.

Other reported benefits of PA

The Sargents have used yield mapping to conduct variety trials with some surprising results. In both 2005 and 2006 Drysdale wheat has out-yielded Yitpi by 10%. National Variety Trials in the Mid North suggest Yitpi should out-yield Drysdale by 3%. However, these sites are at least 100km from their farm, so on-farm testing of new varieties appears to be quite important.

Despite Drysdale being a lower quality grain, a 10% increase in yield equates to an annual benefit of $11.30/ha across the farm.

Malcolm and Brian have also used their PA equipment to conduct a compaction experiment in 2006. With 2cm autosteer, wheel traffic from all seeding and spraying operations have been confined to the same area of the paddock for three years. Individual crop rows were hand harvested to test the yield under wheel traffic compared to yield where no wheel traffic had occurred. There was an 8% decrease in yield for wheat under wheel traffic, which was considered due to soil compaction, which equated to a 2.6% yield decrease across the whole paddock ($7/ha). This result and further experimentation will be used to evaluate the financial benefits of moving to a full controlled traffic system.

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PA has enabled Randal Wilksch to improve the timeliness and accuracy of night time spray, seeding and harvesting operations by using autosteer with 2cm guidance and at the same time reduce operator fatigue.

Randall, Jordan and Max Wilksh

Estimated annual benefit from PA

$21/ha

In 2008, the Wilksch family will be cropping 3000 hectares at Yeelanna on Eyre Peninsula, SA. Of this 60% will be sown to wheat and barley, 25% is canola, with the remainder sown to beans and lupins. The 10 year average wheat yield is 3.0t/ha on the property. Average annual rainfall is 410mm and April to October rainfall is 320mm.

There are two main soil types on the farm:

- red brown earths which comprise of clay loams overlying red clay;
- sandy loams overlying red/ yellow sodic clay that are high in ironstone and known as 'buckshot clay'.

Savings from less overlap

The Wilkschs considered savings in overlap were not an important factor when deciding to purchase guidance and PA equipment. In their situation they calculated savings would only be approximately 1% in overlap by adopting autosteer and guidance.

PA equipment

Table 1. *Details of the Wilksch's investments in PA equipment.*

Type	Year	Cost	Purpose
CASE AFS yield monitor	2000	$ -	Yield mapping
gps-Ag Eziguide lightbar	2006	$ 4000	Sprayer and spreader guidance
gps-Ag AutoFarm 2cm autosteer	2006	$69,000	Autosteer on seeding tractor and harvester
gps-Ag AutoFarm 2cm autosteer	2007	$32,000	Autosteer on spraying tractor
Total cost and cost per ha		**$105,000**	**$35/ha**

Note: The Case AFS yield monitor came as standard equipment with the harvester. The AutoFarm is a dual frequency unit with a base station and steer kits fitted to two tractors and their harvester. A repeater tower is used to extend the range of the base station signal.

With variable input costs of $260/ha this equates to a saving of $2.60/ha or $7,800 per year over the whole cropping program.

Economics of VR

Historic soil phosphorus (P) data suggests some savings in fertiliser are achievable. For example, soil tests show that the current fertiliser regime is maintaining soil P in the more productive red brown earths.

However, in the lower producing sandy loam over sodic clay it appears that soil P levels have been building and the rate of fertiliser could be reduced (Table 2).

VR trials were carried out in this paddock during 2007. However, due to an exceptionally dry growing season, results were not significant.

Variable rate nitrogen (N) application using the Yara N Sensor has been trialled on the

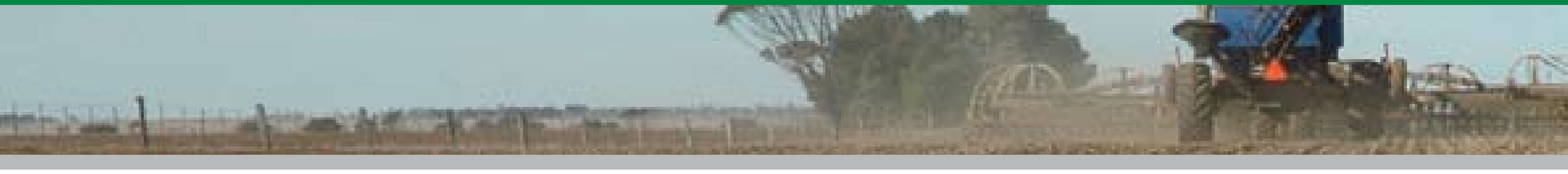

Table 2. *Colwell P levels (ppm) in Paddock 170A.*

Soil type	1984	1990	1994	1999	2007
Sandy loam over sodic clay	37	40	44	35	51
Red brown earth	34	31	28	24	29
Difference	**3**	**9**	**16**	**11**	**22**

farm to better match in-season N application with crop requirements. The Yara N Sensor uses optical sensors to measure the level of crop greenness, and this information can be used to develop an N application map to apply N to meet crop requirements. Results so far have been mixed with no clear economic benefit from variable rate N, but further testing and experimentation will continue. Yield benefits of up to 4% have been achieved from using the N sensor in other experiments across SA.

Inter-row sowing

The Wilkschs are adopting inter-row sowing with the aim of improving stubble handling in their no-till system. The benefits they are looking for are:

- less stubble clumping, which causes issues with plant establishment and harvesting windrowed barley;
- increased barley yields with better establishment in wheat stubble;
- increased canola yields with better establishment and early vigour in cereal stubbles;
- reduced need to slash stubbles.

Trial results in SA suggest they should achieve these benefits with their 2cm autosteer system (McCallum 2006). Cost savings on slashing and yield increases for canola (0.1t/ha) and barley (0.2t/ha) would equate to an annual benefit of $18.60/ha across the farm ($55,800 per year). However, these benefits are yet to be realised and experimentation and observation over the next two years will prove whether PA will result in a financial return. 2007 was the first year of inter-row sowing after crops were sown in 2006 with 2cm autosteer. Results so far, with their 16.5m Conservapak with knife points on 300mm spacing have been encouraging with the seeder sowing accurately between the rows 85 to 90% of the time.

Payback period for PA equipment

Based on spraying costs, the calculated payback period for the Agleader lightbar was only one year. If their inter-row sowing system is successful, the estimated payback period for the autosteer will be two years, given that it takes the first year to set-up straight rows of stubble.

Overall economic benefits

The overall estimated annual benefit from PA could equal $63,600 per year or $21.20/ha on the Wilksch cropping operation if the calculated potential is realised.

Other reported benefits of PA

Increased operator efficiency and less fatigue on the spray unit and the harvester have been the biggest benefits since purchasing the autosteer. Autosteer allows the operator more time to concentrate on maximising the capacity of the harvester. This was especially the case during 2007 when very poor crops on rocky country could be safely harvested close to the ground as the driver could concentrate on avoiding rocks without having to worry about driving straight.

When spraying there is the opportunity to observe weed populations and crop growth, and to think about future herbicide requirements. Autosteer also allows accurate spraying at night, which is especially valuable in summer when after sunset is often the only period when temperature and humidity, the critical factors for herbicide efficacy, are suitable. Being able to accurately sow into heavy stubbles at night is another benefit of autosteer.

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The Wilkschs hope inter-row seeding will give them yield benefits due to improved establishment.

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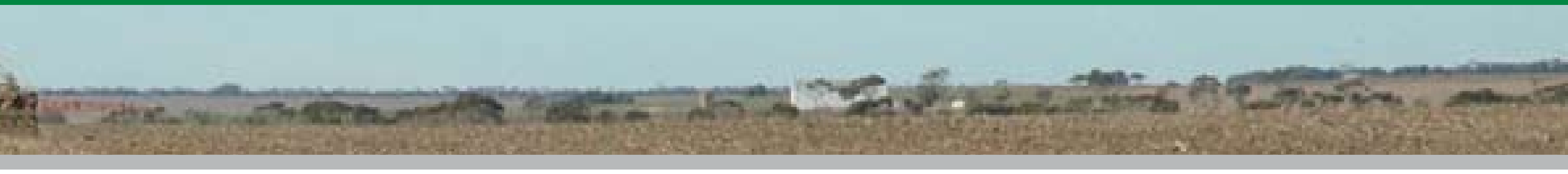


Richard Turner estimates that over the last five years his phosphorus replacement strategy has resulted in a 20% reduction in fertiliser use, representing a substantial cost saving.

Richard and Craig Turner

Estimated annual benefit from PA

$15/ha

Richard and Craig Turner farm 2340 hectares on two properties located at Snowtown and Lochiel, SA. Wheat is the main crop grown on about 1100 hectares, the remainder of the farm is sown to barley, field peas, faba beans and some pasture.

The 10 year average yield of wheat is 2.8t/ha. Average annual rainfall is 400mm and April to October rainfall is 300mm. Red brown earth is the predominate soil type at Snowtown and sandy loam over clay at Lochiel.

Savings from less overlap

Average annual variable input costs are $168/ha, and Richard has calculated overlap reduced by 3% after adopting GPS guidance (10cm pass-to-pass accuracy) on his spraying and seeding equipment. This equates to an annual saving of $11,700 per year or $5/ha across the whole farm.

PA equipment

Table 1. *Details of the Turner's PA purchases.*

Type	Year	Cost	Purpose
Microtrak yield monitor with Omnistar GPS	1997	$11,550	Yield mapping
Farmscan Farmlap guidance system with VR capacity	1997	$7,570	Spray guidance and variable rate fertiliser
CASE AFS yield monitor	2001	$ -	Yield mapping
KEE Zynx guidance system with VR capacity	2004	$15,312	Sowing guidance and variable rate fertiliser
Total cost and cost per ha		**$34,432**	**$15/ha**

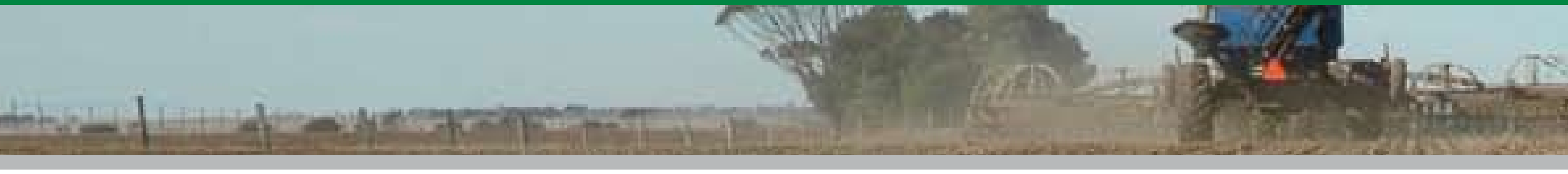
Note: The Microtrak yield monitor was purchased from Pivot Fertilisers (now Incitec Pivot Ltd) after it was trialled on the farm in 1996. The Omistar GPS receiver was used on both the yield monitor and the Farmlap guidance system. The Case AFS yield monitor came as standard equipment with the harvester. An annual subscription of $2,500 is paid to Omnistar.

Savings using VR

Richard and Craig first started yield mapping in 1997. Soil testing within zones across a paddock revealed that low yielding areas of paddocks were high in phosphorus (P) (more than 70ppm), while high yielding areas of the paddock were lower in P (15 to 30ppm).

The Turners use their yield maps as P replacement maps for the following year's crop eg.

- 4.5kgP replaced for every 1t/ha of cereal grain removed;
- 7kgP replaced for every 1t/ha of legume grain removed.



They initiated this strategy in 2002. Before this, a standard fertiliser practice of applying a blanket rate of between 16 and 20kgP/ha across the whole farm and 50 to 64kgN/ha applied to wheat and barley. Over the last five years it is estimated that this P replacement strategy has resulted in a 20% reduction in fertiliser use. This equated to a $10/ha saving or $23,400 per year across the whole farm.

Richard feels PA is helping them achieve production increases on high yielding areas of paddocks that were previously under-fertilised. However, currently no data exists to prove this is the case.

Payback period for PA equipment

Based on spraying costs, the calculated payback period for the GPS guidance was only one year. The payback period for VR equipment (yield monitor, VR controller) was six years because it was five years before a VR program was implemented.

Overall economic benefits

The overall annual benefit from PA equals $35,100 per year or $15/ha on Richard and Craig's property.

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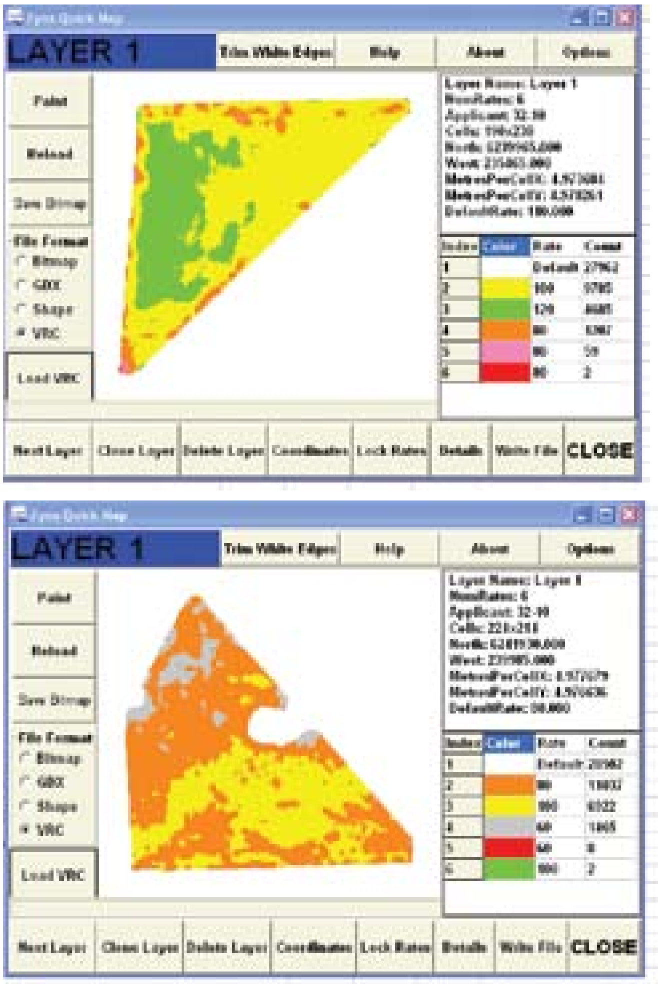

Examples of Richard Turner's variable fertiliser application maps.

Implementing VR fertiliser on 70% of Graeme Baldock's farm on Upper Eyre Peninsula is estimated to lift yields by 5%.

Graeme Baldock

Estimated annual benefit from PA

$10/ha

Graeme Baldock crops 4475 hectares at Buckleboo, Eyre Peninsula, SA. His cropping program is divided into 65% wheat, 25% barley and the remainder is cropped to canola, field peas and oats.

Average yields for wheat are 1.4t/ha and barley 1.5t/ha. Average annual rainfall is 300mm and April to October rainfall is 210mm.

The majority of Graeme's property is gently undulating dune/swale formation with sandy loam soils on the dunes and red loam with a clay subsoil on the swales. This clay subsoil is often high in salt and boron, which constrains crop production later in the growing season. Some grey Mallee loam soils exist on the property that are high in magnesium salt.

Savings from less overlap

Graeme has calculated he saves 3% in less overlap with spraying operations, and 2% for sowing. These combined savings equal $2.40/ha or $10,740 per year.

PA equipment

Table 1. *Details of PA purchases by Graeme Baldock.*

Type	Year	Cost	Purpose
KEE Zynx guidance	2002	$18,000	Spray guidance
KEE Zynx 10cm Autosteer with VR capacity	2004	$34,000	Autosteer on seeding tractor
John Deere Autotrac 30cm autosteer - SF1	2006	-	Autosteer on spray tractor
Total cost and cost per ha		**$52,000**	**$12/ha**

Note: The John Deere yield monitor came as standard equipment with the harvester. The KEE autosteer is linked to an Omnistar HP correction signal, and the John Deere system to StarFire1. In this case, the John Deere autosteer came as standard equipment with the tractor. An annual subscription of $2,500 is paid to Omnistar.

Graeme has upgraded his spray equipment to a Hardi system with a 7000 litre tank, 36 metre boom and a Hardi 5500 controller. A Kee Zynx X10 controller is used to operate the autosection shut-off and to provide an on-the-go coverage map. The auto shut-off has been found to be a great benefit on the six section boom. It reduces overlap, saving input costs and crop damage and makes spraying much less stressful.

The spray-rig is now pulled by a John Deere 8330 tractor fitted with Autotrac. The John Deere StarFire1 system provides guidance with sub-meter accuracy. The auto guidance is adequate to reduce overlap and operator fatigue, although Graeme has found the JD StarFire1 system struggles to keep up at operating speeds over 20 kilometres per hour.

The purchase of an additional system has resulted in Graham Baldock having three processors and screens in the cab, making it very cluttered. With newer models this would not necessarily be the case.

The Omnistar VBS signal is no longer used for guiding the spray rig, but instead the StarFire1 signal is used for both the JD Autotrac and the Zynx X10 in the tractor.

The biggest headache Graeme has had with the spray-rig guidance system, purchased in early 2007, is that there are now three processors and screens in the tractor cab.

Economics of VR

Graeme has started soil testing in different zones within paddocks. His thoughts are to decrease fertiliser inputs in low yielding flats, and to maintain or increase nutrition on the higher producing dunes. He estimates 70% of his farm would be suitable for VR. Farmer experience and research from the SA Mallee suggests this strategy should be successful and could lift yields by 5%. If achieved this yield increase across his cereal program would result in an annual benefit of $33,522 or $7.50/ha over the farm.

Payback period for PA equipment

Based on input costs, the calculated payback period for the PA equipment was 5 years.

Overall economic benefits

The overall estimated annual benefit from PA could equal $44,262 per year or $9.90/ha on Graeme's farm.

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Mark Branson

Mark Branson is now using a Greenseeker® to refine his in crop nitrogen applications and anticipates this will be a very profitable decision.

Estimated annual benefit from PA

$37/ha

Mark Branson farms at Stockport, SA and crops 80% of his 1200 hectares. Of this 60% is sown to wheat and barley with the remainder sown to canola, faba beans and field peas.

Average cereal yields are 4.0 to 4.5t/ha. Average annual rainfall is 425 to 525mm and April to October rainfall is 330 to 400mm.

Major soil types are black cracking clays and red brown earths, with small areas of grey calcareous soils.

Savings from less overlap

Average annual variable input costs for cropping are $250/ha, and Mark has calculated he overlaps 5% less since using GPS guidance with 2cm accuracy. This equates to an annual saving of $10/ha or $12,000 per year across the farm.

Savings using VR

Mark first started yield mapping in 1997 and conducting VR experiments on nitrogen (N) and phosphorus (P) inputs in 2003 through SPAA. These trials complemented his on-going trial program. Soil tests indicate adequate levels of soil P, so yield maps are now used as the basis for P replacement maps for the following year's crop.

For example:

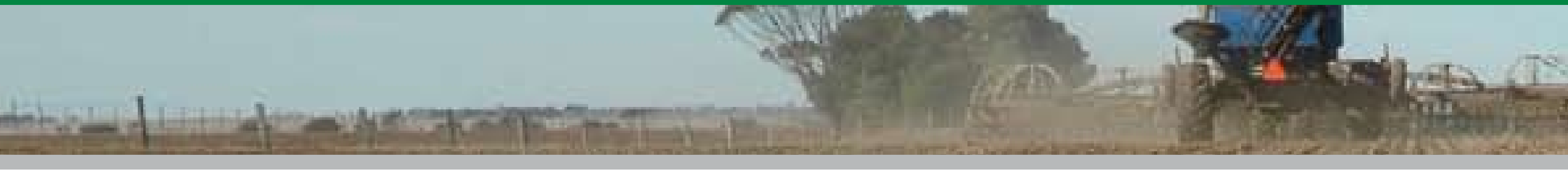
- 3.5kgP is replaced for every 1t/ha of cereal grain removed;
- 4.4kgP replaced for every 1t/ha of legume grain removed;
- 7.5kgP replaced for every 1t/ha of canola grain removed.

PA equipment

Table 1. *Details of Mark Branson's PA equipment purchases.*

Type	Year	Cost	Purpose
Microtrak yield monitor with Omnistar gps	1997	$11,550	Yield mapping
CASE AFS yield monitor	2002	$ -	Yield mapping
KEE Zynx with VR capacity	2002	$7,250	Variable rate fertiliser and guidance
KEE Zynx 2cm autosteer	2004	$55,000	Autosteer on seeding tractor
Greenseeker® hand held	2006	$2,800	Nitrogen recommendations.
Total cost and cost per ha		**$76,600**	**$64/ha**

Note: The Microtrak yield monitor was purchased from Pivot Fertilisers (now Incitec Pivot Ltd) after it was trialled on the farm in 1996. The Case AFS yield monitor came as standard equipment with the harvester. The KEE autosteer is a dual frequency unit with a permanent base station and a steer kit fitted in the main tractor. An annual subscription of $2,500 was paid to Omnistar prior to purchasing the base station.



In addition a blanket rate of 2kgP per tonne of grain removed is applied to account for P tie-up in straw and the soil.

Mark initiated this strategy in 2005. Before this, a standard fertiliser practice of applying 22kgP/ha was used across the whole farm. The cost savings in fertiliser depend on the yields of the previous season. Because yields were high in 2005, overall fertiliser application in 2006 was only reduced by 5% across the farm. In 2007, there will be a 20% reduction in fertiliser used because of low yields in 2006. On average, this strategy will see overall fertiliser use decrease by 15%, which equates to $9/ha across the farm or $10,800 per year.

In 2006, Mark purchased a hand held Greenseeker® to help improve his in-crop nitrogen decisions. The Greenseeker® is used to evaluate crop nitrogen requirements in comparison to a strip of crop that has received what is considered the maximum economic amount of nitrogen that the crop might require. At the timing of writing no economic benefit had been defined from this equipment.

More recently the Greenseeker® has helped Mark determine that nitrogen availability in the paddock was not limiting. This has given Mark the confidence not to top-dress that season's crop with nitrogen that has generated considerable savings in fertiliser.

Controlled traffic

Mark implemented a controlled traffic system in 2004, guided by 2cm autosteer, with all sowing, spraying and spreading operations running the same tracks but not the harvester. Mark is convinced yields have increased with controlled traffic because he feels that the water holding capacity and the amount of plant available water in his soils has increased. His water use efficiency for wheat has increased from 14.5kg/ha/mm to 16.5kg/ha/mm of effective rainfall over the last five years.

Mark estimates yield increases of 4% have been achieved with controlled traffic. Yield increases of between 2 and 7% attributable to controlled traffic benefits were measured in research trials at Roseworthy on a similar soil type. A 4% increase in yield equates to a $18/ha benefit over the farm or to $22,080 per year.

Payback period for PA equipment

The payback period for the autosteer was three years based on cost savings and benefits from controlled traffic that were realised in the third year of autosteer. The payback period for VR equipment (yield monitor, VR controller) was nine years because it was seven years before a VR program was implemented.

Overall economic benefits

The overall annual benefit from PA equals $44,880 per year or $37.40/ha across Mark's farm.

Other reported benefits of PA

Mark believes one of the biggest benefits of PA is that it helps him become a better agronomist for his own farm, because it enables him to take results from small plot trials and test them on a paddock scale. This gives him the confidence to make agronomic decisions that can substantially influence profits.

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Ashley Wakefield

Following several years of teething problems the on-the-go protein meter is now able to provide paddock protein maps that will be used to assess the success of Ashley's variable rate nitrogen strategies.

Estimated annual benefit from PA

$14/ha

Yorke Peninsula farmer Ashley Wakefield, annually crops 1300 hectares of which approximately 33% is wheat, 33% is barley and the remainder consists of canola, lentils and peas.

The ten year average yield for wheat is 3.7t/ha and for barley 3.5t/ha. Yields for pulse and canola crops average 1.5 to 2.0t/ha.

Average annual rainfall is 400mm and April to October rainfall is 325mm. Soils consist of grey Mallee loams, and some sandy loam soils in a dune/swale formation.

Savings from less overlap

The use of GPS guidance (10-30cm pass-to-pass accuracy) for spraying resulted in a saving of 5% of inputs due to reduced overlap; this equates to $5/ha or $6,500 per year. When autosteer (2cm accuracy) and autoboom shut-off were added this saving increased to 9% of spray inputs, equating to a saving of $9/ha or $11,700 per year.

PA equipment

Table 1. *Details of Ashley Wakefield's PA equipment investment.*

Type	Year	Cost	Purpose
Microtrak yield monitor with Omnistar GPS	1996	$11,550	Yield mapping
Farmscan PFA guidance system	1996	$7,570	Spray guidance
JD yield monitor	1998	$ -	Yield mapping
KEE Zynx X10	1999	$16,000	Spray guidance
Nirtech Protein Monitor	2002	$20,000	Real time protein monitoring on header
KEE Zynx X15 with 2cm autosteer	2003	$50,000	Autosteer on seeding tractor, spray tractor and header
KEE autoboom control	2003	$ -	Automatic boom shut-off
KEE Zynx X20	2006	$5,000	Upgrade from X15
Yara N sensor	2007	$25,000	Real time N sensing for in-crop variable rate N application
Total cost and cost per ha		**$135,120**	**$104/ha**

Note: A corrected Omnistar signal is used with guidance equipment and yield monitoring. The JD yield monitor came as standard equipment with the harvester. The KEE autosteer is an RTK dual frequency unit with base station. The KEE autoboom control system was negotiated as part of the autosteer purchase in 2003.

Ashley Wakefield is the first farmer in Australia to purchase a Yara N Sensor to gather biomass data for fertiliser and herbicide management.

The use of autosteer on the seeding tractor and harvester reduced variable costs associated with these operations by 5%, saving a further $5/ha or $6,500 per year. Total savings from reduced overlap equal $14/ha or $18,200 per year.

Protein mapping

Despite fitting the protein monitor in 2002, Ashley only produced his first map in 2006. This is due to a range of on-going problems with the grain sampling mechanism of the unit, which have now been rectified. By monitoring levels of grain protein Ashley aims to quantify if his nitrogen fertiliser strategy is achieving maximum potential across paddocks. If 90% of the paddock is achieving a protein level of 10.5% or more (wheat), he is confident that nitrogen has not been a limiting factor in crop production.

Yara N sensor

Ashley is the first farmer in Australia to purchase a Yara N sensor from Europe. The Yara N Sensor uses optical sensors to measure crop greenness; this information can be used to develop a nitrogen application map based on crop requirement. Ashley plans to use the Yara N sensor for this purpose in 2008. He calculates that if a 3% yield increase is achieved by using this technology it will result in the unit paying for itself within one year. Up to a 4% yield increase has been achieved using the sensor in SPAA trials. Harvest protein maps will be used to help measure the success of the Yara N sensor.

Future plans for PA

In 2007, Ashley mounted a direct injection chemical system on his air-seeder. He plans to weed map his paddocks using the Yara N sensor and target problem weed patches with combinations of herbicides. Targeting more expensive herbicide only where they are required has the potential to reduce herbicide costs considerably. For example, a whole paddock would receive a blanket spray of Trifluralin ($7/ha) and only 20 to 30% of the remaining area would be sprayed with a combination of Dual® and Avadex® ($40/ha). Ashley also plans to build his own inter-row shielded sprayer to apply knockdown herbicides between his 300mm crop rows.

Payback period for PA equipment

Based on input cost savings, the calculated payback period for the GPS on the sprayer was between one and two years, and seven years for the autosteer equipment. Yield mapping, protein mapping and the Yara N sensor are yet to result in a measurable profit on Ashley's farm.

Overall economic benefits

The overall annual benefit from PA is estimated to be $18,200 per year or $14/ha.

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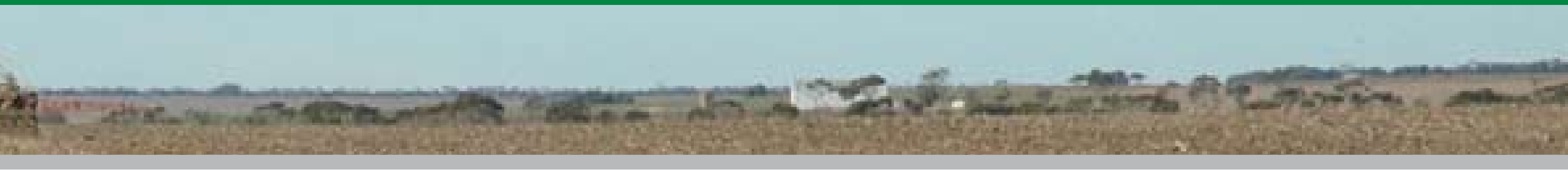

The 2cm autosteer fitted to the sowing and spraying tractors has enabled Neale Postlethwaite to adopt precision spraying techniques in wide row crops.

Neale, Trevor, Allen and Yvonne Postlethwaite

Estimated annual benefit from PA

$19/ha

Allen and Yvonne Postlethwaite, with sons Neale and Trevor, annually crop 2400 hectares at St Arnaud, Victoria. Each year 50% of the crop area is sown to wheat, barley and canola, while the remainder is sown to legumes (chickpeas, faba beans, lentils, vetch or green manure).

Long term average yields are: wheat 2.4t/ha, barley 2.0t/ha, chickpeas 1.5t/ha, faba beans 1.2t/ha, lentils 1.2t/ha and canola 1.2t/ha.

Average annual rainfall is 400mm and April to October is 275mm. A relatively uniform grey vertosol is the predominant soil type on the farm, with some areas of red vertosol and red sodosol.

PA equipment

Table 1. *Details of PA equipment investment by the Postlethwaites.*

Type	Year	Cost	Purpose
Microtrak yield monitor	1995	$8,000	Yield mapping
Trimble Ag132 GPS	1996	$14,000	Visual guidance for spraying
Trimble lightbar	1997	$4,000	Visual guidance for spraying
AgGuide Furrow Guide system	2000	$20,000	Autosteer on sowing tractor
AgGuide Row Guide RTK 2cm system	2001	$50,000	Autosteer on spray tractor
AFS Yield monitor	2001	-	Yield mapping
Steer kit for sowing tractor	2002	$10,000	Upgrade from Furrow Guide to Row Guide
Total cost and cost per ha		**$106,000**	**$44/ha**

Note: Cost of Trimble Ag132 includes four years of signal subscription. The AFS yield monitor came as standard equipment with a header upgrade.

Savings from less overlap

Before the purchase of GPS guidance and autosteer equipment the Postlethwaites were already 'up and back' sowing and spraying.

However, the adoption of 2cm autosteer further minimised overlap by 3.5%. With average variable input costs of $162/ha (2007/08), an annual saving of $5.67/ha or $13,608 per year is achieved.

Spraying savings

The 2cm autosteer fitted to the sowing and spraying tractors has enabled the Postlethwaites to adopt precision spraying techniques in wide row crops.

The ability to selectively spray the crop row or inter-row is resulting in savings of $27/ha in pesticides.

All pulse crops are sown 1m apart in paired rows (225mm apart) and shielded spraying and band spraying techniques are used to apply a reduced amount of pesticides on these crops. Wide row crops allow cheaper knockdown herbicides (Roundup®, Sprayseed®) to be sprayed on the inter-row using a shielded sprayer and more expensive selective herbicides (eg. Select®) and fungicides to be sprayed just on the row itself.

Cost savings in pesticides on pulse crops are in the order of $27/ha or $32,400 ($13.50/ha across the whole farm). The precision spraying equipment was manufactured by the Postlethwaites at minimal cost, and they are now making these commercially at a cost of $20,000 to $30,000.

The Postlethwaites have compared wide row with conventional row spacing in a range of crop types, over the last 10 years. Their trials have indicated no yield penalty for wide rows in barley, canola, pulses and often a yield advantage. They have observed that wheat behaves differently to other crops and 'flip-flops' between yield advantage and disadvantage depending on the season. All cereals and canola are still sown on 225mm spacing.

Payback period

Based on input cost savings of 3.5%, the calculated payback period for the visual guidance equipment was two years and the autosteer five years.

Overall economic benefits

The overall annual benefit from PA is calculated at $46,008 or $19.17/ha.

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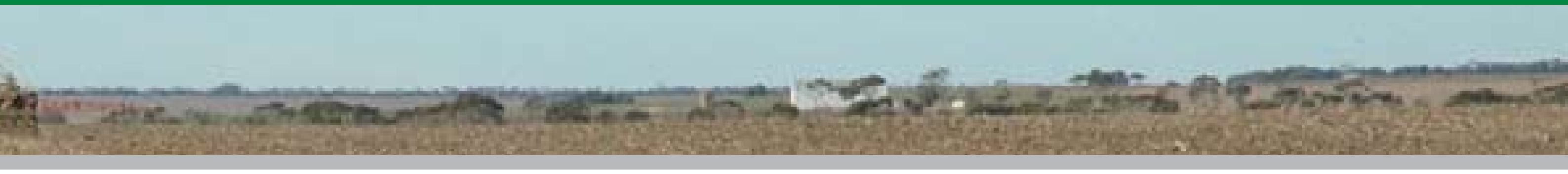


Does PA pay? Part 2

'The economic benefits of precision agriculture: case studies from Australian grain farms' was a project supported by the Grains Research and Development Corporation (GRDC) and CSIRO Sustainable Ecosystems. The project was executed by Michael Robertson, Peter Carberry and Lisa Brennan and the report on the six case studies was released in March 2007. A full copy of the report is available on the SPAA website.

The farm case studies covered a range of agro-climatic regions (Mediterranean, uniform and summer dominant rainfall patterns), cropping systems (wheat-lupin, wheat-canola, and winter and summer crops), farm sizes (1250 to 5800 hectare cropping program), soil types (shallow gravels to deep cracking clays), and production levels (average wheat yields from 1.8 to 3.5t/ha). The farmers had been involved in PA from two to 10 years (Table 1) and covered the range of PA technologies that are commonly used by Australian grain farmers. Among the six farmers, all had invested in guidance and were practising some form of variable rate management of fertiliser. However, only some were using autosteer and tramlining. One was using normalised difference vegetation index (NDVI) and another Greenseeker® technology. As such, the data set covered the range of likely situations confronting practitioners of PA in the Australian wheatbelt.

What was done

Each case study was developed following two to three interviews with the farmer by one member of the research team. Information was gathered on:

- area of cropping program, crops grown, area of the cropping program to which PA technologies are applicable, average cropping gross margin;
- PA equipment purchased, including date and cost;
- management actions associated with PA technology implementation;
- yield in each management zone, if these could not be supplied these were calculated from yield maps or based on data from representative paddocks. Differences in average yield of the low and high zones was calculated as a gross measure of within-paddock variability in yield;
- growers' opinion of non-monetary benefits of PA.

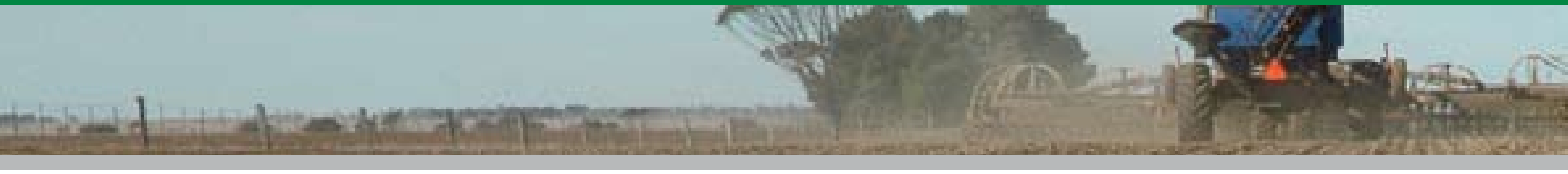
Uniform versus variable rate fertiliser

If grower records were not available, the average yield in each fertiliser management zone was determined using the boundaries of the zones overlaid on the yield maps.

In order to calculate the benefit of variable rate fertiliser application, some estimate had to be made of yield on each zone if uniform management had been applied rather than variable rate. Two approaches, arrived at after discussion with the farmer, were taken depending upon the circumstances of each case study.

Table 1. *Summary details of the six cases study farms in the CSIRO economic study.*

Farmer	Location	Average growing season (GSR) or annual (A) rainfall (mm)	Area annually cropped (ha)	Years experience in PA
1	Mullewa, WA	336 (GSR)	2,600	9
2	Cunderdin, WA	350 (GSR)	5,800	2
3	Buntine, WA	330 (GSR)	3,400	6
4	Moree, NSW	620 (A)	1250	7
5	Gunnedah, NSW	630 (A)	3430	8
6	Barmedman, NSW	470 (GSR)	4000	10



Either the high yield potential zone is assumed to be nutrient limited and therefore, increases in yield under variable rate, while the low potential zone is nutrient non-limited and yield increases by 5% due to less haying-off. The medium zone remains unchanged.

Or all zones are assumed to be nutrient non-limited under uniform management and do not increase in yield under variable rate, with the exception of the low potential zone where yield increases by 5% due to less haying-off.

Economic analysis

For this project the six farmers were interviewed in 2006. Partial gross margins were calculated for uniform and variable rate management using standard prices ($180/t), $1/kg for nitrogen fertiliser, $2.5/kg for phosphorus fertiliser and $0.8/kg for potassium fertiliser. As other variable costs were assumed the same between uniform and variable rate management they were not included in the gross margin calculation.

An investment analysis was used to estimate when the initial investment in PA would be paid off. Annual benefits and costs attributable to PA were listed in time order when they occurred, adjusted for inflation using the Consumer Price Index and accumulated from the time of entry into PA. In addition, a real discount rate of 8% was applied to calculate a net present value in 2006. If entry into PA had only occurred recently the costs and benefits were projected forward to a 10 year time horizon. There was no salvage value assumed for PA equipment.

The estimated annual benefits from PA ranged from $14 to $30/ha (Table 2). The financial benefit gained varied by operation (Table 3).

The breakeven analysis showed that the initial capital outlay was recovered within two to five years of the outlay, and in four out of the six cases in two to three years. The gross margin benefits were well in excess of the typical increases required to yield a breakeven on the investment.

Table 2. *Summary across six farmer case studies of capital investment in PA, estimated annual benefits and year when initial investment is recovered.*

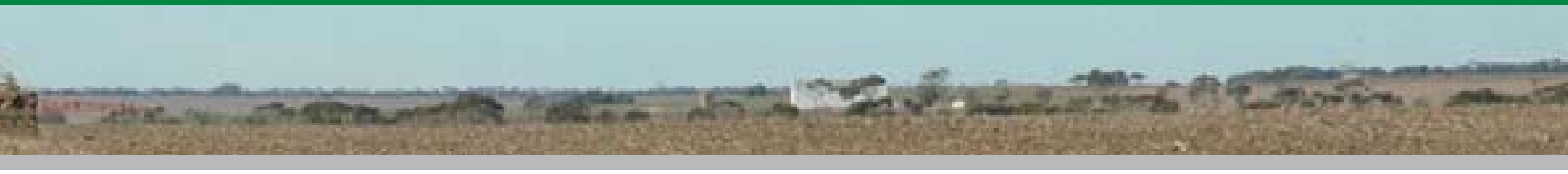
Farmer	Capital Investment in PA		Annual estimated benefits to PA* ($/ha)	Years to breakeven
	total $	$/ha		
1	90,000	35	21	4
2	189,000	33	22	2
3	65,000	19	21	2
4	55,000	44	30	2
5	95,000	28	24	3
6	56,000	14	14	5

** excluding cost of capital*

Table 3. *Summary across six farmer case studies of annual benefits ($/ha) from PA, separated into categories.*

Farmer	Reduced overlap	Fertiliser management	Other
1	5	16	-
2	15	7	-
3	12	1	8
4	8	22	-
5	-	20	4
6	7	7	-

SPAA Southern Precision Agriculture Association
Australian Government Department of Agriculture, Fisheries and Forestry National Landcare Programme
GRDC Grains Research & Development Corporation
CSIRO



David Forrester (L) with CSIRO researcher Michael Robertson has nearly 10 years of experience with variable rate fertiliser. The impact of VR on gross margin has been found to vary with crop, paddock and season but the overall annual benefit just from varying fertiliser is $16/ha.

David and Christina Forrester

Estimated annual benefit from PA

$21/ha

Varying fertiliser rates to soil potential provides David Forrester with substantial annual savings across the farm.

David and Christina Forrester farm 3400 hectares at Mullewa, WA. About 2600 hectares are cropped each year and the yellow sand plain and white sand over gravel or clay soils are under a six year wheat–lupin rotation, with the occasional crop of canola or barley. This is followed by a three year pasture phase of Cadiz clover. Their average growing season rainfall is 336mm and average wheat yields are 3t/ha. They also run approximately 2000 sheep.

Unlike many other practitioners of variable rate management in WA, David does not use autosteer or tramlining. However, he does use guidance and autoboom shut-off for his spraying operations.

David began yield mapping in 1997 and started varying rates of fertiliser to paddock zones on the farm the following year. Before 1997 David tried to raise yield on the poor performing zones through high rates of fertiliser, based on the belief that poor performance was largely due to nutrient limitations. Since moving to variable rate he has seen that lower, rather than higher, rates on such areas are more cost effective and agronomically sensible.

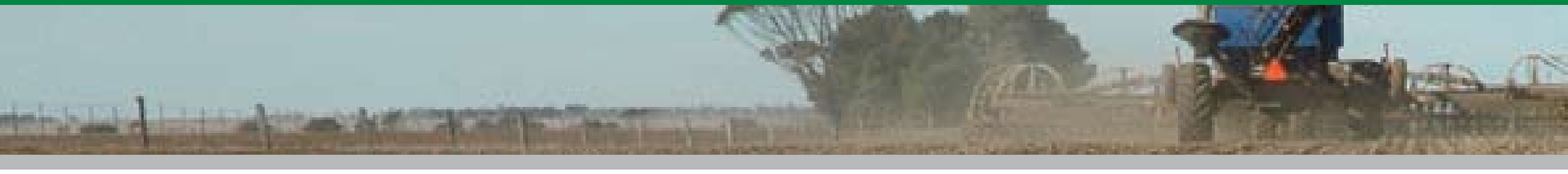
Zones have been defined on the basis of soil type and the native vegetation and are refined as more yield mapping is done. Biomass imagery supplied by a consultant was used to confirm the zone boundaries. However, David has stuck largely to his original zone definitions, which have been more or less fixed for the last four seasons. Most paddocks have three zones (low, medium and high yield potential) with some paddocks having four. Fertiliser rate maps are produced from the preceding year's yield maps, with drought years being discounted.

Comprehensive soil testing by zone has been conducted since 1998. There is no net cost due to this as

PA Investment and benefits

Table 1. *Details of the Forrester's PA equipment investment and annual benefits achieved.*

Operation	Costs	Annual benefits
Guidance and autoboom spraying	Set-up: $20,000	• Reduction in overlap with spraying = $13,000 • Increase in gross margin due to variable rate fertiliser = $41,600
Yield monitor, map and interpretation	Set-up: $38,000 Annual $3,000	
Variable rate controllers	Set-up: $30,000	
Definition of zones	Set-up: $2,000	
GPS licence	Annual: $3,000	



it is included as part of the service supplied by the fertiliser company. David would like to move to varying his rates of lime some time in the future.

PA equipment

The Forresters started with and continue to use two Rinex Farmtrax systems that give them 10cm accuracy. This level of accuracy is sufficient for their needs (yield monitoring and variable rate application) as they are not using autosteer.

Guidance and autoboom for spraying

David did not pay for this equipment but estimates that the cost would have been $20,000 if this had been purchased. The analysis assumes that the equipment was purchased.

David pays an annual subscription to Omnistar for the DGPS signal ($2,700); this is a farm licence that covers the two units . One of the GPS units is swapped between the harvester and sprayer.

Yield monitoring

One Rinex system is mounted in the John Deere 9760STS harvester connected to an AgLeader yield monitor ($28,000 in 1998).

Variable rate fertiliser

The other Rinex system ($24,000 as part of a funded project) is either in the John Deere 9320 or 8320 tractor. It is either connected to a Farmscan 22C1 controller ($5,000 including wiring loom) to regulate fertiliser output from the Simplicity air-seeder box or it controls the Marshall spreader when top-dressing fertiliser ($1,200 for an actuating cable) or to guide the boomspray.

Other data

David defined the zones on each paddock through his own knowledge of soil type and productivity. In addition biomass imagery was analysed and mapped ($1,660).

Labour

In the early days of PA David spent about 20 days setting-up the system. David estimates he spends five days per year setting-up and running the system, and one day per year processing yield maps. At $500/day this is costed at $10,000 for set-up and $3,000 per year for operating the system.

Benefits

Guidance and autoboom for spraying

David estimates there is a 10% saving due to a reduction in spraying overlaps. With an average spray cost of $50/ha, a 10% reduction in overlap spread over 2600 hectares amounts to an annual benefit of $13,000. This means that the set-up cost of $20,000 was recovered within two years.

Yield monitoring

There are no estimated direct benefits from yield mapping. The main indirect benefit has been the definition of the management zones, with yield maps being used in conjunction with knowledge of soil type and original native vegetation.

Variable rate fertiliser

Variable rate application of starter fertiliser occurs on cereals and lupins and top-dressing of nitrogen (N) only occurs on the cereal portion of the cropping program.

In the early years of VR, rates were varied by 10% above and below the paddock average on the low and high zones, respectively. Since 2000, David has been more adventurous in raising the rates on the high performing areas and lowering them on the low performing areas, with the overall constraint that the paddock average rates remains similar to that under uniform management.

By 2006 all paddocks on the farm had received variable rate fertiliser at least once since 1998.

Cereals and lupins receive similar rates of starter fertiliser (60, 90 and 120kg product/ha for low, medium and high zones, respectively). Potash is applied at 60, 80 and 100kg/ha of muriate of potash. Urea is applied to cereals at rates of 50, 70, and 90kg/ha of urea and in good seasons this is topped up in-season with 10, 20 and 30kg/ha of urea plus sulphur. David occasionally varies these rates if soil tests indicate there is a need.

An estimate was made of the benefits of variable rates of nitrogen, phosphorus and potassium on nine cropping paddocks where yield maps were collected during 1997-2005. These paddocks were randomly chosen from the full set of yield maps collected by David over the last few years, and were considered representative of his whole cropping program.

Across the 24 wheat paddock by season combinations, the difference between the yield from the high and low zone ranged from 400kg/ha in the most uniform situation to 2100kg/ha in the most variable situation with the mean being just over 1000kg/ha. The benefit due to variable rate varied from -$15/ha to +$50/ha, with an average of $14/ha.

Across the 21 lupin paddocks by season combinations, the difference between the yield from the high and low zone ranged from 300kg/ha in the most uniform situation to 1700kg/ha in the most variable situation with the mean being just over 800kg/ha. The benefit due to variable rate varied between $1/ha to $42/ha, with an average of $19/ha.

For wheat there were five instances where the return was negative and 10 out of 24 where the return was greater than $20/ha. On paddocks with ahistory of yield maps there

Table 2. *Mean increase in paddock gross margin ($/ha) due to variable rate fertiliser application by crop type on David Forrester's farm.*

Crop	Season									
	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean
Barley	13								34	23
Lupins	10	17			14	12	12	22	30	19
Wheat	25	26	5	19	22	8	16	9	7	14
Mean	16	23	5	19	18	9	13	13	27	16

were some that consistently performed poorly with variable rate fertiliser and others that performed consistently well.

Average increase in gross margin over the whole cropping program attributable to PA technology is estimated at $21/ha, split as $16/ha for variable rate fertiliser and $5/ha for reduced overlap in spraying.

The example paddocks chosen give on average a $16/ha benefit to variable rate over the paddocks and crops examined (Table 2). If this benefit is extrapolated over the entire cropping program of 2600 hectares then annual benefits are calculated to be $41,600.

Net present value

David started using variable rate fertiliser in 1998 but did not see substantial benefits until 2001 when he started to vary rates by a reasonable amount. The lag between purchase of the yield monitoring and variable rate systems in 1997 and the start of substantial benefits in 2001 must be accounted for in a discounted cash flow analysis. Annual benefits exceeded costs by 1999, and cash flow is positive by 2000. The net present value over a 10 year timeframe came to about $300,000 in 2006.

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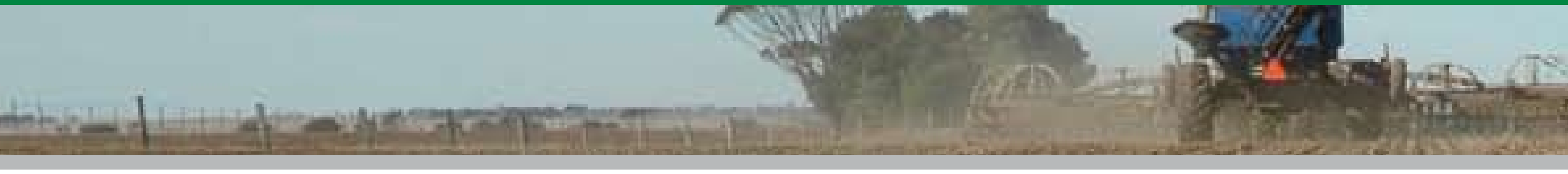

Reduced overlap has produced the greatest financial benefits for David Fulwood. Reducing overlap not only saves inputs but also used about 8% less time, that is five minutes saved per hour.

David, Greg and Malcolm Fulwood

Estimated annual benefit from PA

$22/ha

Reduced overlap due to tramlining, and the use of guidance and autosteer provide the Fulwoods with the greatest savings related to investments in PA technology.

David Fulwood farms 5800 hectares near Cunderdin, WA in partnership with his father Malcolm and uncle Greg. The total area is made up of two separate farming businesses, which share some land and all of the main machinery and guidance equipment.

The cropping program is approximately 70% cereals and 30% grain legumes (field peas and lupins). Soil types range from deep yellow sands to duplex soils to gravels. There has been a gradual move to eliminate sheep from the system. Long term average rainfall is 350mm and average yields in 2005 were 2.75t/ha for cereals and for lupins 1.35t/ha.

The Fulwoods have been using PA technology since 1999 when they started yield mapping; variable rate fertiliser management was started in 2005. Greg originally purchased an aftermarket autosteer and base station system in 2003 and set-up machinery with two metre wheel spacing for tramlining with a shielded sprayer. Shielded spraying is used to control weeds in lupins.

PA Investment and benefits

Table 1. *Details of the Fulwood's PA equipment investment and annual benefits achieved.*

Operation	Costs	Annual benefits
Autosteer in two tractors	Set-up: $65,000	• Reduced overlap and labour with tramlining = $93,600 • More efficient harvesting = $10,150 • Variable rate fertiliser ($13/ha) over 4060ha = $26,390
Autosteer in sprayer/ harvester (includes spray controller & seven section autoboom shut-off)	Set-up: $43,000	
GPS base station	Set-up: $12,000	
Variable rate controllers for seeder, spreader, shielded sprayer (2 Kee Zynx controllers, electric drives on air-seeders, spreader proportional belt speed controller)	Set-up: $30,000	
Zone definition	Set-up: $23,100	
Soil testing and recommendations for each zone	Annual: $10,500	
Labour in equipment set-up and data management	Set-up: $15,000 Annual: $3,000	

The 2006 season was the second in which all the equipment (spraying, seeding, fertiliser spreading, harvesting) was lined up on nine metre tramlines with three metre wheel spacing and the cropping program was approximately 5000 hectares, with the expectation that all land would be cropped in 2007 (5,800 hectares).

PA equipment

Shielded spraying

The shielded sprayer was a custom-built piece of machinery ($50,000). It is difficult to compare this investment cost with an equivalent piece of machinery in a non-PA setting, however, a nominal marginal cost of $10,000 compared to a tow-behind sprayer was assumed.

Autosteer

The farm operates two tractors, one self-propelled sprayer and one harvester. Autosteer is installed in the two tractors ($32,500 per vehicle). Another autosteer system ($26,000) is moved between the sprayer and harvester. In addition, the sprayer and harvester have been modified to make them autosteer capable ($17, 500).

GPS and controllers

The RTK base station ($12,000) for the two tractors is used during seeding and shielded spraying to achieve 2cm accuracy. Kee Zynx controllers ($7,500 each) were installed in the two tractors. A total of $8,000 was spent to set-up the air-seeders with triple electric drives capable of variable rate. One of the existing Kee Zynx controllers is used to make the fertiliser and lime spreader variable rate capable and to control the shielded sprayer.

Yield mapping and variable rate fertiliser

David's family has been collecting yield maps since 1999. These were used in conjunction with historical normalised difference vegetation index (NDVI) imagery, supplied by a consultant, to define fertiliser zones for each paddock ($600 per paddock). Each paddock has high, medium and low input zones defined and these are used for starter fertiliser and top-dressed nitrogen applied as urea granules in June/July, but not for seed or lime application.

Soil tests were carried out in each zone, which increased the cost of soil testing by three to four fold but this cost has been absorbed into the fertiliser bill for the farm. Yield potential and soil test results are used to define fertiliser rates for the 42 paddocks in crop in any single year ($250 per paddock per year).

Labour

David estimates he spends five days per year setting-up and running the system, and one day per year processing yield maps. With his time valued at $500/day this amounts to a recurring annual cost of $3,000.

For initial set-up 30 days at $500/day were budgeted in each of the first two years.

Benefits

Shielded spraying

David inter-row sprays his lupins using a shielded boom with a non-selective herbicide. Row spacing is taken out to 750cm with no yield penalty. This gives another tool in the fight against ryegrass herbicide resistance while maintaining his paddocks in crop. However, it is slow work with the sprayer only moving at nine to 13km/hr compared to 25 to 35km/hr for traditional broadacre spraying, depending on the water rate required and the terrain. Weed control in the row is not fully effective with the shielded system.

In this study it has not been attempted to place a monetary value on the shielded spraying.

Tramlining

With spraying, seeding and spreading occurring on the tramline system a reduction in overlap of 10% for spraying and 7% for fertiliser has been achieved. Labour costs are $29/hour and overlap savings can be translated into labour savings. Average variable costs for cropping are $234/ha, so an average saving of 8% over the cropping program is 5000ha x 8% x $234/ha = $93,600.

The benefit of harvesting with a full front is estimated to save 5% on harvesting costs (assumed to be $35/ha). This would have a combined benefit over the whole cropping program of $10,150.

Variable rate fertiliser

Variable rate application of starter fertiliser and top-dressing only occurs on the cereal portion of the cropping program. David used variable rates of fertiliser on paddock zones in 2005 and 2006. An estimate was made of the benefits of variable rates of nitrogen (N), phosphorus (P) and potassium (K) on seven cereal paddocks where yield maps were collected at harvest in 2005. The average yield in each fertiliser zone was determined using the boundaries of the zones overlaid on the yield maps and yields assumed under uniform management. Typical rates of N, P and K applied to one paddock are shown in Figure 1.

Across the seven paddocks the difference between the yield from the high and low zones ranged from 430kg/ha to 1140kg/ha. The benefit due to variable rate varied from $4/ha to $23/ha, with an average of $13/ha (8%).

If an average benefit of $13/ha is assumed to occur in one year out of two and will occur over the cereal portion of the cropping program, the aggregate annual benefit will be $22,750.

Other benefits

One of the expected benefits of tramlining is that the frequency of deep ripping on the 25% of the farm that responds to this treatment will drop from once every four to five years to perhaps once every six to seven years. If the cost of deep ripping is assumed to be $100/ha this means the benefit is $8/ha spread over the whole cropping program ($8/ha x 5,800ha = $46,400). As this benefit has not been realised yet, it is not included in our calculations.

Net present value

When the costs and benefits were listed and a discounted cash flow analysis applied from 2005 when VR started, the net benefits were negative in the first year with the large set-up costs, but quickly became positive by year two (2006). If the time horizon is projected out to 2014 (ten years after the initial investment) the net present value for the whole farm due to PA would be about $670,000.

Average increase in gross margin over the whole cropping program attributable to PA technology is estimated at $20/ha, ($7/ha for variable rate fertiliser and $15/ha for reduced overlap in chemicals, fertiliser, seeding and harvesting). Across the cropping program this represents an annual benefit of $116,000.

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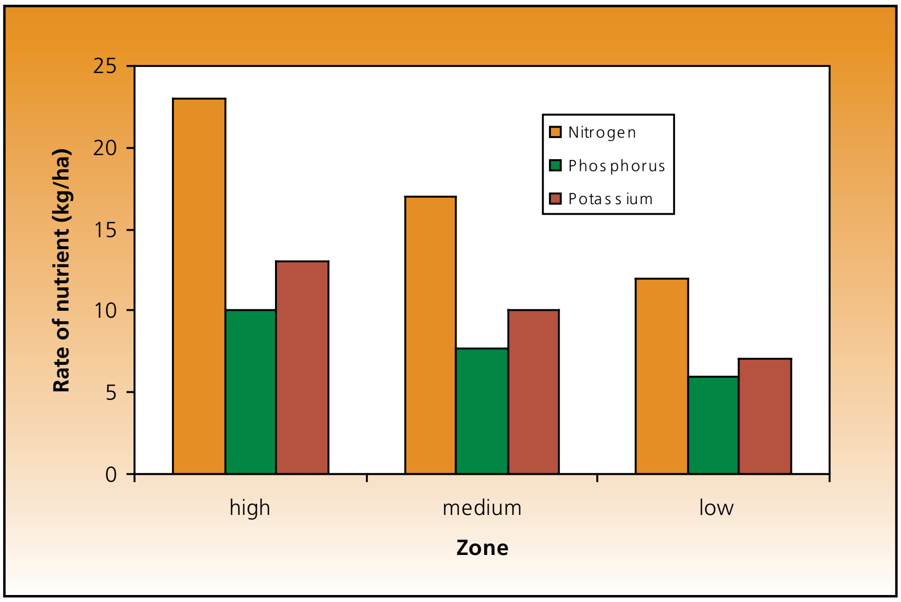


Figure 1. *Rates of nutrient applied in each zone in an example paddock from David Fulwood's farm.*

Reduced overlap and more timely seeding are the two greatest benefits Stuart McAlpine has gained from the use of PA technologies. Despite being an early adopter of PA he has only recently experimented with variable rate fertiliser.

Stuart and Leanne McAlpine

Estimated annual benefit from PA

$21/ha

For Stuart McAlpine the major annual benefit from investing in PA comes from reduced overlap and labour costs due to tramlining and guidance.

At his property near Buntine, WA, Stuart in partnership with his wife Leanne crops on average 3400 hectares of wheat, barley, canola and lupins. Long term annual rainfall is 330mm and soil types range from deep yellow sands, to duplex soils to gravels.

Stuart began yield mapping in 1996 and uses guidance and tramlining. While Stuart has been yield mapping and using guidance for a number of years he has yet to embark on a full program of variable rate application of nutrients.

PA equipment

Guidance and tramlining

Stuart decided to move into guidance and tramlines six years ago, after using marker arms to guide application of crop inputs.

PA Investment and benefits

Table 1. *Details of Stuart McAlpine's PA equipment investment and annual benefits achieved.*

Operation	Costs	Annual benefits
Autosteer	Set-up: $40,000	• Reduced overlap etc = $17,000 • More timely seeding = $17,000 • Variable rate application of nitrogen = $4,500
GPS base station	Set-up: $20,000	
Yield monitor	Set-up: $5,000	
Yield monitoring	Annual: $2,000	
Labour, software and data management	Set-up: $6,000 Annual: $2,000	

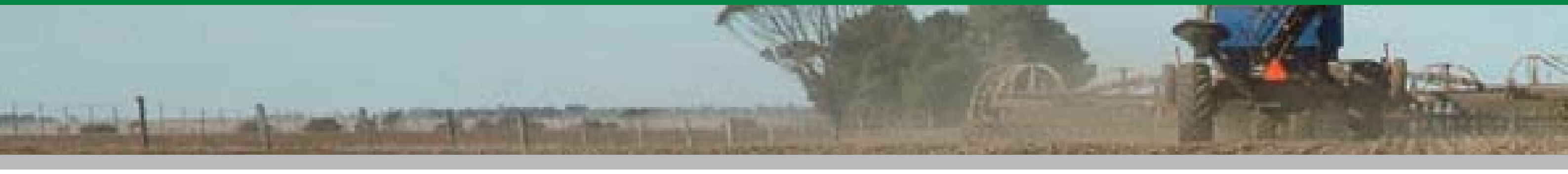
The set-up cost was $40,000 for the steering and $20,000 for the GPS base station.

Yield mapping

Stuart has been collecting yield maps on most of his paddocks since 1996. At that time, the cost of installing a yield monitor was $5,000. More recently, the yield monitor came pre-installed on the harvester and has not been considered a cost. There have been other minor costs associated with purchase of software to download, process and graph yield maps ($1,000). A PA consultant has not been used.

Variable rate application of nutrients

While Stuart has been yield mapping and using guidance for a number of years he has yet to embark on a full program of variable rate application of nutrients. He sees the current unreliability of variable rate equipment as a major barrier and prefers to use a 'low tech' approach. This approach consists of a uniform rate of basal fertiliser and varying rates of nitrogen (N) via flexi-N through the boomspray, which he controls manually.



Flex-N is varied both at seeding and through the season in response to unfolding conditions. He sees major potential for tools like Yield Prophet® to help manage seasonal conditions and direct fertiliser decisions.

On a handful of paddocks in the last few years, patches or zones within paddocks have been fertilised differentially and the definition of these patches has been aided by the collection and interpretation of yield maps, as well as his knowledge of paddock variability and other spatial information such as NDVI analysis.

Labour

Management time has been costed at 20 hours per year at $50/hour and initial set-up costs at $5,000.

Benefits

Guidance and tramlining

Stuart estimates that the use of marker arms saved him 4 to 11% in reduced overlap for fertiliser, seed, and herbicides and that the guidance system bought another 4% in savings for average input costs of $100 to 150/ha. A saving of 4% on $125/ha ($5/ha) over 3,400 hectares this is a total benefit of $17,000 each year.

In addition, a major economic benefit of guidance has been the ability to sow crops in a timely manner in dry seasons. Before the use of guidance, in dry seasons dust at night hindered seeding operations and effectively delayed operations by two to three weeks in one year in three on about one-third of the cropping program. With a yield penalty for delayed sowing of 20 to 50kg/ha/day for wheat, the benefits of guidance in timelier crop establishment can be considerable. The size of the yield penalty will depend on seasonal conditions and will in general be greater for delays later in the season. From these figures a 3% improvement in gross margin, which equates to $4.60/ha, due to more timely sowing of crops in dry years has been estimated:

Stuart knows that there have been fuel savings with the use of tramlines due to better traction and reduced traffic on the paddock. He cannot put figures on this, so instead Department of Agriculture and Food WA (DAFWA) estimates have been used, these are 25% savings on a baseline fuel cost of $20/ha (Blackwell et al 2004), which is $5/ha or 3% of the baseline gross margin.

Other benefits such as: increased crop yields due to less compaction, reduced stress and fatigue on operators, and less mistakes have not been accounted for here as they are difficult to quantify.

The total benefit due to guidance and tramlining is a 10% increase on gross margin.

Yield mapping

Stuart believes the main benefits he has obtained from yield maps is the ability to monitor paddock performance, locate constraints (eg. weed patches) and identify errors in crop operations, such as misses in sowing. He uses them as a point of reference and record keeping when planning his cropping program each year.

For example, on about 50% of his program in any one season Stuart has been fine-tuning nitrogen inputs to maximise profitability in terms of yield and protein (particularly with noodle wheats). Yield maps have been the primary PA technology influencing nutrient management decisions. It is difficult to quantify the financial benefits of this practice, so no account of it has been made in this analysis.

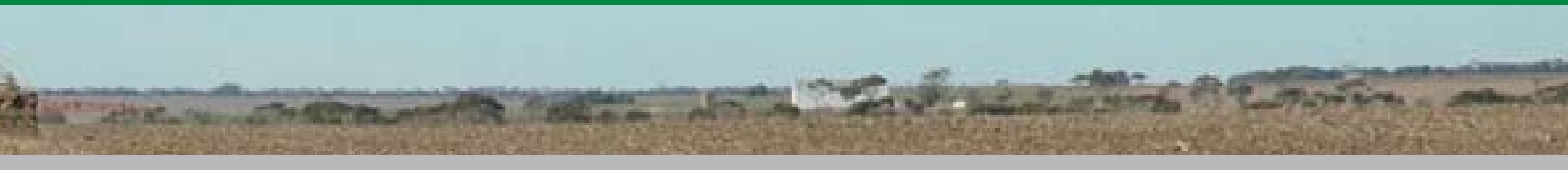
Variable rate application of nutrients

For variable rate application of fertiliser to 'patches' it is difficult to estimate the economic benefit of this type of management as there are no records of pre and post rates of fertiliser nor the area of the farm to which this form of management was applied. Therefore, an estimate of the potential benefits of variable rate management of nitrogen (N) on wheat using the framework described by Robertson et al. (2006) is used here.

Assumptions:

- about half of the 3,400 hectare cropping program shows enough within paddock variation to be worth using variable rate (Stuart's estimate);
- on these paddocks the variation in potential yield between the highest and lowest yielding thirds of the paddock is 2.0t/ha (Stuart's estimate). From Robertson et al. (2006) this translates to a benefit of $4/ha. It is important to realise that benefits estimated here are only for variable rate of N on wheat. The benefits will be greater where other nutrients are included;
- that the maximum gains from variable rate compared to uniform management are captured in two years out of three. Gains do not accrue in every year because of seasonal variation, but gains are higher than that expected in other parts of Australia because of the opportunities for in-season management in WA (Flexi-N and reliable short term rainfall predictions).

Combining these assumptions (3,400ha x 0.5 x $4/ha x 0.66 frequency) gives a total benefit of $4,500, or $1.3/ha over the entire cropping program or 1% over the baseline gross margin. It is assessed that these benefits have been gained at minimal cost – the equipment to apply N differentially to patches is no different to that used in conventional management and there have been few other



significant costs such as extra management time.

Benefits of precision agriculture technologies come from guidance (less overlap of chemical applications, more timely sowing, and fuel savings), yield mapping (improved knowledge for crop management) and variable rate application of nitrogen (improved targeting to yield potential). Where actual economic benefits are able to be quantified they add up to a $21/ha total increase in gross margin. Across the 3,400 hectare cropping program that is an annual benefit of $68,000.

Net present value

When the costs and benefits were listed and a discounted cash flow analysis applied, the net benefits were negative in the first year with the large set-up costs, but quickly became positive by year two (1999). If the time horizon is projected to 2007 (ten years after the initial investment) the net present value for the whole farm due to PA would be $345,507.

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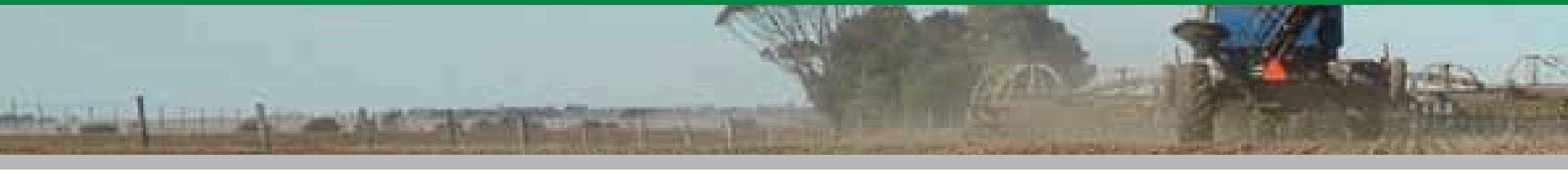

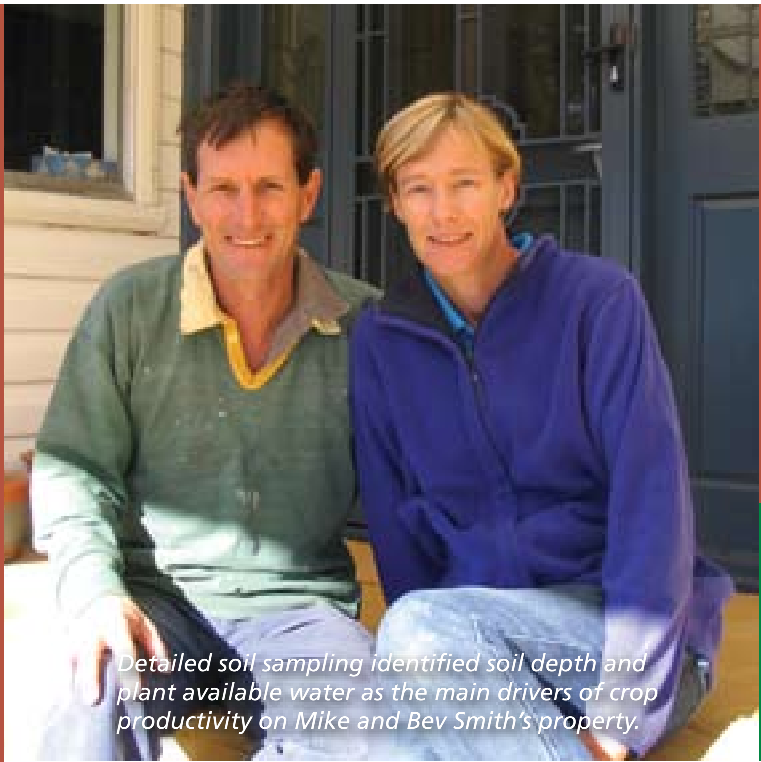

Detailed soil sampling identified soil depth and plant available water as the main drivers of crop productivity on Mike and Bev Smith's property.

Mike and Bev Smith

Estimated annual benefit from PA

$30/ha

On Mike Smith's property the greatest gross margin benefits from variable rate nitrogen have been achieved in sorghum and wheat crops, which both have a high nitrogen requirement.

Mike and Bev Smith farm 1600 hectares, of which 1250 hectares is cropped each year, near Moree, NSW. The black Vertisol soils are cropped to wheat, canola, chickpea, barley, sorghum and sunflower. The depth of the black soil to the underlying layer of decomposing sandstone influences the plant available water for crop production. Where black soils are 60cm deep this equates to 70mm of plant available water, 100cm to 120mm and 180cm to 240mm. Annual rainfall is 620mm and summer dominant.

Yield monitoring and soil depth mapping started in 1996, followed by identification of zones of differing soil depth. In 1999, the application of variable rate technology commenced. Their current PA system includes variable rate fertiliser and chemical applications, yield monitoring and autosteer. A key objective is to better target crop yield potential to each zone within a paddock by varying the amount of applied inputs between zones but not necessarily changing the total inputs applied to a paddock.

An important component to the successful early adoption of PA technology has been Mike's close involvement with PA researchers who have assisted him in collecting and interpreting the large datasets collected from PA equipment.

PA Investment and benefits

Table 1. *Details of the Smith's PA equipment investment and annual benefits achieved.*

Operation	Costs	Annual benefits
Guidance and autoboom spraying	Set-up: $30,000	• Reduction in overlap with spraying = $10,000 • Increase in gross margin due to variable rate fertiliser = $28,000
Yield monitor	Set-up: $5,000	
Variable rate controllers	Set-up: $15,000	
Definition of zones	Set-up: $10,000	
GPS licence and labour	Annual: $7,000	

PA equipment

Guidance and tramlining

Mike started using tramline farming in 1996 and feels it provides greater timeliness and efficiencies. The farm uses a John Deere GreenStar AutoTrac autosteer system on nine metre machinery widths. The autosteer system is moved between his tractor and harvester ($30,000 including to set-up).

Yield mapping and VR

Mike established soil depth and its influence on plant available water

content as the major source of soil variability. In 1998, he purchased a variable rate driver for the air-seeder, 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 harvester 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.

Mike estimates the costs of VR set-up on his boomspray and Gyral air-seeder to be around $15,000. This includes the spray controller ($4,000), which would have been needed even without VR. VR is used for the application of seed, fertiliser and insecticide (once in chickpeas) across three to four zones per paddock.

Labour

Mike spent considerable time in the early days mapping soil depth over the entire farm using a soil probe. $10,000 has been costed to account for this time and the time required for equipment set-up. An annual labour cost of $2,000 (40 hours) has been allowed to account for equipment set-up, data processing, etc.

Benefits

Guidance and tramlining

A major benefit has been reduced overlap and improved operational efficiencies including less driver fatigue. Mike estimates a 7% saving in the application of seed, fertiliser and chemicals due to reduced overlap ($8/ha), which equates to approximately $10,000 each year.

One full time employee is no longer required, which saves over $40,000 each year, due to improved operational efficiency.

Yield mapping and VR

Mike keeps detailed records for each crop on each paddock. Through mapping soil depths and yields he has defined three zones in most paddocks based on 80, 100 and 125% of average yield.

He has determined fertiliser rates for each zone relative to the recommended uniform rate and for the paddocks used in this analysis these rates average 118%, 97% and 71% of the uniform rate.

Benefits due to variable rate fertiliser application ranged from -$7/ha to +$57/ha and averaged a gross margin benefit of +$22/ha across the 27 crop-paddock years. The difference in gross margin of VR relative to the assumed outcome from uniform management was negative for only one crop (chickpea in 2002 season). The poorest returns were in the 2002 drought season and, understandably, with the four chickpea crops given that fertiliser is a lesser determinant of chickpea yield.

Sorghum and wheat, having a high nitrogen (N) fertiliser requirement, showed the highest returns from VR. Mean benefits did not vary greatly between paddocks suggesting that variations in soil depth and PAWC were indeed the driving influences in spatial variation. Likewise, annual variation in average benefit across paddocks and crops was not great, excepting the severe drought year of 2002.

Net present value

Using the assumption that an average gross margin return of $22/ha can be gained from the application of VR across the 1250 hectares annually cropped, then the increase in gross margin equates to $28,000 each year. Reduction in overlap with spraying contributes $8/ha of benefits.

Table 2. *Average increase in paddock gross margin ($/ha) across 27 paddocks due to variable rate fertiliser application for different crops grown on Mike Smith's farm between 1999-2005.*

Crop	Paddocks	Average benefit
Wheat	11	27
Sorghum	6	31
Canola	3	14
Chickpea	4	4
Sunflower	3	10

When the costs and benefits were listed and a discounted cash flow analysis applied, the net benefits were negative in year one with the large set-up costs, but quickly became positive by year two (1999). If the time horizon is projected to 2007 (ten years after the initial investment) the net present value for the whole farm due to PA would be $186,461.

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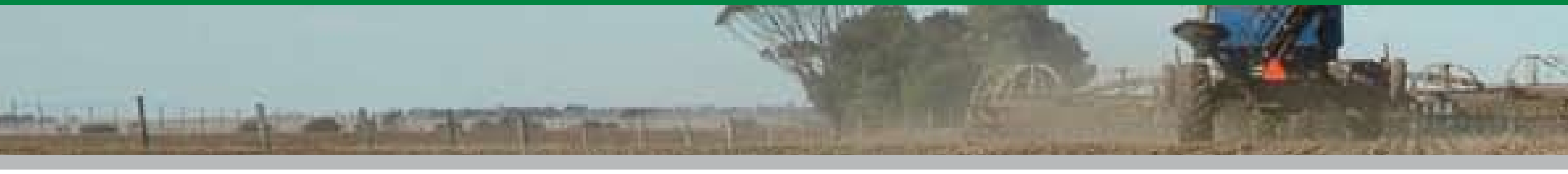
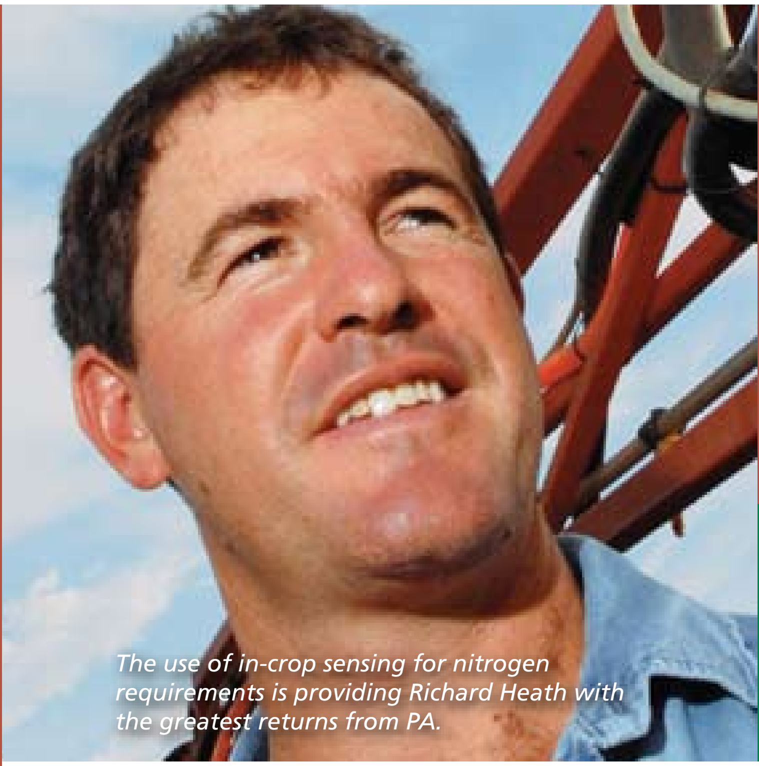
**CANBus ISO 11783 is the upcoming standard in the agricultural area for electronic system network components used in agricultural machinery.*

Southern Precision Agriculture Association
Australian Government Department of Agriculture, Fisheries and Forestry National Landcare Programme
GRDC Grains Research & Development Corporation
CSIRO





The use of in-crop sensing for nitrogen requirements is providing Richard Heath with the greatest returns from PA.

Richard Heath

Estimated annual benefit from PA

$24/ha

For Richard Heath PA technologies offer valuable validation tools to check and revise nutrient input applications and the results are proving more reliable than traditional soil tests.

Richard and Tammy Heath run the cropping enterprises for a family farming operation, 'Pine Cliff', near Gunnedah, NSW. Annual rainfall is 630mm, split between summer and winter growing seasons. The farm opportunity crops 3430 hectares of durum and bread wheat, barley, faba beans, canola, sorghum, maize and sunflowers. Crop potential is high due to relatively cool spring seasons and the predominantly heavy black vertosol soils, which store 250 to 300mm of plant available water. Water logging is a reasonably regular event and is an important source of spatial variation within paddocks.

Richard has been exploring in-season nitrogen (N) application with on-farm trials since 2001. In 2003, he undertook a Nuffield Scholarship on this topic, which also enabled him to explore international experiences with PA technologies. Prior to 2003, Richard applied N fertiliser as anhydrous ammonia or urea that was incorporated either before or at the time of sowing. Since 2003 he has applied in-season applications of liquid fertiliser as a top-dressing to his cereal crops.

PA Investment and benefits

Table 1. *Details of the Heath's PA equipment investment and annual benefits achieved.*

Operation	Costs	Annual benefits
Guidance	Set-up: $30,000	• Reduction in compaction from harvester = $15,000 • Increase in gross margin due to in-season monitoring = $40,000
Autosteer	Set-up: $45,000	
Greenseeker® RT200	Set-up: $20,000	
Labour	Set-up: $5,000 Annual: $2,000	

PA equipment

Guidance and tramlining

A no-till, tramlined farming system has been implemented since 1998, originally using a Satlock visual guidance system ($30,000). In 2005, autosteer with 2cm accuracy using a Farmscan system ($45,000 per unit including base station) has enabled all operations including harvesting to be performed on the same wheel tracks spaced at 12m widths. Three Farmscan systems are swapped between a spray rig, harvester and two tractors.

Yield mapping and VR

Yield mapping started in 2002 and yield maps, along with local knowledge and elevation (areas on the sides of hills have a lower

plant available water capacity), have been used to develop management zones. To date, statistical procedures have not been used to help define these management zones. The zoning is used to apply variable rate starter fertiliser and to help situate test strips for fertiliser trials.

In late 2005, Richard purchased a Greenseeker® RT200 ($20,000). This system uses six optical sensors mounted on the boomspray to measure reflectance from the crop canopy, which is converted to a normalised difference vegetative index (NDVI). Recommended practice is to compare measurements from an unfertilised crop with in-crop strips where luxury rates of fertiliser have been applied pre-sowing. The differential between NDVI readings from these fertilised strips and the rest of the paddock provides an indication of fertiliser requirement.

Labour

Set-up labour in 1998 when the guidance system was being installed was estimated at $5,000, and a recurring annual labour cost of $2,000 is assumed.

Benefits

Guidance and tramlining

While agreeing that efficiencies in chemical applications in broadacre agriculture can be achieved with guidance and tramlining, Richard does not claim significant savings in his case because the farm has been set-up for row cropping. This suggests that growers who have tramlines in place will gain minimal savings from autosteer, but that is not necessarily the case. In 2005, Richard added autosteer to the harvester to match comb and planter widths. He has estimated that having the harvester adhere to the farm's tramline system has saved in the order of $15,000 each year, due to reduced compaction across the 2500 hectare cropping program.

Yield mapping

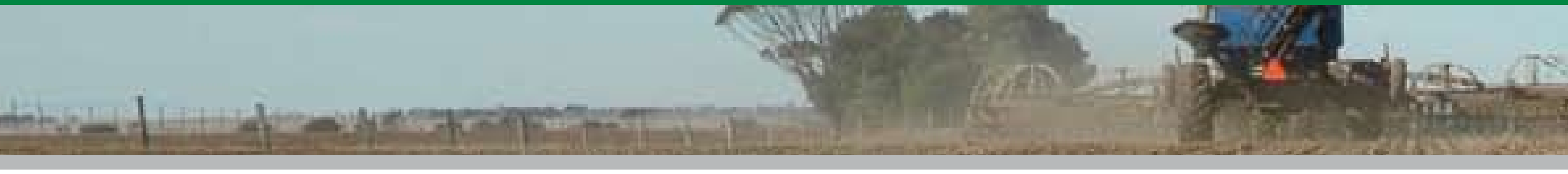
Since 2003, Richard has used test strips within paddocks to compare pre-sown, in-season top-dressing and zero applications of N fertiliser in wheat, maize and sorghum crops.

In 2005, sufficient evidence was accumulated to change fertiliser practice from applying all N upfront to winter cereal crops to only applying starter fertiliser at the time of sowing and then top-dressing crops with liquid fertiliser. Top-dressing rates were determined from observations made at growth stage GS30 in comparison to in-paddock N-rich test strips. Control strips were included in each paddock to represent the past practice of pre-sowing applications of the recommended N rates based on deep soil tests.

By comparing paddock yields with the control strips using yield monitoring data, Richard calculated a net benefit of $20/ha accross the whole farm. Across eight blocks, consisting of 816 hectares of durum wheat, this saving equated to a benefit of $16,863 in that season (Table 2). This benefit consisted of both cost savings from the application of less N fertiliser and

Table 2: *Data for eight blocks for the 2005 durum wheat season for both actual applied top-dressed fertiliser and for test strips of pre-sowing applications of recommended nitrogen rates based on deep soil tests.*

Block	Area ha	Soil test recommendation				Actual applied				Benefit	
		Strip yield t/ha	N rate kg N/ha	N cost $/ha	Margin return to N $/ha	Block yield t/ha	N rate kg N/ha	N cost $/ha	Margin return to N $/ha	Actual – soil test strip $/ha	Actual – soil test strip $/block
Eloura South	102	4.35	10	$10	$686	4.49	44	$60	$658	-$28	-$2,815
Eloura North	110	3.52	80	$80	$483	3.94	44	$60	$570	$87	$9,592
LST North	83	4.46	70	$70	$644	4.25	44	$60	$620	-$24	-$1,959
Lst South	77	4.53	0	$0	$725	4.49	15	$20	$698	-$26	-$2,033
Shinrone	202	3.91	110	$110	$516	4.25	75	$104	$576	$60	$12,201
GE House	35	4.23	110	$110	$567	4.28	75	$100	$585	$18	$630
Top Well	106	4.97	20	$20	$775	4.97	12	$17	$778	$3	$318
BGEE	101	4.4	0	$0	$704	4.57	13	$18	$713	$9	$929
Average	102	4.30	50	$50	$637	4.41	40	$55	$650	$13	$2,108
Farm total	816										$16,863



increases in yields in some blocks. The result was not consistent across blocks with marginal returns in three blocks estimated to be lower than if the recommended N rate had been applied across the whole block.

Variable rate fertiliser application

The Greenseeker® monitoring system has been used to develop variable rate application of in-season N fertiliser for maize and sorghum crops in the 2005/2006 season, and for the 2006 wheat cereal crop. The results were consistent across these three cases with in-season variable rate application using less fertiliser for no change in yield, relative to test strips of recommended N rates based on deep soil tests.

For maize, which averaged 3.9t/ha, the test strip of uniform application incorporated 105kg/ha urea compared to an average 64kg/ha urea for the top-dressed variable application. This fertiliser saving equated to $19/ha. Likewise for sorghum, 175kg/ha urea was applied to the uniform test strip compared to an average of 165kg/ha urea applied as a variable rate recommendation from the Greenseeker®, a saving of $5/ha. While the results of the 2006 winter crop had not been analysed at the time of the report, Richard suggests that less N fertiliser was applied using the Greenseeker® for little difference in yields.

With an assumption that a $20/ha saving in N fertiliser rates can be gained from variable rate top-dressed N across the 2000 hectare of annual cropped area, then the increase in gross margin equates to $40,000 per annum.

Richard is convinced that the combination of test strips, in-season monitoring and yield maps enable optimal fertiliser rates to be better determined for each crop and season. He is yet to be certain that VR provides benefit beyond this point. However, it is still early days in testing and calibrating the Greenseeker® system linked to VR.

Net present value

When the costs and benefits were listed and a discounted cash flow analysis applied, the net benefits were negative in years one and two with the large set-up costs, but became positive by year three (2000). There was a drop in cash flow in 2005 due to the purchase of the Greenseeker® and 2cm autosteer. If the time horizon is projected out to 2007 (ten years after the initial investment) the net present value for the whole farm due to PA would be about $40,000.

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For Rupert McLaren the benefits of using PA technology are equally balanced between gains from variable rate fertiliser and reduction in overlap. He finds savings in overlap can be substantial in irregularly shaped paddocks in hilly terrain.

David, Angus and Rupert McLaren

Estimated annual benefit from PA

$14/ha

The combined savings from reduced overlap and variable rate fertiliser have helped the McLarens pay for their PA equipment in under three years.

David, Angus and Rupert McLaren with spouses Rosemary, Claire and Karen operate an 8000 hectare farming and grazing enterprise near Barmedman, NSW. They currently run 6000 wethers and crop 2000 hectares of cereals and 2000 hectares of canola. Soil types range from red earths to grey cracking clay to ironbark soils. Their average growing season rainfall is 470mm and average wheat yields are about 3.5t/ha and canola yields are 1.8t/ha. The last five years have been much drier than the long-term average (less than 400mm).

PA equipment

Guidance

The McLarens bought a Trimble AgGPS132 ($12,000) in 1998 for the harvester and a Trimble Lightbar ($4,000), which was used in the spray unit. A second AgGPS132 ($8,000) came with the Concord variable rate seeder bought in 2000.

The farm has three mobile sub-meter GPS units. The third one was purchased in 2000 ($4,000), which are used with lightbars and a sub-meter base station (conversion cost $3,500). They plan to upgrade the system to a higher resolution. Before 2005 they paid an annual licence fee to Omnistar ($2,500).

A lightbar and sprayer fitted with autoboom shut-off are used to reduce overlaps. Autosteer and tramlining have not been adopted. Rupert believes that the main advantage of tramlining is to reduce compaction and does not think this is a serious issue for his soil types.

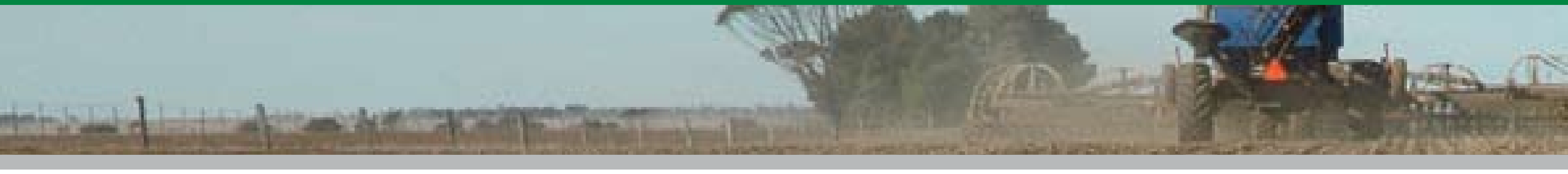
Yield mapping

They began yield mapping in 1996 when they trialled an AgLeader monitor for Case for two years.

PA Investment and benefits

Table 1. *Details of the McLaren's PA equipment investment and annual benefits achieved.*

Operation	Costs	Annual benefits
Lightbar	$4,000	• Reduced spray overlap before 2006 ($2.5/ha) $10,000, after 2006 including. ($6.5/ha) $26,000 • Variable rate P ($7/ha) $28,000
Autoboom spray	$12,000	
Yield monitor, variable rate controllers and GPS	$40,000	
GPS licence	$2,500	
Software	Set-up: $2,200	
Labour	Set-up: $15,000 (2000) Annual: $5,000	



Since then have been yield mapping their entire cropping program. Yield maps are used to delineate fertiliser management zones, which generally line up with soil type differences.

Variable rate

The seeder was sold to the McLarens at a special price because of the trial work that had been done with their Concord VR unit in the previous year. The changeover price was $16,000 for going from a two year old ground drive Concord 3400 to an electric over hydraulic drive Concord 3400 with Universal Display Plus.

In 2004, they upgraded the Bogballe Spreader to VR by purchasing an iPAC ($600) with Farm Site Mate software to run on the iPAQ ($1,200) and a null modem cable ($4) and connecting it to the Bogballe control unit.

Last year they used the iPAQ to control a Dicky John controller in the contractor's lime spreader.

Most of the farm was mapped with EM38 in 2005 ($2,000). This information has been used to guide lime and gypsum rates. The contract lime and gypsum spreader has a Rinex in the spreader, which has been used for the past 10 years to vary lime and gypsum applications. The benefits of variable lime and gypsum are difficult to quantify at this stage and so have also been excluded from this analysis.

In general, the previous three yield maps are used to define fertiliser zones for the coming season. Mono-ammonium phosphate (MAP) is the fertiliser varied at sowing on both wheat and canola. Paddocks (50 to 100ha) are divided into two or three fertiliser management zones, although in years with a dry start to the season no zones are applied. Rupert uses yield maps to help define zones for lime and gypsum as well as fertiliser.

In 2006, the McLarens purchased a Rinex autoboom shut-off unit ($12,000).

Software

In addition to Farm Site Mate the McLarens have bought a couple of desktop software packages. Initially, Surfer ($1,200) was used to help with the mapping and the statistics package Jump was also purchased ($1,000). They have stopped using Surfer because Vesper, a far superior programme in their view, is available for free as a download from the Australian Centre for Precision Agriculture web site.

Labour

Rupert spent 30 days of his time in the early years setting-up the system (valued at $15,000) and estimates that he spends 100 hours each year on zone definition and setting-up fertiliser trials ($5,000 each year). In future this task will be reduced as paddocks are being merged into larger blocks of 400 to 500 hectares.

Benefits

Guidance and autoboom shut-off for spraying

About 40% of the farm has hilly and irregularly-sized paddocks where Rupert estimates 25% savings are made on reduced spray overlap. On flat or regular-sized paddocks (60% of the farm) he estimates a 5% saving in reduced overlap is made. Average spraying costs are $50/ha. Reduced overlap gives a benefit over the cropping program of $6.5/ha or $26,000 each year. As the autoboom was purchased in 2006 this benefit was only allocated to the 2006 season.

The use of the lightbar from 1998 to 2005 was assumed to benefit a conservative 5% gain in reduced overlap over the whole cropping program equating to $2.5/ha or $10,000 each year.

Yield monitoring

There are no estimated direct benefits from yield mapping. The main indirect benefit has been the definition of the management zones, with yield maps being used in conjunction with knowledge of soil type.

Yield monitoring has also been used to measure results from the fertiliser trial program and has given him more confidence about varying his phosphorus (P) and nitrogen (N) rates.

Variable rate fertiliser

Variable rate application of starter fertiliser occurs on cereals and canola. An estimate was made of the benefits of variable rates of mono ammonium phosphate (MAP) on eight cropping paddocks, where yield maps were collected during 2003 to 2006. The average yield in each fertiliser zone was determined using the boundaries of the zones overlaid on the yield maps. Gross margins were then calculated using actual fertiliser rates, yields, standard prices and other variable costs. In this case all zones are assumed to be nutrient non-limited under uniform management and not to increase in yield under variable rate, with the exception of the low potential zone where yield increases by 5% due to less haying-off.

Across the 29 paddock by season combinations, the difference between the yield from the high and low zones ranged from 19kg/ha in the most uniform situation to 776kg/ha in the most variable situation with the mean being just under 250kg/ha. The benefit due to variable rate varied from -$1/ha to +$22/ha, with an average of $7/ha.

Breaking the figures down to consider wheat and canola separately, for wheat (16 paddocks) the difference between the yield from the high and low zones ranged from 34kg/ha in the most uniform situation to 776kg/ha in the most variable situation, with the mean being just under 300kg/ha. The benefit due to variable rate was on average $8/ha.

For canola (13 paddocks) the difference between the yield from the high and low zones ranged from 19kg/ha in the most uniform situation to 661kg/ha in the most variable situation, with the mean being just under 200kg/ha. The benefit due to variable rate was, on average, $6/ha.

There were no instances where the return was negative and in only one out of 29 instances the return was greater than or equal to $20/ha. There were some paddocks that consistently performed lower in return on variable rate and others that performed consistently well.

The example paddocks chosen gave on average a $7/ha benefit to variable rate over the paddocks and crops examined. If this benefit is extrapolated over the entire cropping program of 4000 hectares then annual benefits are calculated at $28,000.

Net present value

Average increase in gross margin over the whole cropping program attributable to PA technology in 2007 is estimated at $13.5/ha, split evenly between benefits from variable rate fertiliser and reduced overlap in spraying. When the costs and benefits were listed and a discounted cash flow analysis applied from 1998, the year yield mapping started, the annual net benefits were negative or close to zero in the first three years with the large set-up costs and VR not starting until 2001, but became positive by 2001. In 2007, ten years after the initial investment, the net present value for the whole farm due to PA is estimated at about $108,000.

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