The economic benefits of precision agriculture: case studies from Australian grain farms

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1. Executive summary

In commercial practice in Australia the implementation of precision agriculture (PA) has in common the use of spatially-aware technologies made possible through the use of global positioning systems (GPS). Most commonly this includes, the use of vehicle guidance to reduce overlap in application of agricultural chemicals, reduced traffic associated with tramlining to reduce compaction and operator fatigue, shielded spraying of pesticides in row crops, yield monitoring, variable rate technology (VRT) for application of agricultural chemicals, especially fertiliser, and within-paddock zone management for agricultural operations.

Although PA technology has been available in Australia for more than a decade, it has been estimated that only around 3% of Australian grain growers are using some form of the technology (Price, 2004). One of the chief reasons for low adoption of PA is the reluctance of farmers to invest many thousands of dollars in PA without knowing if the technology will return a profit. A number of studies have reported the economic benefits of tramline farming and guidance for chemical application. Few studies have examined the value of variable rate technology and zone management.

In this study we attempt to quantify the economic benefits of PA on six case study farms from the Australian wheatbelt. We did not confine our analysis to VRT alone but also considered benefits to guidance and reduced traffic.

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 (1,250 to 5,800 ha cropping program), soil types (shallow gravels to deep cracking clays), and production levels (average wheat yields from 1.8 to 3.5 t/ha). The farmers had been involved in PA from 2 to 10 years 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 auto-steer and tramlining. One was using NDVI and another, the GreenSeeker technology for in-season nitrogen management. As such, the data set covered the range of likely situations confronting practitioners of PA in the Australian wheatbelt.

Each grower was interviewed and information was collected 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, included date and cost, management actions associated with PA technology implementation, the estimated reduction in overlap for tramlining / guidance, the rates of fertiliser applied in each zone for zone management, areas of management zones in each paddock, rates of fertiliser applied for uniform zone management, yield in each management zone, and growers' opinion of non-monetary benefits of PA. Standard economic analyses were applied including gross margin calculations and discounted cash flow analysis.

The level of capital investment in PA varied from $55,000 to $189,000, which is typically at the medium to high end of investment for Australian grain growers. When expressed as capital investment per hectare cropped it varied by a factor of three from $14 to $44/ha. The estimated annual benefits from PA ranged from $14 to $30/ha and consequently the investment analysis showed that the initial capital outlay was recovered within 2-5 years of the outlay, and in four out of the six cases within 2-3 years.

For all farmers we were able to quantify benefits to variable rate fertiliser management, ranging from $1 to $22/ha across the six farms. On a per paddock basis, benefits ranged from -$28 to +$57/ha/year. Variation in monetary benefits from farm to farm could be explained by (1) whether or not starter fertiliser was being varied and not just nitrogen topdressing, and (2) the degree of within-paddock yield variation. The methodology for estimating the benefits of VRT requires further testing on paddock-scale data where yields and fertiliser rates are recorded for uniform and VRT-managed strips.

Benefits due to reduced overlap of spraying were typically in the order of 10% savings on spraying costs. Other benefits nominated by farmers and estimated by us were less fuel use, less soil compaction, less hired labour requirement and more timely sowing. Intangible benefits listed by farmers were: the ability to conduct on-farm trials, increased knowledge of paddock variability, increased confidence in varying fertiliser rates, and better in-crop weed control due to shielded spraying.

All farmers were all highly literate in the use of computers, GPS technology, and variable rate controllers, routinely soil tested and kept good farm records. All invested considerable time in setting up their system in the beginning (with considerable teething problems in some cases), but on-going labour demands were minimal. Some did not use a consultant, while others placed heavy reliance on consultants for zone definition, yield map processing and variable rate map production. We also found that, while a number of farmers are trialling VRT in test strips within paddocks, it seems that very few have taken the jump into full commercial implementation of VRT on their farms.

This study is the first of its kind to estimate the economic benefits of precision agriculture in a commercial context. It demonstrates that Australian grain growers have adopted systems that are profitable, are able to recover the initial capital outlay within a few years, and also see intangible benefits from the use of the technology. While the results here will go some way towards informing the debate about the profitability of PA, it also illustrates that the use of, and benefits from, PA technology varies from farm to farm, in line with farmer preferences and circumstances.

2 Background

In commercial practice in Australia the implementation of precision agriculture (PA) encompasses the use of vehicle guidance to reduce overlap in application of agricultural chemicals, reduced traffic associated with tramlining to reduce compaction and operator fatigue, shielded spraying of pesticides in row crops, yield monitoring, variable rate technology (VRT) for application of agricultural chemicals, especially fertiliser and within-paddock zone management for agricultural operations. All of these activities have in common the use of spatially-aware technologies made possible through the use of global positioning systems (GPS). While the exact boundaries of what does or doesn't constitute PA could be debatable, our definition is confined to the use of the above listed technologies and this seems to match what most Australian grain growers understand by the term PA. Readers are referred to reviews by Cook and Bramley (1998), McBratney et al. (2005), Robertson et al. (2007b), Whelan and McBratney (2003), Jochinke et al. (2006) and Price et al. (2005) for overviews of the state of play of PA in Australia.

Adoption of PA is like any other innovation in that it is influenced by a number of variables (e.g. Marsh and Pannell, 1997) including:

- the relative advantage (or perceived profitability) of the option relative to current practice,
- compatibility with current farming practices,
- ease of acquiring and utilising the option,
- trialability of new option (e.g. can it be tested on a small scale?),
- observability of the risks, advantages and limitations of the option by both the farmer and neighbouring farmers, and
- social context (will adopting the option improve the farmer's social esteem and/or provide opportunities for sharing the experience).

One of the chief reasons for low adoption of PA is the reluctance of farmers to invest many thousands of dollars in PA without knowing if the technology will return a profit (Dobermann et al. 2004, Jochinke at el. 2006). Early PA adopters are often moving into systems based on high cost 2cm accurate GPS auto-steer systems with capital costs ca. $60 000 (Table 1). To potential adopters this seems too expensive and they question the application of PA to their farming system. In Australia the early adopters often crop large areas (above 3000ha) which means highly accurate auto-steer 2cm systems are a good investment based on 10% savings in inputs from less overlap (Stone 2004). GPS costs can range from $800 to $22,000 depending on what accuracy is most appropriate for the operation (Table 1). Highly accurate GPS systems are not an essential piece of the equipment for VRT.

Table 2.1: Typical configurations and costs for investment in equipment and services for precision agriculture technology. Source: Robertson et al (2007b).

Level of investment	Total cost	Equipment and services
Low	$17,300	Variable rate controller - $3,500
		GPS - $800
		Zone analysis (using NDVI) - $3,000
		Existing seeder variable rate ready
		10 cm accuracy auto-steer - $10,000
Medium	$45,000	Yield monitoring and mapping - $7,500
		Conversion of machinery to be variable rate capable - $10,000 to $30,000
		10 cm accuracy auto-steer - $10,000
		Annual subscription - $2,000
High	$75,000	Auto-steer - $32,000 per vehicle
		2 cm accuracy GPS - $18,000 to $22,000
		Controllers for seeding, fertiliser spreading, pesticide spraying - $16,000

Zone analysis (using NDVI, yield maps, soil testing) - $20,000

A range of factors affect the investment value of PA including the current farm gross margin, cost of PA equipment, the area and number of years over which the equipment is used and the rate at which benefits from adoption start to occur (Stone, 2004; Jennings, 2005). An investment analysis using a ‘discounting’ process has been used to calculate a required ‘break even’ increase in gross margin, enabling the investor to reflect on how achievable could a break-even increase in gross margin be in practice. Table 2.2 illustrates the impact of variation in the amount invested in PA and area of cropping benefiting from PA on the required gross margin increase. Clearly, the increase in gross margin required depends on the size of the investment and will be lower if the benefits can be spread over a wider area.

Table 2.2: Increase in gross margin ($/ha) required over 10 years to cover the cost of investment in PA equipment. Discount rate was 8% and annual operating costs for PA were $1000 (Robertson et al. 2007b).

Investment in PA	Area benefiting (ha)	Increase in gross margin ($/ha)
$5 000	500	5
	1000	3
	2000	1
	4000	1
$20 000	500	11
	1000	6
	2000	3
	4000	1

Typical gross margin increases required to offset the PA technology costs can be calculated for different regions in the wheatbelt according to statistics of cropped area on farms. For example, grain growing properties in the northern agricultural areas of WA average 3600 ha, of which about 1700 ha is cropped each year. Given these farm sizes, the range of gross margin increases required to break even from investment in PA is less than $5/ha depending on the level of investment and assuming that benefits accrue over the entire cropping program on the farm starting at year 2 after equipment purchase and persist through a 10 year period. Average farm size in the central agricultural area and southern cropping areas of WA is similar at about 2300–2600 ha. About 1000 ha of this land is cropped each year. For these areas, the break-even increase in gross margin will be $3-6/ha depending upon the size of the investment.

A number of studies have reported the economic benefits of tramline farming and guidance for chemical application, and fewer examining the value of variable rate technology and zone management due to the lower uptake of the latter. The use of one is linked to the other through the use of common technologies like GPS. Hence, in this study we have not attempted to confine our analysis to VRT alone but have considered the complete package where this is appropriate.

In this study we attempt to quantify the economic benefits of PA on six case study farms from the Australian wheatbelt.

3 Methodology

3.1 Case studies

Case studies were selected to cover a range of cropping systems, yield levels, farm sizes and agro-climatic zones in the broadacre cropping regions of Australia. Due to the greater uptake of PA in Western Australia, three of the six case studies come from that state (Table 3.1).

Table 3.1: Summary details of the six case studies used for this analysis.

Farming family	Location	Cropping program	Years experience in PA	PA technologies used
David and Christine Forester	Casuarinas, WA	2,600 ha of wheat, barley, lupins	9	Guidance Variable rate fertiliser
David and Jo Fulwood	Cunderdin, WA	5,800 ha of wheat, barley, lupins	2	Auto-steer Tramlining Shield spraying Guidance Variable rate fertiliser
Stuart and Leanne McAlpine	Buntine, WA	3,400 ha of wheat, barley, canola, lupins	6	Auto-steer Tramlining Guidance Variable rate fertiliser
Michael and Bev Smith	Moree, NSW	1250 ha of wheat, barley, sorghum, chickpeas, canola, sunflower	7	Auto-steer Tramlining Guidance Variable rate fertiliser and pesticides
Richard and Tammy Heath	Gunnedah, NSW	3430 ha of wheat, barley, fababean, canola, sorghum, maize, sunflower	8	Auto-steer Tramlining Guidance Variable rate fertiliser In-season NDVI
Rupert and Claire McLaren	Barmedman, NSW	4000 ha of wheat and canola	10	Guidance Variable rate fertiliser In-season NDVI

Three other leading PA practitioners in southern Australia were also approached and initially agreed to be included in this study. All three had implemented PA technologies such as auto-steering, tramlining and guidance on their farms and had several years of yield monitoring data for past crops. Likewise, all were early pioneers in analysing yield map data to develop management zones and had implemented strip trials to test technologies such as variable rate fertiliser applications across these zones. One of these farmers was also testing in-season NDVI monitoring as an information source for in-season fertilizer applications.

For two of these farmers, the 2006 wheat crop was the first year where variable rate fertiliser applications were implemented as whole farm strategies. Both farmers applied P fertilizer as variable rate. As yield and economic data from the 2006 wheat crop were unavailable at the time of writing this report, the economic analysis of VRT, as applied in commercial practice, could not be completed for these two farms. Without VRT as a component of the proposed economic analysis of PA in commercial practice, it was decided not to include these farms within the reported case studies.

The third farmer likely had the data to test the benefits of PA, including VRT, but these data were not in adequate form to readily undertake the analyses as proposed within the timeframe of this study.

A learning from this study has been the reality that, while a number of farmers are trialling VRT in test strips within paddocks, it seems that very few have taken the jump into full commercial implementation of VRT on their farms.

3.2 Information sourced

Each grower was interviewed by one of the research team, usually over 2-3 occasions, and information was collected 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. If relevant, the marginal cost of such equipment compared to similar equipment used for the same task in the absence of PA applications was estimated
- Management actions associated with PA technology implementation:
  - Tramlining / guidance – estimated reduction in overlap
  - Zone management – rates of fertiliser applied in each zone, areas of management zones in each paddock, rates of fertiliser applied for uniform zone management
- Yield in each management zone: for some case studies the grower was not able to supply us with yields in each zone, so yield maps were obtained and yields calculated for each management zone, which had been pre-determined by the farmer. This was not possible for all paddocks on the farm because of a patchy record of maps or time constraints for the analysis, so a few representative paddocks were chosen and these analysed in some detail, sometimes over a run of seasons. In figures presented under each case study the differences in average yield of the low and high zones was calculated as a gross measure of within-paddock variability in yield (Robertson et al 2007a).
- Growers' opinion of non-monetary benefits of PA

3.3 Benefits of tramlining and guidance

The experience of Western Australia Department of Agriculture and Food staff, encapsulated in a spreadsheet calculator (Blackwell and Webb 2003), was used in this study to quantify benefits of tramlining and guidance gained through reduction in fuel, fertiliser and chemical use and more efficient use of labour. In each case study, the benefits were checked against what the grower thought the benefits had been.

3.4 Uniform vs. variable rate fertiliser management

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.

Estimation approach 1

In these situations (David Forrester, David Fulwood and Mike Smith) it was assumed that the yield and fertiliser rate of the medium zone would have been unchanged between uniform and variable rate management. Further, it was assumed that under uniform management the high yielding zone was nutrient-limited and hence would have a lower yield under uniform management, assumed for simplicity to be average of that in the medium zone and that in the high zone under variable rate. The low yielding zone was assumed to be nutrient non-limited under uniform management and hence the yield was unchanged from the variable rate situation and less fertiliser was therefore applied for the same yield. Two growers insisted that yields were on the whole *higher* in the low zone under variable rate and they put this down to less "haying off" and better grain quality (less screenings). When asked to nominate how much higher they thought yields would be in the low zone under variable rate they suggested 5% higher, and this figure was used in calculations. Overall in these cases, total fertiliser use was unchanged between uniform and variable rate situations, and hence the economic benefits of variable rate were through more yield on the higher zone at a higher fertiliser rate and a 5% higher yield on the low zone but at a lower fertiliser rate (see Table 3.2a for an illustration).

Estimation approach 2

In one case study (Rupert McLaren) the comparison between variable rate and uniform management had to account for *lower* fertiliser rates on medium and low zones, and unchanged rates on the high zones under variable rate. This situation occurred because of high nutrient (principally P) levels that justified a reduction in fertiliser rates on medium and low zones and maintenance of rates on high zones. In effect, all zones were assumed to be nutrient non-limited under uniform management and hence 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" (see Table 3.2b for an illustration).

Table 3.2a: Example of assumed yield and fertiliser rates under uniform management when yields and fertiliser rates in management zones under variable rate management are known. In this case (case 1 described in section 3.4) the high zone yield potential is assumed to be nutrient-limited and hence 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.

Zone yield potential	Under variable rate management		Under uniform management	
	Grain yield (t/ha)	Fertiliser rate (kg/ha)	Grain yield (t/ha)	Fertiliser rate (kg/ha)
High	3.0	75	2.75	50
Medium	2.5	50	2.5	50
Low	2.0	35	1.9	50

Table 3.2b: Example of assumed yield and fertiliser rates under uniform management when yields and fertiliser rates in management zones under variable rate management are known. In this case (case 2 described in section 3.4) all zones are assumed to be nutrient non-limited under uniform management and hence 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".

Zone yield potential	Under variable rate management		Under uniform management	
	Grain yield (t/ha)	Fertiliser rate (kg/ha)	Grain yield (t/ha)	Fertiliser rate (kg/ha)
High	3.0	75	3.0	75
Medium	2.5	50	2.5	75
Low	2.0	35	1.9	75

3.5 Economic analysis

Partial gross margins were calculated for uniform and variable rate management using standard prices ($180/t), and $1/kg for nitrogen fertiliser, $2.5/kg for phosphorus fertiliser, and $0.8 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.

We used an investment analysis to estimate when the initial investment in PA would have been 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. In some case we projected forward the costs and benefits to a 10 year time horizon if the entry into PA had only occurred recently. There was no salvage value assumed for PA equipment.

4 Case Studies

4.1 David Forrester

David and Christina Forrester farm 3400 ha at Mullewa in the northern Western Australia wheatbelt. About 2600 ha are cropped each year and the yellow sand plain and white sand over gravel or clay soils are under a 6 year wheat–lupin rotation, with the occasional crop of canola or barley. This is followed by a 3-year pasture phase of Cadiz clover. Their average growing season rainfall is 336 mm and average wheat yields are about 3 t/ha. They also run approximately 2000 sheep.

Unlike many other practitioners of variable rate management in WA, David does not use auto-steer or tramlining. However, he does use guidance for his spraying operations with an auto-boom. His main reasons for not venturing into tramlining and auto-steer is that at this stage it would require a large capital outlay to change his machinery over to a compatible wheel spacing. David has also been gradually reducing the size of his paddocks over time (from an average of 180 ha to an average of about 90 ha today) so that he can stock large mobs of sheep to exert enough grazing pressure to control weeds, and such small paddocks are not ideal for tramlining layouts. He does not rule out the possibility of converting to a tramlining system sometime in the future "when the time is right".

David began yield mapping in 1997 and started varying rates of fertiliser to paddock zones on the farm the following year. Before 1997 David was conscious of trying to raise the poor performing zones in paddocks through high rates of fertiliser under 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 is more cost effective and agronomically sensible. Zones have been defined on the basis of soil type and the native vegetation and he has been gradually refining the zones as more yield mapping is done. Biomass imagery was used from Silverfox a few years ago to confirm the zone boundaries, but David has stuck largely to his original zone definitions, and these 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 preceding year's yield maps, with drought years being discounted.

In the early years of VRT, rates were varied by 10% above and below of the paddock average on the low and high zones, respectively, before he could be convinced it was the right way to go. 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. Since 2001 David maintains that he has started to see observable responses in paddock profitability. Interestingly, he maintains that the yield and quality on low zones has increased with reduced fertiliser rates and he puts this down to lowering toxicity and less "haying off". In 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 120 kg product/ha for low, medium and high zones, respectively). Potash is applied at 60, 80 and 100 kg/ha of muriate of potash. Urea is applied to cereals at rates of 50, 70, and 90 kg/ha of urea and in good seasons this is topped up in-season with 10, 20 and 30 kg /ha of urea + S. David occasionally varies these rates if the soil test indicates that this is needed. He has also experimented with applying more on the medium zones and less on the high zones to see if productivity differences are related to nutrient deficiencies, but most of the time this has not turned out to be the case.

Comprehensive soil testing by zone has been conducted since 1998, however there is no net cost of moving to this as it is included as part of the fertiliser service from his company. David would like to move to varying his rates of lime some time in the future.

4.1.1 Costs

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

David pays an annual subscription to Omnistar for the DGPS signal — this is a farm licence and covers the two units for $2970 (including GST) each year. One of the GPS units is swapped between the header and sprayer.

Guidance and auto-boom for spraying
David did not pay for the gear required for this but he estimates that the cost would have been $20,000 if he had had to purchase it. Our analysis here assumed that the equipment was purchased.

Yield monitoring
One Rinex system is mounted in the John Deere 9760STS header connected to an AgLeader yield monitor (cost $28,000 in 1998). David has a hassle-free system of collecting and printing out yield maps. During harvest he spends a few minutes at the end of each day in the office downloading and printing maps off the card from the header.

Variable rate fertiliser
The other Rinex system is either in the John Deere 9320 or 8320 tractor (cost $24,000 as part of a funded project). It is either connected to a Farmscan 22C1 controller to regulate fertiliser output from the Simplicity airseeder box (cost $5,000 including wiring loom) or it controls the Marshall spreader when topdressing fertiliser (cost $1200 for an actuating cable) or to guide the boom spray.

Other data
David defined the zones on each paddock through his own knowledge of soil type and productivity. The SilverFox analysis using biomass imagery, including a farm map, cost $1660.

Labour
In the early days of PA David spent about 20 days getting the system setup and running. David estimates he spends 5 days per year getting the system setup and running, and one day per year processing yield maps. At $500/day this is costed at $10,000 for setup and $3000 per year for operating the system.

4.1.2 Benefits

Guidance and auto-boom for spraying
He estimates that there is a 10% saving in reduction of spraying overlaps. With an average spray cost of $50/ha, a 10% reduction in overlap spread over 2600 ha amounts to a benefit of $13,000 pa. This means that the setup cost of $20,000 is 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 topdressing of N only occurs on the cereal portion of the cropping program.

In the early years of variable rate David was tentatively varying rates by 10% above and below the paddock average for the high and low zones, respectively. However, since 2000 he has varied rates more strongly. An estimate was made of the benefits of variable rates of N, P and K on 9 cropping paddocks, where yields maps were collected during 1997-2005. 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, standard prices and other variable costs, and the assumptions outlined above for the yield under uniform management (see case 1 under section 3.3 above). There were 24 wheat and 21 lupin paddocks analysed. These paddocks were randomly chosen from the full set of yield maps collected by David over the last few years, and are hence considered representative of his whole cropping program.

Across the 24 wheat paddock x season combinations, the difference between the yield from the high and low zone ranged from 400 kg/ha in the most uniform situation to 2100 kg/ha in the most variable situation with the mean being just over 1000 kg/ha (Figure 4.1.1). The benefit to variable rate varied from -$15/ha to +$50/ha, with an average of $14/ha.

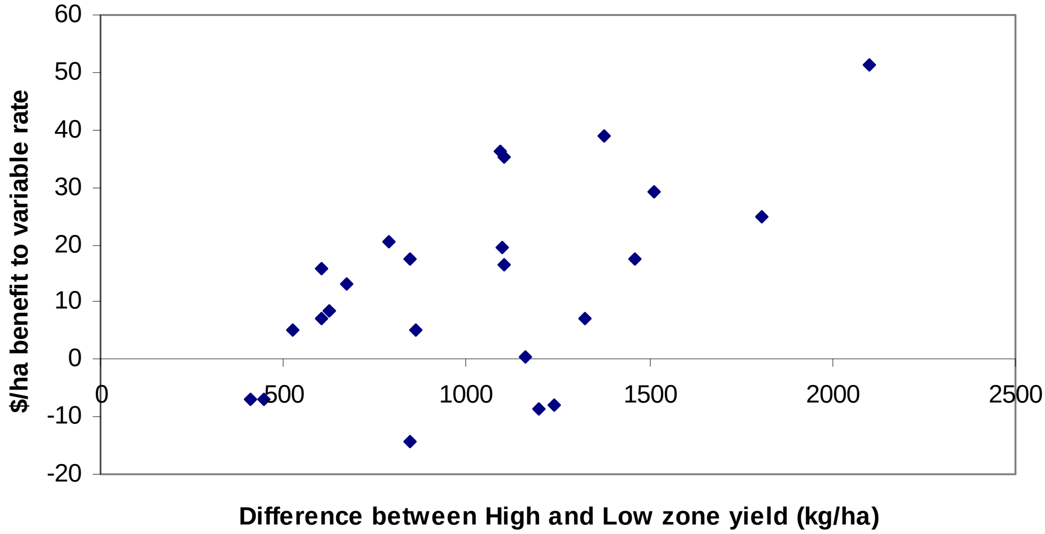

Figure 4.1.1: Relationship between paddock variation (difference between yield of high and low zone) and the $/ha benefit to variable rate for wheat.

Across the 21 lupin paddocks x season combinations, the difference between the yield from the high and low zone ranged from 300 kg/ha in the most uniform situation to 1700 kg/ha in the most variable situation with the mean being just over 800 kg/ha (Figure 4.1.2). The benefit to variable rate varied from $1/ha to +$42/ha, with an average of $19/ha.

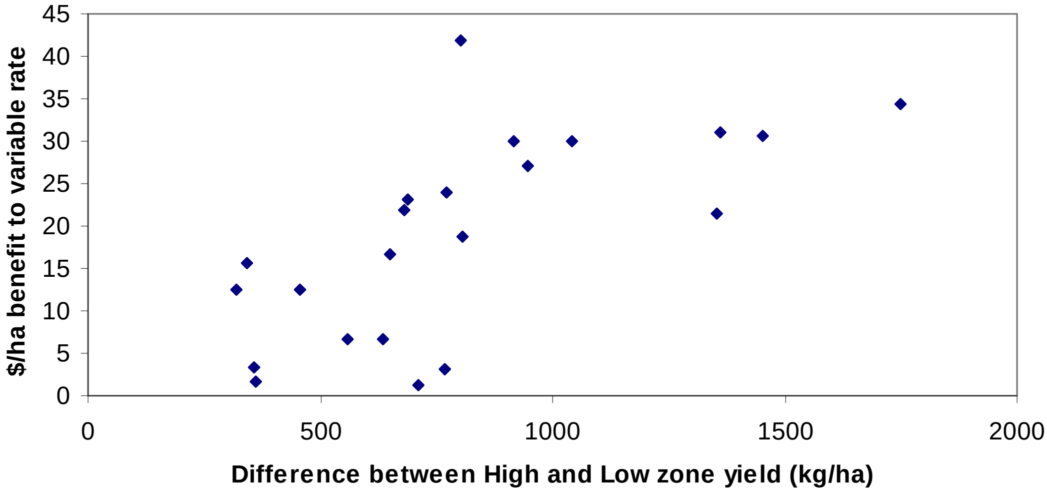

Figure 4.1.2: Relationship between paddock variation (difference between yield of high and low zone) and the $/ha benefit to variable rate for lupins.

Table 4.1.1 shows that 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 a consistent record of yield maps (e.g Dam, Berts_SE, Tank) there were some paddocks that consistently performed poorly in return on variable rate (e.g. Berts_SE) and others that performed consistently well (e.g. Dam). The data shows that some paddocks are consistently far better candidates for VRT than others.

Table 4.1.1: Increase in paddock gross margin ($/ha) due to variable rate fertiliser application in 9 paddocks on David Forrester's farm for wheat grown across a range of seasons.

Paddock	Season									
	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean
Berts_SE		1	5		7		-8		7	2
Bessy						9		17		13
Dam		51		25		18		20		28
Hut						35		16		25
Maddog						-7		-7		-7
Newts						-14		-8		-11
Sec A	29									29
Tank	21			13	36		39			27
Tower						5		16		11
Mean	25	26	5	19	22	8	16	9	7	14

Table 4.1.2: Increase in paddock gross margin ($/ha) due to variable rate fertiliser application in 9 paddocks on David Forrester's farm for lupins grown across a range of seasons.

Paddock	Season						
	1997	1998	2001	2002	2003	2004	2005	Mean
Berts_SE	3			3		1		3
Bessy					12		34	23
Dam	16		27		7		30	20
Hut					23		30	27
Maddog					13		31	22
Newts			2		7		21	10
Sec A						42		42
Tank		17		22		24		21
Tower							31	31
Mean	10	17	14	12	12	22	30	19

With lupins there were no instances where the return to variable rate was negative, due to the fact that N is not varied on lupins and hence the risks of not returning a response to variable rates are less. Responses varied from $1 to 42/ha and there were 11 instances out of 21 where the return was greater than $20/ha.

The season influence on returns can best be seen in Table 4.1.3 where returns tended to be lower in 1999, 2002 and for wheat in 2004 and 2005. An analysis of climatic conditions in those seasons may reveal some insights as to why returns were lower than in other seasons.

Table 4.1.3: Mean increase in paddock gross margin ($/ha) due to variable rate fertiliser application by crop type on David Forrester's farm.

Season

Crop	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

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

Photo 4.1: David Forrester with the report senior author at harvest 2006.

4.1.3 Summary of costs and benefits

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.

David started using variable rate 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 exceed costs by year 1999, and cashflow is positive by 2000 (Figure 4.1.3). The NPV over a 10 year timeframe comes to ca. $300,000 in 2006.

The annual benefits to variable rate ($41,600) exceed those to reductions in spray overlap ($13,000). On the basis of the evidence presented here PA technologies are making more than a large enough return to justify the investment made. David Forrester is a good example of a farmer who is benefiting to the use of variable rate technology without having invested in auto-steer and controlled traffic.

Table 4.1.4: Summary of monetary costs and benefits associated with the use of precision agriculture technologies on David Forrester's farm.

<table>
<tr><td>Operation</td><td>Costs</td><td>Benefits</td></tr>
<tr><td>Guidance and auto-boom spraying</td><td>Setup: $20,000</td><td rowspan="2">• Reduction in overlap with spraying =</td></tr>
<tr><td>Yield monitor, map and interpret</td><td>Setup: $38,000</td></tr>
</table>

	Annual $3,000	$13,000 pa • Increase in gross margin due to variable rate fertiliser = $41,600 pa
Variable rate controllers	Setup: $30,000	
Definition of zones	Setup: $2,000	
GPS licence	Annual: $3,000	

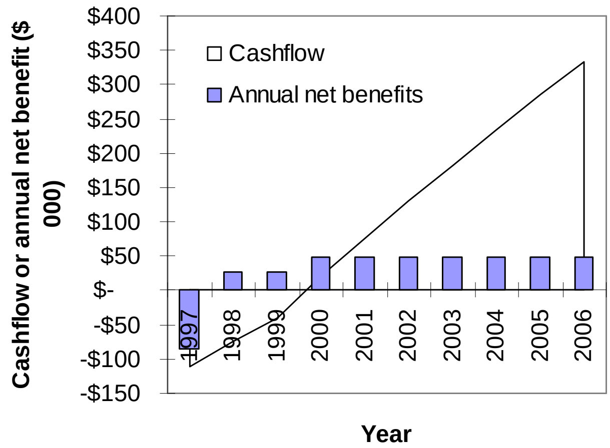

Figure 4.1.3: Cumulative net cashflow adjusted to 2006 real prices (line) and annual net benefits for costs and benefits (bars) (summarised in Table 4.1.4) associated with the adoption of precision agriculture technology on David Forrester's farm. The net present value in 2007 (assuming a discount rate of 8%) was $193,229**.**

4. 2 David Fulwood

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

The Fulwoods have been using PA technology since 1999, when they started yield mapping and variable rate fertiliser management was started in 2005. Greg originally purchased an after market auto-steer & base station system in 2003 and set up machinery with 2 metre wheel spacing for tramlining with a shielded sprayer. Shielded spraying is used to control weeds in lupins. The 2006 season was the second in which all the equipment (spraying, seeding, fertiliser spreading, harvesting) was lined up on 9 m tramlines with 3 metre wheel spacing and the cropping program was approximately 5000 ha, with the expectation that all land would be under cropping in 2007 (5,800 ha).

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 farm, and a number of fences have been removed to enlarge paddocks and make them compatible with tramline farming. Long-term average rainfall is 350 mm and average cereal yields in 2005 were 2.75 t/ha and for lupins 1.35 t/ha.

4.2.1 Costs

Shielded spraying
The shielded sprayer was a custom-built piece of machinery worth $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.

Auto-steer
The farm operates 2 tractors, one self-propelled sprayer and one header. The cost of installing auto-steer into the two tractors was $32,500 per vehicle, comprising $11,000 for screen, processor and receiver, $15,500 k for a card, $6,000 for hydraulics. Another system (costing $26,000) is moved between the sprayer and header. In addition, $5,500 and $12,000 was spent on the sprayer and header to make them auto-steer capable. All up across the 4 vehicles on the farm $26,000 each was spent equipping them for auto-steer.

GPS and controllers
The RTK base station for the two tractors cost $12,000 (used during seeding and shielded spraying). Kee Zynx controllers costing $7,500 each were installed in the two tractors. A total of $8,000 was spent to setup the airseeders with triple electric drives capable of variable rate. One of the existing Kee Zynx controllers is used to make the fertiliser and lime spreader VR capable and control the shielded sprayer.

Yield mapping and variable rate fertiliser
David's family have been collecting yield maps since 1999. These were used in conjunction with historical NDVI imagery from SilverFox to define fertiliser zones for each paddock. The cost of this service was $600 per paddock. Each paddock has high, medium and low input zones defined and this is used for starter fertiliser, topdressed N (urea granules in June-July), but not seed or lime application. Soil tests were carried out in each zone, which would have increased the cost of soil testing by 3 to 4 times but this cost has been absorbed into the fertiliser bill for the farm. Definition of fertiliser rates based on yield potential and soil test results costs $250 per paddock per year (there are 42 paddocks in any one year in the cropping program).

Labour

David estimates he spends 5 days per year getting the system setup and running, and one day per year processing yield maps. With his time valued at $500/day this amounts to a recurring annual cost of $3000.
We have tried to factor in a labour cost for the initial setup phase of getting the system operational, as this is often cited as a barrier to the adoption of PA technology. We budgeted 30 day at $500/day over years 1 and 2 to account for this.

4.2.2 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 to the crop. This gives him another tool in his fight against ryegrass herbicide resistance whilst maintaining his fields in crop. However, it is slow work with the sprayer only moving at between 9 -13km/hr compared to 25-35km/hr for traditional broad acre spraying, depending on the water rate required and the terrain.

The benefit will be seen in the long-term in the form of less weed resistance and the flexibility to use a range of alternative herbicides. David says that weed control in the row is not fully effective with the shielded system, and so will wait to see if overall better weed control results from the system. We have not attempted to place a monetary value of the shielded spraying.

Photo 4.1: Inter-row shielded spraying of lupins (left), and seeding rig on 9 m tramlines and 3 m wheel spacings (right) on David Fulwood's farm. Photo courtesy of David Fulwood.

Tramlining
With spraying, seeding and spreading occurring on the tramline system results in reduction of overlap of 10% for spraying and 7% for fertiliser. 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 5000 ha x 8% x $234/ha = $93,600.

Having harvesting operations occurring on the tramlined system means that the header capacity is more fully-utilised with the front nearly always full. David estimates this saves 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 topdressing only occurs on the cereal portion of the cropping program. David used variable rates of fertiliser on paddock zones in 2005 and the 2006 harvest will be his second season. An estimate was made of the benefits of variable rates of N, P and K on seven cereal paddocks on his home farm, where yields maps were also collected at 2005 harvest. 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 was calculated using the approach

described for case 1 in section 3.3. Typical rates of N, P and K applied to one paddock are shown in Figure 4.2.1.

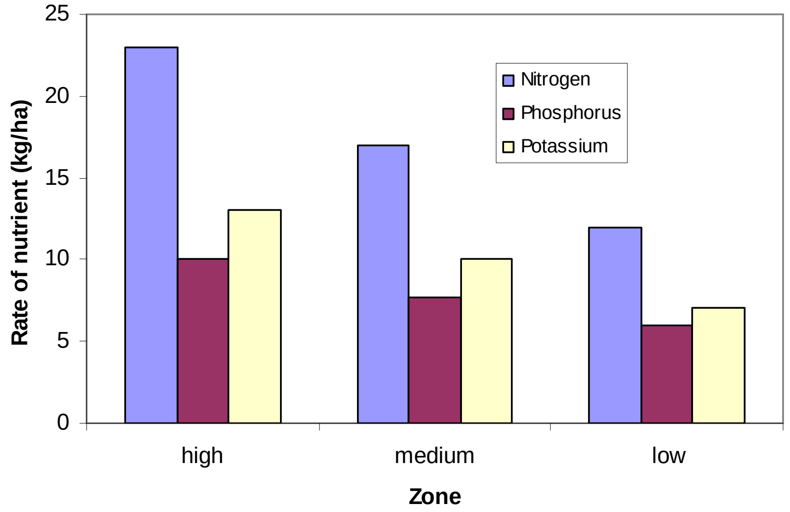

Figure 4.2.1: Rates of nutrient applied in each zone in an example paddock from David Fulwood's farm.

Across the seven paddocks the difference between the yield from the high and low zone ranged from 430 to 1140 kg/ha. The benefit to variable rate varied from $23/ha to $4/ha, with an average of $13/ha (8%). Figure 4.2.2 shows that there was positive correlation between yield differences between high and low zones and the economic benefits of variable rate over uniform management. Scatter in the relationship is mainly due to variation in the proportion of each paddock in the high, medium and low zones. As some paddocks only have small areas of low and high yielding zones, these are unlikely to be good $ candidates for VRT.

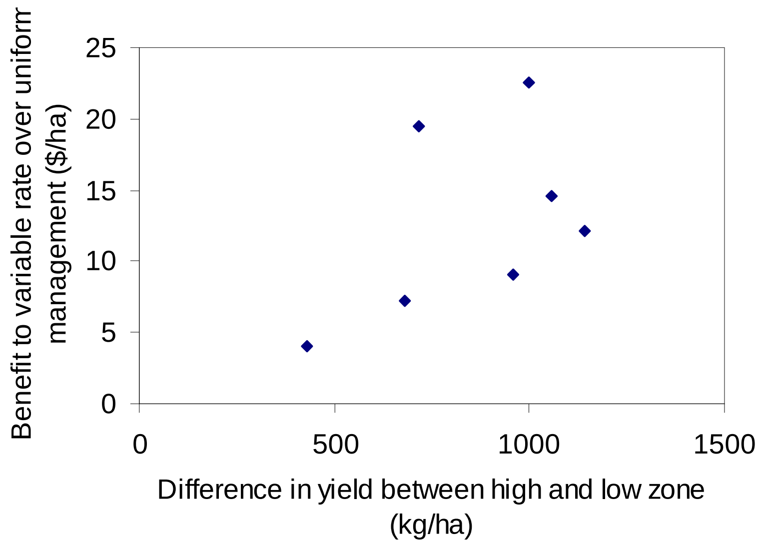

Figure 4.2.2: Relationship between the economic benefits of variable rate fertiliser over uniform application ($/ha) and the yield difference (kg/ha) between high and low productivity zones for 7 paddocks at David Fulwood's farm in 2005.

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

- While David has been yield monitoring for 8 years. The main use yield maps have been put to is to verify the fertiliser management zones defined in 2005 by NDVI analysis. Yield maps also provide a means for yield records.
- 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 4-5 years to perhaps once every 6-7 years. If the cost of deep ripping is assumed as $100/ha then this means the benefit is $8/ha spread over the whole cropping program ($8/ha x 5,800 ha = $46,400). As this benefit has not been realised yet, it is not included in our calculations.

4.2.3 Summary of costs and benefits

Average increase in gross margin over the whole cropping program attributable to PA technology is estimated at $20/ha, split as $7/ha for variable rate fertiliser and $13/ha for reduced overlap in chemicals, fertiliser, seeding and harvesting. When the costs and benefits were listed and a discounted cash flow analysis applied from 2005 when VRT started, the net benefits were negative in year 1 with the large setup costs, but quickly became positive by year 2 (2006) (Figure 4.2.2). If the time horizon is projected out to 2014 (ten years after the initial investment) the NPV for the whole farm due to PA would be ca. $670,000. The major annual benefits come from reduced overlap and labour costs with the tramlining and guidance. Benefits of variable rate application of fertiliser were valued at ca. $25,000 per year. More efficient harvesting at $10,000 is the smallest benefit. Of the benefits listed here there is some uncertainty over those attributed to variable rate fertiliser. The evidence for benefits from variable rate come from only one season and although we have assumed that benefits of $13/ha will occur one year in two, more data in the form of yield maps and applied fertiliser will have to be collected to verify this. Further benefits from the shielded spraying and less deep ripping would be expected to increase returns above these reported here.

Table 4.2.1: Summary of monetary costs and benefits associated with the use of precision agriculture technologies on David Fulwood’s farm.

Operation	**Costs**	**Benefits**
Auto-steer in two tractors	Setup: $65,000	• Reduced overlap and labour with tramlining = $93,600 • More efficient harvesting = $10,150 pa • Variable rate fertiliser ($13/ha) over 4060 ha = $26,390 pa
Auto-steer in sprayer/header (includes spray controller & seven section auto-boom shutoff)	Setup: $43,000	
GPS base station	Setup: $12,000	
Variable rate controllers for seeder, spreader, shielded sprayer (2 Kee Zynx controllers, electric drives on airseeders, spreader proportional belt speed controller)	Setup: $30,000	
Zone definition	Setup: $23,100	
Soil testing and recommendations for each zone	Annual: $10,500	
Labour in equipment setup and data management	Setup: $15,000 Annual: $3,000	

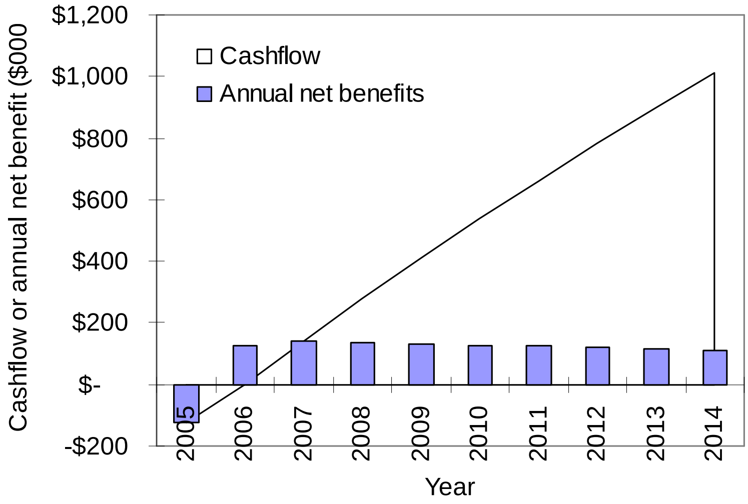

Figure 4.2.2: Cumulative net cashflow adjusted to 2006 real prices (line) and annual net benefits for costs and benefits (bars) (summarised in Table 4.2.1) associated with the adoption of precision agriculture technology on David Fulwood's farm. The projected net present value in 2014 (assuming a discount rate of 8%) was $673,021.

4.3 Stuart McAlpine

Stuart crops on average 3400 ha of wheat, barley, canola and lupins at his property he farms in partnership with his wife Leanne near Buntine in the northern wheatbelt of Western Australia. Long-term annual rainfall is 330 mm and soil types range from deep yellow sands, to duplex soils to gravels.

Stuart began yield mapping in 1996 and has been using yield maps as a record-keeping mechanism. He also 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.

4.3.1 Costs

Guidance and tramlining

Stuart decided to move into guidance and tramlines six years ago, after a period using marker arms to direct application of crop inputs. The setup cost $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 a cost of $5,000 to install a yield monitor at the time. More recently, the yield monitor has come 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 ($1000). There has been no use of a PA consultant.

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 so prefers to use a “low tech” approach. This approach consists of a uniform rate of basal fertiliser and varying rates of N via flexi-N through the boom spray, 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 own knowledge of paddock variability and other spatial information such as NDVI analysis.

Labour
We have costed management time (20 hours per year @ $50/hour) and initial setup costs in the early days of getting into PA ($5000).

4.3.2 Benefits

Guidance and tramlining

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

On top of the reduced overlap of inputs, a major economic benefit of guidance has been the ability to sow crops in a timely manner in dry seasons. Before the advent of guidance, in dry seasons dust at night hinders seeding operations and effectively delays operations by 2-3 weeks in 1 year in 3 on about one-third of the cropping program. With a yield penalty for delayed sowing of 20-50 kg/ha/d 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 we estimate a 3% improvement in gross margin due to more timely sowing of crops in dry years: 14 days delay x 20 kg/ha/day x $0.15/kg wheat price x 0.33 frequency of dry years x 0.33 proportion of cropping program affected = $4.6/ha, which is 3 % of the baseline gross margin.

Stuart knows that there have been fuel savings with the use of tramlines due to better traction and reduce traffic on the paddock. He cannot put figures on it, so instead we have used DAFWA estimates of 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.

Adding up these costs gives a total benefit due to guidance and controlled traffic of 10% increase on the baseline gross margin.

Yield mapping

Stuart believes the main benefit he has obtained from yield maps has been the ability to monitor paddock performance, locate constraints (e.g. 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 that has been used here to inform management. It is difficult for us to quantify the benefits of this in financial terms, so no account has been made of it for 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 is no records of pre and post rates of fertiliser nor the area of the farm to which this form of management was applied. Hence, here we provide an estimate of the *potential* benefits of variable rate management of N on wheat using the framework described by Robertson et al. (2006).

Our assumptions are:

- About half of the 3,400 ha cropping program is variable enough within paddocks 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 2.0 t/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 for variable rate of *N only* on wheat. The benefits will be greater where other nutrients are included, as is the case for the Fulwood and Forrester case studies (see above).
- That the maximum gains from variable rate compared to uniform management are captured in 2 years out of 3. Gains do not accrue in every year because of seasonal variation, but gains 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 (3,400 ha x 0.5 x $4/ha x 0.66 frequency) gives a total benefit of $4500, or $1.3/ha over the entire cropping program or 1% over the baseline gross margin. It is our assessment 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.

4.3.3 Summary of costs and benefits

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 $20/ha total increase in gross margin. Potential benefits of variable rate N are 1% (or about $1.3/ha) increase in gross margin. The largest benefits come from reduced overlap ($12/ha), less fuel use ($4/ha), and more timely sowing ($4/ha). Other benefits include reduced operational efficiency and deeper knowledge of crop performance over seasons and paddocks.

When the costs and benefits were listed and a discounted cash flow analysis applied, the net benefits were negative in year 1 with the large setup costs, but quickly became positive by year 2 (1999) (Figure 4.3.1). If the time horizon is projected out to 2007 (ten years after the initial investment) the NPV for the whole farm due to PA would be $345,507. The major annual benefit comes from reduced overlap and labour costs with the tramlining and guidance. The evidence for the benefits for variable rate application of N are assumed at this stage and more comparisons would have to be made to confirm these figures.

Table 4.3.1: Summary of monetary costs and benefits associated with the use of precision agriculture technologies on Stuart McAlpine's farm.

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

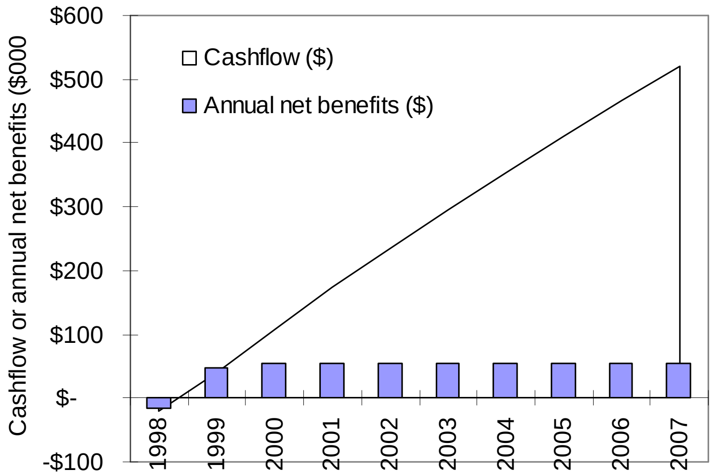

Figure 4.3.1: Cumulative net cashflow adjusted to 2006 real prices (line) and annual net benefits for costs and benefits (bars) (summarised in Table 4.3.1) associated with the adoption of precision agriculture technology on Stuart McAlpine's farm. The net present value in 2007 (assuming a discount rate of 8%) was $358,958.

4.4 Mike Smith

Mike and Bev Smith farm near Gurley in northern NSW and their pioneering efforts in using precision agriculture have been well documented in a number of events and articles[1]. Their property is 1600ha (1250ha cropping) of black Vertisol soils which supports 100% cropping efficiency of wheat, canola, chickpea, barley, sorghum and sunflower. The black soils, which vary in depth to an underlying layer of decomposing sandstone, are variable in the plant available water capacity (PAWC) available for crop production – 60cm depth equates to 70mm PAWC, 100cm to 120mm and 180cm to 240mm. Annual rainfall is 620mm.

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

A key component to the successful early adoption pf 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.

4.4.1. Costs

Guidance and tramlining

Mike started using controlled traffic in 1996 and feels it provides greater timeliness and efficiencies. The farm uses a John Deere Greenstar AutoTrac auto-steer system for controlled traffic farming on 9m machinery widths. The auto-steer system is moved between his tractor and header and cost around $30,000 to setup. A major impact has been reduced overlap and operational efficiencies as he doesn’t have to employ a full time employee which not only saves over $40,000pa but also results in less driver fatigue. Mike estimates a 7% saving in the application of seed, fertilizer and chemicals due to overlap efficiencies ($8/ha), which equates to approximately $10,000pa.

Yield mapping and VRT

Mike himself established the major source of soil variability as soil depth and thus plant available water content and set up his equipment to utilise variable rate technology. In 1998, he purchased a variable rate driver for the airseeder, a Raven 700, two channel controller, and up-graded the yield monitor to an AgLeader PF3000 capable of variable rate control. They now have a John Deere Greenstar yield monitor/controller which is used in the JD 9660STS header and JD 8220 tractor. Greenstar is CANBUS rated, making it compatible with other CANBUS rated equipment; it also has a serial port on the GPS allowing connection to the AgLeader monitor.

Mike estimates his costs of VRT setup on his boom spray and Gyral air-seeder at around $15,000 which includes the spray controller ($4,000) which would have been needed even without VRT. The equivalent off-the-shelf cost could be around $60,000. VRT is used for the application of seed, fertilizer and insecticide (once in chickpea) across 3-4 zones per paddock. Zones have been established to fit generally 80, 100 and 125% of average yield.

Labour

Mike spent considerable time in the early days mapping soil depth over the entire farm using a soil probe, and $10,000 has been costed to account for the time this, and equipment setup, involved. An

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[1] www.grdc.com.au/growers/gc/gc47/pa.htm; www.usyd.edu.au/su/agric/acpa/symposiums/Proceedings_05.pdf

annual labour cost of $2000 (40 hours) has also been allowed for to account for equipment setup, data processing, etc.

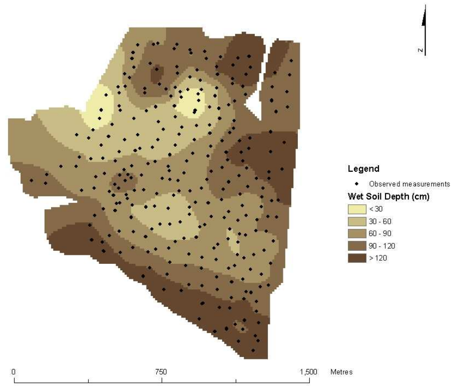

Photo 4.4.1: Mike Smith measuring soil depth using a push probe (left) and a map of one paddock showing sampling points for soil depth and a kriged soil depth map (right). Photo courtesy of Mike Smith.

4.4.2 Benefits

Guidance and tramlining
Mike estimates a 7% saving in the application of seed, fertilizer and chemicals due to overlap efficiencies, which given his annual variable costs on these items, equates to approximately $10,000pa.

Yield mapping and VRT

Mike keeps detailed records for each crop on each paddock and, through mapping of soil depths and yields, has defined three zones in most paddocks. He has determined fertilizer rates for each zone relative to the recommended uniform rate and for the paddocks used in this analysis these rates averaged at 118%, 97% and 71% of the uniform rate. Tables 4.1 and 4.2 show the estimated benefits to variable rate fertiliser application in four paddocks and five crop species across seasons 1999-2005 using actual costs, prices and yields for each zone. As previously stated, benchmark yields under uniform management were assumed for the high zone (average of yields in the medium and high zone), medium zone (same) and low zone (same).

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 (Table 4.4.1, 4.4.2). The difference in gross margin of VRT 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, given their high N fertiliser requirements, showed the highest returns from VRT. Mean benefits did not vary greatly between paddocks which suggests that variations in soil depth and PAWC were indeed the driving influences in spatial variation and management in their respect has been worthwhile. Likewise, annual variation in average benefit across paddocks and crops was not great, excepting the severe drought year of 2002.

Table 4.4.1: Increase in paddock gross margin ($/ha) due to variable rate fertiliser application in four paddocks on Mike Smith's farm across seasons 1999-2005.

Paddock	Season

	1999	2000	2001	2002	2003	2004	2005	Mean
BCN	8	50	18		4	57	19	26
BCSth	12	45	20	28	13	18	8	20
BT	25	9	57	3	41	10	46	27
Com B	13	28	39	-7	33	0	8	16
Mean	15	33	33	8	23	21	20	22

Table 4.4.2: Average increase in paddock gross margin ($/ha) due to variable rate fertiliser application for different crops grown on Mike Smith's farm between 1999-2005.

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

The relationship between gross margin benefit and the range in yield difference between the high and low yielding zones on each of 27 crop paddock-years is presented in Figure 4.4.1. Between zone differences in yield ranged from 38kg/ha in a chickpea paddock (with an average yield of 0.48t/ha) up to 3142 (paddock yield of 4.55t/ha). There is a reasonably strong relationship between the degree of between zone variability and resultant return to variable rate.

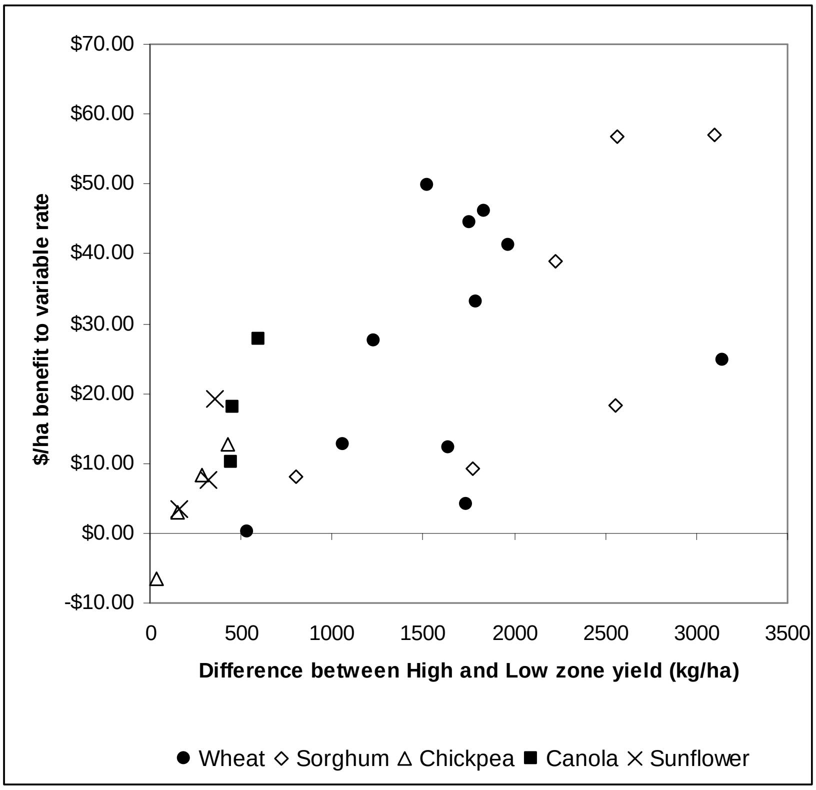

Figure 4.4.1: Relationship between gross margin benefit and the range in yield difference between the high and low yielding zones on each of 27 crop paddock-years

4.4.3 Potential Benefits

In an analysis undertaken as part of a RIRDC-funded project, Brennan et al (2005), using APSIM modelling, estimated the likely long-term return from VRT on Mike Smith's farm. Summary results are presented in Figure 4.4.2. Note that these returns are specific to the particular spatial layout of the property – i.e. it assumes 3 zones (shallow, medium, deep) of equal area. If the deep zone dominates the benefits increase.

If no account is taken for seasonal variation, but adjustments by zone is made using the long term optimum rate to each zone, the benefit is estimated at $10/ha over the long term. If seasonal variation can be narrowed down to one of three types (good, medium, bad) and fertiliser rate is adjusted accordingly in each zone to the long run optimum for season type, the average benefit increases to $50/ha. Getting these returns are contingent on being able to pick the season type at the time of N fertilising. It should also be noted that almost 90% of this benefit could be realised just by picking the season type and doing nothing about VRT.

This report concluded that better dealing with temporal variability may provide higher payoffs to investment in technology and management compared to variable rate technology. However, the estimated average gross margin of $10/ha from this simulation study for nitrogen fertiliser only is significantly lower than the $22/ha estimated from actual paddock data from Mike Smith's farm, which includes the benefit of variable rate application of other fertilisers as well as nitrogen.

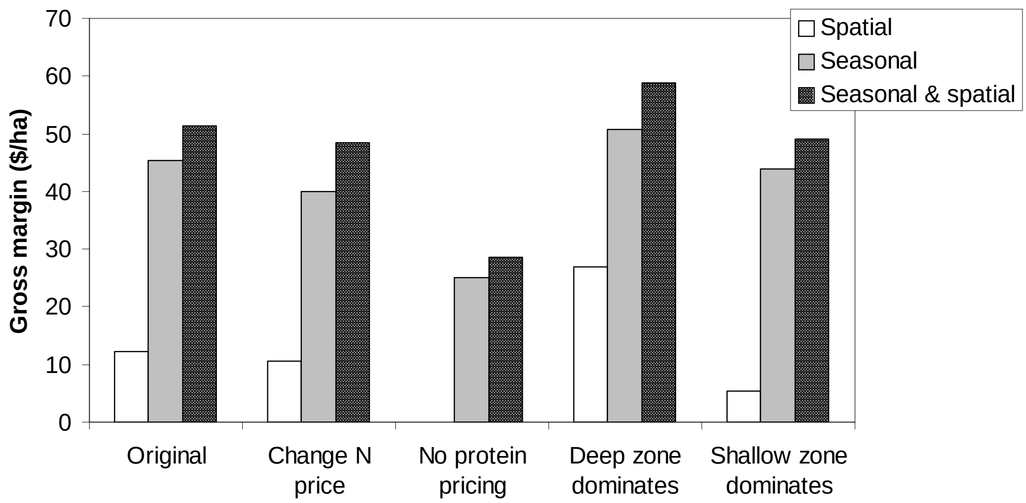

Figure 4.4.2: Estimated average gross margin benefits from VRT (□) relative to hypothetical technologies to manage temporal variability under a range of assumptions.

4.4.4 Summary of costs and benefits

Mike is in the enviable situation where the spatial variability of his property is reasonably well defined, understood and mapped. He also now has considerable experience in using precision agriculture technology and makes use of VRT, especially in the variable application of fertiliser between management zones. Using the assumption that an average gross margin return of $22/ha (Table 4.1) can be gained from the application of VRT across the 1250ha of annual cropped area, then the increase in gross margin equates to $28,000. Reduction in overlap with spraying contributes $8/ha of benefits.

When the costs and benefits were listed and a discounted cash flow analysis applied, the net benefits were negative in year 1 with the large setup costs, but quickly became positive by year 2 (1999) (Figure 4.4.3). If the time horizon is projected out to 2007 (ten years after the initial investment) the NPV for the whole farm due to PA would be $186,461.

Table 4.4.3: Summary of monetary costs and benefits associated with the use of precision agriculture technologies on Mike Smith's farm.

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

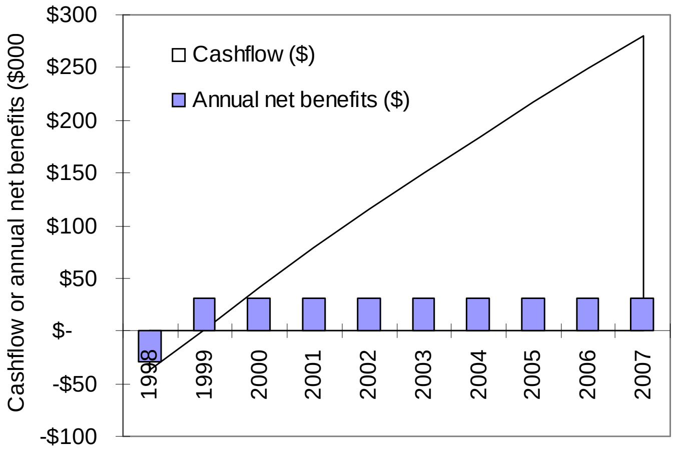

Figure 4.4.3: Cumulative net cashflow adjusted to 2006 real prices (line) and annual net benefits for costs and benefits (bars) (summarised in Table 4.4.3) associated with the adoption of precision agriculture technology on Mike Smith's farm. The net present value in 2007 (assuming a discount rate of 8%) was $186,461.

4.5 Richard Heath

Richard and Tammy Heath run the cropping enterprises for a family farm operation, 'Pine Cliff', near Gunnedah on the Liverpool Plains in NSW. Annual rainfall is 630mm, split between summer and winter growing seasons. The farm opportunity crops 3430ha of durum and bread wheat, barley, fababean, canola, sorghum, maize and sunflowers. Crop potential is high due to a relatively cool spring seasons and the predominantly heavy black vertosol soils which store significant amounts of soil water (250-300mm PAWC). Water logging is a reasonably regular event and is a main source of spatial variation within paddocks.

Richard has been exploring in-season nitrogen application in on-farm trials since 2001 and, in 2003, he undertook a Nuffield Scholarship on the topic "*The potential for increased nitrogen use efficiency with improved agronomy and developing technology*" which enabled him to explore international experiences with PA technologies (www.nuffield.com.au/report_f/2002/heath.pdf). Prior to 2003, Richard applied N fertilizer as anhydrous ammonia or urea incorporated either prior to or at the time of sowing. Since 2003 he has applying in-season applications of liquid fertilizer as a top dressing to his cereal crops.

Richard summarises his experience to date in that the biggest benefits to adoption of PA technologies is as validation tools to check and revise input applications. His use of crop growth measurement in high nitrogen test strips has proved more effective in determining optimum fertiliser requirements than pre-season soil tests on the Liverpool Plains.

4.5.1. Costs

Guidance and tramlining

A zero-tillage, controlled traffic farming system has been implemented since 1998, originally using a Satlock visual guidance system ($30,000 purchase price). In 2005, auto-steer 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 set of wheel tracks spaced at 12m widths. Three Farmscan systems are swapped between a spray rig, harvester and two tractors.

Yield mapping and VRT

Yield mapping started in 2002 and yield maps, along with local knowledge and elevation (areas on the sides of hills have lower PAWC), 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 fertilizer and to help situate test strips for fertilizer trials.

In late 2005, Richard purchased a Greenseeker RT200 ($20,000), the sensors of which are fitted to the booms of his spray rig – see photos. This system uses six optical sensors to measure reflectance from the crop canopy which is converted to a normalised difference vegetative index (NDVI). Oklahoma State University, the developer of the Greenseeker system, provides correlation algorithms between NDVI taken at growth stage Z30 and recommended N fertilisation rates. Recommended practice is to compare measurements from an unfertilised crop with in-crop strips where luxury rates of fertilizer were applied pre-sowing. The differential between NDVI readings from these fertilised strips and the rest of the paddock provide the indication for rates of top-dressed fertilizer. Through his experience with his own crops, Richard has modified some of these algorithms for his farm.

The Greenseeker software system provides paddock maps of NVDI and consequent recommended rates of fertilizer which are spatially mapped. These maps are provided as input to the boom spray controller for variable rate application of in-season liquid N fertilizer.

Labour

Setup 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.

Photo 4.5.1: Photos of a Greenseeker RT200 sensor fitted to the spray rig boom (Photos courtesy of Richard Heath).

4.5.2 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 setup for row cropping over many years and such efficiencies had been largely gained. This suggests that those growers who have tramlines in place already will not gain a lot in savings from auto-steer. However, only in 2005 was auto-steer added to the header to match comb and planter widths and Richard has estimated that having the header adhere to the farm's controlled traffic system has saved in the order of $15,000 per annum in reduced compaction across the 2500ha of annual cropping.

Yield mapping

Since 2003, Richard has used test strips within paddocks to compare treatment combinations consisting of pre-sown applications, in-season top-dressing and zero applications of N fertilizer in wheat, maize and sorghum crops. Treatments included the recommended fertilizer rates based on fallow deep soil tests analysed using the Nutrient Advantage system offered by INCITEC. The contribution of PA technologies to these trials was in the yield maps providing a ready means of measuring strip yields.

In 2005, sufficient evident was accumulated to change fertilizer practice from putting on nitrogen as an all upfront application to winter cereal crops to a practice of applying only starter fertilizer at the time of sowing and then top-dressing crops with liquid fertilizer. Rates of top-dressing were determined from observations made at Z30 in comparison to in-paddock nitrogen-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 (see www.grdc.com.au/growers/res_upd/north/n06/heath.htm). Across eight blocks, consisting of 816ha of durum wheat, this saving equated to a benefit of $16,863 in that season (Table 4.5.1). This benefit consisted of both cost savings from the application of less N fertilizer and 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.

Table 4.5.1: Data for eight blocks for the 2005 durum wheat season for both actual applied top-dressed fertilizer and for test strips of pre-sowing applications of recommended N rates based on deep soil tests (data taken from www.grdc.com.au/growers/res_upd/north/n06/heath.htm).

Block	Area	Soil test recommendation				Actual applied				Benefit	
		Strip yield	N rate	N cost	Margin return to N	Block yield	N rate	N cost	Margin return to N	Actual – soil test strip	
	ha	t/ha	kg N/ha	$/ha	$/ha	t/ha	kg N/ha	$/ha	$/ha	$/ha	$/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

Variable rate fertilizer application

The Greenseeker monitoring system has been applied to develop variable rate application of in-season N fertilizer for three crops to date – 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: in-season variable rate application used less fertilizer 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 64 kg/ha urea for the top-dressed variable application. This fertilizer 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 are yet to be analysed, Richard suggests that less N fertilizer was applied using the Greenseeker for little difference in yields.

4.5.3 Summary of costs and benefits

Since the 2003 winter season, test strips comparing zero and high N fertilizer rates have consistently proved more effective in determining fertiliser requirements than pre-season soil tests on ‘Pine Cliff’. A Greenseeker system, measuring NDVI and calibrated to produce maps for variable rate application of in-season N fertilizer, has reduced fertilizer usage with no yield penalty compared to rates recommended from pre-season soil tests. With an assumption that a $20/ha saving in N fertilizer rates (Table 4.5.1) can be gained from in-season crop monitoring informing topdressing rates across the 2000 ha 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 can enable optimal fertilizer rates to be better determined for each crop and season. He is yet to be certain that VRT provides benefit beyond this point. However, it is still early days in testing and calibrating the Greenseeker system linked to VRT.

When the costs and benefits were listed and a discounted cash flow analysis applied, the net benefits were negative in years 1 and 2 with the large setup costs, but became positive by year 3 (2000) (Figure 4.5.1). The drop in cashflow in 2005 was due to the purchase of the Greenseeker and 2 cm auto-steer. If the time horizon is projected out to 2007 (ten years after the initial investment) the NPV for the whole farm due to PA would be ca. $40,000.

Table 4.5.2: Summary of monetary costs and benefits associated with the use of precision agriculture technologies on Richard Heath's farm.

Operation	Costs	Benefits
Guidance	Setup: $30,000	• Reduction in compaction from header = $15,000 pa • Increase in gross margin due to in-season monitoring = $40,000 pa
Auto-steer	Setup: $45,000	
Greenseeker RT200	Setup: $20,000	
Labour	Setup: $5,000 Annual: $2,000	

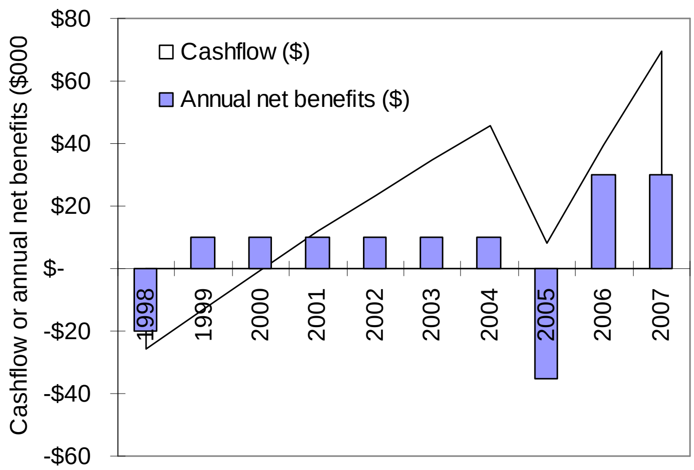

Figure 4.5.1: Cumulative net cashflow adjusted to 2006 real prices (line) and annual net benefits for costs and benefits (bars) (summarised in Table 4.5.2) associated with the adoption of precision agriculture technology on Richard Heath's farm. The net present value in 2007 (assuming a discount rate of 8%) was $39,744.

4.6 Rupert McLaren

David, Angus and Rupert McLaren with spouses Rosemary, Claire and Karen operate a 8000 ha farming and grazing enterprise near Barmedman in Central NSW. They currently run 6000 wethers and crop 2000 ha of cereals and 2000 ha of canola. Soil types range from red earths to grey cracking clay to ironbark soils. Their average growing season rainfall is 470 mm and average wheat yields are about 3.5 t/ha and canola yields are 1.8 t/ha. The last 5 years have been much drier than the long-term average (<400 mm).

They began yield mapping in 1996 when they trialled an AgLeader Monitor for Case for 2 years, and since then have been yield mapping their entire cropping program. Yield maps are used to delineate fertiliser management zones, which generally line up along soil type differences. In general the previous three yield maps are used to define the zones for the up coming season. Mono-ammonium phosphate (MAP) at sowing is the usual fertiliser varied on both wheat and canola. Paddocks (ranging from 50-100 ha) have either 2 or 3 fertiliser management zones, although in some years no zones have been applied due to dry conditions at the start of the season. More background on the methods Rupert uses for yield map manipulation and definition of fertiliser, lime and gypsum zones are given at http://www.regional.org.au/au/gia/08/235mclaren.htm.

They started into VRT in 2001 by moving fertiliser rates around modestly. This year was used to sort out zones and get equipment working properly. Inconsistent correlations between fertiliser applied and yield over the last few years led Rupert in 2003 to embark on an extensive rate trial with roughly fifty sites. The sites consist of several hectares. The treatments are in hectare squares and are usually 10 and 20 units of P with 0 units in about 10 sites to check for response. He has been trying to repeat this with N but the recent run of dry years has not made this possible. The yield monitor is used to measure yields of the trial plots.

Soil testing was used quite a lot initially to benchmark soil P levels. However, as soil P levels were found to be high across the farm (Colwell values around 50 ppm), yield potential is now used as a guide for P rates. Before VRT, the same rate of P was applied to the paddock irrespective of yield potential, whereas now less is applied to low and medium yield potential zones and a maintenance rate is applied to the high yielding zones.

From 2004 if seasonal conditions permit, in-season urea was sometimes varied on wheat and canola in addition to MAP at sowing. This was done by using an in-season Landsat or SPOT NDVI image to guide zone definition for nitrogen need. On-ground verification of crop stage and condition is used to confirm the rates to be applied. Results have been inconsistent due to dry seasons and this aspect has not been included in our analysis here. Rupert sees some value in technology like the GreenSeeker to manage in-season nitrogen.

Most of the farm was mapped with EM38 in 2005 at a cost of $2000. This has been used to guide lime and gypsum rates. The contract lime and gypsum spreader has a Rinex in the spreader which they have 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 our analysis.

A lightbar and auto-boom is used to reduce overlaps, however auto-steer and tramlining has not been adopted. Rupert believes that the main advantage of tramlining is to reduce compaction and does not think it is a serious issue for his soil types.

4.6.1 Costs

They bought a Trimble AgGPS ($12,000) in 1998 for the header and a Trimble Lightbar ($4000), which was used in the spray unit. A second AG132 ($8,000) came with the Concord variable rate seeder bought in 2000. The seeder was sold to the McLarens a special price because of the trialling work that had been done with their Concord VRT unit in the previous year. The changeover price was

$16,000 for going from a 2 year old ground drive Concord 3400 to an electric over hydraulic drive Concord 3400 with Universal Display Plus.

Currently the farm has 3 mobile sub meter GPS units (the third one was purchased in 2000 for $4,000) with lightbars and a sub meter base station (conversion cost $3,500) that they allow local farmers to use for free rather than paying for a GPS licence. They plan to upgrade the system to a higher resolution. Before 2005 they paid $2,500 annual licence fee to Omnistar

In 2004 they upgraded the Bogballe Spreader to VRT by purchasing an iPAC ($600) Farm Site Mate to run on the iPac ($1200) and a null modem cable ($4) and connecting it to the Bogballe control unit.

Last year they used the iPaq to directly control the contract lime spreading with a Dicky John controller.

The McLarens purchased in 2006 a Rinex auto-boom shut off unit (cost $12,000).

In addition to Farm Site Mate they have bought a couple of desktop software packages along the way. Initially Surfer ($1200) was used to help with the mapping and the statistics package Jump was also purchased ($1000). 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.

Rupert spent 30 days of is time in the early years getting the system set up (valued at $15,000) and estimates that he spends 100 hours each year on zone definition and setting up fertiliser trials (valued at $5,000 pa). This task will become smaller in the future, as paddocks are being merged into larger blocks of 400-500 ha.

4.6.2 Benefits

Guidance and auto-boom for spraying

About 40% of the farm has hilly and irregularly-sized paddocks where he 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. This gives a benefit over the cropping program of $6.5/ha or $26,000 pa. As the auto-boom was purchased in 2006 we allocate this benefit to the 2006 season only.

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 ($2.5/ha or $10,000).

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. Rupert says “farmers don’t necessarily know their paddocks and yield mapping gives an objective picture of patterns”.

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

Variable rate fertiliser

Variable rate application of starter fertiliser occurs on cereals and canola. In the early years of variable rate Rupert was tentatively varying fertiliser rates. However, since 2003 he has varied rates more strongly and the economic analysis of the benefits of variable rate is therefore based on the seasons 2003-2006 inclusive, for a selection of paddocks on the farm that include both wheat and canola. An estimate was made of the benefits of variable rates of MAP on 8 cropping paddocks, where yields maps were collected during 2003-2006. 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. Yield under uniform management was calculated using the approach described for case 2 in section 3.3. In this case all zones are assumed to be nutrient non-limited under uniform management and hence 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”

Across the 29 paddock x season combinations, the difference between the yield from the high and low zone ranged from 19 kg/ha in the most uniform situation to 776 kg/ha in the most variable situation with the mean being just under 250 kg/ha (Figure 4.6.1). The benefit to variable rate varied from -$1/ha to +$22/ha, with an average of $7/ha.

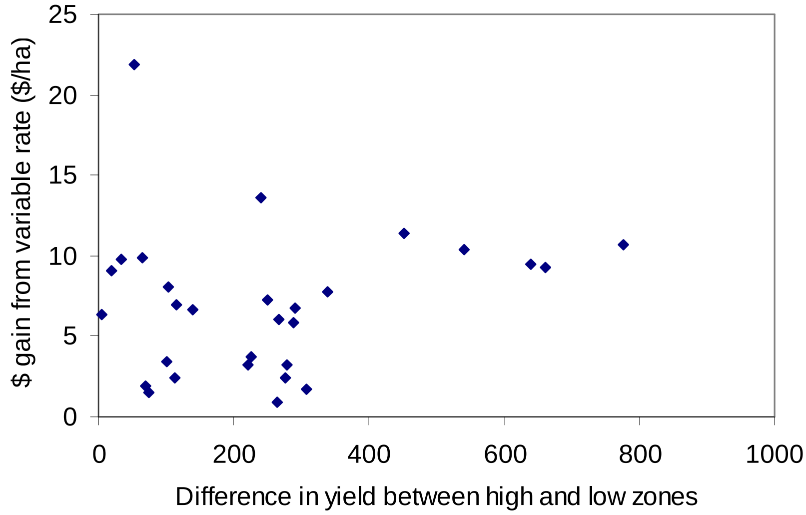

Figure 4.6.1: Relationship between paddock variation (difference between yield of high and low zone) and the $/ha benefit to variable rate for wheat and canola.

Breaking the figures down to consider wheat and canola separately, for wheat (n = 16) the difference between the yield from the high and low zone ranged from 34 kg/ha in the most uniform situation to 776 kg/ha in the most variable situation with the mean being just under 300 kg/ha. The benefit to variable rate was, on average, $8/ha. For canola (n = 13) the difference between the yield from the high and low zone ranged from 19 kg/ha in the most uniform situation to 661 kg/ha in the most variable situation with the mean being just under 200 kg/ha. The benefit to variable rate was, on average, $6/ha.

Table 4.6.1 shows that there were no instances where the return was negative and 1 out of 29 where the return was greater than or equal to $20/ha. There were some paddocks that consistently performed lower in return on variable rate (e.g. G) and others that performed consistently well (e.g. WA).

Table 4.6.1: Increase in paddock gross margin ($/ha) due to variable rate fertiliser application in 8 paddocks on Rupert McLaren’s farm for wheat and canola grown across a range of seasons.

	Season				
Paddock	2003	2004	2005	2006	Mean
G	2	4	3		3
HA		14	22	2	12
HI	6	7	9	2	6

J	1	2	3		2
MA	10	8	9	2	7
MB	7	6	10	3	6
U	8	7	10	6	8
WA	7	11	9	11	10
Mean	6	7	9	5	7

The season influence on returns can also be seen in Table 4.6.1 where returns tended to be lower in 2006, although even in this season in one paddock a benefit to variable rate of $11/ha was achieved.

The example paddocks chosen give 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 ha then annual benefits are calculated at $28,000.

4.6.3 Summary of costs and benefits

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 when yield mapping started, the annual net benefits were negative or close to zero in the first 3 years with the large setup costs and VRT not starting until 2001, but became positive by 2001 (Figure 4.6.2). In 2007, ten years after the initial investment, the NPV for the whole farm due to PA is estimated at ca. $108,000.

Table 4.6.2: Summary of monetary costs and benefits associated with the use of precision agriculture technologies on Rupert McLaren's farm.

Operation	Costs	Benefits
Lightbar (1998)	$4,000	• Reduced spray overlap before 2006 ($2.5/ha) $10,000, after 2006 incl. ($6.5/ha) $26,000 • Variable rate P ($7/ha) $28,000
Auto-boom spraying (2006)	$12,000	
Yield monitor, variable rate controllers and GPS	$40,000	
GPS licence (pre-2005)	$2,500	
Software	Setup: $2,200	
Labour	Setup: $15,000 (2000) Annual: $5,000	

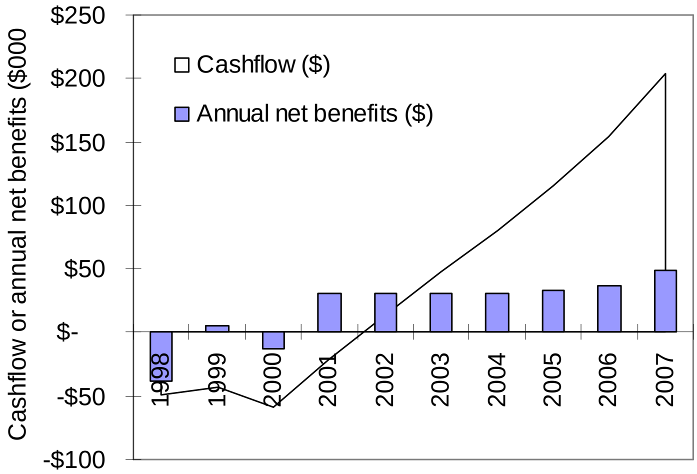

Figure 4.6.2: Cumulative net cashflow adjusted to 2006 real prices (line) and annual net benefits for costs and benefits (bars) (summarised in Table 4.6.2) associated with the adoption of precision agriculture technology on Rupert McLaren's farm. The net present value in 2007 (assuming a discount rate of 8%) was $108,241.

5 Synthesis

Coverage of the case studies

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 (1,250 to 5,800 ha cropping program), soil types (shallow gravels to deep cracking clays), and production levels (average wheat yields from 1.8 to 3.5 t/ha). The farmers had been involved in PA from 2 to 10 years and covered the range of PA technologies that are commonly used by Australian grain farmers (Table 3.1). 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 auto-steer and tramlining. One was using NDVI and another the GreenSeeker technology. As such, the data set covered the range of likely situations confronting practitioners of PA in the Australian wheatbelt.

Level of investment in PA and aggregate benefits

The size of the cropping program and level of capital investment in PA varied markedly (Table 5.1). Capital investment ranged from $55,000 to $189,000, which is at the medium to high end of investment listed in Table 2.2. Cleary, some variation in the level of investment can be attributed to the size of the cropping program, however, even when expressed as investment per hectare cropped it still varied by a factor of three from $14 to $44/ha. The estimated annual benefits from PA ranged from $14 to $30/ha and consequently the break even analysis showed that the initial capital outlay was recovered within 2-5 years of the outlay, and in four out of the six cases in 2-3 years. The gross margin benefits were well in excess of the typical increases required to yield a break even on the investment (see Table 2.2).

Table 5.1: Summary across six farmer case studies of capital investment in precision agriculture technologies, estimated annual benefits and year when initial investment is recovered.

Farmer	Size of cropping program (ha)	Capital Investment in PA		Annual estimated benefits to PA* ($/ha)	Years to break even
		total $	$/ha		
Forrester	2,600	90,000	35	21	4
Fulwood	5,800	189,000	33	22	2
McAlpine	3,400	65,000	19	21	2
Smith	1,250	55,000	44	30	2
Heath	3,430	95,000	28	24	3
McLaren	4,000	56,000	14	14	5

** excluding capital costs*

Benefits of variable rate fertiliser

For all farmers we were able to quantify benefits to variable rate fertiliser management, ranging from $1 to $22/ha across six farms (Table 5.2). On a per paddock basis, benefits ranged from -$28 to +$57/ha/year. This wide range can be explained in part by two factors. Most farmers varied starter fertiliser as well as nitrogen topdressing, however one farmer (McAlpine) only varies topdressing and the benefits to VRT were lower for him than the other case studies. The degree of within-paddock yield variation also contributed to differences among farms in the benefits to VRT. The degree of within-paddock variation was noticeably less in the case of McLaren (Figure 4.6.1) where VRT benefits were on average $7/ha, compared with Smith (Figure 4.4.1) or Forrester (Figures 4.1.1 and 4.1.2) where benefits were >$20/ha. The difference between the average yield of the pre-determined high and low zones was always positive and substantial, suggesting that growers were successful in identifying zones of that perform differentially across seasons.

Rupert McLaren was the only farmer who had a deliberate strategy of reducing fertiliser inputs overall upon moving to a VRT situation, whereas others either maintained or increased fertiliser use. In the case of McLaren the reduction of fertiliser P rates was due to a history of P build-up before the adoption of VRT and this necessitated lower rates of P especially on medium and low yield potential zones of his paddocks.

Where VRT benefits were able to be estimated across a run of seasons for a given paddock, it was noticeable that benefits, albeit diminished, still accrued in below average years, such as the 2002 drought. This suggests that, once zones have been defined, benefits from VRT will occur in most seasons.

In the case of Fulwood, benefits to VRT were based on only one season’s results, and the estimate for McAlpine were based solely on farmer estimates, rather than records of yield variation and fertiliser rates. Hence, results from these farms should be generalised with caution. The methodology for estimating the benefits of VRT requires further testing on paddock-scale data where yields and fertiliser rates are recorded for uniform and VRT-managed strips. Where such studies have been conducted (e.g. Webb et al. 2004, Isbister et al 2005) the benefits recorded are in line with what we have estimated from farmer records. There were no clear trends for differences in benefit due to crop type, with canola and wheat (McLaren), wheat and lupins (Forrester) performing similarly. In the case of Smith, chickpea gave lower returns to VRT than wheat because of less nitrogen applied on the former.

Table 5.2: Summary across six farmer case studies of benefits ($/ha) to precision agriculture technologies, in total and separated into categories.

Farmer	Total	Reduced overlap	Fertiliser management	Less soil compaction	Fuel savings	Other
Forrester	21	5	16			
Fulwood	22	13	7			2
McAlpine	21	12	1		4	4
Smith	30	8	22			
Heath	24		20	4		
McLaren	14	7	7			

Other benefits

All farmers, except a row-cropper (Richard Heath), attributed benefits to guidance of reduced overlap of spray application. Benefits were typically in the order of 10% savings. Others, (e.g. David Fulwood) nominated benefits due to application of other agricultural chemicals and more efficient harvesting. The gains in reduction of overlap due to guidance is clearly easily and reliably captured by growers upon adoption of guidance.

Apart from guidance and VRT, other benefits nominated by farmers and estimated by us were less fuel use, less soil compaction, and more timely sowing. Intangible benefits listed by farmers were the ability to conduct on-farm trials, increased knowledge of paddock variability, increased confidence in varying fertiliser rates, and better in-crop weed control due to shielded spraying. It was noted that no farmer nominated pest management, grain marketing or nutrient budgeting as benefits from the use of PA.

Management of PA by farmers

A clear impression gained through interviewing each farmer is that they were all highly literate in the use of computers, GPS technology, and variable rate controllers. All invested considerable time in setting up their system in the beginning (with considerable teething problems in some cases), but on-going labour demands were minimal. Some did not use a consultant, while others placed heavy reliance on consultants for zone definition, yield map processing and variable rate map production.

All farmers soil tested, often in conjunction with a fertiliser company representative and used this information to inform the setting of fertiliser rates. In two cases, farmers told us that the extra soil testing that inevitably accompanies the use of more management zones on the farm under VRT, tended to be absorbed as a cost by the fertiliser company in return for the anticipated extra business.

Summary

This study is the first of its kind to estimate the economic benefits of precision agriculture in a commercial context. It demonstrates that Australian grain growers have adopted systems that are profitable and recovering the initial capital outlay with a few years, and also see a number of intangible benefits from the use of the technology. While the results here will go some way towards informing the debate about the profitability of PA, it also illustrates that the use of, and benefits from, PA technology varies farm to farm, in line with farmer preferences and circumstances.

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7. Glossary of terms

Geographical information systems (GIS): Software packages allowing organisation, analysis and illustration of maps, images and points.

Global positioning system (GPS): A positioning system based on an array of 24 satellites which orbit the earth. This is a key technology on which precision agriculture depends since it enables precise spatial location within paddocks.

Kriging: A sophisticated interpolation methodology which, in addition to estimating data values at unsampled points, also gives a measure of the precision of the estimate.

Precision Agriculture (PA): A suite of technologies (Yield monitor, GPS, VRT and GIS) which promote improved management of agricultural production by accounting for variations in crop performance in space. Also sometimes called “precision farming”, “site-specific management” or “information-intensive farming”.

Remote sensing: An all-encompassing term for a range of technologies which allow indirect measurement of something, often from afar. Examples include satellite or airborne imagery, or electromagnetic (EM38) soil survey.

Response curve: A curve or equation to a curve describing the marginal increase in crop yield obtained as a result of marginal increases in the application of fertilizer, spray or soil amendment.

Soil testing: The process of sampling and (chemically) analysing soils with a view to making informed fertilizer management decisions.

Strips: The basic building blocks of many simple experimental designs. These may be one-way or two-way.

Treatments: The net result of combining variables and levels. An experiment in which five levels of a single variable is being applied has five treatments.

Variable rate technology (VRT): A new technology which enables agricultural inputs such as fertilizers to be varied continuously within or between paddocks. It comprises one or more of the following components in a spreader or sprayer: variable rate capacity; dGPS; digital map control.

Yield monitor: The cornerstone of PA - a sensor installed within a header which enables continuous measurement of yield during harvest. Must be connected to dGPS to generate maps.

Yield response: The marginal increase in yield obtained from application of (usually) fertilizer. See also “Response curve”.