



# An Economic Analysis of the GRDC Investment in Precision Agriculture Variable Rate Technology (VRT)



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# **An Economic Analysis of the GRDC Investment in Precision Agriculture Variable Rate Technology (VRT)**

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## 1. Background

In 2001, GRDC sought project proposals to substantially accelerate the adoption of Precision Agriculture (PA) methods by Australian grain growers. The primary goal was to develop practical methods so growers could manage landscape variability to improve profitability and environment sustainability. During the last two decades there has been a rapid expansion in technologies that can give farmers easier access to a wider range of spatial data on the state of their crops and soils.

There are several related practices commonly considered to be part of PA as it is implemented commercially in Australia. A common but not mandatory feature is a dependence on global positioning systems (GPS) to define a location. Robertson et al (2007) have described the practices that have developed or are currently evolving, and these include:

- vehicle guidance to reduce overlap in spraying or spreading agricultural chemicals,
- accurate vehicle positioning to enable controlled traffic or tramlining, resulting in less soil compaction and improved crop growth,
- use of guidance, often with auto-steer, to reduce operator fatigue,
- shielded spraying of pesticides in row crops, and sowing of crop into last year's inter-row (e.g. for disease control),
- yield monitoring, and preparation of gross margin maps,
- use of biomass maps, electromagnetic induction survey or other imagery to locate problem areas for further on-ground investigation,
- location-specific crop sensing to identify nutritional or disease status,
- variable rate technology (VRT) for application of agricultural chemicals, especially fertiliser, and
- within-paddock zone management for agricultural operations.

With spatial data, farmers can answer the key question of whether it is profitable to vary management within a paddock that previously had to be managed on a uniform basis. VRT seeks to exploit knowledge of spatial variability. The current level of variability is a combination of the remaining inherent variation (in elevation or soil type for example), or variability that is a legacy of farming operations and past land uses.

There are also potential applications of PA at a whole-farm or landscape scale. In an application of PA termed mosaic farming, Brennan et al (2007) evaluated the benefits of changes in land use. On grain farms where salinity is an important issue to be managed, there is scope to introduce trees or pastures in suitable areas to restrict recharge.

Research over a decade ago had developed PA-related approaches producing more sustainable paddock lay-outs, for example to reduce water-logging and avoid compaction effects from heavy machinery. The trend to larger paddocks from wider machinery can increase erosion risk. Rows are more likely to be well aligned and match variable topography if they are based on a detailed elevation map which can be easily produced using a Real-Time Kinematic GPS. Controlled Traffic Farming (CTF) or Tramlining are

approaches now being increasingly adopted around Australia, in many cases as a result of earlier research by GRDC and State Departments of Agriculture. An evaluation of the benefits from adoption of controlled traffic tillage on 100,000 ha of Queensland cropping country showed benefits of \$65 m are expected to result from an R&D investment of \$14 m (present value) over twenty five years, with major savings in soil erosion, fuel costs, water quality and greenhouse emissions (LWA, 2005). But the evaluation also noted that the lack of advisory services for what could be a complex transition from conventional farming was constraining adoption. CTF and Tramlining had been the focus of a GRDC project in Western Australia where versions of Tramlining have been widely adopted (Webb et al, 2004).

Precision Agriculture has become a general term to encompass the ever expanding range of new tools that helped achieve what was once called site-specific crop management. GPS positioning and yield monitoring were outstanding examples of new technologies giving farmers new opportunities to understand and manage crop variability within paddocks.

But as Cook and Bramley (2000) summarised “*Given the current state of development of precision agriculture in Australia, few seem certain about methods of exploiting these opportunities, and fewer still capable of delivering them. Progress in the development of methods and applications has been much slower than expected*”.

By 2002 it was clear that progress on PA was being hampered by the lack of consolidated information on likely benefits for various regions and for the variety of farming systems. There were some pioneering applications in grains, cotton and other industries but it seemed clear that the adaptations needed to make better use of PA technology would need to be developed on an industry basis. In addition, the rate of adoption as shown by experience in the United States would be dependent on support from advisers able to adapt general approaches to the specific needs of individual regions or farms (Cook and Bramley, 2000).

As a GRDC workshop showed, there was a lack of information on how to go about PA, and an absence of simple pathways for farmers to get the skills to even try out some of the many aspects of PA that might be relevant to their situation (Wylie, 2001). GRDC began a national PA Initiative in 2002-03 with funding of \$6 m over five years. The initiative, a strategic investment program called SIP 09, focused on the less researched aspects of PA, particularly on understanding within-paddock variation and whether it is a good financial investment to manage this, on identifying which of the many types of spatial data are most useful in particular circumstances, and on using PA to better match land use and land capability.

## **2. The Program**

### **2.1.Objectives**

SIP 09 was established in 2002-03 as a national initiative to offer tangible and significant benefits (to graingrowers) through a combination of:

- better matching of land use to land capability,
- ability to match landscape/paddock characteristics with optimal agronomic practice (e.g. zone management),
- applying inputs at levels and locations where return will be maximised (e.g. VRT methods),
- ability to match within-season agronomy (e.g. additional fertiliser, pesticides) to mapped variation in measured crop performance,
- increased value of outputs (more grain, or grain targeted at higher value segregations or markets),
- reduced off-site impacts (recharge, sediment, nutrients, pesticides), and
- reduced contribution to greenhouse gas emissions (e.g. lower use of fossil fuels, lower nitrous oxide emissions from nitrogen fertiliser).

Projects funded within the Initiative were also required to:

- ensure a coordinated approach that brings together key stakeholders to develop world class research, development and implementation of PA in Australia, with strong linkages to overseas work of this type;
- facilitate training and support of researchers, advisers and growers to ensure there is capacity in cropping regions for consistent and reliable interpretation and use of PA information;
- ensure that growers can make sound management decisions based on the information generated by PA technologies, and will gain economic returns through better decision making;
- ensure the development of a range of PA systems ( including software and machinery) that are relevant and appropriate for different agroclimatic zones and cropping systems across Australia; and
- facilitate the adoption of effective systems that produce economic benefits to growers.

### **2.2.Costs and Associated Projects**

Estimates of the total investment by GRDC and others are provided in Table 1 for each of the years specified; the total investment is the sum of the project costs as listed in Table 2)

Table 1: Estimate of Investment in SIP 09 PA (2002 to 2007, nominal \$m)

<b>Year ending June</b>	<b>GRDC</b>	<b>Research partners, farmers</b>	<b>Total</b>
2003	1.173	1.951	3.124
2004	1.173	1.951	3.124
2005	1.173	1.951	3.124
2006	1.173	1.951	3.124
2007	1.173	1.951	3.124
<b>Total</b>	<b>5.864</b>	<b>9.754</b>	<b>15.628</b>

Source: GRDC. Research partners have contributed funding to approximately match the GRDC funding. Additional funding is mainly in-kind contributions from the farmers involved in SIP 09. Funding has been assumed to be evenly spread over the five years. Totals do not balance due to rounding.

### 2.3. Program Description

The program of 11 projects includes five in the five major grain producing states to develop the capacity of State Government research and extension agencies in facilitating adoption of effective PA systems. There are also projects with commercial organisations, CSIRO and the University of Sydney. The program included supporting activities providing resources and spatial data to regional projects.

Table 2: List of Projects in SIP 09

<b>Project</b>	<b>Project Title and Research Organisation</b>	<b>GRDC funding (\$)</b>	<b>Partner Contribution (\$)</b>
CSO00017	Precision Agriculture Initiative (CSIRO)	1,200,000	1,084,629
CTF00002	Precision Agriculture Initiative (CTF Solutions)	741,500	2,365,000
DAN00054	Precision Agriculture Initiative (New South Wales Department of Primary Industries)	402,713	1,926,675
DAQ00067	Precision Agriculture Initiative - Eye in the sky to revolutionise northern crop production (Queensland Department of Primary Industries and Fisheries)	417,852	873,780
DAS00035	Managing diseases using Precision Agriculture (South Australian Research and Development Institute)	552,115	848,506
DAV00030	Precision Agriculture Initiative (Department of Primary Industries Victoria)	741,294	886,510
DAW00084	Diagnostic support and training for Precision Agriculture (Western Australia Department of Agriculture)	400,000	1,110,024
SFX00001	Gammaradiometric & EM31/38 data acquisition and distribution for Precision	259,000	0

	Agriculture (Silverfox Solutions)		
SFX00002	Support for Precision Agriculture initiative and testing of stability zones and pseudo harvest index measures across core sites (Silverfox Solutions)	61,500	106,500
SPAA0003	Improvement of Nutrient Management through Effective use of Precision Agriculture Technologies in the Southern Australian Grains Industry (Southern Precision Agriculture Association)	238,500	302,200
US00017	Precision Agriculture Initiative (University of Sydney)	850,004	250,000
TOTAL		5,864,478	9,753,824

### 3. Outputs

The principal outputs for the investment include new opportunities to combine PA with other technology to help growers fine-tune their sowing and in-season decisions and to develop more sustainable cropping patterns based on land capability. The first four outputs in the following list are all part of VRT tools and techniques that can be applied to vary management and inputs particularly within paddocks. The last one is on PA at whole-property and catchment scales.

The outputs include (GRDC, 2007a):

- guidelines on the value of new sources, types and scales of PA data linked to diagnosis of underlying causes of spatial variability in yield and gross margins
- decision framework to assist growers/advisers in making agronomic decisions based on data about soil-borne disease inoculum levels in paddock management zones
- updated and expanded guidelines enabling growers to undertake on-farm testing of new varieties, variable rate application, and other innovations in agronomy, using PA methods
- tested methods to combine paddock/farm management classes with real-time crop sensing (e.g. for weeds, moisture, and N status) to improve the profitability of seasonal crop management
- extension of PA methods to whole-property and catchment scales to improve land management decisions

The outputs produced by the projects conducted with grower groups in the main grain producing regions have been consolidated and integrated in one key output, the Precision Agriculture Manual (GRDC, 2006). The Manual presents the key learnings from the project in four key stages for growers to progress through.

<u>Stage</u>	<u>Question answered by the PA Manual</u>
1	Is there spatial variation?
2	What are likely causes?
3	Is it worth changing to non-uniform management?
4	What needs to be done to manage the spatial variation?

Simple and tested rules of thumb are now available to support decision-making on whether to vary management within a paddock (i.e. whether it is likely to be economically worthwhile to do so). Key questions that determine whether there are likely to be significant benefits include:

- how big does a paddock need to be? (a Western Australian example is of the order of 60 ha), and
- how much yield variation is needed within the paddock? (a Western Australian example is of the order of 1 to 1.5 t/ha).

Other key outputs that will underpin adoption of PA include the development of training materials and well-tested and rigorous protocols published in the leading international agronomy journal to cut through the complexity of the data analysis (Taylor et al, 2007). The GRDC together with the Cotton Research and Development Corporation and the Grape and Wine Research and Development Corporation are presently funding the construction of training materials for industry and tertiary level workshops and courses in PA.

#### **4. Outcomes and Benefits**

The primary outcome is from grain farmers changing crop management activities to take account of improved knowledge of landscape and paddock variability. Farmers will be able to answer the key question of whether it is profitable to vary management within a paddock that previously had to be managed on a uniform basis. Changes apply to land use for better matching with land suitability, and to crop inputs using VRT. Varying fertiliser inputs by management zones will result in a better match between the fertiliser applied and crop requirements, and reduce off-site impacts.

A summary of the principal types of benefits and related costs associated with the outcomes of the project is shown in Table 3.

Table 3: Categories of Benefits from the Investment

<b>Benefits</b>
<p><u>Productivity and Profitability</u></p> <ul style="list-style-type: none"> <li>• Increased profitability including from time savings and from better control of inputs</li> <li>• Opportunities for improved risk management</li> <li>• Development of a market for PA technology</li> </ul>
<p><u>Environmental</u></p> <ul style="list-style-type: none"> <li>• Reduced off-site impacts from excess nutrients and herbicides resulting in improved water quality and aquatic habitats</li> <li>• Reduced degradation of natural resources from improved match between land capability and land use</li> <li>• Improved capacity to show increased sustainability using Environmental Management Systems</li> </ul>
<p><u>Social</u></p> <ul style="list-style-type: none"> <li>• Benefits in terms of reduced operator fatigue contributing to improved occupational health and safety outcomes, and opportunity to use less skilled labour for machinery operation</li> <li>• Strengthening capacity of rural regions to use new developments in information technology</li> </ul>

#### **4.1. Public versus Private Benefits**

The benefits readily identified from the investment in PA are predominantly private benefits and will be captured by grain producers. The benefits associated with natural resources and lowered contaminants in waterways (stemming from less available nutrients and herbicides) can be considered public benefits that are spinoffs from the productivity-driven management changes.

It is likely that some further development of PA and its adoption would have occurred if GRDC had not supported the SIP 09 program. This scenario is explored later where benefits from the investment are compared to what would have happened without the investment.

If GRDC did not receive funding (or received less funding) from the Commonwealth, most of the SIP 09 projects probably still would have been funded at some lower level. It is considered the investment was about “in the middle” of the list of GRDC priorities at the time of investment. Indications are the reduced funding would have been more at the expense of the State agencies involved in SIP 09. Some of that investment was considered more as capacity building. SIP 09 would then have had a greater emphasis on research and working with commercial partners. This could have made subsequent adoption more dependent on promotion by commercial service agencies. Risk may have been greater given that many of these are likely to be small firms in a new market.

As GRDC obtains about 40% of its research funding from the Commonwealth, it is estimated that about 60% of the investment in SIP 009 would have been made if GRDC had received no Commonwealth funding. With reduced Commonwealth funding, the level of investment would have been between 60% and 100% of the actual investment.

#### **4.2. Distribution of Benefits Along the Grains Supply Chain**

Some of the benefits from better targeting of inputs and the associated higher production will be passed along the supply chain to grain processors and other users of grain including consumers. As the grains industry is predominantly export orientated, benefits will be captured in the main by grain producers. The impact on suppliers of inputs (such as fertiliser) is uncertain. The project can be expected to give a significant boost to industries developing and supporting the range of electronic technologies on which PA is based. Much of the development will be in farming regions.

#### **4.3. Benefits to other Primary Industries**

In so far as there may have been collaboration with other primary industries (e.g. cotton and grapes) it is possible there were some spinoff benefits from the investment to other primary industries. However, these spinoffs could have flowed both to and from the grains industry.

#### **4.4. Match with National Priorities**

The Australian Government's national and rural R&D priorities are reproduced in Table 4.

Table 4: National and Rural R&D Research Priorities 2007-08

<b>Australian Government</b>	
<b>National Research Priorities</b>	<b>Rural Research Priorities</b>
1. An environmentally sustainable Australia	1. Productivity and adding value
2. Promoting and maintaining good health	2. Supply chain and markets
3. Frontier technologies for building and transforming Australian industries	3. Natural resource management
4. Safeguarding Australia	4. Climate variability and climate change
	5. Biosecurity
	<i>Supporting the priorities:</i>
	1. Innovation skills
	2. Technology

SIP 09 has made an important but difficult to quantify contribution to National Research Priority 1 and Rural Research Priority 3 through better matching land use to land capability and reduced nutrient and chemical loss off farms with ensuing water quality in waterways and groundwater with potentially enhanced biodiversity implications.

The major contribution however is to Rural Research Priority 1 where higher crop yields together with lowered input use are being observed. In this context the investment also addresses Rural Research Priority 4 as seasonal climate predictions can be taken into account in the technologies being applied.

The investment has made also a large contribution to National Research Priority 3 and has demonstrated innovation skills and new technologies (Supporting Rural Research priorities). Examples include use of GPS technologies, implements with variable rate capacity and variable rate controllers.

## **5. Quantification of Benefits**

### **5.1. The scope of SIP 09**

The initiative, SIP 09, focused on the less researched aspects of PA, particularly on understanding within-paddock variation and on opportunities to use other than uniform management. The most widely adopted PA tools are GPS positioning and guidance systems, particularly for controlling crop spraying and avoiding overlap. The affordability and ease of use has increased rapidly in the last few years. The driving factor has been the development of harvester yield monitors coupled with GPS revealing the patterns of yield variability within paddocks.

SIP 09 included assessments of new tools, particularly VRT based on more effective yield mapping. Yield mapping requires a GPS, a sensor data logger and software to compile a yield map, while variable rate technology (VRT) requires additionally a variable rate controller and an implement with variable rate capability.

The focus in this evaluation of SIP 09 is on the benefits arising from technologies and from information developed by the projects in SIP 09, rather than the broader benefits from the adoption of PA. The boundary of the evaluation is defined in principle clearly enough. In practice the benefits from SIP 09 are only those additional to the benefits being realised and accruing as a result of a range of prior investments in PA by numerous organisations and by individual farmers over the last decade. A survey at the beginning of SIP 09 showed that only one third of the respondents to the survey form in the GRDC publication, "*Ground Cover*" were using PA. Yield monitors, GPS guidance and controlled traffic farming systems were used by one half the respondents using PA during 2003-04 (Price, 2004). In addition to contributions to the broader PA approach from research, there have recently been rapid developments in machinery with basic PA components becoming standard on some farm machinery and with costs falling rapidly.

By 2002 there had been developments in some of the aspects of PA, particularly in Controlled Traffic and Tramlining. These applications were to some extent dependent on PA technologies, such as GPS and guidance systems. In some regions, spraying contractors with GPS can provide a low cost entry to Tramlining and Controlled Traffic. Guidance systems and yield monitors are increasingly becoming standard items in new farm machinery. The evaluation will therefore assume conservatively that the outcomes

of SIP 09 will be from adoption of the newer practices such as VRT by farmers already using basic PA technologies.

SIP 09 will result in a wider range of benefits than those that can be more easily quantified by adopting VRT. Growers who adopt some aspects of PA, such as use of 2 cm GPS or analysis of biomass imagery, can gain a range of benefits such as an elevation map to help manage frost risk or improve paddock layout, an ability to use shielded sprayers or to sow into the inter-row, identification of problem areas for closer inspection on the ground, or simply a greater knowledge of which parts of the paddock or farm produce the biggest share of profit and should therefore be the highest priority for agronomic management. Other benefits reported by growers involved in SIP 09 included accurate area maps of paddocks (valuable in negotiating contracted operations), an ability to measure the effectiveness of contracted operations such as fertiliser spreading, greater understanding of where paddock zones are on fertiliser response curves and hence likely response to further nutrient inputs, and ability to improve the financial return from disease control methods by targeting zones with high inoculum levels.

Environmental benefits could be substantial from less wastage of fertiliser. The majority of social benefits from PA emanate from guidance and auto-steer, as opposed to VRT. Such benefits include reduced fatigue and ability to use less skilled labour.

However, all these potential benefits are difficult to assess quantitatively as their application and scale will vary widely between locations and individual cropping enterprises. Hence the analysis below deals only with the benefits related to greater uptake of VRT.

## **5.2. The economic benefits from using VRT**

The benefits arise primarily from changing from managing a paddock uniformly to managing according to variability. The diagnosis of the underlying factors determining yield variability can be complex. A wide range of confusing (at least initially) zonal maps can be produced, for example based on yield from yield monitors. The yields and grain protein data could then be used to generate gross margins. Other maps can be readily purchased from a range of crop (biomass) imagery usually available for several years previously and indicating the status of the crop. In some locations, a series of maps over several years might be analysed and synthesised. A high yielding zone in one year can be low yielding the next. An analysis over four seasons using high, medium and low clusters showed that only 7 per cent of one 100 ha paddock was consistently in the same cluster each year (Brennan et al, 2007). The SIP 09 projects developed guidelines to break through the complexity, for example defining how much of a paddock needed to be consistent from year to year to justify VRT. But the extent to which VRT can be applied generally cannot easily be estimated. There are large tracts of land used by the grains industry which at least superficially appear relatively uniform in yields.

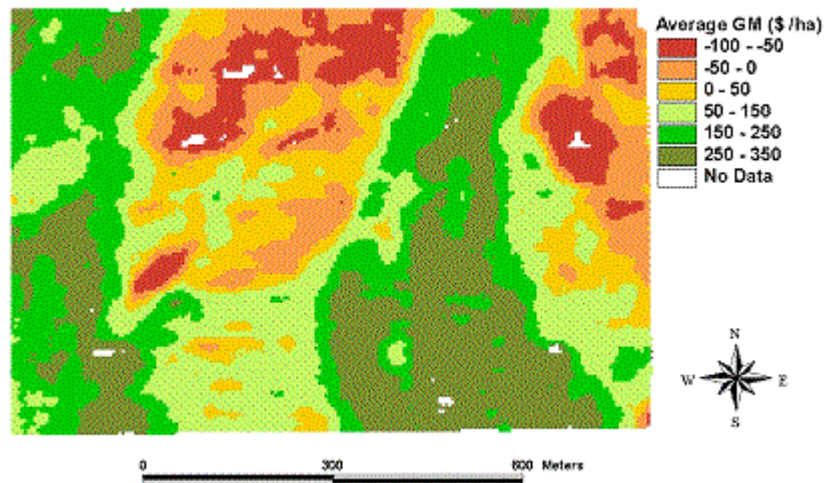


Figure 1: Areas of Profit and Loss for a Paddock in Western Australia

Figure 1 shows areas of profit and loss for a paddock in Western Australia, based on average gross margins for five years (GRDC, 2006). The gross margin map provides the basis for decisions on varying input rates or other aspects of crop management. Where the farmer has confidence in the underlying environmental factors contributing to the variation, the maps can then be used to define zones where inputs can be varied. In the example above, there are some areas where average gross margins are actually negative and might therefore only be profitable by reducing some inputs. In extreme cases and where the size and location are suitable, there will be areas where cropping is discontinued and a more sustainable land use introduced.

The aim of a VRT approach is to integrate a range of information on the crop and from either paddock-wide or targeted soil measurements to optimise profitability. Soil electrical conductivity and digital elevation are two most useful environmental data layers that only need to be measured once to define and map variability. Conductivity can be highly correlated with available soil water, often a key factor in determining yield variability. SIP 09 has established a statistical protocol using readily available freeware to determine the most effective data based on production and environment layers (Taylor et al, 2007). Typically a paddock would then be managed as zones each with its own optimum level of inputs. Test strips and targeted soil sampling would first determine the optimum levels. The inherent complexity will inevitably result in a lag between the initial VRT expenditure and resulting benefits. The example in Table 5 illustrates the basics of VRT aimed at increasing overall paddock profitability.

With VRT, inputs such as fertiliser can be varied by a controller on the fertiliser spreader. The zone of the spreader's current location is determined by a GPS. In the Table 5 example, the optimum fertiliser rate is increased on the High Productivity Zone and reduced on the Low Productivity Zone. The comparisons are with the Medium Zone where the rate is unchanged. The increased yield from a lower rate in the Low Zone

results from excess fertiliser reducing yield from too rapid early growth and subsequent haying off and production of a high level of screenings.

Table 5: Example of Changes in Inputs and Outputs using Variable Rate Technology

<b>Zones (based on productivity)</b>	<b>Compared with Medium Zone</b>	
	<b>Increased Fertiliser %</b>	<b>Increased Yield %</b>
High	+50%	+10%
Medium	No change	No change
Low	-30%	+5%

Source: Robertson et al (2006)

The benefits from VRT will vary between seasons, paddocks, farms and regions. The benefits are highly dependent on

- the temporal and spatial variability in yields, and
- the sensitivity of the optimal profit to varying levels of inputs.

Within a paddock, the optimal level of an input such as nitrogen fertiliser will vary with the site within the paddock and the season. For example the optimal level of nitrogen in a deep soil with a high water holding capacity will be much higher in a good season than for a shallow soil in a poor season. A capacity to monitor soil water at the start of the season and to forecast seasonal rainfall can therefore be important prerequisites if within paddock variability is to be managed by varying nitrogen rates. These are practices that are increasingly being adopted within the grain industry.

The sensitivity of profit to input level is shaped by the relative prices of the inputs and outputs together with the biophysical response of the crop for the specific site and season. In a general sense, the response curve is typically flat in the vicinity of the optimal level of the input. For the paddock analysed by Brennan et al (2007), applying nitrogen at one half the optimal profit-maximising rate only reduced profit by about 10%. Clearly in some situations, there will be no return from too much effort in fine-tuning inputs.

Survey results are available for 12 farms representing the major grain regions (Table 6). The first six farms (Robertson et al, 2006) include three from Western Australia and three from New South Wales. The other six farmers are from South Australia (McCallum, 2007). The surveys are based on all additional costs of changing to VRT and include changes in fertiliser costs, the farmers labour costed at \$500/day to prepare yield maps, and other costs either capital or annual to purchase additional equipment and maps.

Table 6: Benefits from Precision Agriculture and Variable Rate Technology for 12 Australian Farmers

Farmer code	Years PA experience	Area Cropped (ha)	Capital Investment in PA including VRT (\$/ha)	Annual Benefit (\$/ha)		
				VRT	Other	Total
WA 1	9	2,600	35	16	5	21
WA 2	2	5,800	33	7	15	22
WA 3	6	3,400	19	1	20	21
NSW 1	7	1,250	44	22	8	30
NSW 2	8	3,430	28	20	4	24
NSW 3	10	4,000	14	7	7	14
SA 1	7	3,000	23	7	4	11
SA 2	8	1,600	62	5	8	13
SA 3	2	2,700	27	0	21	21
SA 4	10	2,340	15	10	5	15
SA 5	5	4,475	12	8	2	10
SA 6	10	1,200	62	9	28	37
Average	7	3,000	31	9	11	20

Sources: Robertson et al (2007) and McCallum (2007)

PA has only a brief history in applications in Australian farming and VRT even less. As discussed previously some applications related to PA were beginning to be more widely adopted in the late 1990s and then when SIP 09 began in 2002. The farmers in the survey were therefore clearly pioneers in adapting PA and in making practical use of VRT. Prior to SIP 09 there had only been minor research expenditure on VRT. Early farmer applications were dependent on farmers developing computing skills as needed, and backed up by advisers and consultants. Software was often developed on the job or adapted from overseas. Thus in 2002 when SIP 09 began there would have been only a small prior research expenditure or benefits that could be attributed to VRT.

The survey of benefits from PA shows that benefits from VRT averaged \$9/ha with a between-farm range from zero to \$22/ha. The farm with the zero VRT benefit had only recently started. The farm with \$1/ha benefit was using yield mapping to guide inputs on only a small part of the farm because of uncertainty on benefits in other areas. Benefits in the 'Other' category are primarily from reduced spray overlap. Benefits from reduced spray overlap are now easier to achieve given the PA capacity in terms of guidance and auto-steer that are now standard in new machinery and have therefore not been attributed to SIP 09.

Variable rate applications of herbicide are likely to be an increasing area of application of VRT in the future. There was only one example in the survey of a farmer where there

were benefits from reduced herbicide application apart from reductions due to minimising spray overlap. Weed activated mapping and spraying systems based on VRT are currently being developed. Savings in herbicide are between \$20 to \$30 per hectare (Brownhill, 2006). The benefits that can be attributed will be limited to technology already available. Investment additional to SIP 09 may be needed to develop new technologies based on VRT.

The changes in gross margins need to be reduced by an annual capital allowance based on extra capital required for VRT. For farmers already set up with key PA components, the additional capital costs for VRT are now only of the order of \$10,000 which includes a variable rate controller where not included and some initial zone analysis. The controller will be adequate for a range of farm sizes. Based on \$10/ha for a 1,000 ha cropped area and a life of 10 years, an approximate annualised capital cost is of the order of \$1/ha. A reduction of \$1/ha results in benefits for VRT of \$8/ha. In some respects, this is a conservative estimate of the benefits likely to be available in future. The survey farmers were pioneering and did not have the advantage of all outputs from SIP 09. But, they did have atypical skills and levels of support not likely to be characteristics of adoption more generally. Another factor to take into account is that some of the farmers had limited data on VRT other than from trial strips and these may overestimate benefits on larger areas. To ensure a conservative approach, a 25% reduction is warranted to give an assumed benefit of \$6/ha. In addition to account for the time taken to fully trial and implement VRT, benefits are assumed to lag adoption and increase from zero to \$6/ha over four years.

### 5.3. Farmers potentially benefiting from SIP 09

There is a wide range of grain farms particularly in terms of their dependence on income from grain and on size of the farm business. Many grain farms have major sheep or beef cattle enterprises often closely integrated with grain farming. Experience with PA has shown that larger farms are more likely to invest in PA, particularly because there are economies of scale and components of PA such as vehicle guidance systems and yield monitoring are becoming standard on larger machinery purchases. A size of 1,000 ha cropped is suggested as a minimum necessary for a profitable investment in PA generally and in VRT (GRDC, 2006). For ABARE farm surveys the Australian grains industry is taken to comprise broadacre cropping and livestock grazing farms. A farm is considered to be a ‘specialist’ grain farm if more than half of total cash receipts are received from crop sales. These farms (Table 7) average about 1,000 ha cropped so are a convenient starting point for this evaluation.

Table 7: Characteristics of ‘Specialist’ Grain Farms Potentially Benefiting from SIP 09 (ABARE, 2006)

Number of businesses	13,293	Capital Investment/ha	\$1,430
Area operated (ha)	2,056	Grain sales (% total sales)	84
Area cropped (ha)	991	Wheat sales (% total grain sales)	57

The number of specialist farms has changed little over the last two decades. The average area cropped and the total area has each increased by about one half over that period. The area cropped on specialist farms is of the order of 13 m ha. The key figure required is the total grain area potentially managed by VRT. The overall area sown to grains and oilseeds has been about 20 m ha recently and expected to expand to 24 m ha by 2011-12. (ABARE, 2006). Areas suitable for VRT have the following characteristics:

- Larger farms to justify the extra capital and expertise required,
- Large paddock sizes (inherently more likely on larger farms), and
- Variable yields and sufficient manageable variability in paddocks to justify departing from fixed input rates.

SIP 09 had a focus in its projects on managing variability based on better understanding of the spatial patterns in profitability. The diagnosis of the patterns has often been problematic. There are many possible causes relating to:

- Previous farming operations, for example from machinery compaction,
- Variable seasonal and spatial responses to inputs such as fertiliser, or
- State of the natural resource, for example soil type, water holding capacity, topography and drainage.

Most VRT will be applied on larger specialist farms. Apart from that there is no consolidated data and only some observations to go on to determine areas potentially suitable for VRT. A figure of 6.5 m ha or 50 per cent of the area of specialist farms has been suggested by two advisers involved in SIP 09 as an achievable maximum level of adoption. The key assumptions for areas suitable for adoption of VRT are therefore assumed to be as follows:

- Most adoption will be on specialist grain farms that have a total area of 13 m ha.
- As adoption approaches 6.5 m ha (equivalent to 50% of the area cropped on specialist grain farms), the rate of adoption will be constrained by the limited areas remaining that are suitable for VRT.

#### **5.4. Factors influencing the rate of adoption of VRT**

The rate at which Australian grain farmers change their current fixed rate practices and adopt VRT will be determined initially by their awareness of the technology and their perception of the benefits. There has been a rapid increase in the proportion of farmers with the basic equipment needed for VRT. Whelan (2007) quotes market penetration of 30 per cent of the broadacre/row crop farmers with some form of guidance system and 40 per cent of those with autosteer function. Therefore it can be assumed that the farmers likely to adopt VRT will already have PA capability justified by benefits from various forms of guidance and particularly from savings in spray overlap.

Awareness of VRT will be determined primarily by the strategies of the agencies involved in the promotion and servicing of VRT and also from farmer contacts within their networks. VRT is assured of a high profile in GRDC activities given that its adoption will often be dependent on promotion and farmer adoption of more general PA practices. The GRDC Strategic Plan (GRDC, 2007a) has for its objective on adoption of practices:

Key performance indicator – ‘*The proportion of growers taking up precision agriculture and related technologies and practices represents 60% of growers surveyed.*’

Support from the services sector will be another key factor. The current market for services relating to VRT is still limited and evolving, and therefore risky for new entrants. However the growth in the broader PA field and the contribution that SIP 09 has made will act as a catalyst. There are an increasing number of services being routinely provided on a commercial basis. Farm machinery dealerships around the country now routinely support PA equipment and software. Also as detailed by Whelan (2007), the growing levels of support to underpin high rates of adoption are now:

- 10 companies that make and or market vehicle guidance equipment and other PA hardware,
- 4 that provide imagery services,
- 7 that provide soil conductivity mapping,
- 7 that provide commercial data analysis and storage solutions, and
- 3 that provide other commercial PA software solutions.

SIP 09 has had an important role in capacity building, particularly in providing guidelines and support so that commercial and advisory services can more easily meet increasing demand for VRT. SIP 09 projects in each of the major grain producing states have also contributed to the increased capacity needed to support future adoption of VRT. State agriculture agencies are more likely to support opportunities provided the following are established:

- a coordinated national approach,
- evidence of economic, environmental and social benefits, and
- a well consolidated body of knowledge suitable for use in training courses, as in the PA Manual produced by SIP 09.

An evaluation of a reduced tillage program (Scott and Farquharson, 2004) in northern NSW shows how important follow-on investment can be in ensuring high rates of adoption from an R&D program. The research phase had been funded by equal contributions from industry funds and the NSW Agriculture Department. When the extra extension costs to 2020 were accounted for, the share of investment was 32% industry and 68% NSW Agriculture. In SIP 09 the research partners have also contributed approximately matching funds over the research phase. The research partners are also generally involved in promotion and extension of PA and VRT. For this evaluation, it is assumed that other agencies will continue to support extension aimed at promoting adoption of VRT for a further decade but with a total input of \$3 m, one half of that during the research phase.

Mid 2007 (when SIP 09 ends) is a convenient reference point for estimating the overall adoption pattern. There are no accurate data on actual adoption but estimates based on emerging experience around Australia is less than 10 per cent of grain growers in Australia are currently using PA methods in any form and less than 3 per cent are using the full suite of PA data and methods which would include some using VRT (GRDC, 2006). The 2006 survey results included farmers with an average of 7 years PA

experience but generally a shorter period for paddock-scale VRT. The SIP 09 involved a number of farmers equivalent to about 2 per cent of the 13,000 specialist farmers who are the main target for VRT adoption. Based on these indications, the adoption of VRT is assumed to start in 2003 to coincide with the start of the SIP 09 investment.

Typical cumulative adoption curves are sigmoidal (a stretched S shape) with initially low rates as innovators trial new technology and then with rates accelerating as more farmers become aware of the benefits. Rates ultimately decline as ceilings are reached or as alternative technology is introduced. The following figure for adoption of no-till is a useful analogy ( Note the data are annual rates and not cumulative). In Western Australia it took 14 years for cumulative adoption to reach 50 per cent of respondents. In South Australia adoption was still less than 50 per cent after decades. Concerns on risks and benefits in the farmers own situation were major factors determining the adoption rates.

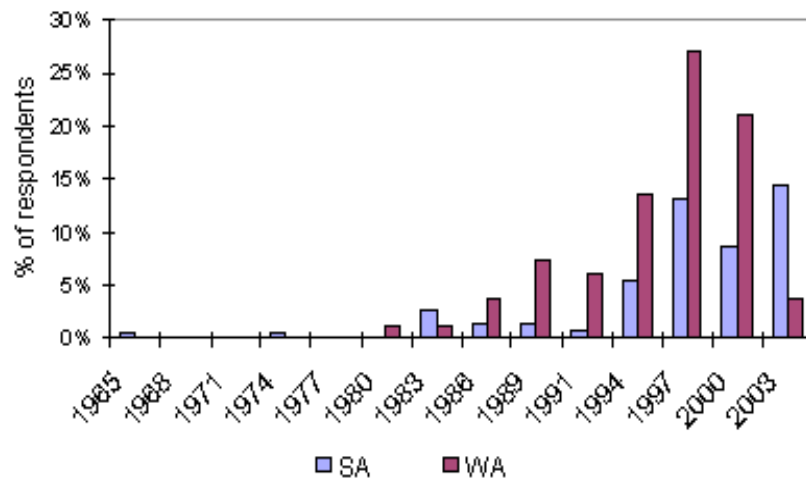


Figure 1: Stated Time of First Adoption of No-till by Grain Growers in South Australia and Western Australia (D’Emden and Llewellyn, 2004)

In contrast to surveys and reports highlighting the potential of VRT as an exciting new technology, there are reports that question benefits in particular environments. For example for the low and variable rainfall environment of the Eyre Peninsula:  
*“While VRT sounds promising, the jury is still out in this environment. Reduced inputs in poor performing areas of paddocks may pay off in seasons with a tight finish, but how much yield would be compromised in a good season and how does this affect profitability over the long term?”* (Hancock, 2007).

In similar vein, Ambrosio et al (2006) reported from a survey of Victorian grainfarmers that they do not deem variability within a paddock to be sufficient enough to warrant more precise treatment. These results are not unusual with new technology and simply demonstrate that farmers and their advisers reasonably assess new research as risky until they have better evidence of its applicability in their environment. In Table 8, the key factors that contribute to adoption are listed together

with examples of how SIP 09 contributed. The SIP 09 contribution is limited to the benefits from VRT, the major output for which quantified benefits are available.

Table 8: SIP 09 VRT Outputs Relevant to Typical Farmer Adoption Criteria

<b>Adoption Criteria</b>	<b>General Farmer Perspective on Adopting a New Approach (tools, technology, or information)</b>	<b>SIP 09 VRT Contribution to Precision Agriculture</b>
Return	How profitable compared with alternative investments?	The first surveys published on actual farmer benefits from overall PA applications and from VRT in different regions.
Risk	The likelihood of achieving profitability and is it knowable?	Clarified by surveys including between-farm variability and average on-farm profitability over several years, and by guidelines showing where variable rates are likely to be optimal in terms of profitability.
Researchability	How easy is it for the farmer to test the approach?	Projects developed simple incremental four-stage approach to on-farm trialling and developing zones to apply VRT. Basic instructions (e.g. to produce a yield map) included in the PA Manual
Compatibility	How does the approach fit with the current farm set-up and the farmer's social context?	Guidelines developed to build on existing tools and to use farmer knowledge of variability.
Complexity	How easy to use, or to get new skills?	Farm machinery increasingly has inherent VRT capacity or compatibility; four stage approach developed and tested in a range of situations, and further support services, freeware, education and training materials being developed.
Communication	How easy is it to see the benefits and understand the approach?	Pilot projects have been effected in major regions; wider range of maps and tools developed to highlight key management issues, including education resources for farmers and advisers.

Future adoption rates depend on judgments by farmers and advisers on the importance of the above factors. The returns data have led to an assumption of \$6/ha benefit. This is a

significant benefit in relation to typical gross margins of from \$100 to \$200/ha. Further, the benefit allows for a relatively minor initial capital cost of the order of \$10/ha so the pay-back period will be short, even taking into account that there is a learning period likely before full benefit is reached. In any case SIP 09 has produced outputs that will make it much easier for farmers to assess the likely benefits and to test without outlaying significant resources.

Estimates to 2017 of likely adoption rates and attribution to SIP 09 have been obtained from the key researchers and advisers involved (Table 9). As one researcher stated: *“Farmers looking to adopt PA in the future are better positioned to make VRT pay within 2-3 years because of access to lower cost equipment (yield monitor, VRT equipment) and more information on the likely financial returns”*.

Table 9: Cumulative Adoption (%) by Specialist Grain Farmers of VRT, and Attribution to SIP 09 for either Australia, or Specific GRDC Regions (estimated by 6 SIP 09 researchers and advisers)

Year	Australia			Northern	SA	WA	Australian Average (estimated)
<b>Adoption (cumulative % of Specialist Grain Farmers)</b>							
2007	4	5	2	2	2	5	4
2017	50	50	60	20	40	15	40
<b>Attribution to SIP 09 (% of adoption achieved)</b>							
2007	90	80	25	100	80	5	80
2017	90	80	75	85	60	30	70

The next section considers in more detail the likely adoption rates to be achieved taking into account possible constraints, particularly paddocks likely to be sufficiently variable to justify VRT. But first, the likely influence of a range of factors are summarised in Table 10.

Table 10: Factors Driving Adoption Rates of VRT

Negative Factors Reducing Adoption Rates	Possible Countervailing Factors
Conflicting messages on likely benefits and risks of VRT for key decisions such as fertiliser rates	Increasing availability of examples of benefits in standard applications, and of examples of innovative uses of VRT approaches
Perceived complexity of the technology in terms of identifying zones for VRT	PA Manual published with tested guidelines reducing dependence on farmer computer skills
Area ceiling because VRT limited to large paddocks with sufficient variability to shift from uniform	Larger farms have higher average profitability and are more likely to already have prerequisite technologies (guidance and auto-

management	steer)
In the short term, reduced capital investment following drought will limit investment in VRT	Short pay-back period for VRT; capital costs are likely to continue to decline and new machinery has inherent PA capability or will be readily adapted to VRT
Time lag in getting operational and the limited numbers of technical and advisory support to implement VRT	Basic PA technology is increasingly becoming accepted and is standard on new machinery; there is increasing availability of advisers and machinery dealers with PA/VRT competence
Seasonal variability may dominate and complicate identification of zones increasing the time taken to set up and maintain information required to underpin VRT	Likely benefits of VRT can be assessed without major investment
Environmental benefits from reducing fertiliser and herbicide losses by using VRT undervalued by farmers	Increasing input costs and community concerns with off-site impacts will increase likely benefits from VRT as a key component of Environmental Management Systems
Rising cost of key inputs will result in an increase in areas that are no longer sustainable	VRT can identify parts of farms where land use is not well matched with land capability

### **5.5. Adoption rates of VRT with and without SIP 09**

Taking into account the range of negative and in some cases off-setting positive factors likely to influence VRT adoption, a conservative approach is warranted assuming a slower rate than that proposed by researchers and advisers in SIP 09 (Table 9). The rate will also depend on further expenditure by GRDC and other agencies and as discussed previously a continuing input is assumed to support VRT education and adoption. The rates in Table 11 assume a 22.5 per cent adoption by 2017 compared with 40 per cent in Table 9. Approaches developed by SIP 09 are likely to be superseded but provide the competitive base on which future benefits are evaluated.

For the without SIP 09 situation, adoption was assumed to start from zero in 2003. By then some farmers were independently trialling VRT and some continuing level of adoption would have been feasible without SIP 09. However the benefits achieved from isolated cases of innovative farmers and advisers developing their own approaches would be unlikely to be competitive with the more efficient approaches developed by SIP 09. Some limited research support for VRT would also have been available, mostly from agencies that were involved as partners in SIP 09 in any case. A one third reduction in the benefits, from \$6/ha for those farmers using a SIP 09 approach to \$4/ha in the without situation, is assumed. In the without situation, some acceleration in the rate of adoption is likely as a critical mass of experience is built up. As the level is still low in relation to the ceiling of about 50 per cent, a slowing down is unlikely by 2032.

Table 11: Changing Adoption Trends (% of 13m ha potential area)  
With and Without SIP 09 from 2003 to 2032

Period	Without SIP 09 (%)		With SIP 09 (%)	
	Trend pa over the period	Cumulative level reached by end of period	Trend pa over the period	Cumulative level reached by end of period
2003-05	0.25	0.5	0.25	0.5
2005-07	0.25	1.0	1.0	2.5
2007-17	0.5	6.0	2.0	22.5
2017-27	1.0	16.0	2.0	42.5
2027-32	1.0	21.0	0	42.5

### Summary of Assumptions

A summary of the key assumptions made is shown in Table 12. It should be noted that while benefits are estimated to take 4 years after adoption (in the case of with SIP 09) to reach their maximum for a given farm, the spreadsheet in the evaluation (reflected in the table below) assumes for simplicity the equivalent pattern of a two year lag in benefits but the full benefits occurring after two years. A similar approximation is used for the without SIP 09 scenario (3 year lag).

Table 12: Summary of Assumptions

Variable	Assumption	Source
Number of potential adopters (represented by specialist grain farmers)	13,000	ABARE, 2007
Average cropped area of potential adopters	1,000 ha per farm	ABARE, 2007
Area potentially adopting	13,000,000 ha	Derived from above
<i>Without GRDC Investment</i>		
Ongoing investment in extension associated with PA	\$50,000 per annum for 2007/08 to 2016/17	Consultant estimate
Annual net benefit to adopters	\$4/ha	
Number of years between adoption and full benefit	3 years	Consultant estimate
Adoption	Adoption pa (%)    Cumulative (%)	From Table 11
2003/04 to 2004/05	0.25                      0.5	
2005/06 to 2006/07	0.25                      1.0	
2007/08 to 2016/17	0.5                        6.0	
2017/18 to 2026/27	1.0                        16.0	
20027/28 to 2031/32	1.0                        21.0	

<i>With GRDC Investment</i>			
Ongoing investment in extension associated with PA	\$300,000 per annum for 2007/08 to 2016/17		Consultant estimate
Annual net benefit to adopters	\$6/ha		Consultant estimate based on farmer survey
Number of years between adoption and full benefit	2 years		Consultant estimate
Adoption	Adoption pa (%)	Cumulative (%)	From Table 11
2003/04 to 2004/05	0.25	0.5	
2005/06 to 2006/07	1.0	2.5	
2007/08 to 2016/17	2.0	22.5	
2017/18 to 2026/27	2.0	42.5	
20027/28 to 2031/32	0.0	42.5	

## 6. Results

All past costs and benefits were expressed in 2006/07 dollar terms using the CPI. All benefits after 2006/07 were expressed in 2006/07 dollar terms. All costs and benefits were discounted to 2006/07 using a discount rate of 5%. The base scenario used the best estimates of each variable, notwithstanding a high level of uncertainty for many of the estimates. The benefit period was defined as the number of years after the last year of R&D investment.

Investment criteria were estimated for both total investment and for the GRDC investment alone. Each set of investment criteria were estimated for different periods of benefits. The investment criteria were all positive when the benefit period exceeded 10 years as reported in Tables 13 and 14.

Table 13: Investment Criteria for Total Investment  
(discount rate 5%)

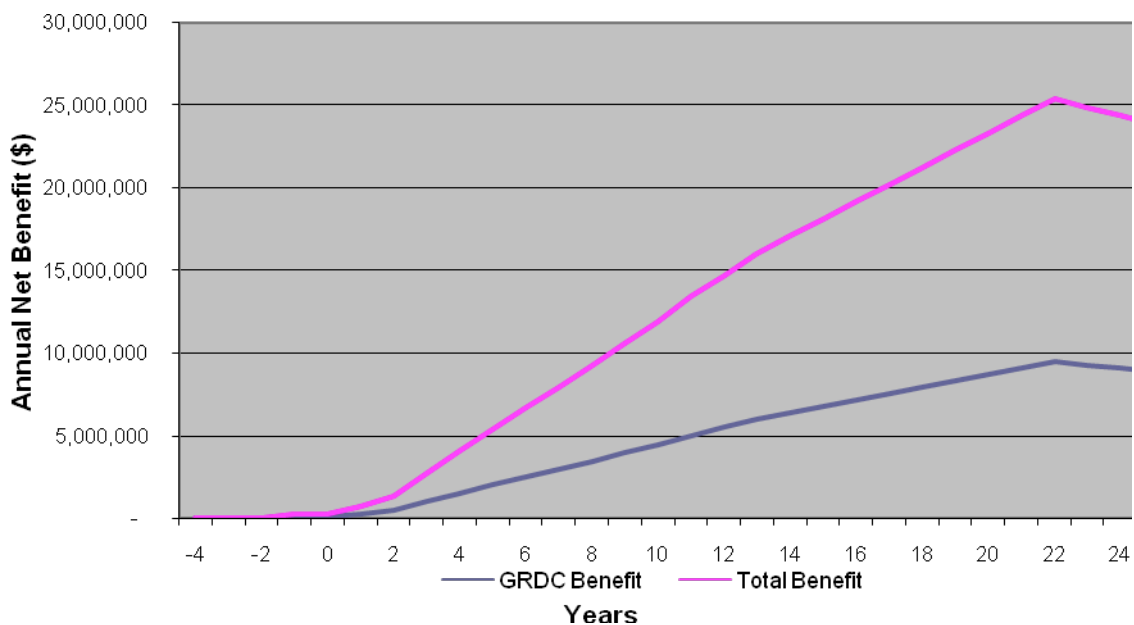
<b>Criterion</b>	<b>0 years</b>	<b>5 years</b>	<b>10 years</b>	<b>15 years</b>	<b>20 years</b>	<b>25 years</b>
Present value of benefits (m\$)	0.5	12.2	43.1	84.8	128.8	168.8
Present value of costs (m\$)	18.3	18.3	18.3	18.3	18.3	18.3
Net present value (m\$)	-17.8	-6.1	24.8	66.6	110.5	150.5
Benefit cost ratio	0.03	0.66	2.4	4.6	7.0	9.2
Internal rate of return (%)	Negative	Negative	15.7	20.4	21.9	22.4

Table 14: Investment Criteria for GRDC Investment  
(discount rate 5%)

Criterion	0 years	5 years	10 years	15 years	20 years	25 years
Present value of benefits (m\$)	0.2	4.6	16.2	31.9	48.4	63.4
Present value of costs (m\$)	6.9	6.9	6.9	6.9	6.9	6.9
Net present value (m\$)	-6.7	-2.3	9.3	25.0	41.5	56.5
Benefit cost ratio	0.03	0.66	2.4	4.6	7.0	9.2
Internal rate of return (%)	Negative	Negative	15.7	20.4	21.9	22.4

Figure 2 demonstrates the rate at which net benefits accrue.

Figure 2: Annual Net Benefit Flow



### Sensitivity Analyses

Sensitivity analyses were carried out on two variables and results are reported in Tables 15 and 16. Both sensitivity analyses were performed using a 5% discount rate with benefits taken over the life of the investment plus 20 years from the year of last investment. All other parameters were held at their base values. Table 15 shows the sensitivity to the annual net benefit per hectare due to adoption of the technology. The analysis assumes that both the with and without values change. Table 16 shows the sensitivity to adoption. It should be noted that in the high adoption scenario, the adoption ceiling of 50% of potential adopters is maintained.

Table 15: Sensitivity to Annual Net Benefit to Adopters  
(GRDC investment, 5% discount rate; 20 years)

Criterion	Annual Net Benefit to Adopters (both with and without SIP 09)		
	50% of Base	\$4/ha without SIP 09 \$6/ha with SIP 09 (Base)	150% of Base
Present value of benefits (m\$)	23.8	48.4	72.9
Present value of costs (m\$)	6.9	6.9	6.9
Net present value (m\$)	16.9	41.5	66.0
Benefit cost ratio	3.5	7.0	10.6
Internal rate of return (%)	14.8	21.9	26.6

Table 16: Sensitivity to Adoption Levels  
(GRDC investment, 5% discount rate; 20 years)

Criterion	Adoption Level With SIP 09		
	50% of Base	Base Scenario (see Table 12)	150% of Base
Present value of benefits (m\$)	18.3	48.4	76.7
Present value of costs (m\$)	6.9	6.9	6.9
Net present value (m\$)	11.5	41.5	69.9
Benefit cost ratio	2.7	7.0	11.2
Internal rate of return (%)	12.6	21.9	27.4

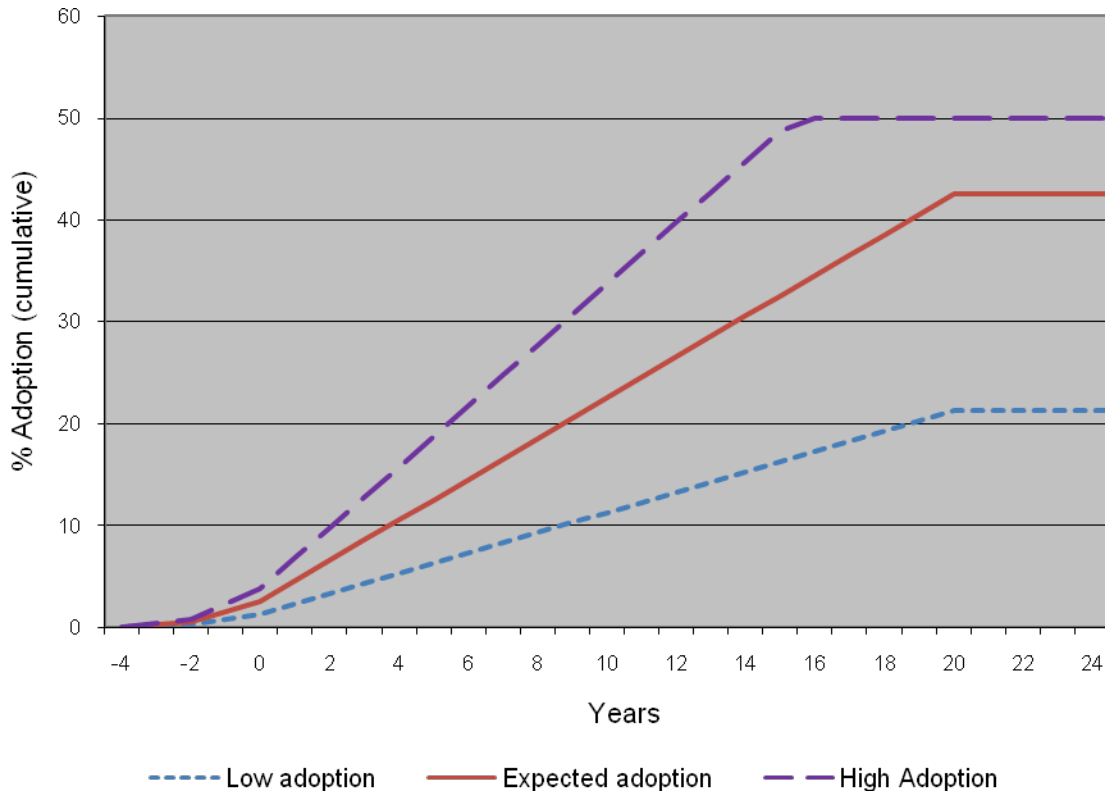
Table 17 presents the net present value (NPV) for low, expected and high adoption assumptions for each of the 0, 5, 10, 15, 20 and 25 year timeframes (for all investment).

Table 17: Net Present Value Sensitivity to Adoption  
(all investment; 5% discount rate; \$m)

NPV	Project Horizon					
	0 years	5 years	10 years	15 years	20 years	25 years
Low (50% of expected)	-18.1	-14.1	-2.1	14.5	30.6	43.8
Expected	-17.8	-6.1	24.8	66.6	110.5	150.5
High (150% of expected)	-17.5	1.8	51.6	118.6	186.1	236.2

Figure 3 shows the low, expected and high adoption trends (percent adoption, cumulative)

Figure 3: Low, Expected and High Adoption



## 7. Conclusions

The cost benefit analysis demonstrates that investment in better adapting an emerging technology can be highly profitable where it has a major role in ensuring wide spread adoption across the grains industry. The timing of the investment was significant in that there had been some early experience in PA by innovators and this helped clarify what were the key constraints to more widespread adoption.

VRT is essentially managing variability within paddocks by adjusting major inputs such as fertiliser to their optimum profit level. A synthesis of previous yield maps, imagery and soils data can be used to define zones within paddocks that warrant varying levels of inputs.

As is the case for much agricultural research, the benefits from a specific investment are often difficult to isolate. For this analysis, the only benefits quantified were for farmers adopting VRT. It should be remembered that grain growers adopting a PA approach may gain significant benefits in addition to those due only to use of VRT for fertilisers and pesticides.

A key assumption was prior adaptation of PA capacity particularly as yield monitors and guidance capability have rapidly become standard. Farmers will increasingly have PA

capacity as they replace machinery. VRT can then be readily adopted at a relatively minor capital cost. Identifying the potential to vary inputs on a paddock basis has now been simplified by the experience and the tools developed as part of SIP 09.

The benefits for VRT were based on conservative estimates of the increased profits for a sample of farms, and of the total area of the industry likely to benefit. The area suitable for VRT is constrained to larger paddocks or where there is a manageable level of variability. There are significant off-site benefits likely from VRT through reduced inputs of herbicides and less fertiliser wastage. More generally SIP 09 will improve the capacity to better match land use and land capability. These environment benefits were not quantified. Social benefits include reduced operator fatigue by being able to automatically vary inputs.

The estimates of benefits and the rate of adoption were conservative but were subject to a sensitivity evaluation. The investment was still profitable for benefits reduced by one half and in a separate evaluation with the original benefits maintained but adoption rates halved. For the low adoption scenario, the investment takes more than a decade before benefits exceed costs. This pattern is typical of investments where benefits grow slowly as determined by the cumulative levels of adoption achieved.

The evaluation takes into account the likely counterfactual situation in order to show the difference SIP 09 is expected to make. In the absence of a SIP 09 approach, a continuing low but increasing level of adoption of VRT was assumed but with lower profitability than achievable following SIP 09. The assumption recognises that SIP 09 was designed as a well coordinated national approach in contrast to the counterfactual characterised by a number of inefficient and independent small-scale efforts. SIP 09 was a catalyst able to synthesise what was being learnt in a range of regional applications and test and develop generic approaches. The major output of SIP 09 was the recently launched PA Manual, a CD being widely promoted in the grains industry. The major outcome will continue to be increasing areas of grain managed for increased profitability by VRT.

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