SOUTHERN REGION
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PROFIT FROM PRECISION AGRICULTURE

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GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

Rural Directions Pty Ltd

Think Agri Agri Expertise

> A SUMMARY OF CURRENT INFORMATION ON THE ECONOMIC VALUE OF PRECISION AGRICULTURE TOOLS IN THE GRDC SOUTHERN REGION

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INTRODUCTION

Precision Agriculture (PA) is now part of grain growing vernacular. PA as previously defined by GRDC is simply:

- doing the right thing
- in the right place
- in the right way
- at the right time.

Site Specific Management (SSM) refers to PA applications for precise broadacre paddock management and most of the technologies featured here fit under that banner. The base technology required is a navigation guidance system, georeferencing of data, and software to enable georeferenced data to be interrogated and synthesised into a usable map or prescription (GRDC 2006).

Adoption of relatively simple applications such as auto steer and auto-section control are in the order of 80% across the region with higher rainfall areas closer to 70% and medium and low rainfall regions between 80 and 90% (Umbers 2017). The rate of adoption has been higher than other PA practices such as yield mapping (Lewellyn and Ouzman 2015).

Adoption of other applications have been much slower, even if clearly demonstrated to provide value. These include variable rate application of fertiliser or soil ameliorants on different soil types across a paddock, yield monitoring and yield mapping to aid decision making, and selective spot spraying of weeds.

The slow adoption is despite considerable investment by GRDC in the Precision Agriculture Initiative from 2006 to 2010 and continued work by specialist groups such as Society of Precision Agriculture Australia (SPAA), regional farming systems groups and expert consulting businesses.

Impediments to adoption cited by growers and advisers include:

- a lack of compatibility between hardware and software across different machinery
- the management time required to capture, process, and interpret data
- the disconnect between machinery and hardware suppliers and agronomic advisers in some districts
- the real or perceived capital cost to adopt the practice
- a lack of observability- i.e not clearly observing the benefits over the fence.

The perceived lack of robust and independent evidence quantifying the economic value of PA tools or PA across the whole farm is also cited as a significant barrier to adoption (GRDC 2017).

This comes at a time when grain yield achievement (Ya) relative (Yr) to water limited potential (Yw) is often below a reasonably expected Yr of 80% of Yw with considerable variation between and within regions (Hochman et al 2016). For example, a survey of 52 southern region paddocks in 2015 and 2016 found 62% of paddocks achieved yields below 80% of Yw (Lawes et al 2018).

Profit and return on capital achieved by grain growers is also highly variable with the upper 20% of farm businesses achieving returns far greater than the average return (Figure 1).

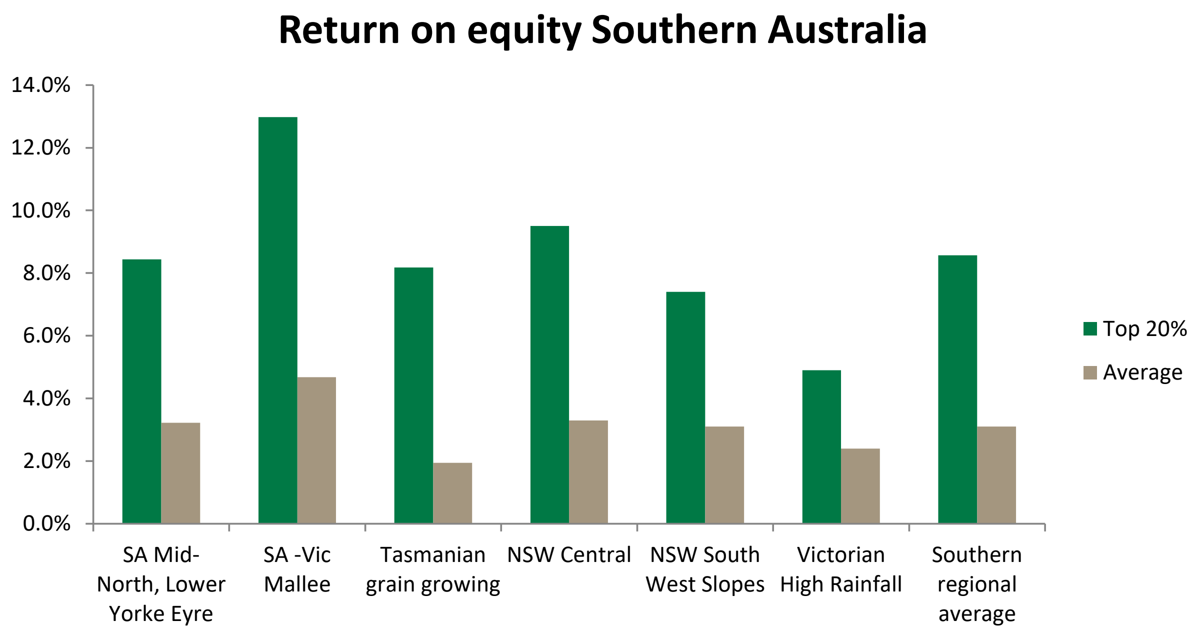

FIGURE 1. Return on Equity for 100 farm businesses in Southern Australia (GRDC RDP00013 2016)

The consistent trend of substantial variation in both profit achievement and grain yield among growers in similar environments demonstrates the opportunity for many growers to improve their bottom line and move closer to enduring profits.

PA applications can improve yield and or reduce the cost of production, thereby having a positive influence on profit when applied in the appropriate situation.

This document summarises those situations where PA can value to the farm business through either a clear economic contribution or through harder to quantify factors such as ease of use or improved timeliness.

An evidence-based approach (Barends et al 2014), was undertaken to assess PA profit gain opportunities as follows:

1. Relevant information from published research and industry case studies was sourced critically evaluated and combined with
2. Industry knowledge, experience and recent data to ensure relevance in today's crop production context, culminating in
3. A considered and practical appraisal of how PA can contribute to profit now and into the future.

ABOUT THIS PUBLICATION

This resource is for grain growers and their advisers who are asking:

How does Precision Agriculture (PA) improve farm business profit?

We summarise the situations and technologies where PA has improved the profitability of cropping systems within GRDCs Southern Region (Tasmania, South Australia and Victoria).

Precision Agriculture can mean many things to many people and is often interlinked with terms such as **digital agriculture**, **decision agriculture**, **big data**, and **agtech**. The glossary in Tool Box 1 unpacks some of these terms. For the purposes of this report PA is taken to mean the actual change in practice, rather than the data associated with that change.

The focus is on assessing economic value and contribution to profit. This is not a 'how to' manual for Precision Agriculture Tools. Toolbox 2 lists several excellent technical reference materials.

This report forms the first output of 'Assessing the economic value of precision agriculture tools for grain farming businesses in the Southern Region'. Subsequent outputs will include a management guideline, specific extension material with economic information for various PA applications, and a series of workshops on getting the most economic returns from PA adoption. These outputs will go into more depth on specific PA applications and economics.

The purpose of this publication and project is to focus on the relevant on-farm benefits of PA. Whilst there is further potential for supply chain, provenance, and environmental benefits from the adopting of other PA applications, these are not covered in this report and are beyond the scope of this project.

MORE ON FARM BUSINESS PROFIT GAIN OPPORTUNITIES

A recent GRDC funded analysis of 300 grain focused businesses across Australia between 2009 to 2013 identified common attributes among the most profitable business (GRDC RDP00013 2016). *Gross margin optimisation; low-cost business model; risk management;* and *people and management* were the four themes identified (Table 1). High performing businesses were strong in all four areas – simply being very strong at gross margin optimisation or having a lean business model was not enough.

Factors explaining the variation in financial returns include achievement of grain yield; management of both fixed and variable costs; efficient use of people, machinery and capital; the ability to withstand business shocks; considered and timely decision making; and implementation of operations.

Scale of operation and commodity price were poor explainers of performance, as was found in a similar study of Western Australian farms (Lawes and Kingwell 2012). While rainfall influenced grain yield in both studies, there was considerable variation among performance in similar districts, indicating the strong influence of farm management. Critically, the high performing business can be making more than double the returns of the average business.

PA must positively impact on at least one of the four profit drivers to consistently influence profit. There is also potential for an inappropriate focus on one profit driver to the detriment of others. For example, the pursuit of *gross margin optimisation* with high capital cost machinery can have a negative impact on the *low-cost business model* area, and result in poorer overall financial performance.

Another profit driver that is critical for successful implementation of PA is *people and management*. This is driven by having people with the right skills and motivation to implement PA accessible to the grower. This could be from within the farm team or through external service providers, but without the people element a strong economic impact from PA is unlikely.

TABLE 1. PROFIT DRIVERS IDENTIFIED FOR SOUTHERN REGION FROM A SURVEY OF 100 FARM BUSINESSES (GRDC RDP00013 2016)

PROFIT OPPORTUNITY	KEY MANAGEMENT CONSIDERATIONS
Gross margin optimisation (cost effective production)	Enterprise choice Crop rotation Timeliness of operations Sound agronomy driving high water use efficiency and yield Variable costs control Maximising quality
Low-cost business model (profit focus)	Overhead cost control Labour efficiency Machinery investment matched to business size Finance costs actively managed
Risk management	Able to withstand seasonal or other business shocks
People and management	Getting things done in a timely manner and to a high standard Clear and balanced decision making Systems and processes to support work flow

PA PROFIT PATHWAYS

PA alone will not overcome the major management considerations associated with the key profit drivers outlined in Table 1. In other words, it will not make up for deficiencies in other areas of the business, such as high cost structure, or poor agronomy. Yet evidence does support PA leading to economic gain in three pathways outlined below.

It's important to note that the contribution to profit will not be realised if the pathway to achieving the productivity gains compromises farm business cost structure. This can occur by over investment in machinery, increased labour, high cost of data acquisition, or compromised timeliness of key farm operations.

The three pathways identified that growers can take to improve profit with PA are:

Pathway 1. Strategic - Unlocking yield potential by cost effectively managing site specific soil constraints and/or enabling cost effective farming systems changes

- Examples include variable rate lime and gypsum, more precise drainage, subsoil amelioration, claying and delving planning
- Operations that are high cost are more targeted by only treating the responsive areas thus becoming economically viable
- PA is the enabler for the practice adoption and productivity uplift by identifying where to target large investment into capital projects
- PA also enables some strategic farming systems changes, that unlock multiple benefits beyond simply managing site specific soil constraints. For example, the adoption of inter-row sowing is a small change in itself, but could be the enabler of a controlled traffic farming (CTF)
- These projects often take more than one year to plan and implement, but have long term paybacks over many years, and can be transformative for the farm business.

The gains available here are generally of higher value than Tactical or Reactive categories

Pathway 2. Tactical - Achieving water limited yield potential in a cost-effective manner while managing production risk

- Examples include variable rate P, N, K, S and seeding rate, for site specific weed detection and control, on-row or inter-row sowing
- These tactics are often used each year with some minor refinements between seasons, but the same basic process is applied each year
- The gains are achieved by managing seasonal yield constraints and better managing between year variation, improved timeliness of operations and learning by doing (on farm test strips and trials to refine management approaches and facilitate adoption).

The gains available here are generally individually small but can collectively be significant.

Pathway 3. Reactive - Optimising quality and price and therefore increasing revenue

- Responding quickly to unplanned seasonal events to capture an opportunity or reduce a loss
- Examples include selective harvesting to manage frost damage, protein tracking to blend grain deliveries, patching out weedy or frosted areas for hay
- These applications are usually opportunistic and time sensitive and usually an added extra rather than the reason for implementing a PA practice.

Given their reactive nature, the gains here may be reduced if the extra labour or effort required exceeds the potential advantage.

Table 2 summarises typical constraints and opportunities that impact on profit in the GRDC Southern Region. These mostly relate to gross margin optimisation in the profit driver framework of Table 1.

TABLE 2. LIKELY SITUATIONS WHERE PA MAY CONTRIBUTE TO PROFIT

STRATEGIC	TACTICAL	REACTIVE
Unlocking yield potential by cost effectively managing site specific soil constraints and/or enabling cost effective farming systems changes	*Achieving water limited yield potential in a cost-effective manner while managing production risk*	*Optimising quality and price and therefore increasing revenue*
• Sodicity • Salinity • Acidity • Non-wetting sand • Compaction • Soil density • Soil texture • Waterlogging	• Soil nutrition • Matching yield potential to plant available water • Crop monitoring • Root disease management • Fallow management of weeds • In crop weed management	• Frost • Heat stress • Harvest management • Patchy weed infestations

ESTIMATING VALUE AND CONTRIBUTION TO PROFIT

Quantifying the economic value of PA is a challenge and the source of much debate. There are two main approaches that are used, and both have merit.

The *'Partial Budget'* approach involves assessing the change in practice and returns due to that change (GRDC RDP00013 2015). This can be a combination of change in cost and/or change in revenue. This is the simplest method of assessing economic value from PA adoption but has some weaknesses in dealing with the different results that can be achieved in different seasons. That said, partial budgeting is a good conservative starting point.

Variation between seasons (temporal variation) is generally greater than spatial (proximal) variation within fields so understanding the probabilities of achieving a benefit based on seasonal volatility could further enhance the partial budgeting approach.

'Whole Farm Analysis' is favoured by some to examine the impact, probability and profitability of the management change at the whole farm level over time. Generally whole farm benefits are assumed to be greater than those calculated in partial budget.

The challenge in whole farm analysis is that often paddock scale benefits are simply multiplied up to a whole farm level. This may be over or understating the variability between paddocks across the farm. The scale of variability is inconsistent – even at a paddock level. Across a farm there will not necessarily be a uniform benefit from adopting PA. This can further add to the complexity of decision making for PA, compared to the more 'one in all in' adoption decisions that apply across a farm, such as a new variety or moving to no-till (Lawes and Robertson 2011).

Where possible, we summarise both the monetary value using Partial Budgeting and/ or Whole farm analysis and the indirect (non-monetary) value including a qualitative judgement on likelihood of contribution to profit.

PA implementation requires dedicated *time and labour* in excess of normal farm operations. This could be in the data collection and analysis phase, the machine setup and monitoring, or the investigation phase. Economic analysis of the benefit needs to recognise the value of the time and labour that has gone into the project, even if it is internal family labour.

Recognising the *capital investment* required for PA is also important when assessing its economic value. Grain farms are capital intensive businesses, and profitable deployment of capital is critical for financial success. The investment of capital comes with an opportunity cost and this needs to be reflected in the economic analysis of any capital investment for PA.

Depreciation of PA equipment is another consideration. The nature of PA equipment is that there is a continued evolution, innovation and improvement in the technology that underlies it. This increases the speed at which previously useful equipment is superseded and potentially rendered obsolete. Allocating a minimum of 15% depreciation rate when costing PA equipment will account for this (GRDC RDP00013 2015).

The capital cost of the PA component of machinery varies considerably. For older technology like autosteer, the cost of accessing the technology is effectively built into the price of a machine. This results in a very low capital investment to access the tool itself. Some of the reactive PA applications such as selective harvesting for frost may have no capital outlay. For other tools such as pH mapping accessing capital is often done through using a contractor to complete the task. An example of a capital-intensive application of PA is the purchase of an optical spot sprayer for managing summer fallows. For capital intensive PA applications, adoption is often limited by scale and the ability to spread the cost.

OPERATIONAL TIMELINESS AND PA

Timeliness of all operations remains the major management related profit driver in the Southern Region, Timelly fallow management, earlier sowing and appropriate crop management all contribute to improving water use efficiency and yield (Robertson et al 2016). When PA improves timeliness it indirectly improves profitability.

PA can be an enabler for larger management units to increase work rate without sacrificing sound agronomy. As paddock sizes have increased to enable larger machinery to operate at greater field efficiency, PA is providing a means of continuing to treat different soil types or paddock history with integrity. Hence a grower can get more done without the potential missed opportunity of a blanket input approach.

Another improvement to timeliness can come in the form of strategic amelioration projects. Large capital inputs such as lime to treat acid soils, gypsum to treat sodicity, or clay spreading and delving on non-wetting sands are a substantial investment for a business, yet with large production gains possible. Adopting a PA approach to these projects will allow more efficient targeting of responsive areas.

For example, if the capital budget allows for 100ha of liming each year, a blanket approach may apply lime to 70ha of responsive soil types and 30ha of no response. Using PA to target 100ha of responsive soils each year effectively improves the timeliness of liming on 30ha, bringing forward the production benefits by a year on that area. For a 1,000ha farm this scenario would cover the whole farm in seven years rather than 10.

Further to this, the time period for reapplication could be increased by targeting problem areas with a more appropriate higher rate of lime the first time.

'Precision Monitoring' is an effective tool to reduce the risk of untimely monitoring constraining crop yield and profit. Thorough crop monitoring is critical to maximising water use efficiency by ensuring that in-season yield limitations are identified and addressed in a timely manner. Timeliness of crop monitoring can become a profit limiting factor as farm scale increases.

Understanding inherent spatial variability using data layers such as historic yield maps or imagery, or in season NDVI imagery can help growers and agronomists make better use of crop monitoring time. In season imagery can help target monitoring and sometimes provide an alert to an emerging issue before it is obvious at ground level in the paddock (e.g early stage N deficiency). When combined with ground truthing, earlier intervention may occur. Conversely, relying entirely on remote sensing of crop growth differences to identify anomalies and prompt action can be too late for early weed infestations or insect damage that can cap yield potential (and profit) in the crop establishment phase.

PA can have a negative impact on timeliness and therefore profit when it's not implemented well. This can occur by:

- increasing complexity of an operation
- misplaced priorities (taking time to setup for the last 1% gain at the expense of getting the job done)
- creating a system that is heavily reliant on technology that is prone to greater downtime when things aren't working.

The increasingly sophisticated electronics involved in farm machinery is taking much of the maintenance and repair away from the grower. The result is that problems can take longer and cost more to fix, whereas in times past growers were able to identify and rectify basic mechanical issues and get on with the job.

ON-FARM LEARNING

A further indirect benefit from PA is the ability to conduct trials and test new approaches on an individual farm. This can be used in a multitude of ways from variety selection and fertiliser strategy, through to higher cost soil amelioration projects. The nature of PA also requires a level of curiosity into the underlying constraints in a paddock.

The process of exploring these constraints is a fantastic learning tool and can increase the rate of adoption of new practices. In this way there can be value in exploring spatial data to assist with identifying and solving a problem, even if it does not lead to a move to a more targeted or variable rate approach.

A PROFIT FIRST, PA SECOND APPROACH

The financial gain from PA is best optimised by identifying the farm business profit opportunities first, then considering if a PA practice can help realise that opportunity more effectively. Table 3 explains the steps to that approach along with an example.

TABLE 3. THE PROFIT OPPORTUNITY FIRST APPROACH

STEPS TO IDENTIFYING PA PROFIT GAIN OPPORTUNITIES	EXAMPLE
1. Understand profit gain opportunities for the farm business using the profit drivers framework (Table 1)	We have low pH soils limiting yield potential in some but not all areas on the farm
2. Does PA have a role in addressing those constraints?	Soil types are variable within paddocks so variable rate application of lime could be an option
3. Determine the cost and benefit of implementing the PA practice using a partial budget approach	A partial budget analysis compares using PA or not, (e.g VR lime v Uniform spreading) to address the issue
4. Are there other benefits to consider?	Lower liming costs will mean more paddocks can be amended in one season
5. Does the business have the capacity to usefully implement?	The PA profit ready check list in Tool Box 3 is a good place to start

The likelihood of PA effectively contributing to profit will vary for each individual farm business and each potential application due to the physical farm attributes, current equipment base, and seasonal, market and input price conditions. In other words, the odds of a PA application contributing to profit is very situational.

Paddock variability plays a major role in determining the economic benefits from PA adoption. If there is insufficient variability within a paddock, then there is unlikely to be a strong business case for the effort and expense of a site-specific approach to soil amelioration or crop nutrition. Paddock variability of 10 to 15% co-efficient of variation (CV) is often enough to expect a financial benefit from managing the variability while CV > 15% is considered highly likely to achieve a financial payback from managing the variability. The extent of variability required to warrant spatial management will also be dependent on crop type and value (Sauer *et al* 2013).

Data layers that contribute to an understanding of paddock variability include yield maps and remote images such as satellite derived NDVI maps and soil surveys as well as farmer knowledge.

Care is required when using any of these spatial variability maps as they require ground-truthing to ascertain the reason for the variability. Visual assessment of the crop, soil and tissue testing, and soil surveying can all be useful to determine the underlying cause of the variability. This investment in ground-truthing makes up part of the cost of implementing PA but is an important stage in the process.

The size of the cost or benefit to be realised will also influence how much variability is required to make a PA approach economically worthwhile. A high cost per hectare treatment such as claying requires relatively little variability to show a benefit from PA if it can be targeted more effectively. A relatively low-cost saving per hectare treatment such as site-specific spot spraying of weeds requires much higher levels of spatial variability to achieve an economic benefit. This also demonstrates why the relative economic gains to be made from the Strategic PA pathway tend to be larger than the Tactical PA pathway.

The benefit from smaller cost saving items is greater where the targeted intervention increases yield or prevents yield loss (Trengove 2018). An example of this using PA derived soil variability knowledge to inform where to apply lower rates of metribuzin on sandy soils and higher rates on heavier soils in the same paddock. The financial benefit comes from avoiding yield loss caused by metribuzin induced crop damage rather than the small savings in herbicide.

UNDERSTANDING YOUR REGION

The Southern Region has a diverse array of soil types, climates, and farming systems. The economic value and opportunity of PA tools for each farm business in the region will vary accordingly. This section looks at the broad issues affecting different zones within the region, and where PA is likely to have the highest impact on profit for each zone.

GRDC divides the Southern Region into three broad zones based on high, medium and low rainfall (Figure 3). These can then be split further into subregions based on soil type and landscape.

Table 4 summarises the soil type and farming system attributes affecting grain yield in each zone and Table 5 summarises the most likely fit of PA applications in each zone. These tables were derived by identifying the highest and lowest impact opportunities for each region utilising the judgement and experience of the steering committee combined with available published evidence. It is not intended as an exhaustive list or definitive analysis. It aims to illustrate the degree of prevalence of an issue within a subregion rather than the complete presence or absence. This is intended as a quick reference guide to what may be impacting profit in your zone, so that the highest priorities can be recognised.

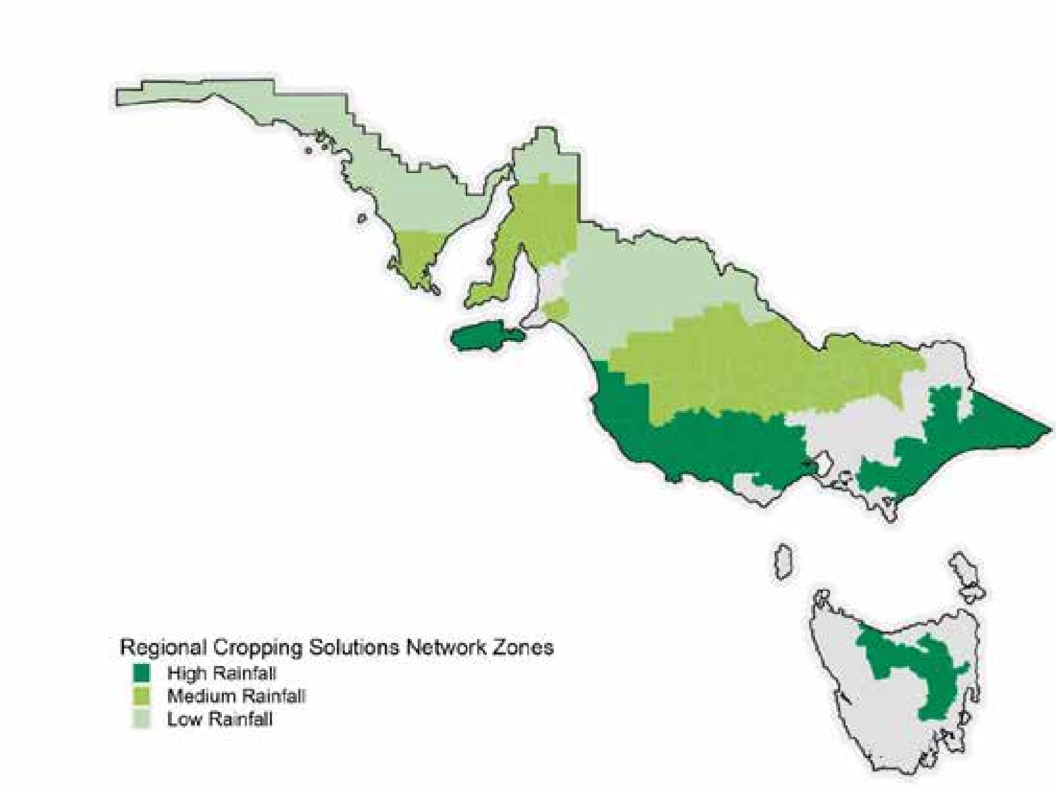

FIGURE 3. GRDC Southern Region and rainfall zones

TABLE 4. DISTRIBUTION OF SOIL TYPE ATTRIBUTES AND SOME MAJOR FACTORS KNOWN TO INFLUENCE GRAIN YIELD ACROSS THE SOUTHERN REGION

RAINFALL ZONE	SUBREGION	PAW	SANDY SOILS	ACID SOIL	SALINITY	SODICITY	WATER LOGGING	COMPACTION	NPKS NUTRITION	FALLOW MANAGEMENT	HERBICIDE RESISTANCE	FROST	HEAT STRESS
Low	Upper EP		√			√		√			√	√	√
	Western EP		√			√		√			√		√
	Upper North		√	√	√	√		√			√	√	√
	SAVIC N Mallee		√		√	√		√			√	√	√
	SAVic S Mallee		√		√	√		√			√	√	√
	Vic C Mallee		√		√	√		√			√	√	√
Medium	Lower EP		√	√	√	√	√	√			√	√	
	Central YP		√					√			√		
	Lower YP		√		√			√			√		
	Northern YP - Mid North	All zones	√	√	√	√		√	All zones	All zones	√	√	√
	Wimmera-Bordertown		√		√	√	√	√			√	√	√
	SA Upper South East		√	√	√	√		√			√	√	√
	Central Vic			√	√	√	√	√			√	√	√
	Nth Central Vic			√	√	√		√			√	√	√
High	SA Lower South East + Kangaroo Island		√	√	√	√	√	√			√		
	Southern Vic			√	√	√	√	√			√	√	√
	North East Vic slopes			√	√	√	√	√			√	√	√
	Tas Grain			√		√	√	√			√	√	

TABLE 5. SPECIFIC PA APPLICATIONS THEIR LIKELY CONTRIBUTION TO PROFIT ACROSS THE REGION BASED ON SUITABILITY AND AREA AFFECTED (GREEN - HIGHLY LIKELY; YELLOW- SOMETIMES LIKELY; ORANGE - LESS LIKELY)

		STRATEGIC					TACTICAL							REACTIVE		
RAINFALL ZONE	SUBREGION	Drainage mapping	Zoned claying/ delving	Zoned ripping/ spading	Zone management through variable rate application of:				Vehicle autosteer	Implement steering (Protrakker)	Compaction management with CTF	Inter-row or on-row sowing	Site specific weed detection and control	Decision support for soil & crop monitoring	Mapping weeds	Protein Mapping
					Lime	Gypsum	Seed	N, P, K, S								
Low	Upper EP	Orange	Green	Green	Orange	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Western EP	Orange	Green	Green	Orange	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Upper North	Orange	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	SAVIC N Mallee	Orange	Green	Green	Orange	Yellow	Green	Green	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	SAVic S Mallee	Orange	Yellow	Yellow	Orange	Green	Green	Green	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Vic C Mallee	Orange	Yellow	Yellow	Orange	Green	Green	Green	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
Medium	Lower EP	Green	Green	Green	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Central YP	Orange	Orange	Orange	Yellow	Orange	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Lower YP	Orange	Yellow	Orange	Orange	Orange	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Northern YP - Mid North	Orange	Yellow	Yellow	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Wimmera-Bordertown	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	SA Upper South East	Orange	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Central Vic	Green	Orange	Green	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Nth Central Vic	Yellow	Orange	Green	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
High	SA Lower South East + Kangaroo Island	Green	Yellow	Yellow	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Southern Vic	Green	Orange	Green	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	North East Vic slopes	Green	Orange	Green	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
	Tas Grain	Green	Orange	Green	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow

A REVIEW OF THE ECONOMIC VALUE OF PA APPLICATIONS

This section collates previously published economic studies. The criteria for inclusion were full accounting of costs including capital outlay, depreciation, labour and operational costs as described earlier. Previously reported benefits based on anecdotes are not included. We have focused on Strategic and Tactical pathways to profit. The reactive pathway by nature is more variable and situational and will be demonstrated later in this project through case studies.

PA PROFIT PATHWAY 1		STRATEGIC - UNLOCKING YIELD POTENTIAL BY COST EFFECTIVELY MANAGING SITE SPECIFIC SOIL CONSTRAINTS			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?
IMPROVING PAWC- **SOIL PH AND LIME APPLICATION**	Low Soil pH areas: **LRZ** Upper North **MRZ** Lower EP NYP Mid North SA Upper SE Central Vic Nth Central Vic **HRZ** SA Lower SE + KI Vic Sth NE Vic slopes Tas Grain	Improving PAWC and thus crop or pasture production by increasing soil pH above 4.8 (CaCl2) is common practice Liming acidic soils needs to be maintained and potentially increased to counteract acidification over time In SA, VR liming is increasing but only across 6% of suitable areas thus far (Harding et al 2018) In Vic, VR liming adoption is increasing but there is significant potential for further adoption	• Soil pH spatial variability is mapped and lime is applied at varying rates depending on soil pH responsiveness • As a high capital cost activity, liming is more cost effective through targeted zone management and VR • Profit gains come from: • unlocking yield potential by addressing soil acidity and improving PAWC (e.g 15% to 50% yield response depending on crop type and starting pH in SW Vic) (Miller 2015) • more efficient allocation of expenditure increasing marginal return on investment and reducing the payback period • applying lime to areas that would not have been treated in the absence of spatial pH data	• Lime savings of 30 to 75% in NE and SW Vic, with 10% being required to cover the cost of the mapping process (Whitlock 2015; SPAA 2011) • $16-$73/ha from lime savings case studies in 2016 (RDP00013a 2016) • Oliver *et al* (2010) estimated 1 to 2 year payback period from VR liming in WA wheat belt when yield response to liming was included in the analysis	• Level of variability in soil pH and lime responsiveness across a paddock or farm • Water limited yield potential-(Higher pay offs in high rainfall zones) • Cost and access to lime product. Not readily available in some areas, so there is value allocating limited tonnages to the most responsive parts of the farm • Access to a variable rate lime spreader (although not essential)

PA PROFIT PATHWAY 1		STRATEGIC - UNLOCKING YIELD POTENTIAL BY COST EFFECTIVELY MANAGING SITE SPECIFIC SOIL CONSTRAINTS			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?

DRAINAGE MAPPING TO ADDRESS WATER LOGGING	High Rainfall regions and low-lying areas prone to water logging in Medium Rainfall zones
	MRZ
	Lower EP
	Wimmera-Bordertown
	Central Vic
	HRZ
	SA Lower SE + KI
	Vic Sth
	NE Vic slopes
	Tas Grain
		Several commercial PA providers particularly those servicing the HRZ, provide drainage management advice based on PA technology in Southern and NE Victoria and in Tasmania and SE South Australia	• Paddock areas prone to crop loss through water inundation are reclaimed through data derived and well-planned drainage
			• Elevation maps and water movement simulation are used to plan effective drainage or divert water before in reaches low lying areas
			• As an often-high capital cost activity, benefits are derived from allocating costs effectively and ensuring maximum return on investment
			• Profit gains come from:
			  • unlocking yield potential of areas prone to inundation water logging
			  • increased trafficability improving timeliness of operations
			  • more efficient allocation of expenditure (by putting the drains in the right spots) increasing marginal return on investment and reducing the payback period
			  • removing the need for raised beds in some situations, reducing capital costs
			  • more efficient fertiliser use through less denitrification losses (Whitlock and Torpy 2017)
				No published economic studies were found	• The relative area of productive land prone to inundation and water logging
					• The frequency of which inundation occurs
					• Cost of acquiring drainage simulation and cost of drainage works

PA PROFIT PATHWAY 1		STRATEGIC - UNLOCKING YIELD POTENTIAL BY COST EFFECTIVELY MANAGING SITE SPECIFIC SOIL CONSTRAINTS			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?
IMPROVING PAWC- **RIPPING DENSE OR COMPACTED SUBSOIL**	Sandy or poorly structured duplex soils within: **LRZ** Upper EP Western EP Upper North SA/Vic N,S,C Mallee **MRZ** Lower EP Central YP Lower YP NYP Mid North SA Upper SE Central Vic Nth Central Vic **HRZ** SA Lower SE + KI Vic Sth NE Vic slopes Tas Grain	Ripping to open up subsoils has been sporadically adopted throughout the decades (Sale et al 2016) Ripping is used to reduce compaction in sandy soils; reduce hard pan in duplex soils and to facilitate root growth in dense subsoils with varied levels of success (Sale et al 2016) Overall adoption is relatively low	• Soil type variability, clay content and depth to clay is mapped to identify areas that may respond to ripping. Identify areas containing toxic levels of Boron, Sodium, Chloride or Aluminium, that may need to be avoided so as not to bring toxic soil to the surface • Profit gains come from: • unlocking yield potential and improving PAWC through increased rooting depth in the most cost-effective manner possible • more efficient allocation of expenditure increasing marginal return on investment and reducing the payback period • reduced risk of bringing problem soils to the surface by treating inappropriate areas	While studies have demonstrated the economic impact of ripping application per se in sandy soils (Hall 2017); no studies reporting the economics of using PA to target dipping depth and area were found	• Cost of data layers • Access to equipment or skilled contractors to carry out ripping • Cost of amelioration relative to yield potential and income gains - payback is shorter where the yield gap is the greatest, often in higher rainfall zones • Complicated relationships exist between the soil survey factors and identifying responsive soils. Care needs to be taken interpreting data and a pilot approach is useful before full scale remediation is undertaken • Increasing the length of benefit by avoiding re-compaction

PA PROFIT PATHWAY 1		STRATEGIC - UNLOCKING YIELD POTENTIAL BY COST EFFECTIVELY MANAGING SITE SPECIFIC SOIL CONSTRAINTS			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?

IMPROVING PAWC-
 	
SOIL STRUCTURE AMELIORATION WITH GYPSUM
	Areas where sodicity is a constraint within
	
	LRZ
	Upper EP
	Western EP
	Upper North
	SA/Vic N,S,C Mallee
	
	MRZ
	Lower EP
	NYP Mid North
	SA Upper SE
	Central Vic
	Nth Central Vic
	
	HRZ
	SA Lower SE + KI
	Vic Sth
	NE Vic slopes
	Tas Grain
		Increasing PAWC and trafficability through the application of gypsum is common practice for high density, dispersive clay-based soils, many which are sodic (Sale et al 2016)
		
		Variable rate application of gypsum is known to occur in Northern Victoria and southern NSW but the extent of adoption across the region is unknown
			• Spatial variability of soil type and gypsum responsiveness is mapped, and gypsum is applied at varying rates to amend sodicity or dispersiveness due to low Ca relative to magnesium
			• As a high capital cost activity, gypsum application is more cost effective through targeted zone management and VR
			• Early season NDVI maps can be a useful indicator of sodic topsoil if poor crop emergence or vigour is related to sodicity
			• Profit gains come from:
			  • unlocking yield potential by reducing soil sodicity and improving PAWC
			  • increased trafficability and improving timeliness of operations
			  • more efficient allocation of expenditure increasing marginal return on investment and reducing the payback period
				Studies reporting on the economics of using PA for soil amelioration with gypsum were not found	• Level of variability in sodicity or soil dispersiveness across a paddock or farm
					• Cost and access to gypsum product. It is not readily available in some areas, so there is value allocating limited tonnages to the most responsive parts of the farm
					• Access to a variable rate gypsum spreader

GRDC

PA PROFIT PATHWAY 1		STRATEGIC - UNLOCKING YIELD POTENTIAL BY COST EFFECTIVELY MANAGING SITE SPECIFIC SOIL CONSTRAINTS			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?

IMPROVING PAWC-
 	
SOIL STRUCTURE AMELIORATION WITH ANIMAL MANURE BY SURFACE APPLICATION
	Areas where sodicity is a constraint, and manure is available within
	
	LRZ
	
	Upper EP
	
	Western EP
	
	Upper North
	
	SA/Vic N,S,C Mallee
	
	MRZ
	
	Lower EP
	
	NYP Mid North
	
	SA Upper SE
	
	Central Vic
	
	Nth Central Vic
	
	HRZ
	
	SA Lower SE + KI
	
	Vic Sth
	
	NE Vic slopes
	
	Tas Grain
		Surface application of animal manure can increase PAWC and trafficability in high density clay soils (Armstrong et al 2007;2015)
		
		Adoption is restricted by high tonnages required and subsequent cost of freight and handling
		
		Is increasing in popularity in northern and southern Victoria on duplex soils
			• Spatial variability of soil type and responsive to manure is mapped and manure is applied at varying rates to amend sodicity or dispersiveness due to low Ca relative to Magnesium or high Na%
			
			• As a high capital cost activity, manure application is more cost effective through targeted zone management and VR
			
			• Profit gains come from:
			
			  • unlocking yield potential by reducing soil sodicity and improving PAWC
			
			  • increased trafficability improving timeliness of operations
			
			  • more efficient allocation of expenditure increasing marginal return on investment and reducing the payback period
			
			• There may also be a nutrient response in some years (Celestina et al 2018)
				Studies specifically reporting on the economics of using PA for soil amelioration with animal manure were not found	• Level of variability in sodicity or soil dispersiveness across a paddock or farm
					
					• Cost and access to manure product. Not readily available in some areas, so there is value allocating limited tonnages to the most responsive parts of the farm
					
					• Access to a variable rate manure spreader

PA PROFIT PATHWAY 1		STRATEGIC - UNLOCKING YIELD POTENTIAL BY COST EFFECTIVELY MANAGING SITE SPECIFIC SOIL CONSTRAINTS			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?

IMPROVING PAWC-
 	
AMELIORATING WATER REPELLENT SANDS VIA CLAYING, DELVING, SPADING OR INVERSION
	Areas of non-wetting soil within:
	
	LRZ
	
	Upper EP
	
	Western EP
	
	Upper North
	
	SA/Vic N,S,C Mallee
	
	MRZ
	
	Lower EP
	
	Central YP
	
	Lower YP
	
	NYP Mid North
	
	SA Upper SE
	
	Wimmera-Bordertown
	
	HRZ
	
	SA Lower SE + KI
		First adopted in the 1990s in SE SA and far western Victoria, clay spreading and delving per se have been used to improve non-wetting (water repellent) sands for many years. There remain further areas to treat across the southern region
		
		There has been limited adoption of PA tools for mapping to improve efficiency of clay spreading and delving
			• Spatial variability of soil type including location and depth of clay is mapped from EM or gamma radiometric surveys
			
			• Spading, clay spreading and clay delving zones are identified
			
			• Delving is cheaper than clay spreading, and results in significant savings
			
			• New delving technology can adjust depth based on a prescription, enabling 'VR delving'
			
			• Profit gains come from:
			
			  • unlocking yield potential and improving PAWC in the most cost-effective manner possible
			
			  • improving crop competitive ability against weeds
			
			  • more efficient allocation of expenditure increasing marginal return on investment and reducing the payback period
			
			  • more even wetting aids patch management of weeds through crop competition
				Little data is available on the economic contribution of PA to this practice	• Cost of data layers
					
					• Access to equipment or skilled contractors to carry out claying/ delving
					
					• Cost of amelioration relative to Yield potential and income gains -payback is shorter in higher rainfall zones
					
					• Complicated relationships exist between the soil survey factors and identifying responsive soils. Care needs to be taken interpreting data and a pilot approach is useful before full scale remediation is undertaken

GRDC

PA PROFIT PATHWAY 1		STRATEGIC - UNLOCKING YIELD POTENTIAL BY ENABLING COST EFFECTIVE FARMING SYSTEMS CHANGE			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?

AUTOSTEER	All regions	Adoption is generally high across the Southern Region, with higher rainfall areas close to 70% and medium and low rainfall regions between 80 and 90% (Umbers 2017)	• There is an initial benefit on reduced overlap and input savings
			• Secondly and more significantly in the long term, steering guidance enables defined farming systems changes (e.g CTF) and high impact "systems type" integrated crop management practices that contribute to a flexible adaptive approach to optimising yield potential and managing risk
			• Examples of systems type actions include
			  • interrow weed control as part of IWM via shielded spraying or interrow cultivation
			  • stubble management through interrow sowing (IRS)
			  • trellising of lentils through IRS into stubble and improving harvestabilityo
			  • on or near row sowing to capture moisture or access residual nutrients
			  • IRS to reduce root disease risk
			• Such actions widen crop choice and provide a more robust crop rotation
			• Other gains come from increasing workrate from reduced operator fatigue and enabling night operations
				• Overlap savings of $2-$16/ha have been recorded (SPAA 2008)
				• Systems changes are very difficult to quantify
					• Equipment capable of autosteer
					• Higher input costs per ha will result in greater savings from overlap
					• Proactive and opportunistic approach to utilise precision steering for a crop management opportunities as they emerge

PA PROFIT PATHWAY 1		STRATEGIC - UNLOCKING YIELD POTENTIAL BY ENABLING COST EFFECTIVE FARMING SYSTEMS CHANGES			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?
IMPROVING TRAFFICABILITY AND MOISTURE INFILTRATION WITH CTF	All regions	Controlled traffic farming is increasing across the region but remains low. Adoption levels range from 5-50% by subregion in 2016 (Umbers 2017)	• Precision use of traffic across a paddock to reduce compaction and improve trafficability • Preservation of benefit from other amelioration tools such as ripping • Profit gain comes from increased yield from improved moisture infiltration, reducing run off, increased porosity and improved work rates and timeliness when conditions are wet	• A void of economic data for the Southern region • In WA $36/ha assuming 5% yield gain with 2 year payback for $200K machinery investment (Kingwell and Fuchsbichler 2011) • Payback period is highly dependent on capital invested, expected yield increase and location (soil type and yield potential) (Blackwell et al 2016)	• Soil types with an ability to store large amounts of moisture • Equipment that is already partly aligned for CTF (to reduce capital outlay) • The base level of random traffic occurring on the paddock which determines the relative benefit remaining

PA PROFIT PATHWAY 2		TACTICAL - ACHIEVING WATER LIMITED YIELD POTENTIAL IN A COST-EFFECTIVE MANNER WHILE MANAGING PRODUCTION RISK			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?

IMPROVED PHOSPHOROUS (P)MANAGEMENT	Anywhere in the region with enough variability.	Adoption of VR P varies widely across the region. In dune/ swale land systems where variability is easily seen adoption levels are as high as 70% in the Vic Mallee (GRDC 2016). Lower adoption regions such as Wimmera were less than 33%	• Variability in soil type and P status is mapped and P rate zones are derived
			• Yield maps, previous NDVI maps, soil testing and soil survey methods can all be used to define zones
			• Profit gains come from:
			  • more efficient allocation of expenditure increasing marginal return on investment
			  • potential yield response in some zones
				• Variable cost savings of -$5 to $13/ha (RDP00013 2015)
				• Variable cost savings of $5-$10/ha (McCallum 2008)
				• Variable cost savings of $7/ha (Robertson et al 2007)
				• Profit gains from yield responses are not included in the above analyses
					• Cost of data layers to define zones
					• Sufficient variability within the paddock to drive responses
					• Clearly defined zones
					• VR Capable equipment
					• High fertiliser prices increases likelihood of a return from VR application
					• Soil types that are highly P responsive are more likely to provide an economic gain

IMPROVED POTASSIUM (K) MANAGEMENT	**LRZ**
	SA/Vic N, Mallee
	MRZ
	Lower EP
	SA-Mid North
	SA Upper SE
	Wimmera-Bordertown
	HRZ
	SA Lower SE + KI
	Vic Sth
	NE Vic slopes
	Tas Grain
		Lightly textured acidic soils can be deficient in K. Variable rate application of K fertiliser occurs to a limited extent in southern Victoria
		There is generally low adoption of utilising gamma radiometry to detecting spatial variation of potassium in Eastern Australian
			• Soil type variability is mapped and differences in K may occur
			• Greater precision in K mapping is possible using via gamma radiometry (Wong et al 1999)
			• K fertiliser is applied at variable rates according to yield responsiveness
			• Profit gains come from:
			  • more efficient allocation of expenditure increasing marginal return on investment
			  • unlocking yield potential in K deficient zones that may not have been treated if uniform K application was the only option
				• Cost -benefit studies of PA to define and manage K variability were not found. (Several studies lumped VR N P K together without dissecting where the benefit was derived from)	• Cost of soil surveys to define zones
					• Sufficient variability within the paddock to drive responses
					• Clearly defined zones
					• VR Capable equipment
					• High fertiliser prices increase likelihood of a return from VR application

PA PROFIT PATHWAY 2		TACTICAL - ACHIEVING WATER LIMITED YIELD POTENTIAL IN A COST-EFFECTIVE MANNER WHILE MANAGING PRODUCTION RISK			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?

IMPROVED N MANAGEMENT	Anywhere in the region with enough variability	Adoption of VR N varies widely across the region. In dune/swale land systems where variability is easily seen adoption levels are higher than in more visibly uniform land types
		
		As the cost of lab analysis decreases more intensive grid sampling may increase adoption of VR fertiliser
			• Distinct N management zones are derived from a range of data layers (e.g yield maps, previous NDVI maps, optical sensors, soil testing and soil survey methods can all be used to define zones)
			• N application strategy (timing and rate) is tailored to each zone according yield potential and soil N status
			• Profit gains come from:
			  • more efficient allocation of N fertiliser expenditure and greater marginal return on investment
			  • previously unrealised yield potential on higher yield potential zones in favourable years
			  • reduced risk of haying off on lower yield potential areas in drier years
			  • possibly improved grain quality through protein manipulation
				Payback from increased yield of $8/ha (RDP00013 2015)
				
				This highlights that VR nitrogen is highly applicable to paddocks with high spatial variability in order to maximise yield and/or ROI in individual paddock zone
					• The ability to combine seasonal climate forecasting information and plant available water status into potential yield estimation for each management zone
					• Seasonal variability of nitrogen demand is often greater than spatial variability – see estimating yield potential
					• VR capable equipment

PA PROFIT PATHWAY 2		TACTICAL - ACHIEVING WATER LIMITED YIELD POTENTIAL IN A COST-EFFECTIVE MANNER WHILE MANAGING PRODUCTION RISK			
PROFIT OPPORTUNITY	**MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE**	**ADOPTION STATUS**	**WHAT'S THE PA VALUE PROPOSITION?**	**REVIEW OF ECONOMIC STUDIES**	**WHAT INFLUENCES SUCCESS?**
ESTIMATING YIELD POTENTIAL BY UNDERSTANDING SEASONAL AND SPATIAL VARIATION	Has region wide application	Adoption of zone based plant available water monitoring and yield estimation is thought to be low across the region Practical incorporation of likely seasonal outcomes based on previous years performance using PA tools is low	• Soil PAWC is mapped from a range of data layers (yield maps, NDVI ,EM survey) and management zones are defined • Historical data is used to understand yield performance in varying seasonal variation • Current season yield range is estimated using real time NDVI and PAW status relative to historical data • Yield range is refined using with Seasonal Climate information • Profit comes from: • improved likelihood of ROI from N or fungicide • Improved risk management in general and increased confidence in managing grain sales and insurance positions	No studies were found that specifically measured the marginal benefit of the PA contribution to managing seasonal and spatial variation in yield potential	• Understanding the likely performance of zones relative to seasonal conditions • Incorporation with climate driver and seasonal forecast decision support • Thorough knowledge of soil N supply in each management zone each season

PA PROFIT PATHWAY 2		TACTICAL - ACHIEVING WATER LIMITED YIELD POTENTIAL IN A COST-EFFECTIVE MANNER WHILE MANAGING PRODUCTION RISK			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?

FALLOW MANAGEMENT OF WEEDS	Has region wide application	Fallow management has been a driver of improved water use efficiency in the past decade
		
		More recently the ability of optical sensor spraying technology to precisely target weeds in a paddock has become available. Adoption has been relatively strong in the Mallee, whilst other regions have been slower to take it up
			• Optical sensors (camera spray technology) control nozzle function to target individual weeds or green patches
			• Profit comes from:
			  • reduced herbicide costs
			  • improved control of hard to kill weeds - higher herbicide rates can afford to be used on a small spray area)
				Including capital cost results ranged from -$2/ha to $4/ha from variable costs savings ha (RDP00013 2015)	• The dependence of the farm on fallow weed control to store moisture
					• Cost of herbicide program
					• Likelihood of multiple sprays in a given fallow period
					• Accessing the technology in a low capital manner (scale or contracting)

GRDC

PA PROFIT PATHWAY 2		TACTICAL - ACHIEVING WATER LIMITED YIELD POTENTIAL IN A COST-EFFECTIVE MANNER WHILE MANAGING PRODUCTION RISK			
PROFIT OPPORTUNITY	**MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE**	**ADOPTION STATUS**	**WHAT'S THE PA VALUE PROPOSITION?**	**REVIEW OF ECONOMIC STUDIES**	**WHAT INFLUENCES SUCCESS?**
MANAGING HERBICIDE RESISTANT OR OTHER DIFFICULT TO CONTROL WEED POPULATIONS	Has region wide application	Herbicide resistance is a threat in all regions. There is relatively low adoption of PA tools for the purpose of managing herbicide resistance or hard to control weed populations	• RTK accurate autosteer combined with wide rows facilitates shielded spraying of non-selective herbicides in some crops • Mapping the populations of difficult to kill weeds using sensors or NDVI maps enables targeted application of higher cost herbicide strategies • Economic responses of patch management are impacted by efficacy, target species, cost of herbicide, and weed density (Trengove 2016) • PA enabled novel weed control options reduces the impact of weeds on crop rotation and improves the robustness of the cropping sequence	• Saved variable costs estimated to save $13/ha with shielded spraying (SPAA 2011) • Saved herbicide costs from patch management varied from $5.42-$15.30/ha depending on herbicide approach (Trengove 2013)	• Important of herbicide resistance on profitability • Ability to integrate other tools to reduce reliance on herbicides (strategy shouldn't solely focus on herbicides) • Stable location of weed patches between years • Ability to accurately develop a weed map. The benefit is lost is escapes persist • Crop types suited to shielded spraying (wide row options)

PA PROFIT PATHWAY 2		TACTICAL - ACHIEVING WATER LIMITED YIELD POTENTIAL IN A COST-EFFECTIVE MANNER WHILE MANAGING PRODUCTION RISK			
PROFIT OPPORTUNITY	MOST LIKELY APPLICABLE PLACES IN SOUTHERN ZONE	ADOPTION STATUS	WHAT'S THE PA VALUE PROPOSITION?	REVIEW OF ECONOMIC STUDIES	WHAT INFLUENCES SUCCESS?
STREAMLINING CROP MONITORING	All regions	Adoption of targeted crop monitoring is increasing as tools like NDVI imagery are more readily available. there is considerable opportunity for further adoption as the trend for increasing area under management per farm business	• Larger farms require efficient and targeted crop monitoring techniques to monitor crop health, moisture status, and pest and weed impacts • Using yield maps, NDVI maps or soil surveys to identify or quantify variability in crop to target monitoring • More effective use of monitoring time • Potential to identify and treat problems and opportunities earlier	Anecdotal evidence but no published economic information found	• Effective ground truthing of issues • Timely delivery of imagery at a useful resolution • Not solely relying on targeted monitoring to ensure nothing falls through the gaps

FUTURE PA PROFIT OPPORTUNITIES

PA is constantly evolving, and future opportunities will be defined by a combination of access to new technology, decreasing cost of existing technology, and the emergence of new challenges and opportunities within the farming system.

Llewellyn and Ouzman (2015) highlighted the broad adoption of early stage PA such as autosteer, with 79% and 74% adoption in SA and Victoria respectively (Tasmania was not surveyed). This had jumped significantly from approximately 30% in 2005 and demonstrates the increasing adoption of a technology as the cost decreases and it becomes embedded into existing equipment. This highlights that for current technology such as optical spot sprayers, which are relatively new and expensive, adoption should continue to increase as the cost of technology comes down over time.

There is also potential for evolution of new PA applications as new farming system challenges emerge. As an example, frost has become an increasingly important issue for many growers in the Southern Region in the past decade. This is prompting some to exploit elevation maps as a way of monitoring and subsequently managing frost damage spatially.

This highlights a need for growers to regularly review their position on individual PA tools and applications. Something that may have been deemed unviable 5 years ago may now have a clear financial benefit due to decreasing cost of the technology, or a change in the importance of the issue to their business.

The continued development of new sensing technology will undoubtedly influence PA in the future. As new sensing information emerges, it will provide huge value if it can be integrated to provide greater insight into crop production. When coupled with the increasing computing power available to analyse and interrogate data, more diagnostic and predictive tools will emerge. An example of this is the development of stress indices that can help to pinpoint what is going on in a crop. Whilst not commercial yet it is a matter of time before this information is available (Humpal et al 2018). If this information can be deployed spatially there are endless PA opportunities that could result.

Underlying almost all decision making in cropping is the need to better understand Plant Available Water Capacity (PAWC). There would be a substantial opportunity to improve decision making and profitability if a more granular and real time approach could be taken to understanding PAWC, and how full the profile is at any given time. Continued development of soil and plant sensors in this area would be of huge benefit, as this could provide a direct link to yield estimation.

Recently there has been a step change in the accessibility of low-cost (sometimes free), high resolution NDVI imagery that growers can access at any time on their tablet or computer. This will help to expose underlying paddock variability that is not always obvious, and this increased awareness will likely drive the development of new PA applications that aren't currently known. The accessibility of this imagery is the key driver, as previously it was often yield maps that are only available at the end of the year that enabled growers to see just how variable their paddocks are.

The other advantage of this imagery is the ability to get relatively simple responsiveness strips done in a paddock to guide decision making and have an objective way of checking the response. This can improve nitrogen fertiliser decision making in particular, with the use of N rich or N absent strips. This will be exploited over the short term as the adoption of the use of the imagery increases. The technology already exists.

CONCLUSIONS

The purpose of this report was to identify the ways that PA can improve profit for grain growers in the Southern Region. Taking a profit first, PA second approach, and focusing on the four primary profit drivers clearly illustrates the role PA can play in improving profit. That is – identify the constraints and opportunities for profit on your farm, and then consider if PA has a role in addressing them. Note though, that PA can negatively impact on profitability if poorly implemented, through increasing the business cost base, or delaying rather than improving timeliness of operations.

There are three broad pathways to profit from PA. It is recommended that growers first consider the opportunities for their business at the *strategic* level, as these are likely to have the greatest economic benefit. *Tactical* applications of PA can have merit, but generally enable smaller gains than the strategic pathway. There are also paddock situations where a *reactive* approach to PA can be useful to solve a problem that emerges suddenly, or in response to a seasonal challenge.

This report covers the range of applications and a very broad brush of their potential best fit throughout the region. There were few economic studies that could be applied broadly to the breadth of farm businesses across the region particularly given the high degree of variability between businesses even in the same subregion. Therefore, investment decisions in precision agriculture are best preceded by a thorough business case which includes a fully costed partial budget analysis at a minimum. This project will provide guidelines for such analyses in later publications.

This project will also be collecting some economic data on five specific PA applications as part of future outputs. This will go some way to addressing this economic data gap. The authors would also welcome contact from anyone with information that hasn't been captured in this report but would be useful economic data for the project and industry.

TOOL BOX 1 – GLOSSARY

Derived from Whelan and Taylor (2010) and Leonard et al (2017).

GLOSSARY	
TERM	**DESCRIPTION**
AgTech	Popular term in the investment community to describe the digital technologies used in agriculture
Big data	Computerised analytics systems that interrogate extremely large databases of information in order to identify particular trends and correlations
Coefficient of variation (CV)	A statistical measure of variability, involving the ratio of the standard deviation to the mean
Controlled traffic farming (CTF)	A farming system in which most or all wheeled traffic runs on a set of permanent tracks to restrict soil compaction
Decision agriculture	Conclusion or action resulting from the application of knowledge and/or information that may be derived from digital agriculture
Digital agriculture	Collection and analysis of data to improve both on and off-farm decision making leading to better business outcomes
EM38	A tool to measure electrical conductivity of water in the soil and the soil itself, which is influenced by the soil salt and water content, and the amount and type of clay in the soil. It can help to identify where important subsoil constraints may be present in paddocks and in assessing variation in the amount of soil water that can be available to plants
GNSS	The standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. GNSS allows small electronic receivers to determine their location (longitude, latitude, and altitude) using time signals transmitted along a line-of-sight by radio from satellites
Gamma radiometry	The measurement of natural gamma ray emissions of radioactivity, primarily from the top 30 - 50cm of soil or rock. Often, this can provide information about the parent material of the soil that can be related to soil types across the region or paddock
Normalised difference vegetation index (NDVI)	A common method of analysing remotely sensed imagery for vegetation health, vigour and greenness. The index is created by subtracting the value of the red band of the imagery from that of the near infrared, and then dividing this by the sum of the red and near infrared bands. Red light is strongly absorbed for photosynthesis and near infrared light is strongly reflected in healthy plants, so a high index value relates to high health and greenness. The NDVI is the most commonly used vegetation index
Optical spot sprayer	A spray system involving a sensor that detects the presence of a plant and automatically activates a valve to direct spray at the plant. Used in fallow situations
PAWC (plant available water capacity)	Proportion of soil water that is available to plants within rootzone
Precision Agriculture (PA)	Farming practices that involve precise spatial management using GPS technologies
Site specific crop management (SSCM)	A management system that considers the variability of crop and soil parameters to make decisions on the application of production inputs
Spatial variability	The variation found in soil and crop parameters (e.g. soil pH, crop yield) across an area at a given time
Temporal variability	The variation found in soil and crop parameters within a given area at different measurement times

TOOL BOX 2 – PA TECHNICAL INFORMATION SOURCES

REPORTS AND REFERENCE MATERIAL		
PA IN PRACTICE II	www.grdc.com.au/PAinPractice2	A seasonal guide to PA applications
APPLYING PA – A REFERENCE GUIDE FOR THE MODERN PRACTITIONER	https://grdc.com.au/resources-and-publications/all-publications/bookshop/2013/11/applyingpa	A practical guide to implementing PA
CALCULATING RETURN ON INVESTMENT FOR ON FARM TRIALS DIY PRECISION AGRICULTURE	https://grdc.com.au/__data/assets/pdf_file/0026/233945/diy-pa-calculating-roi-for-on-farm-trials.pdf.pdf	A guide to conducting on farm trials
UNIVERSITY OF SYDNEY PA MODULES	https://sydney.edu.au/agriculture/pal/publications_references/educational_resources.shtml	Technical reference material on the development and application of PA in the grains industry

GRDC

TOOL BOX 3 – IS PA FOR ME?

Modified from GRDC RDP00013 2015

CHECKLIST FOR ASSESSING PA OPPORTUNITIES	
1	**Is there potential to improve water use efficiency and yield relative to climate limited potential via crop rotation, crop agronomy, and operational timeliness?** If yes, explore these first.
2	**How long has the PA product or application been around? Has it been robustly tested in a commercial environment?** More established PA products tend to be cheaper with greater capability.
3	**Will the technology influence long term average crop yield?** Technologies which unlock yield potential and result in yield increases, with only a small to moderate increase in cost can deliver substantial net economic benefit.
4	**Is the PA technology the most cost effective mechanism to achieve the outcome that I am striving for?** Sometimes there are other ways to achieve the same outcome. Select the simplest and most cost effective option to achieve a desired outcome wherever possible.
5	**Have I undertaken a robust economic assessment of the opportunity to apply the technology? Did this analysis demonstrates a positive net benefit?** The range in net economic benefits can be substantial and is often very sensitive to the cost of purchasing the technology and the robustness of the assumptions made.
6	**Do I understand how the benefit will be influenced by climatic variability between seasons? Do my assumptions accurately reflect the likely benefit or cost saving by taking a long term perspective which captures the influence of seasonal variability?** Some technologies have very different payoffs under different seasonal conditions. It is important that this difference is understood and captured in an economic analysis. Tools such as CliMate can be used to add rigour to assumptions around seasonality and the way in which it may influence the benefit.
7	**Do I understand how my level of business scale influences the commercial feasibility of applying this technology?** A technology which is commercially feasible for one business may not pass the commercial feasibility test for a smaller scale business.
8	**Have I used long term, decile 5 pricing rather than spot pricing when calculating the net economic benefit or a range of price scenarios?** Spot pricing can substantially influence the value of the possible benefit or cost saving and as a result can be misleading. This is particularly so when spot pricing is substantially different from the longer term average. This principle applies to both input cost prices and grain prices.
9	**Can I access the skill set and capacity to manage the data capture and interpretation required for this PA application?** Most forms of PA require additional data capture, analysis, and preparation to realise the benefit. The impact on labour demand is also important when assessing the application of a PA technology.
10	**Have I completed the economic assessment on the application of this technology without bias?** Personal bias can easily influence an economic assessment. Ensuring that the analysis is undertaken without bias results in more robust assessments.

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